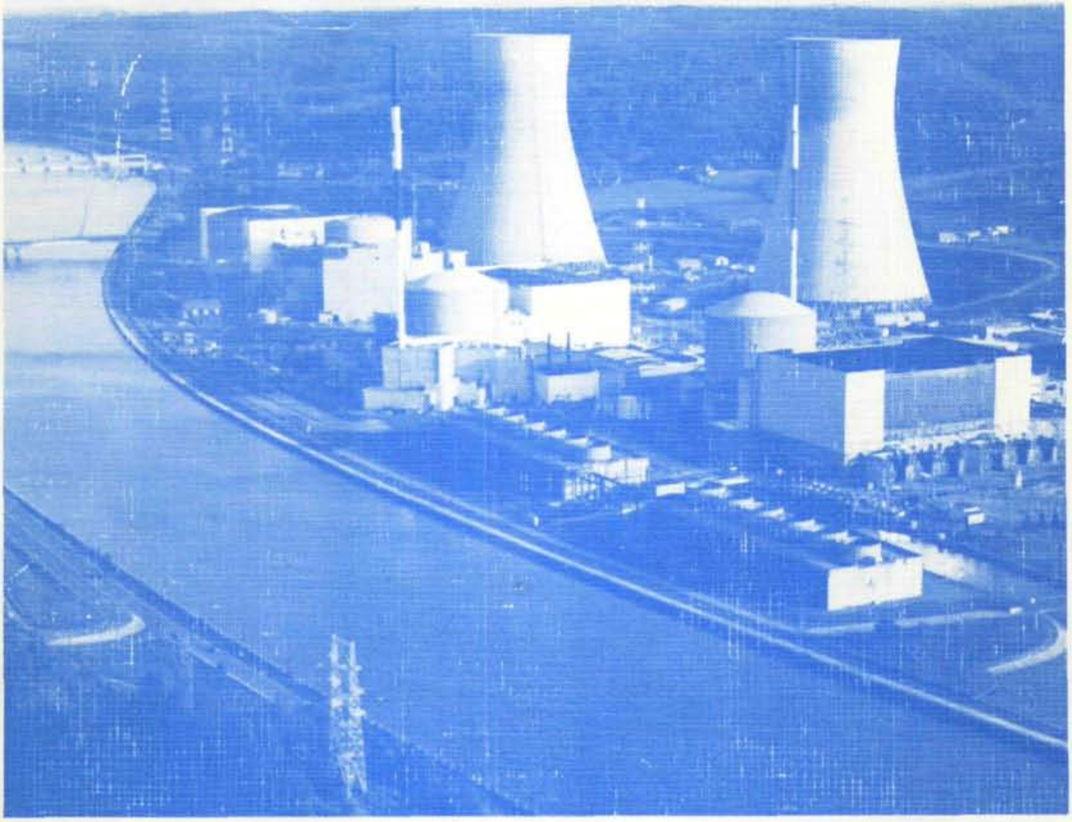

TECHNICAL REPORTS SERIES No. 245

Energy and Nuclear Power Planning in Developing Countries

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1985

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ENERGY AND NUCLEAR POWER PLANNING IN DEVELOPING COUNTRIES

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FOREWORD

The International Atomic Energy Agency (IAEA) wishes to acknowledge the contribution made by Professor I.D. Stancescu (an international energy consultant and formerly technical adviser with the United Nations, New York), who prepared this publication under a contract with the IAEA.

The overall organization of this training manual was discussed and jointly agreed upon by the author and staff members of the Economic Studies Section of the Division of Nuclear Power, in the IAEA Department of Nuclear Energy and Safety. J.P. Charpentier of the Economic Studies Section was the IAEA Technical Officer responsible for preparation of this publication.

The structure relies heavily on the outline of the first IAEA interregional training course on Energy Planning in Developing Countries organized in 1978 at the National Institute of Nuclear Science and Technology at Saclay (France) under the direction of E. Bauer and with the co-operation of the Division of Natural Resources and Energy (United Nations) and of the World Bank.

Finally, the IAEA wishes to acknowledge the substantial contribution made by all lecturers in the six sessions of the IAEA interregional training course on 'Energy Planning in Developing Countries with Special Attention to Nuclear Energy' (Saclay, 1978, 1979, 1980; Madrid 1981; Jakarta 1982; Ljubljana 1983). Their lectures and other reference materials presented during the courses were used extensively in the preparation of this book.

EDITORIAL NOTE

The figures, tables and text of this book are based on a very large number of sources. Inevitably there are some differences in terminology. In particular, designations of countries and areas do not imply any judgement by the publisher, the IAEA, as to the legal status of such countries or territories, of their authorities and institutions, or of the delimitation of their boundaries. The classification of countries into groups does not necessarily imply a judgement about the stage reached by a particular country or territory in the development process, but is merely for statistical convenience.

For figures and tables which the author has obtained permission to use from elsewhere, copyright is held by the sources indicated in the reference quoted in the caption, unless more specifically indicated.

PREFACE

This publication of the IAEA is intended primarily for use as a training manual or textbook in the IAEA interregional training course on Energy Planning in Developing Countries with Special Attention to Nuclear Energy, for the round-table discussion sessions, which are the new, shorter and more efficient form in which the course is now offered.

The book should serve to ensure that all participants – of whatever background, training and experience – possess or acquire the minimum core of knowledge and information on energy, thus enabling them to interact as active partners in the round-table discussion sessions, which are the core of this training course. These sessions are meant not to repeat aspects dealt with in the book, but rather to enlarge on their horizon, bringing additional or updated information, exposing personal views or criticism, etc., thus contributing to the formation of the basic expert position needed to deal with energy, especially planning problems later on.

In order to build up the understanding and interaction potential needed for a fruitful participation in the sessions, the participants should have attentively studied the book in advance and have accordingly prepared questions and comments regarding general aspects or those specific aspects relevant to their country.

The book integrates the two volumes of the first draft manual used in the 1982 and 1983 sessions of this course, held in Jakarta and Ljubljana, updates the material and partly reshapes and extends it according to the practical experience gained in the meantime in the courses and from new developments in the world energy area.

The subject is introduced by a short comment on energy and development and an opening chapter presenting an overview on the technical, economic and planning issues of an overall energy system. After this introduction, four substantive parts follow.

Part I, Energy Demand and Rational Energy Supply, deals with the needs for useful energy as the driving force of the energy system, thoughtful demand management, and end-use (final) energy as the key level of the system, where energy demand and supply interface, are measured, billed, substituted, saved and generally optimized (chapter 2). Chapter 3 offers a summarized view on primary energy resources and reserves, their conversion process to intermediate and final energy forms, and the formation (transport included) of characteristic energy chains between supplier and consumer. Chapter 4 brings additional information on some newer and renewable primary energy resources, such as nuclear, geothermal and solar energy. Chapter 5 deals with the intermediate energy forms and chapter 6 singles out electrical energy as an especially versatile intermediate form of energy. Chapter 7 treats energy transport, storage and distribution, with a special accent on electricity, while chapter 8 addresses general issues of improved energy husbandry and particular conservation aspects. To round up the technical aspects of the energy system, chapter 9 deals with the environmental effects and other constraints on energy development.

Part II, Economic Aspects of Energy Development, presents an integrated view of the basic concepts of energy economics (costs, prices and tariffs), evaluation of alternative energy projects (chapter 10), continued in chapter 11 with an in-depth comparison of electricity generation costs of nuclear and fossil-fuelled power plants. Chapter 12 closes this part, commenting on financing aspects, needs and main international financing sources.

Part III, World Energy Development Status and Trends, begins with an overview of the world energy status and trends as an overall background reference picture (chapter 13) and continues in chapter 14 with a presentation of the energy situation in industrialized countries and in chapter 15 in developing countries.

Part IV, Energy Planning, starts with chapter 16 dealing with the optimization techniques and options of overall energy systems. Chapter 17, the longest in the book, is dedicated to the core of the subject and deals extensively with energy planning concepts and techniques, the latter eventually strongly aided by computerized models. A series of energy demand and supply models are briefly described both as basic concepts and areas of application. While nuclear energy is always included in the previous considerations, it is in the last chapter (18) that the launching conditions and implementation of a nuclear power programme, whenever rational and desired, are described in more detail.

Regarding the reference and bibliography base a mixed approach has been utilized. A first revision of the text was drafted taking into account experience and recommendations from former courses, then searching for supporting materials and checking for possible new issues. From over 2500 sources reviewed, 582 references are given in the text and a bibliographical list (356 titles), related to the individual chapters, has been added for further reading. In general, as many sources as possible were referred to so that material could be easily found by course participants interested in further study; however, pertinent sources of more difficult access were not excluded. The following main bibliographical groups may be mentioned: The papers presented in previous IAEA courses, Saclay 1978, 1979, 1980, Madrid 1981, Jakarta 1982, Ljubljana 1983; other IAEA documents, especially relevant Guidebooks; United Nations documentation, both from Headquarters units – the Division of Natural Resources and Energy (DNRE), the Department of Technical Cooperation for Development (DTCD) and the Department of International Economic and Social Affairs (DIESA) – and from regional economic commissions – mainly the Economic Commission for Europe (ECE); World Bank papers; World Energy Conference publications, a large number for example from the last, 12th Congress in New Delhi in 1983; a series of articles and documents collected from relevant energy institutes such as the Argonne National Laboratory (USA), the Nuclear Energy Research Centres in Jülich and Karlsruhe (Federal Republic of Germany), the Institut économique et juridique de l'énergie in Grenoble (France), and institutions such as the French Commissariat à l'énergie atomique (CEA), the US Department of Energy, Electricité de France (Paris), etc.

AUTHOR'S NOTE

The author would like to stress that it was his intention to try to write a textbook that is not only theoretically sound, but also deeply rooted in practical knowledge and experience, rich in new ideas and trends, and reflecting both the current world status and national realities. It is in this spirit that the author would be grateful for any substantive comments, suggestions and recommendations.

The author, who very much enjoyed participating as a United Nations DNRE delegate and lecturer in the first three IAEA courses and who has remained linked to them as an IAEA consultant, would like to express his gratitude for the opportunity offered by the IAEA to combine the Agency's immense expertise and experience in the subject with the fruits of his own long years of activity in the energy sector and experience of developing countries. This challenging common venture has resulted in the present book. The author would also like to acknowledge the pleasant and efficient co-operation of the officers and professional staff of the Division of Nuclear Power and the Division of Publications and particularly the close and creative collaboration with J.P. Charpentier in the preparation of this textbook.

Vienna, December 1984

Prof. Ioan D. Stancescu

CONTENTS

INTRODUCTION

PART I: ENERGY DEMAND AND RATIONAL ENERGY SUPPLY

PART III: WORLD ENERGY DEVELOPMENT – STATUS AND TRENDS

PART IV: ENERGY PLANNING

INTRODUCTION

ENERGY AND DEVELOPMENT

Energy has become a vital input into economic and social development. Rising economic activity and increased standards of living are linked to growing energy consumption.

However, the relationship between energy consumption and economic growth is much more complex than believed a decade ago, when a series of elasticity coefficients, extra- and interpolation figures, lead to the popular GNP-energy consumption graphs, elegantly traced through a cloud of reference points, most of limited or doubtful reliability. Nevertheless, a relationship between energy and economy exists, but both factors have to be cautiously defined, the new approach being to try to link useful energy consumption on the one side and added value on the other, in an integrating bottom-up process departing from microeconomic subsectorial analyses to replace the macroeconomic (top-down) method so much used in the past. According to the general progress, a multitude of computer models are helping the analyst. How complicated this task is, is shown by the fact that measured in the old way, between 1973 and 1980, the primary energy consumption in the OECD countries as a whole increased by 4% while the GNP growth was 19% [0.1].

Under these conditions, it appears preferable to refrain here from quantitative considerations and to concentrate on the qualitative aspects strongly enough to define the framework of the book. Among them, the following three issues dominate the last decade:

- the unanimous understanding that the era of abundant supplies of cheap energy is now a matter of history,
- that petroleum emerged as a scarce and very expensive primary energy resource, and
- that with the rapidly increasing threshold of opportunity costs, a series of marginal energy resources of different characters are gradually becoming competitive and are subsequently entering the world energy scene.

Accordingly, a radical new energy strategy has become imperative:

While in the past the availability of abundant and cheap energy supplies encouraged intensive and extensive energy consumption patterns, as well as squandering and waste of energy, right now the situation is such that humankind must learn, and learn quickly, the importance of rational use of energy to economic and social development.

Toward that goal, radically improved husbandry of energy is critically important. It can be argued that this may be achieved without jeopardizing overall standards of living or work productivity. While in the developed countries this will require modification in current styles of living and working, in the developing countries future development could be advantageously designed on the basis of less energy-demanding styles of living and working, with the double advantage of less cost and fewer environmental problems. It is, therefore, encouraging that interest in and motivation towards improved utilization of energy is steadily increasing.

As far as petroleum is concerned, it has always been a valuable natural resource, both for industrial feedstock and energy supply. As an energy carrier, it has rapidly conquered the world and become a leading primary energy resource. Its high calorific value, easy transport, storage and distribution, its versatile conversion and final consumption qualities, as well as the environmental advantages, have made petroleum a preferred fossil fuel. However, it was the low price of petroleum that was the main driving force behind its fantastic penetration of the world energy market. Petroleum has opened an era of cheap and abundant energy supply, strongly promoting social and economic development but also profligate consumption, squandering and enormous wastage of energy. Insidiously, it instilled worldwide a terrible dependence on this miraculous fuel.

In the meantime, both under the pressure of a rapidly increasing energy demand and better knowledge of the world energy reserves, petroleum emerged as a scarce resource. Owing to the high demand and its increasing export price, petroleum exerts a considerable impact on the world economy. The economic impact was particularly severe among the developing countries; in some cases, the foreign bill for the imported oil was becoming a serious threat to development aspirations.

Under the pressure of the escalating prices but also in the desire to reduce their imported-oil dependence and the associated political risks, the western industrialized countries made strong efforts to reduce the share of petroleum in their national balances, both by saving and substitution. This policy continues unaffected by the calm situation on the petroleum market, with offer in excess and lower prices, since warnings from competent sources have been expressed not to be misled by the short-term signals of the present period [0.2]. Demand for petroleum will certainly increase again in the future, partly from industrialized countries in spite of their oil-share reduction, but especially from developing countries. In this respect the petroleum-share-reducing policy of the industrialized countries represents a positive contribution to north-south co-operation, since these countries have larger possibilities for oil saving and substitution than the developing countries which need petroleum mainly for non-substitutable purposes, i.e. transportation.

The new awareness of the limited reserves of the conventional fossil fuels, especially liquid and gaseous, as well as the considerably higher level of opportunity costs of energy, has determined a growing interest in alternative energy resources of the most varied character, i.e. non-conventional petroleum, oil-shale and tar sands, expensive macro- and minihydro power, marginal coal reserves, lignite and peat, direct and indirect solar energy, synfuels, etc. Both their increased competitivity and the growing market due to rapidly increasing electrical network capacity opened up great opportunities for nuclear power stations, however, amidst rather adverse public opinion.

Under the above conditions and the prevailing strong economic pressure, it appears, therefore, highly interesting and profitable to review for a multilateral audience the present world energy situation and to evaluate it using the double strategy of simultaneous development of the primary energy base and optimal energy demand management. One might then wisely understand and define the role of nuclear energy in the national energy plans.

CONVERSION TABLE FOR COMMON ENERGY UNITS [2–13]

Since many units commonly used in the field of energy are not standard SI units, the following conversion factors may be helpful to the reader.

	J	Btu	Quad	kcal	mtce	10^6 mtce	boe	10^6 boe
1 J	= 1	947.9×10^{-6}	947.9×10^{-21}	239×10^{-6}	34.14×10^{-12}	34.14×10^{-18}	163.4×10^{-12}	163.4×10^{-18}
1 Btu	= 1055	1	1×10^{-15}	0.2522	36.02×10^{-9}	36.02×10^{-15}	172.4×10^{-15}	172.4×10^{-21}
1 Quad	$= 1055 \times 10^{15}$	1×10^{15}	1	252×10^{12}	36.02×10^{6}	36.02	172.4×10^{6}	172.4
1 kcal	= 4184	3.966	3966×10^{-15}	1	142.9×10^{-9}	142.9×10^{-15}	683.8×10^{-9}	683.8×10^{-15}
1 mtce	$= 29.29 \times 10^{9}$	27.76×10^{6}	27.76×10^{-9}	7×10^{6}	1	1×10^{-6}	4.786	4.786×10^{-6}
10^6 mtce	$= 29.29 \times 10^{15}$	27.76×10^{12}	27.76×10^{-3}	7×10^{12}	1×10^{6}	1	4.786×10^{6}	4.786
1 boe	$= 6119 \times 10^{6}$	5.8×10^{6}	5.8×10^{-9}	1462×10^{3}	0.2089	208.9×10^{-9}	1	1×10^{-6}
10^6 boe	$= 6119 \times 10^{12}$	5.8×10^{12}	5.8×10^{-3}	1462×10^{9}	208.9×10^{3}	0.2089	1×10^{6}	1
1 mtoe	$= 44.76 \times 10^{9}$	42.43×10^{6}	42.43×10^{-9}	10.7×10^{6}	1.528	1528×10^{-9}	7.315	7315×10^{-9}
10^6 mtoe	$= 44.76 \times 10^{15}$	42.43×10^{12}	42.43×10^{-3}	10.7×10^{12}	1528×10^{3}	1.528	7315×10^{3}	7.315
1 m^3 gas	$= 37.26 \times 10^{6}$	35.31×10^{3}	35.31×10^{-12}	8905	1272×10^{-6}	1272×10^{-12}	6089×10^{-6}	6089×10^{-12}
1 ft^3 gas	$= 1055 \times 10^{3}$	1000	1×10^{-12}	252.2	36×10^{-6}	36×10^{-12}	172.4×10^{-6}	172.4×10^{-12}
1 kW·a	$= 31.54 \times 10^{9}$	29.89×10^{6}	29.89×10^{-9}	7537×10^{3}	1.076	1076×10^{-9}	5.154	5154×10^{-9}
1 GW·a	$= 31.54 \times 10^{15}$	29.89×10^{12}	29.89×10^{-3}	7537×10^{9}	1076×10^{3}	1.076	5154×10^{3}	5.154
1 TW·a	$= 31.54 \times 10^{18}$	29.89×10^{15}	29.89	7537×10^{12}	1076×10^{6}	1076	5154×10^{6}	5154

	mtoe	10^6 mtoe	m^3 gas	ft^3 gas	kW·a	GW·a	TW·a
1 J	$= 22.34 \times 10^{-12}$	22.34×10^{-18}	26.84×10^{-9}	948×10^{-9}	31.71×10^{-12}	31.71×10^{-18}	31.71×10^{-21}
1 Bru	$= 23.57 \times 10^{-9}$	23.57×10^{-15}	28.32×10^{-6}	0.001	33.45×10^{-9}	33.45×10^{-15}	33.45×10^{-18}
1 Quad	$= 23.57 \times 10^{6}$	23.57	28.32×10^{9}	1×10^{12}	33.45×10^{6}	33.45	33.45×10^{-3}
1 kcal	$= 93.47 \times 10^{-9}$	93.47×10^{-15}	112.3×10^{-6}	3966×10^{-6}	132.7×10^{-9}	132.7×10^{-15}	132.7×10^{-18}
1 mtce	= 0.6543	654.3×10^{-9}	786.1	27.76×10^{3}	0.9287	928.7×10^{-6}	928.7×10^{-12}
10^6 mtce	$= 654.3 \times 10^{3}$	0.6543	786.1×10^{6}	27.76×10^{9}	928.7×10^{3}	0.9287	928.7×10^{-6}
1 boe	= 0.1367	136.7×10^{-9}	164.2	5800	0.194	194×10^{-9}	194×10^{-12}
10^6 boe	$= 136.7 \times 10^{3}$	0.1367	164.2×10^{6}	5.8×10^{9}	194×10^{3}	0.194	194×10^{-6}
1 mtoe	= 1	1×10^{-6}	1201	42.43×10^{3}	1.419	1419×10^{-9}	1419×10^{-12}
10^6 mtoe	$= 1 \times 10^{6}$	1	1201×10^{6}	42.43×10^{9}	1419×10^{3}	1.419	1419×10^{-6}
1 m^3 gas	$= 823.2 \times 10^{-6}$	832.3×10^{-12}	1	35.31	1181×10^{-6}	1181×10^{-12}	1181×10^{-15}
1 ft^3 gas	$= 23.57 \times 10^{-6}$	23.57×10^{-12}	28.32×10^{-3}	1	33.45×10^{-6}	33.45×10^{-12}	33.45×10^{-15}
1 kW·a	= 0.7045	704.5×10^{-9}	846.4	29.89×10^{3}	1	1×10^{-6}	1×10^{-9}
1 GW·a	$= 704.5 \times 10^{3}$	0.7045	846.4×10^{6}	29.89×10^{9}	1×10^{6}	1	1×10^{-3}
1 TW·a	$= 704.5 \times 10^{6}$	704.5	846.4×10^{9}	29.89×10^{12}	1×10^{9}	1000	1

k kilo = 0^3 G giga = 10^9 P peta = 10^{15} M mega = 10^6 T tera = 10^{12} E exa = 10^{18}.

1 mtce = 1 tonne of coal equivalent.

1 boe = 1 barrel of oil equivalent.

Examples of frequent conversions:

	PJ	TW·h
1×10^6 tce	29.308	8.1388
1×10^6 toe	41.868	11.63
1×10^9 m^3 natural gas	35.169	9.7692

7 barrel crude oil (159 L per b) $\cong$ 1 t

1×10^6 b/d (barrel per day) $\cong 50 \times 10^6$ t/a.

Unless otherwise specified, throughout the book dollars are US dollars, tons are metric, billion is 10^9.

Chapter 1

THE ENERGY SYSTEM

Technical, economic and planning issues

Practical experience both in industrialized and developing countries is increasingly demonstrating the advantages of the use of a system approach in the study and operational solving of their energy problems. It is, therefore, consistent with the concept of this book not only to share this approach but also to contribute to its progress and strongly promote its wider diffusion in the energy world.

Accordingly, this first chapter will present as an introductory overview the technical structure of the energy system, its internal economic issues and relations to the global economy and the planning activities aimed to organize and optimize its further evolution.

1.1. Technical issues

1.1.1. The energy concept

What is energy? To define it one must go back to 1826 when the French physicist J.V. Poncelet coined the name from the Greek "energeia" which means "the driving" in the sense of driving power [1.1]. It was only gradually recognized that heat, motion, light and chemical energy are external forms of the same basic energy. Einstein demonstrated later the identity of energy and matter. The best short definition of energy originates from Max Planck, as the capacity of a system to determine external effects [1.2]. The popular dictionary formulation: energy is the ability to do work [1.3], although very suggestive for the layman, is not completely satisfactory. However, here is not the place to enter into more discussion on the definition aspects. Instead, in subsection 1.1.4 and when need arises in further chapters, a series of basic qualities of energy and the fundamental thermodynamic laws governing its conversion and use will be tackled, but only to the extent necessary to better understand the essence of the technological processes under examination.

To underline the universal character of energy and its natural system behaviour, Fig.1.1 illustrates the energy flux diagram of solar radiation at the earth's surface and its interface with the earth's own and induced energy resources.

While solar energy is dealt with in detail in chapters 3 and 4, Fig.1.1 is supposed to provide the wide energy background determinant for chapter 1 and for all further energy considerations in this book.

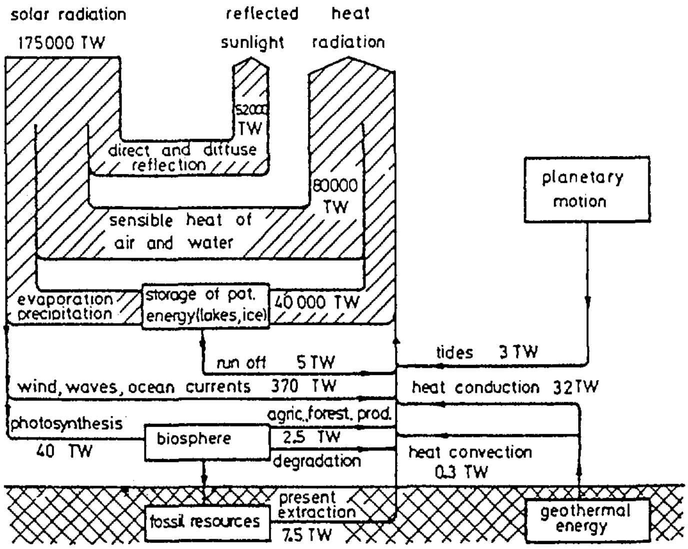

FIG.1.1. Energy flow diagram of solar radiation at the earth's surface [1.4].

According to Fig.1.1, as far as energy is concerned, the biosphere is involved with two categories of primary energy resources:

(1) A continuously renewed presence of an energy potential originating from the permanent action of three main natural energy sources: solar, geothermal and gravitational energy, and

(2) A finite, non-renewable deposit of primary energy resources, which enter its circuit under anthropogenic action.

The main world energy consumption is currently based on the non-renewable reserves of the second group, which in fact represent accumulated solar energy.

The first group, the object of increasing interest in future projection, constitutes the so-called new and renewable primary energy resources, which will be dealt with in detail, as with all other energy resources concerned. However, it is important to make clear here that the term "new and renewable energy sources" is something of a misnomer, since many of the energy sources referred to under this heading are neither new nor renewable. The term does, however, attempt to differentiate between those energy sources which constitute the major current energy sources (such as coal, petroleum, gas and nuclear power) and those energy sources which, although possibly of local importance, have not as yet been fully exploited on a large scale, such as solar, wind, geothermal, agricultural waste, etc. These new energy sources make a small contribution at present to meeting world energy demand, but they could nevertheless play an important role in meeting future energy requirements, in particular in remote areas, rural communities, and in certain energy-consuming sectors such as, for example, in the production of low- and medium-temperature heat, as well as in cooling and drying applications and in meeting low-grade power requirements [1.5].

1.1.2. Basic concept and structure of an energy system

The system concept has begun to be applied to energy production and consumption only during the past decade, although the electrical system has been in common use for a long time and was probably one of the most succesful forerunners of this approach. However, it was not merely by extension that the transition from electricity to energy systems took place. The general evolution of the science and philosophy of system analysis, and the steady broadening of their usage has been another favourable factor.

In spite of its usefulness, efficiency and conceptual refinement, the system approach to energy supply and use is progressing rather slowly. Although it was immediately accepted and promoted by electrical power engineers and economists always receptive to system thinking because of their training, its penetration into the other energy subsectors needs lead time and effort.

An energy system as complex as the one represented in Fig.1.2 has, on the output side, the final forms of useful energy required to satisfy consumer needs and, on the input side, a mixture of primary energy resources available or made available for supply. Physically, it includes all facilities, plants and constructions serving for exploration, extraction, harnessing, conversion, transport, distribution and utilization of primary energy resources and converted energy carriers.

The historic path of energy utilization developed in the past was a production-oriented energy economy, i.e. an abundant offer on the supply side of the energy system, encouraging by sophisticated promotional means and especially by low prices a fast-increasing final energy consumption. This policy resulted in what are now considered excessively intensive and extensive energy consumption patterns, which squander and waste energy.

In the present situation, improved husbandry of energy is imperative. Energy development should, therefore, be approached from the output side of the energy system, aiming to meet the real needs for energy of the final consumers with the most rational expenditure of primary energy resources. The production-oriented energy economy is being replaced by a rational consumer-oriented energy economy [1.7].

It is in this new spirit that the energy system will be dealt with, i.e. starting from the output consuming stage and gradually working back through all the conversion and transport stages to the corresponding primary energy inputs.

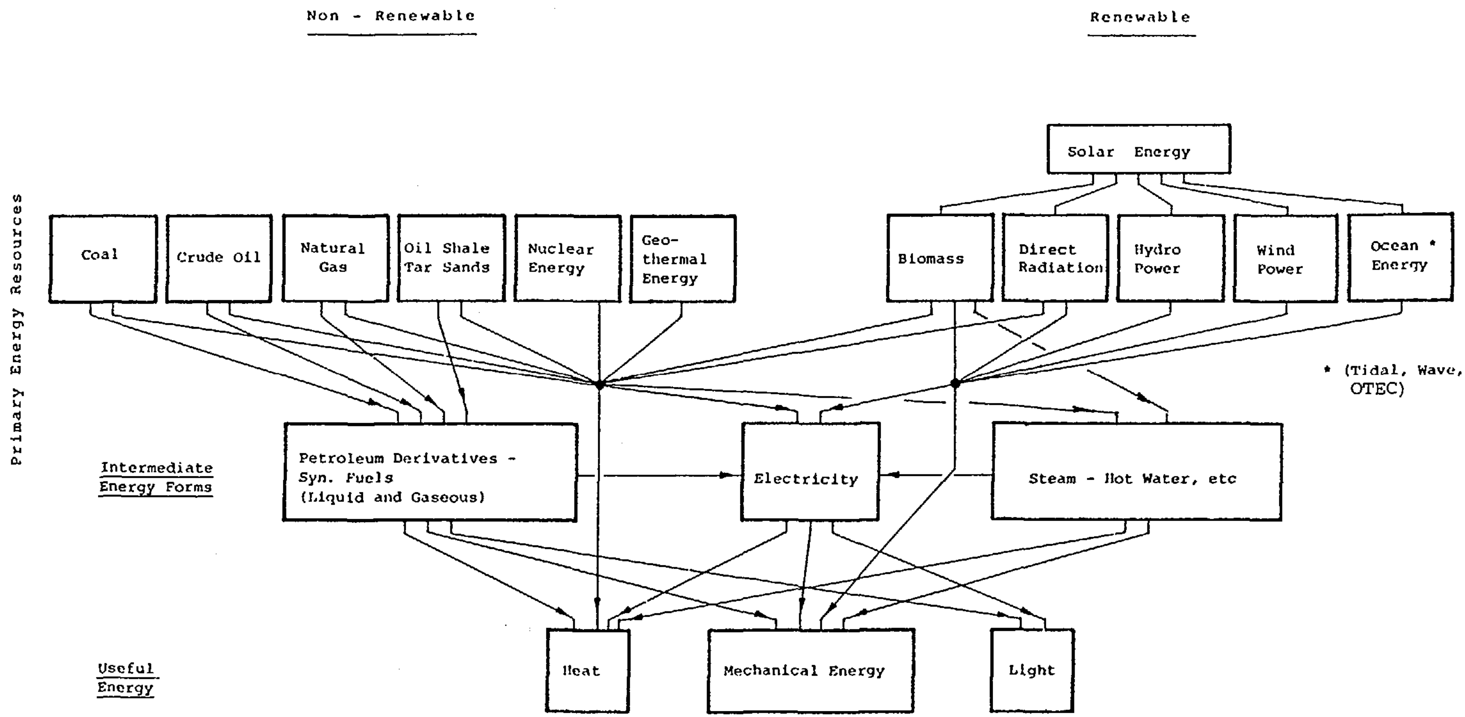

FIG.1.2. Basic structure of an energy system [1.6].

1.1.2.1. Needs for useful energy and supply of final (end-use) energy

Energy is not a basic human need as is air, water, food, clothing and shelter. However, it is an essential input for the satisfaction of these needs and of others for work and amenities which gradually develop with the increase in living standards and work productivity. Accordingly, the needs for energy in the pre-industrial era could be satisfied with relatively low-grade energy inputs widely available as biomass, water power and wind, which led to rather dispersed and low-density activities, largely agricultural. Modern industrial and economic development led to concentration, economy-of-scale organization, etc., paralleled with the utilization of new primary energy resources such as coal, petroleum, natural gas and nuclear energy and a rapid increase of living standards.

To satisfy its needs, humankind requires the services of energy in the following useful forms:

(1) Heat and cold – serving for space heating and conditioning, food preparation and hot/cold water supply as well as for various industrial processes
(2) Mechanical energy – needed for transportation and as prime mover for industrial equipment and domestic appliances
(3) Radiant energy – for lighting and telecommunications.

Some chemical industrial processes, considering the involved reactions, could also require chemically bound energy. To avoid complicating the general presentation, these cases should be dealt with individually, when relevant.

In order to facilitate the analysis of the conversion potential in the final stage of an energy system, it may be helpful to define the relevant terminology as follows [1.7].

(1) Need for useful energy – the amount of one or more useful energy forms absolutely necessary to perform an activity and/or to assure adequate ambient conditions for living and working.

For example, a lathe or turning machine needs a certain amount of mechanical energy to rotate at a certain speed, a living room or an office needs to be held at a given level of temperature and comfort, a workshop needs an optimal level of lighting, etc. These needs could be covered by a corresponding supply of end-use energy to the conversion devices – electric motors, space heating, electric bulbs – which in turn according to their efficiencies deliver the useful energy required. The real processes either themselves absorb the amount of end-use energy necessary to satisfy the demand for useful energy (electric motors) or hand or automatic regulation adapts the end-use energy supply to meet the required output (space heating) or in the case of electric lighting, the bulbs constantly absorb the electric current according to their nominal capacity.

Ideally, when the end-use (final) energy consumed corresponds exactly, taking into account the conversion efficiencies, to the need for useful energy, no energy wastage occurs in the final consuming stage, the demand for useful energy is equal to the needs.

(2) Energy wastage in the final stage. Referring to the examples under item (1): wastage occurs if the lathe turns idly, wastage occurs with even unpleasant or harmful effects if the space is overheated by introducing more final heat than necessary and wastage occurs if the light is not turned off when work is finished. The trouble is that in all these cases a form of useful energy was supplied but not totally usefully consumed.

(3) Usable energy. In order to identify or recognize wastage in the last consumption phase, sometimes a distinction is made between 'usable' and 'useful' energy. In fact it is the same energy form, only useful energy = usable energy – energy wasted, the latter by avoidable negligence or profligate consumption habits.

(4) For keeping further analysis transparent, once the importance of avoiding any energy wastage has been realized, the hypothesis will be accepted that useful energy meets exactly the needs, i.e. useful energy = usable energy, and in this case reference is made only to the first. This position is also conceptually important: in the new approach generally accepted and the premise for the energy system concept, the need for final energy triggers the supply process by formulating the demand for final energy and herewith for end-use energy supply. If more end-use energy is consumed, i.e. usable energy in excess of the useful energy required, then this is a faulty situation which must be corrected when it occurs, and not expressed as an acceptable demand.

(5) Demand for useful energy – the amount of useful energy actually required.

(6) Energy losses. These represent the auxiliary consumption of end-use energy in the final conversion process. They can be reduced but hardly completely avoided. Taking the above examples, such losses depend on the efficiency of the electric motor, on the efficiency of a heating stove or on the quality of conversion of electricity into radiant energy for lighting.

(7) Final energy or energy consumption of the final stage – the energy actually consumed for meeting the required demand for useful energy including losses in the final stage. It is also called "end-use energy", i.e. the energy supplied to the final-stage consuming sectors.

As shown in chapter 2, the end-use or final energy level in an energy system is very important, since it is usually the reference level at which energy consumption of the final subsectors is measured, billed and critically assessed.

1.1.2.2. Primary energy resources

The input side of the energy system represented in Fig.1.2 includes all possible energy resources, which is not necessarily the case with real systems, many of which contain only some of them.

The primary energy resources are basically divided into non-renewable and renewable energy resources. The first group, of depletable character, includes the fossil energy resources: coal, which stands for hard coal of different heat values and composition, brown coal and lignites and finally peat; crude oil (petroleum) including heavy oil deposits; natural gas, including associated gas (with crude oil or geopressure); oil shale and tar sands. To this group also belong the nuclear fuels: uranium, thorium and, later, nuclear fusion materials and geothermal energy. While geothermal energy of dry and wet steam, hot water and mixed fields are correctly ranked as depletable resources, the case of dry-rock geothermal energy is less obvious and as such is open to discussion.

The group of renewable (replenishable) energy resources is based on solar energy either as direct radiation or on its indirect effects or conversion. Classic water flow predominates for the time being with possible variations as tidal, wave and sea currents energy. In addition, there is wind power and ocean thermal energy conversion (OTEC). Direct radiation is an important resource for heat and photovoltaic direct electricity generation. Last, but not least, the biomass represents an immense energy resource in fire- and fuel-wood as well as agricultural waste and biogas. Human and animal energy has not been explicitly included, although historically and in some developing countries still of great influence.

While the foregoing partition of the primary energy resources into the two groups of non-renewable and renewable resources is unequivocal because of its physical evidence, there are two other classifications of more conventional character, which might sometimes lead to slightly different interpretations. However, a consensus has gradually built up to consider as 'commercial' the primary energy resources which are statistically accountable, circulating in a market circuit. Contrary to that, 'non-commercial' primary energy resources not generally bought and sold (though they are in some instances) are collected in a natural, ad hoc out-of-market circuit and are of widespread use in rural areas, in their great majority for domestic needs.

A further classification is in 'conventional' and 'non-conventional' primary energy resources, the first group containing resources usable by well-established technologies while for the second group the conversion processes, although basically established, are still susceptible to substantial progress.

A combination of the above criteria results in the following two main groups, each of them with two more precisely defined subgroups:

(1) The commercial primary energy resources containing:
(1a) the commercial conventional energy resources: solid fuels (hard coal, brown coal, lignites, peat), petroleum, natural gas, hydro- and nuclear fission energy – the latter often improperly designated as 'primary electricity' – and
(1b) the commercial non-conventional energy resources: geothermal energy, heavy oils, geopressure natural gas, oil shale, tar sands and nuclear fusion.
(2) The non-commercial primary energy resources containing:
(2a) the non-commercial conventional energy resources: firewood, dung and agricultural wastes as well as human and animal draught power, this subgroup sometimes being considered as containing the 'traditional' non-commercial primary energy resources, and
(2b) the non-commercial non-conventional energy resources: solar (direct radiation), wind, tidal, wave, OTEC, biomass (except firewood and agricultural wastes).

Following worldwide usage and statistics, the basic classification into commercial and non-commercial primary energy resources will be used in this book.

1.1.2.3. Energy conversion and transport chains – intermediate energy forms

Figure 1.2 schematically visualizes the lines of possible supply of energy to the final consuming stage, either directly by an appropriate primary energy resource and/or via one or even two intermediate energy forms.

There are the following subgroups of intermediate* energy forms or carriers: the petroleum derivatives or refinery products, the coal liquefaction and gasification products (liquid and gaseous), coke and charcoal, synfuels from oil shale and tar sands and, of course, heat and electrical energy.

Conversion into an intermediate energy form to be supplied to the final consumer might be necessary for many reasons, such as technical adequacy, transport possibility, economy, substitution, etc.

The lines of supply of Fig. 1.2 may also represent energy transport flows between the different stages and energy forms of an energy system. Together with the conversion processes they constitute the various energy chains which link the in- and output side of the energy system.

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* It is preferable to use here, for all energy forms between primary and final energy, the denomination of 'intermediate' energy and not of 'secondary' energy forms since, for example, electricity generated from fuel oil is in fact a tertiary and no longer a secondary form. In addition, the term secondary is better reserved for industrial secondary energy resources (ISER) with completely different significance (see subsection 8.2.2).

1.1.3. Energy units and conversion factors

As is well known, as long ago as 1960, in the internationally agreed units system (SI – Système international d'unités) the joule (J) is the only unit for energy and the watt (W) for power. However, although everyone concurs in the necessity of using a single common unit to make statistics and publications of the energy sector readily comparable, a great variety of units is still in use. Even within one and the same country energy production and consumption figures are expressed in different units.

Accordingly, for this book a major effort was necessary for presenting data, tables and figures in joule, either by selecting appropriate illustrative materials or proceeding to time-consuming conversions. Nevertheless, some exceptions were made in order not to interfere too much in original presentations.

Fortunately, these difficulties will gradually be eliminated, since in recent years many governments have decided to make it compulsory for their countries to use the SI system. Such a decision was taken in the Federal Republic of Germany as early as 1970. However, the best hope is with the younger generation, which has been educated only in the new SI units and has no inertial attachments to the old ones.

A more subtle question, of substantive nature, is being debated in connection with the presentation of aggregate data in the energy sector: how to express in such cases in the same energy units quantities of fuels (heat) and of electricity.

A certain consensus – not general – was reached in agreeing to allocate, for hydro and/or nuclear produced electricity, a primary energy consumption equivalent to the fuel which would have been burned to produce the same amount of electricity in an average, typical thermal power plant. The discussion is, however, still open as to how to weigh the end-use energy delivered to a final consumer by one joule of electricity against one joule of heat in cases in which the useful energy output is very different, for example for mechanical energy supply.

This problem is not only important for energy balances of a general character but also for practical energy substitution problems, as well as for special combined processes such as co-generation of heat and power, where the joule of electricity has much higher working values than the joule of heat, which depends to a large extent on the temperature.

It is not possible to enter here into more detail on the above aspects, which are still vividly being discussed. However, the Refs [1.8–1.11], dealing comprehensively with the subject, may offer sufficient material for reflection and orientation. In one paper [1.9], P. Ailleret, in agreement with UNIPEDE (the international union of electricity producers and distributors), strongly advocates that just as at the production level where 1 kW·h is taken as equivalent to approximately 1/3 kgce, or 1 joule of electricity to 2.6 joule of fuel, the same equivalence factor should be used at the final consumption level. Consequently, UNIPEDE and the World Energy Conference issued in 1980 a publication, Substitutions Between Forms of Energy and How to Deal with them Statistically, strongly in support of this view [1.12].

The key issue of this debate is the approach one takes to the double structure of energy, as a sum of exergy and anergy, which is presented in the next section.

1.1.4. Energy as sum of exergy and anergy

Energy is considered a sum of exergy and anergy, and as such obeying the first law of thermodynamics, the law of conservation of energy. Ignoring for a moment the modern, unhappy use of the term conservation for energy husbandry or saving – which occurs only in English and Spanish – the cited law states that energy is never lost, only transformed. That applies as mentioned to the sum energy = exergy + anergy.

Exergy is defined as the maximum mechanical work that could be obtained from a heat carrier in a transformation from a certain physical status down to the ambient temperature. Such transformation is governed by the second law of thermodynamics stating that such a process is not possible unless the heat that has not been converted to mechanical work is evacuated to a second source (sink) of lower temperature. If the latter is of ambient temperature, the evacuated heat is the anergy component of the initial heat (energy) content.

From this over-simplified presentation it follows that for obtaining mechanical work from a heat carrier only its exergy content counts. The higher the temperature of the heat carrier, the higher is the exergy content.

Consider now in the light of the above comments, the equivalence of 1 joule of electricity and 1 joule of heat, this time at the end-use energy level. The equivalence will depend on the relative value of the service each of them offers the final consumer and this value also depends on the nature of the service, i.e. of the useful energy required. Therefore, an equivalence can be sought only if either fuel or electricity can be used competitively.

A few examples may better illustrate the problem:

(1) Demand for mechanical energy. If the end-use energy is carrier heat, then according to the above, for one joule of mechanical useful energy – which represents pure exergy – some 2.6 joule of energy have to be supplied in order to deliver 1 joule of exergy. If electricity is supplied – i.e. pure exergy – then only the small losses for converting electricity to mechanical energy intervene. Hence, 1 joule of effective electricity is equivalent for this purpose to a delivery of 2.6 joule of heat yet to be converted.

(2) Heating. In case of uncontrolled electric heating of entire buildings which were not designed for electric heating, the joule of electricity is worth only slightly more than the joule of fuel oil (about 1.3 times, due to the fact that the consumption of fuel oil necessarily entails chimney losses). This is a type of heating which one would hope will not develop too much.

In the case of rational electric heating where neither the thermal insulation nor the regulation are optimized to the same value for electric heating as for oil heating, the equivalence factor is easily double.

It is even higher in space heating using heat pumps – whose coefficient of performance varies depending on whether or not there is recovery from the extracted air – where the average equivalence factor seems to be between 2.5 and 3 joules of fuel for one joule of electricity [1.9].

(3) Industry. In industrial utilization even higher equivalence factors may be met, especially in many heat processes or drying operations.

Naturally, it is in the areas where the conversion factor is the highest that substitutions of electricity for hydrocarbons are developed most easily, and these substitutions are essential in order for oil to be reserved for its specific utilizations during the critical period which will occur between 1985 and 1995.

By weighting these equivalence factors by the importance of each of the utilizations concerned, an average equivalence factor is obtained which then makes it possible to add joules of fuel to joules of electricity multiplied by this equivalence factor. There are at present no statistical data to evaluate this weighting factor but it is obvious that it is between 2 and 3.

It is not, therefore, very far from the value of 2.6 which corresponds to the substitution of hydro-electricity and nuclear energy in present thermal power stations and in those which will continue to be built in many countries, in particular countries which are rich in coal and in the developing countries.

It would therefore seem judicious to base energy statistics on this factor both for energy at the consumer level and for primary energy, with the possibility of changing it slightly later on, when one had more precise estimates of the coefficient of substitution of joules of electricity for joules of fuel [1.9].

The above equivalence refers to the valuation at the end-use energy delivery level for the same service of useful energy. However, the whole picture of efficiency, i.e. the specific consumption of primary energy for the alternative supplies, depends on the upstream efficiencies in the chain primary energy – end-use energy. If electricity is of hydraulic origin, then it is supplied from a conversion of exergy into energy of high efficiency. If it is produced from coal exergy but via a heat cycle, then it is affected by the high aforementioned energy losses.

Anyhow, the correct approach is to observe in a comparison the double structure exergy-anergy. The sum, energy, is not lost in a conversion, it is conserved, but the quality – exergy – which is determinant for useful energy, diminishes.

For the above reasons the full picture of energy conversion processes is obtained only from a combined exergy – energy evaluation, as for example is undertaken in chapters 6 and 8 for separate thermal electricity production or in co-generation with heat supply.

For aggregation purposes – energy balances and energy flow charts – the equivalences introduced in production and end-use energy would substantially improve the global picture. However, although, with some exceptions, equivalence factors are used at the primary energy level, no national balance is known yet where they have been introduced at the end-use energy level.

Time permitting, it would certainly be worth debating in more detail the above aspects in a round-table discussion of the course, possibly linked to energy as the sum of exergy and anergy components.

1.1.5. Energy flow charts and energy balances

The energy flow chart of an energy system is elaborated by substituting for the thin characteristic lines suggesting possible energy chains in Fig.1.2 the actual energy flows, expressed in a common energy unit and represented on a convenient scale by the width of the respective ramifying bands.

In this manner, a representation is gained which visualizes the physical energy flows so as to give a rapid overview, where not only the structure of the system can be recognized, but also the occurring energy losses identified and evaluated. Such energy flows can refer to a geographical framework which could be a country, a region, the entire world or to a determined entity – an industry, a workshop or even a small energy consumer, a house or an industrial machine.

In parallel to energy flow charts, themselves a graphic energy balance, numerical energy balances – energy balance sheets – are very much used both for accounting purposes and energy efficiency analysis for auditing.

In fact an energy balance summarizes the quantitative behaviour of an energy system for a given time period. It could apply for a past period and as such be based on statistical data or elaborated for the future. It took some time, however, to recognize in the initial energy balance sheets of accounting character an efficient analytic tool reflecting the system dynamics when examining past series, or comparing future alternative energy developments.

At the present stage, with a few exceptions, the energy balances do not extend into the final stage of the energy system, i.e. do not include the consumption of useful energy. They stop short at this point, quantifying only the end-use energy. Therefore, neither the losses nor possible waste in the final consumption stage are accounted for. Nor do they include on the input side figures on energy resources left in situ owing to low recovery factors, nor expand on the potential of the reserves or resources themselves.

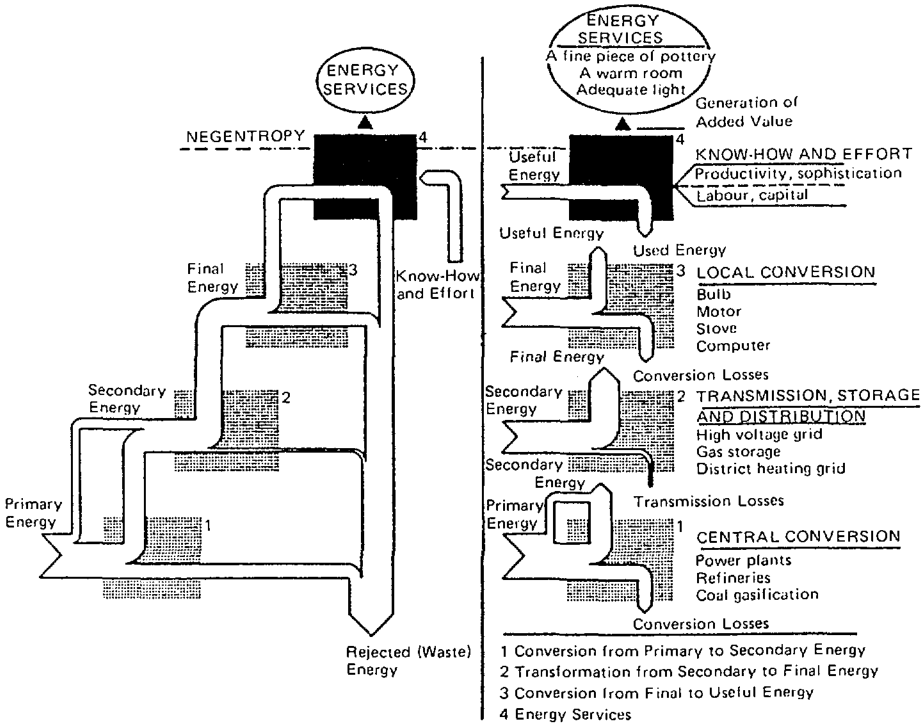


FIG.1.3. Basic energy flows in an energy system [1.13].

However, in spite of the above-mentioned limitations, energy balances are extremely useful instruments both for general assessment of more complex energy systems and for detailed studies of some specific aspects. Global energy balances can for example usefully serve for:

– evaluating the dynamics of the historical evolution of the energy system in relation to the general socio-economic development and the individual economic sectors
– an in-depth study of the structure of the involved energy system
– determining for each energy resource the competitive uses and conservation potential, both for savings as well as for substitution
– better organization and management of energy data and information
– offering a reliable basis for short-term energy planning and supportive reference for medium- and long-term energy projections and scenarios.

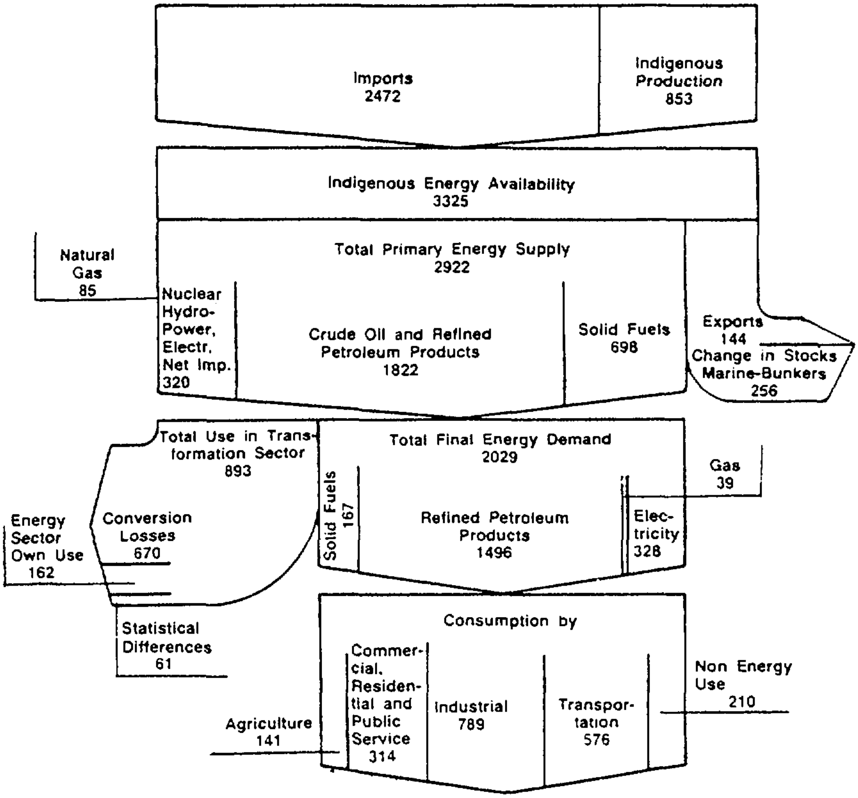


FIG.1.4. Diagram of energy flow in Spain in 1981 (in PJ) [*1.14*].

In addition to global energy balances and based on the same concept and methodology, less comprehensive overall energy balances, or balances for specific energy forms, for example, electricity, can prove of great help for special studies and purposes.

While the techniques for the elaboration of national energy balances for past periods and forecasts for the future will be dealt with in chapter 17, the following figures should offer an overview on the diversity of approach of energy flow charts and energy balances:

(1) Basic presentation. Figure 1.3 displays the energy flow in the basic levels of an energy system.

(2) Energy balance of Spain. Figure 1.4 presents the energy balance of Spain in 1981, expressed in PJ. Impressive is the strong dependence of Spain on imported primary energy, almost 75%.

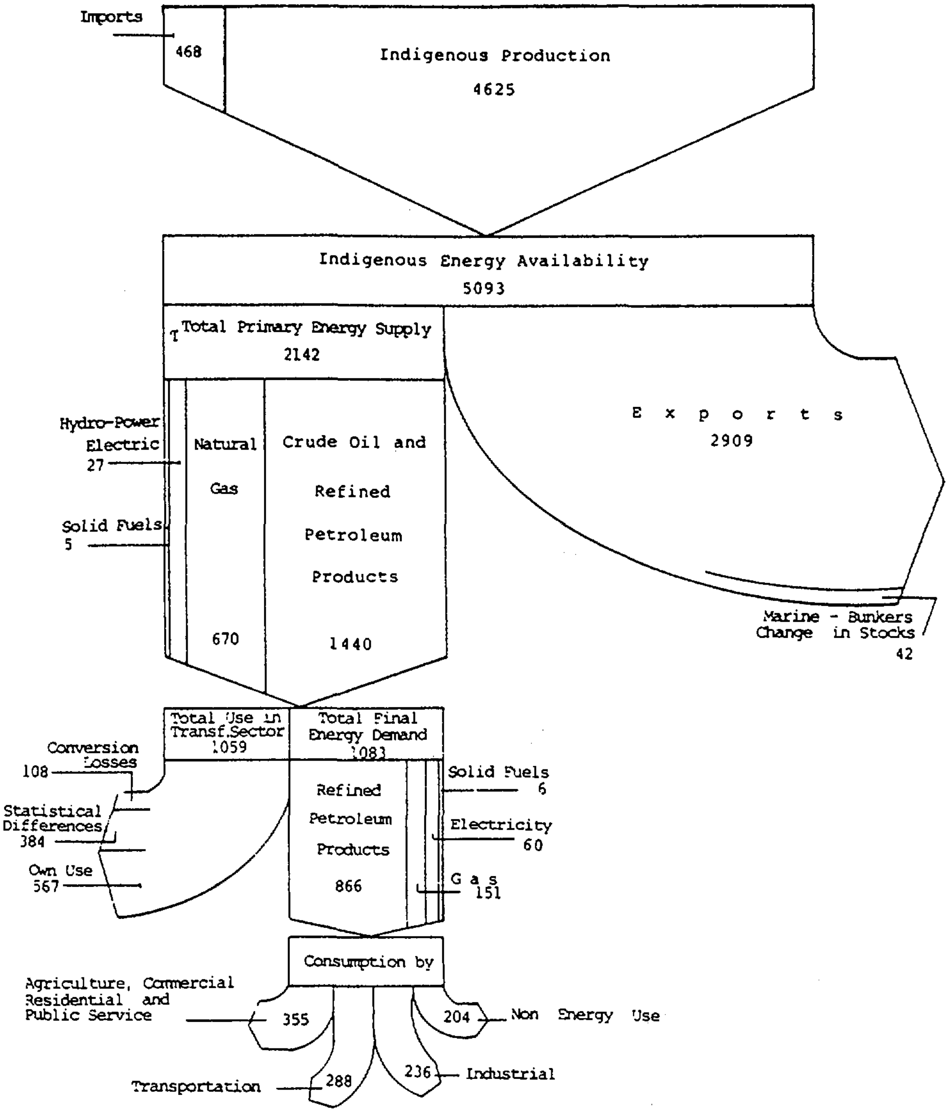


FIG.1.5. Diagram of conventional energy flow in Indonesia in 1981 (in PJ) [*1.15*].

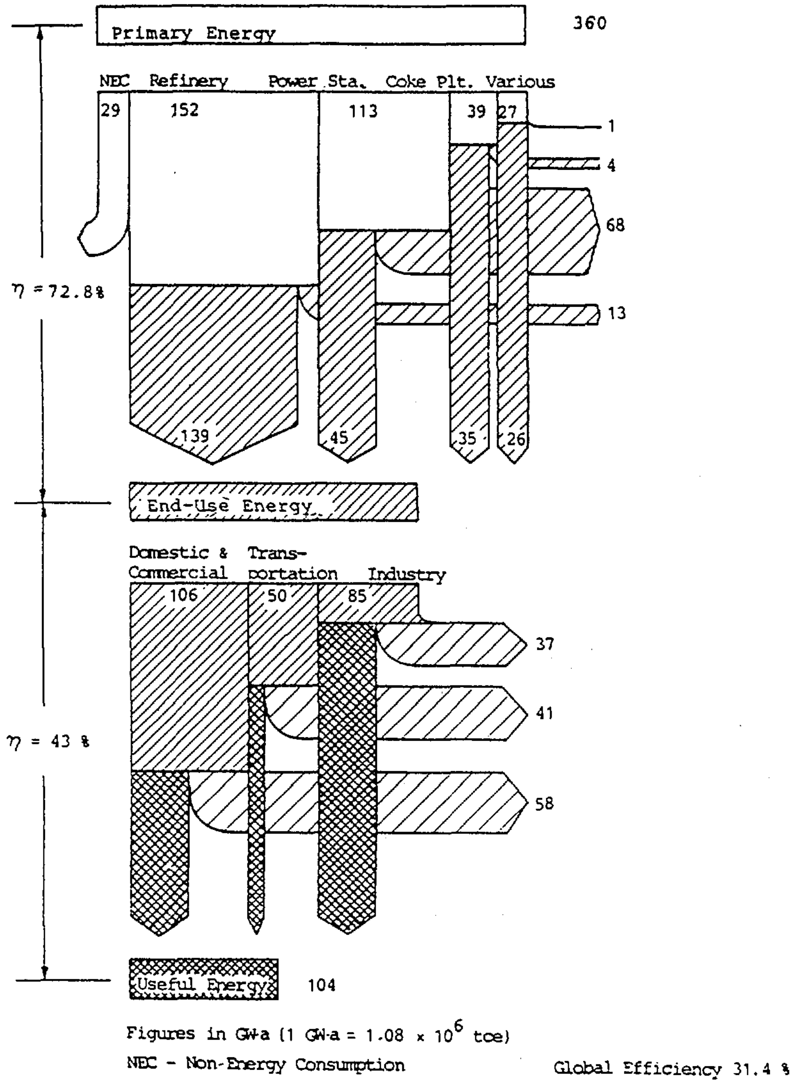
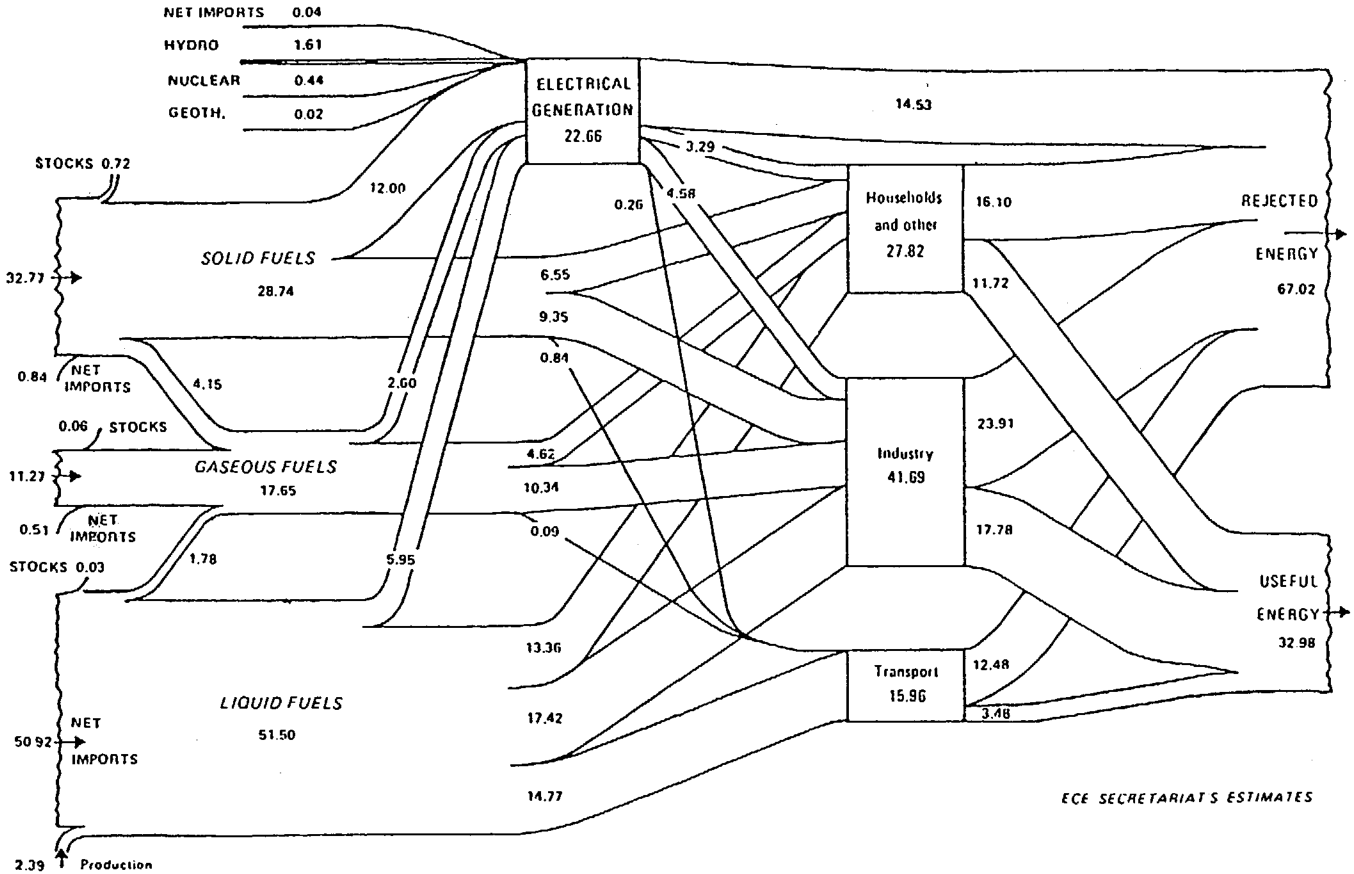


FIG.1.6. Energy flowchart in the Federal Republic of Germany in 1978 [1.16].



* USSR is not included.

FIG.1.7. Energy flow in Europe in 1972 in % [1.17].

(3) Commercial energy flow in Indonesia. Figure 1.5 shows the flow of commercial energy in Indonesia in 1981, expressed in PJ. Notable is the great proportion of exports of crude oil, a small import of petroleum derivatives and an incipient export of LNG. However, Fig. 1.5 does not reflect the real energy balance of the country, since it does not include the consumption of non-conventional primary energy which represents a high share in this country.

(4) Others. It should be mentioned that both Figs 1.4 and 1.5 originate from a set of national energy data reports for the year 1981, which were presented at the 12th WEC Congress in New Delhi, conveniently organized in an unitary presentation, each prepared by the National Committee for the World Energy Conference of the country.

(5) Energy flow chart of the Federal Republic of Germany. Figure 1.6 displays the national energy flow in 1978, including the final consumption stage. The average efficiency in preparing the end-use energy supply was 72.8%, the efficiency of the end consumption was 43%. The global efficiency reached amounted to 31.4%. Remarkable is the useful energy structure: share of the domestic and commercial subsector 45.6%, its final efficiency 48%; transportation has an 8.8% share, for an average efficiency of 18% and industry a share of 45.6% and an efficiency of 56.5%. While the structure of needs (useful energy) was (in %) 46.5:8.8:46.5 the structure of the consumed end-use energy was 44:20.8:35.2. It is really regrettable that no more international information is available on the end-use stage of the national energy systems, since as shown here, the information, even as average figures, provides extremely valuable results, especially for energy saving and substitution.

(6) Energy flow in Europe. In order to illustrate the energy flow in a major region, Fig. 1.7 displays the structure of the energy flow in Europe in 1972, which could still be regarded as characteristic. The overall efficiency is 32.98%, a comparatively good international figure.

(7) Energy flow chart in an industry. Figure 1.8 presents the energy flow chart of an iron and steel plant with an annual output of 500 000 t. The overall efficiency of the plant is about 36.5%, with all quantities of technological heat included and would be only 6.6% if the figure were to refer solely to the useful energy consumed [1.18].

Without entering into more details at this stage, it should be mentioned that for the qualitative and quantitative evaluation of certain conversion processes, the exergy balances and flow charts might prove very useful. However, except for some national exergy balances published for Austria in the 1960s, no other attempts to draw up such balances at national level are known. Instead, there are sufficient simpler cases where the exergy analysis, parallel to the energy analysis, explains the thermodynamic conditions of a thermal conversion process. A typical example is the co-generation

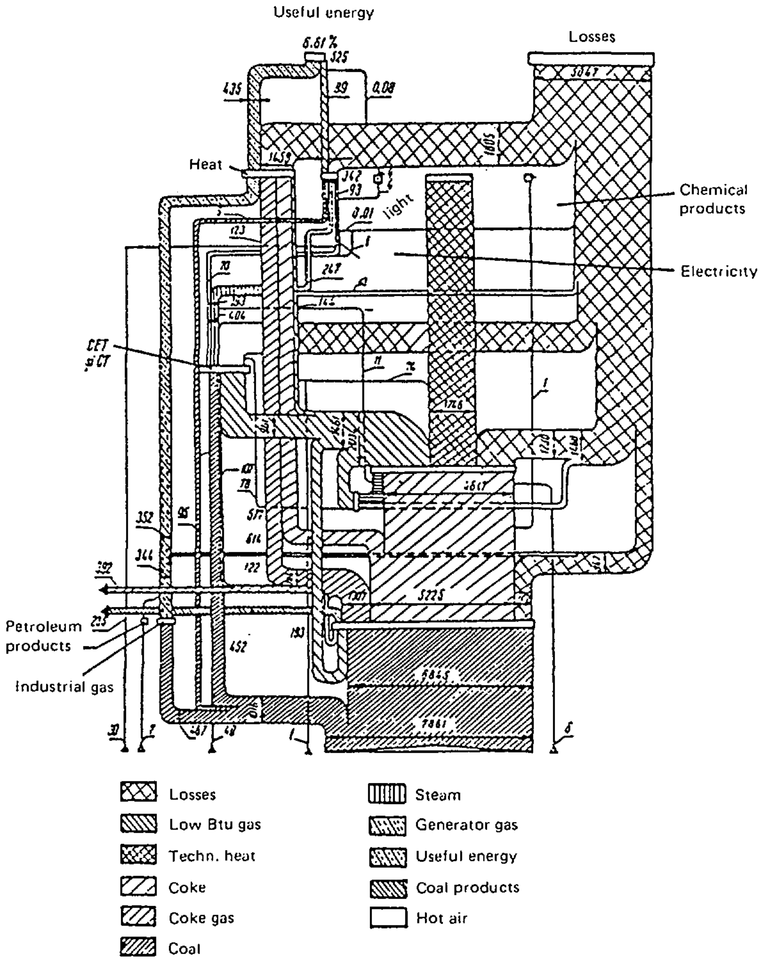


FIG.1.8. Energy flowchart in an iron and steel plant in 10^9 kcal/a (4.185×10^9 kJ/a) [1.18].

of electricity and heat for industrial and district heating supply, dealt with in subsection 8.2.1, where both the exergy concept and balance are commented on and an energy-exergy flow diagram (Figs 8.8–8.10) is shown in illustration.

A simplified representation illustrates in Fig.1.9 the share of exergy (electricity and mechanical energy), useful heat and energy losses in a few characteristic conversion processes. Again, the low efficiency of automotive transportation strikes one as disappointing.

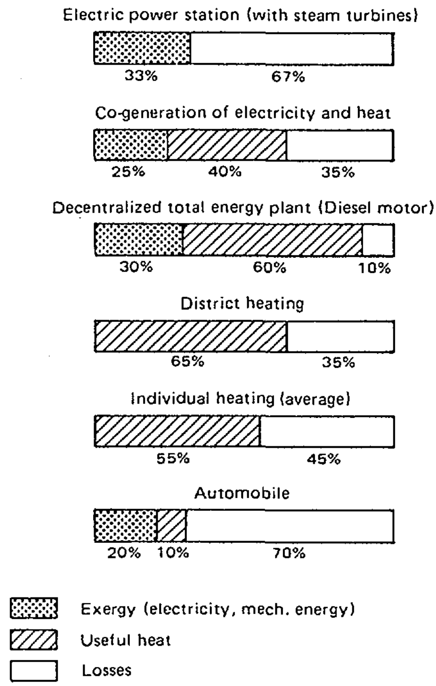


FIG.1.9. Energy, useful heat and energy losses in various conversion processes [1.20].

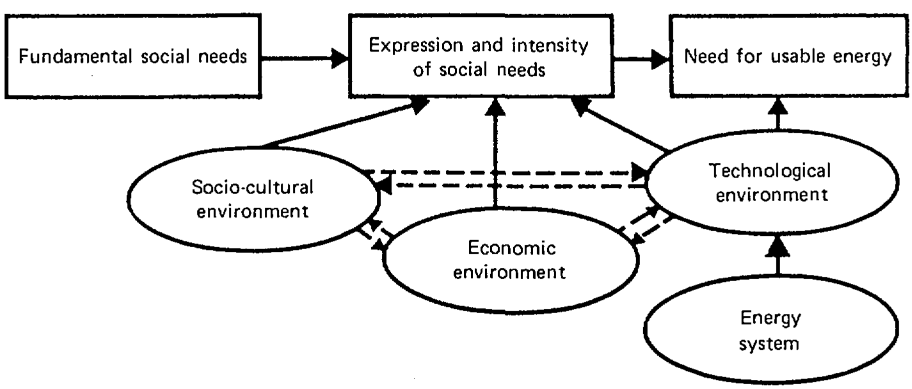


FIG.1.10. The socio-economic integration of the energy system [1.21].

1.2. Economic issues

1.2.1. Socio-economic integration of the energy system

A national energy system is deeply embedded in the country's socio-economic environment and has also external relations of international or even worldwide character. Its integration occurs both at macro- and microeconomic level, since, as M. Munasinghe points out in Ref.[1.20], energy permeates the whole economy and acts as the physical counterpart of money.

The economic and financial aspects of energy are dealt with in detail in chapters 10, 11 and 12 but are, in addition, referred to in other chapters when relevant aspects arise.

Figure 1.10 illustrates the socio-cultural, economic and technological environment in which the energy system is embedded and how it finally serves the fundamental social needs of mankind and society [1.21]. Not represented in Fig.1.10 is the physical environment, which may both favour and constrain the energy system.

The multilateral and complex relationship of the energy system with the biosphere, economy and society makes an optimization of its development very difficult. In fact it could only be tackled with the help of modern tools, in a global systems analysis approach and using computer models of comprehensive structure and high computing power.

Following its heading, this chapter will refer exclusively to the economic aspects of the energy system, and mainly to its external links to the general economy. The internal aspects are treated as mentioned, in the specialized chapters.

1.2.2. Energy and economic development

The historical evolution of different countries or groups of countries over long periods of time confirms the fact that economic growth generally has induced an increase in the total energy consumption and vice versa; more readily and more cheaply available energy has definitely favoured economic development.

Together with dedicated work and high intellectual inputs, increased use of energy in the last century brought the industrialized world an eight times higher real income, half the working hours and twice the life expectancy. However, the increase in energy input is considerable. Compared to a yearly individual physical work potential of around 100 kW·h, the annual electricity consumption alone per head in these countries averages 6100 kW·h. Or, as another example, the specific output of a worker in the energy-intensive steel industry is a thousand times the individual work potential.

While the described situation confirms a relationship between energy and economy, the evolution of recent decades has shown that the relationship

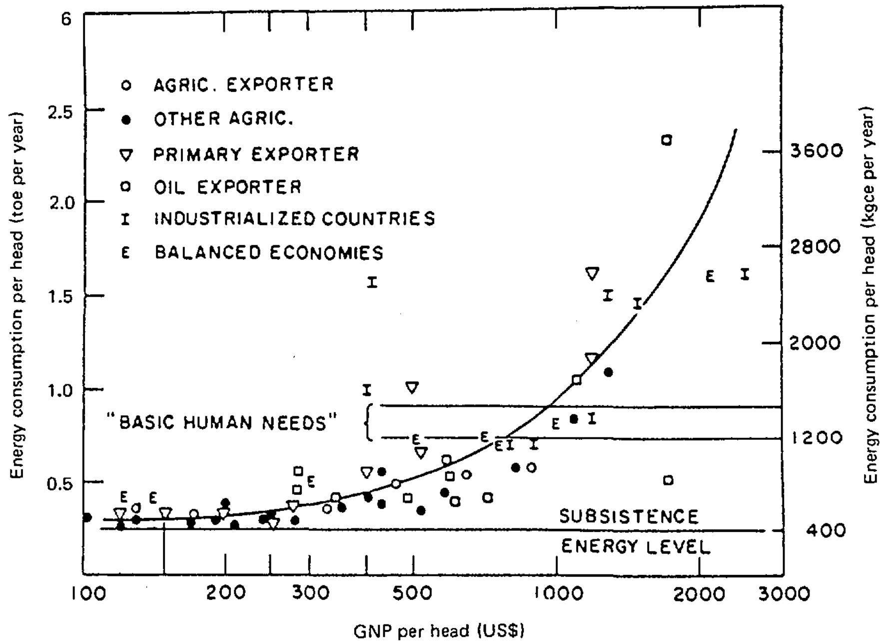


FIG.1.11. Relationship of per head energy consumption to per head GNP [1.23].

between economic growth and energy consumption is much more complex than was believed in the past.

1.2.2.1. Energy/economic growth relationship assumed in the past

Many energy studies carried out in the last fifteen years were based on the following four major assumptions [1.22]:

(1) Energy consumption and gross national product (GNP) are closely correlated. Some authors went even further and said that energy consumption was proportional to the national income.

(2) All countries are following more or less the same pattern of development, the only difference being the time lags. It is like trains following each other on the same track.

(3) Energy sources appear as successive waves which succeed one another inexorably at rates which can be evaluated and extrapolated. D. Marchetti at IIASA has developed this concept very far.

(4) Prices of energy have a direct impact on the amount consumed. These impacts estimated by different types of elasticities on past-time periods can be utilized as forecasting tools.

Each of these assumptions is neither totally wrong nor totally correct and might be discussed and further investigated. However, anybody utilizing them should be aware of the simplifications which lie behind each one and of the risk of uncertainties they may introduce.

(1) Energy consumption versus gross national product (GNP). There have been many graphs published showing the excellent correlation between energy consumption and GNP. Sometimes, these graphs show the evolution of a given country over a long period of time; at other times the graphs are related to a cross-section of different countries at a given time or else they combine both, cross-section and trend evolution. The relationships between energy and GNP are expressed either on the global level or on a per head basis.

Figure 1.11 displays one of these popular curves showing the relationship of per head energy consumption to per head GNP for countries at different development stages.

Figure 1.12 shows fragments of curves relating energy per head (GJ) to GNP per head (10^3 US \$ 1975) in (a) developed and in (b) developing countries.

Plotted on logarithmic scales, all these different clouds of points are analytically estimated by a linear equation in log-log:

$$\log E = a + b \cdot \log Y$$

E is energy consumption and Y is GNP

or a power function: $E = AY^b$

The second step consists of evaluating the coefficient of elasticity between energy and GNP, that is to say, the ratio between the increase rate of both, thus:

$$e = \frac{\Delta E/E}{\Delta Y/Y} = \delta \log E/\delta \log Y = b$$

The coefficient of elasticity b is used later on to make energy forecasts when the future GNP is assumed to be known.

Several remarks could be made on these types of simple and very aggregate relationships:

– Most of the graphs are drawn on logarithmic paper which has a large scale effect, smoothing results which otherwise could appear incoherent.
– The elasticity coefficient thereby obtained is an approximation of the income elasticity. GNP is a useful substitute for the national income generally less ascertainable by statistics. But the tax system of a given country can completely bias the relationship because:

GNP = National Income + Taxes + Depreciation (amortisation)

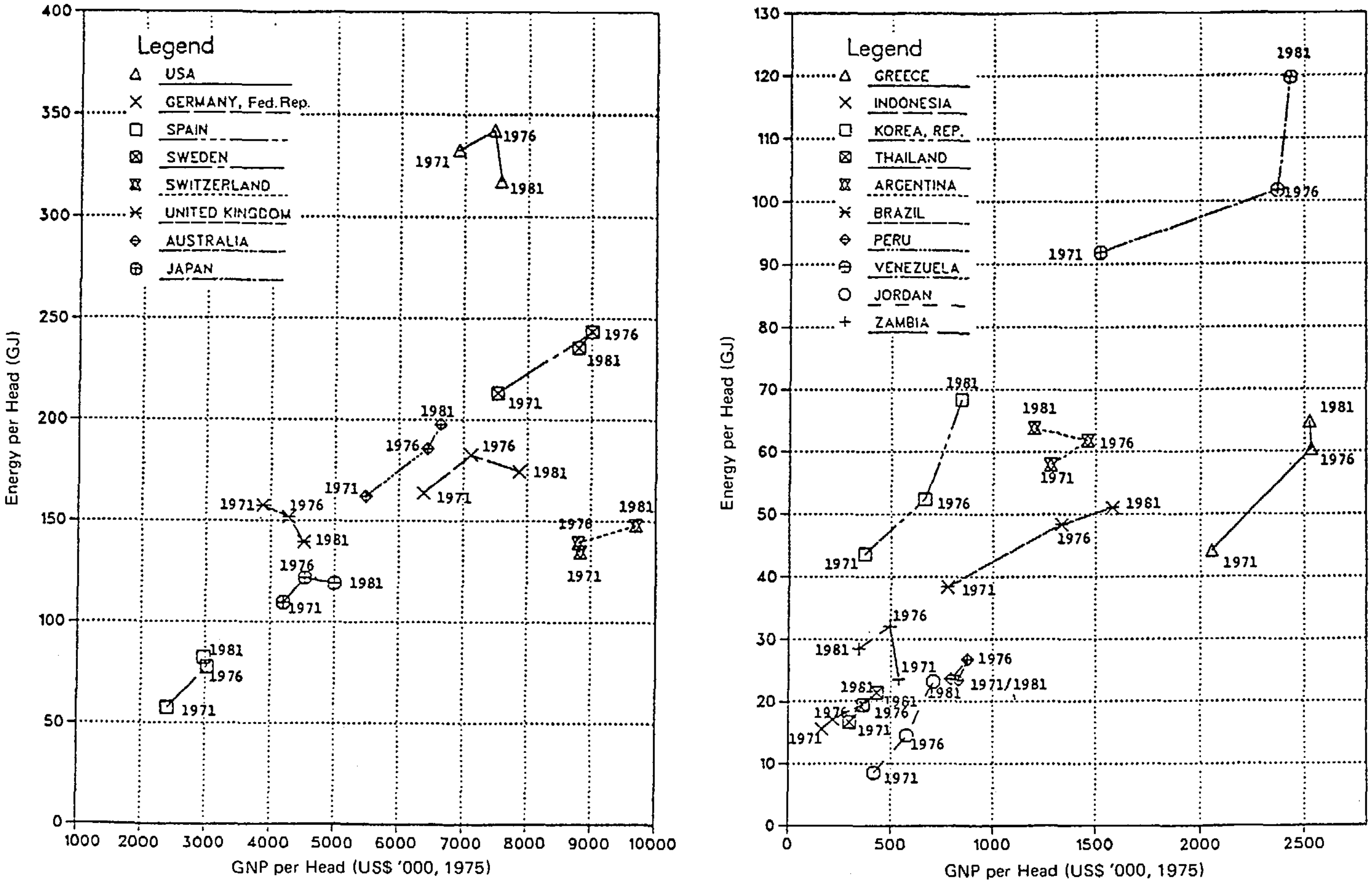


FIG. 1.12. GNP per head versus energy consumption per head in: (a) developed countries, (b) developing countries [1.22].

– If such a correlation between energy and GNP were structurally correct, it should be possible to verify it at any level of the economy's structure; which is not the case. Therefore, one could suspect that such a good correlation is rather due to the effect of large numbers than to a real structural link.

Although such a relationship is too general to be the basis of energy consumption forecasts, it has unfortunately continued to prompt a number of long-term energy demand projections.

(2) Patterns of energy and economic development. Since it was supposed that all countries are following the same pattern of development, defined once and for all by those who started their industrialization first, energy consumption could be forecast based on the historical evolution of the more advanced countries.

It was only after 1975 that the model USA (with an energy consumption of 11.3 tce/head in 1973 and 16.0 in 1980) was not used any more, since it was realized that the Western European countries did quite well at less than half these figures – see Tables 13.IV and 13.V. Subsequently, correction coefficients were introduced in the correlation equations and it was realized that useful energy consumption figures and not primary energy consumption should have been used.

(3) Inexorable succession of energy resources waves. C. Marchetti believes that growth in energy consumption depends neither on economic growth defined in terms of time and place nor on the availability of a particular energy resource, but is prompted by the succession of energy waves (wood, coal, oil, natural gas, nuclear, etc.) whose present rates are proportional to the fraction of the market not yet covered [1.22].

According to his law of market penetration, the change-over from one energy source to another must take place well before all the resources are exhausted. As an example he deduced that the slowness of substitution rates (about 100 years to move from 1% to 50% of the market) precludes the possibility of solar or fusion energy taking a significant share of the market before 2050.

(4) Impact of energy prices on consumption generally is measured by coefficients of elasticity to price:

$$e_i = (\Delta E_i/E_i)/(\Delta p_i/p_i)$$

where E_i is a given form of energy and p_i its price. There are different types of elasticity coefficients: short-term and long-term. There are also cross-coefficients of elasticity, that is to say, coefficients which try to estimate the impact of price evolution of a given form of energy on another form (e.g., impact of price of oil on coal consumption):

$$e_{ij} = (\Delta E_i/E_i)/(\Delta p_j/p_j)$$

TABLE 1.I. COMMERCIAL ENERGY CONSUMPTION AND GNP PER HEAD, AND ENERGY CONTENT OF GNP [1.25]

Country[a]	Consumption of commercial energy (kgce/head)	Per head GNP at market prices (US$)	Energy consumption per unit of GNP (kgce/US$)
AFRICA			
Algeria	662	1 110	0.60
Egypt	467	310	1.51
Kenya	141	270	0.52
Libyan Arab Jamahiriya	936	6 680	0.29
Morocco	293	570	0.51
Nigeria	107	420	0.25
South Africa	3 157	1 340	2.36
Sudan	165	300	0.55
Tunisia	529	860	0.62
Zambia	483	450	1.07
Zimbabuc	598	500	1.20
MIDDLE EAST, ASIA AND THE PACIFIC			
Australia	6 648	7 340	0.91
Bahrein	13 196	3 790	3.48
Bangladesh	39	90	0.43
China	761	410	1.86
Democratic People's Republic of Korea	2 646	700	3.78
Hongkong	1 565	2 590	0.60
India	178	150	1.19
Indonesia	290	300	0.97
Iran	1 542	2 180	0.71
Iraq	647	1 530	0.42
Israel	2 359	2 920	0.81
Japan	3 806	5 640	0.67
Korea, Republic of	1 240	810	1.53
Kuwait	6 616	12 700	0.52
Malaysia	733	930	0.80
New Zealand	3 720	4 370	0.85
Pakistan	170	190	0.89
Philippines	342	450	0.76
Qatar	27 109	11 670	2.32
Saudi Arabia	1 169	4 980	0.23
Singapore	2 433	2 890	0.84
Syrian Arab Republic	982	900	1.09
Thailand	327	410	0.80
Turkey	792	1 110	0.71
United Arab Emirates	18 494	14 420	1.28
Viet Nam	127	170	0.75
EUROPE			
Albania	954	610	1.56
Austria	3 887	6 140	0.63
Belgium	6 058	7 580	0.80
Bulgaria	4 847	2 590	1.87

Country[a]	Consumption of commercial energy (kgce/head)	Per head GNP at market prices (US$)	Energy consumption per unit of GNP (kgce/US$)
Czechoslovakia	7418	4 090	1.81
Denmark	5 535	8 050	0.69
Finland	5 202	6 150	0.85
France	4 353	7 290	0.60
German Dem. Rep.	6 941	4 940	1.41
Germany, Fed. Rep. of	5 783	8 160	0.71
Greece	2 010	2 810	0.72
Hungary	3 437	2 570	1.34
Ireland	3 274	2 880	1.14
Italy	3 128	3 450	0.91
Luxembourg	14 782	7 150	2.07
Netherlands	5 697	7 160	0.80
Norway	5 461	8 540	0.64
Poland	5 457	3 150	1.73
Portugal	1 039	1 850	0.56
Romania	4 059	1 580	2.57
Spain	2 430	3 190	0.76
Sweden	5 948	9 250	0.64
Switzerland	3 679	9 960	0.37
United Kingdom	5 103	4 430	1.15
USSR	5 410	3 010	1.80
Yugoslavia	2 030	1 960	1.04
NORTH AND CENTRAL AMERICA			
Canada	9 994	8 450	1.18
Cuba	1 225	900	1.36
Dominican Rep.	442	840	0.53
Jamaica	1 763	1 150	1.53
Mexico	1 330	1 110	1.20
Puerto Rico	4 638	2 460	1.89
Trinidad and Tobago	4 469	2 380	1.88
USA	11 574	8 640	1.34
SOUTH AMERICA			
Argentina	1 837	1 730	1.06
Bolivia	359	540	0.66
Brazil	770	1 390	0.55
Chile	990	1 170	0.85
Colombia	720	710	1.01
Ecuador	439	770	0.57
Peru	646	830	0.78
Uruguay	1 019	1 450	0.70
Venezuela	2 979	2 820	1.06

[a] Countries consuming over 2 million tons coal equivalent in 1977.
Source: United Nations *World Energy Supplies 1973–1978*, New York (1979), and *World Bank Atlas 1978*, The World Bank, Washington, D.C.

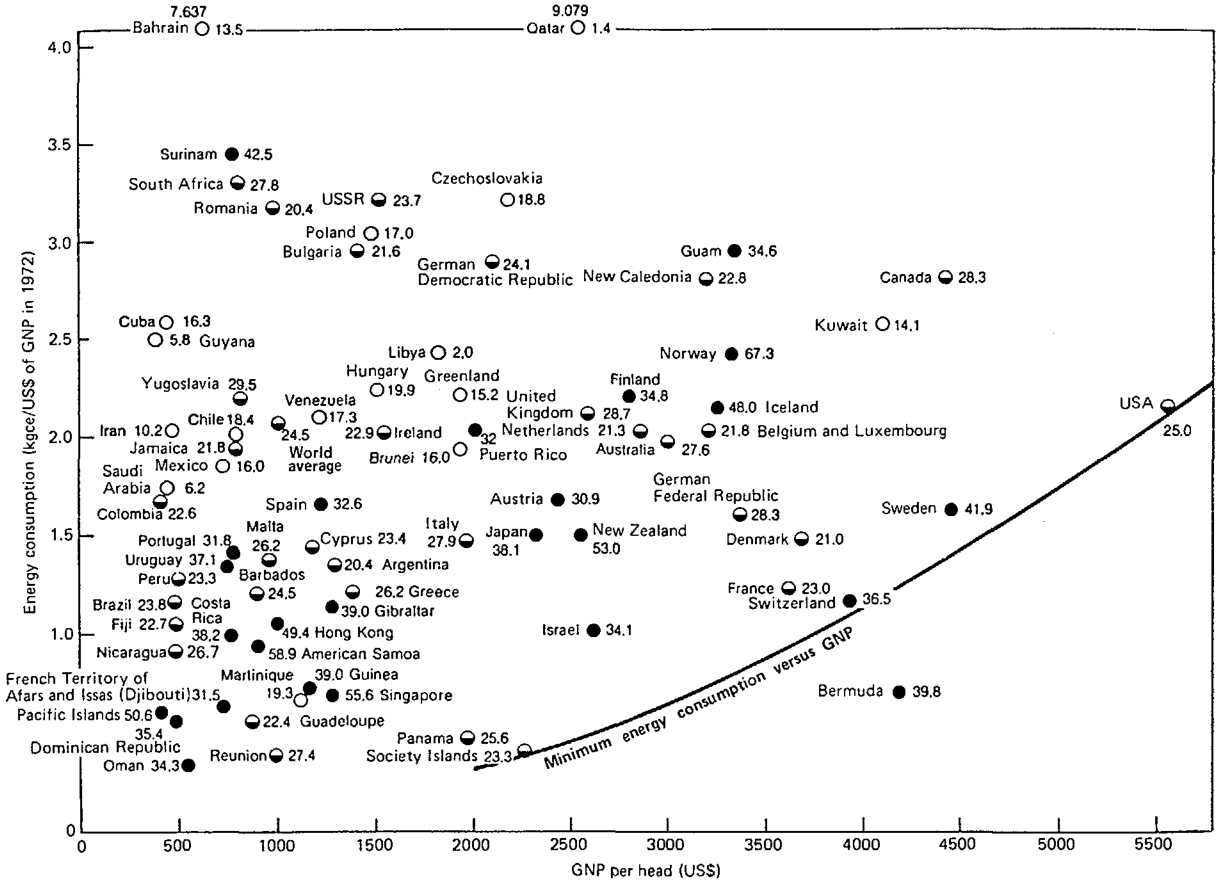


FIG. 1.13. Energy consumption in kgce per US$ of GNP in 1972 [1.26].

The short-term elasticities measure the immediate variations in consumption following a perturbation in prices, incomes or both together. If, after a certain time, these variations produce more profound changes in the economic structures (for example, replacement of individual by collective means of transport, or a change in the methods of heating, etc.) and thereby modify the consumption of energy, the resultant variations are supposed to be measured by the long-term elasticities.

1.2.2.2. The energy content of the GNP

The foregoing subsection concentrated on criticism of the correlation between energy consumption and economic growth used in the past and of some premises, wrongly considered immutable laws. It was considered that a simple warning against any temptation to link energy consumption to GNP growth in ways which are simplistic, rigid and necessarily inaccurate, would not be sufficient to curb inertial habits or even taboos. However, sound reactions against the superseded practices have never been lacking. For example, N.E. Berrah, an energy planner from Algeria, vigorously appealed for a change of attitudes on the subject and for developing countries to look to a new concept of the relationship between energy consumption and development: for the 'tunnel effect' to overcome the 'energy mountain' raised between them and their future well-being [1.24].

However, since in fact energy and the economy are related and especially medium- and long-term energy demand projections must somehow take this linkage into account, a deeper insight into the related aspects is necessary.

An interesting approach consists in the study of the energy content of the GNP. Indeed, the energy sector plays a crucial role in the economy of countries. In most developing countries, for example, the expenditures for fuel consumption represent a significant share of the GNP, varying between 10 and 25% according to the structure of the country, the types of fuel consumed and the level of development. In addition, expenditures for investments in the energy sector often correspond to 9 to 12% of the total investments or to 2 to 3% of the GNP. (In most large developing countries, such as Colombia, Brazil, Indonesia, India, etc., investment expenditures globally represent 20 to 25% of the GNP.)

Altogether, fuel consumption and investments for energy reach 12 to 28% of the total GNP, i.e. an average of close to one quarter.

It appears that it might be possible to draw some conclusions from the comparison of the energy content of the GNP. For this purpose two major groups of factors have to be taken into account:

- those related to the structure of the national economies measured by the relative share of the value-added of each economic sector within the global GNP: VA_i/GNP.

– those involving the way in which energy is used and is directly related to the technology utilized. These factors can be measured by the energy content per unit of each value-added supplied: E_i/VA_i.

If possible, one should go further and ask whether the structural and technological differences either between countries or through time for a given country have not themselves been influenced by given features of the energy supply due to specific conditions only valid for a certain period of time and for a certain region.

However, the analysis of the energy consumption per unit of GNP is not so simple when cross-sectional data for 80 countries are taken, as shown for example for 1977 in Table 1.I [1.25].

The differences between countries are extremely wide. Countries with the highest energy consumption per head do not have the largest per head GNP, and similarly those with low energy use do not necessarily have low levels of income. The energy use per dollar of GNP ranges from the low of 0.23 kg of coal equivalent in Saudi Arabia to the high of 3.78 kg of coal equivalent in the Democratic People's Republic of Korea. To achieve essentially the same level of GNP per head, Poland consumes more than twice the amount of energy per head as Spain. Similarly, Jamaica consumes almost double the energy per head to achieve the economic level of Chile. And comparisons between the developed and the developing countries are perhaps even more revealing. Thus, the Federal Republic of Germany consumes about 0.8 kg of coal equivalent per dollar of GNP, the same as, for example, that used by Turkey or Uruguay at substantially different levels of development.

As can be seen, a similar level of economic development or standard of living does not necessarily mean a similar level of energy consumption. Although there is some tendency for energy consumption to vary with GNP, the large inter-country differences indicate the presence of many other factors which affect the use of energy in each country. These include economic, geographical, cultural and many other factors. In addition, a high level of energy consumption per dollar of GNP may mean a high standard of living or inefficient use of energy. Consequently, it is important to bear in mind when making inter-country comparisons that a high energy/GNP ratio may not necessarily be an indication of inefficiency or waste.

Figure 1.13 visualizes the energy content of GNP versus the per head energy consumption for 84 countries with a GNP per head higher than US \$400 in the year 1972. It complements Table 1.I for a quite notable world overview [1.26].

An interesting analysis was carried out in 1972 by J. Darmstadter [1.27] comparing the energy content of the GNP in the USA and in Western Europe. He estimated this content at 1490 toe per million US dollars in the USA and at 1000 toe per million US dollars in Western Europe on average, and tried to explain the difference of 490 toe per million dollars of GNP. He searched

TABLE 1.II. COMPARISON OF THE ENERGY CONTENT OF GNP IN THE USA AND IN WESTERN EUROPE [1.22]

The US energy GNP content exceeds by +490 TOE the European energy content of GNP	+134 are due transport of people.	+ 58 are due to distances. + 52 are due to means of transport. +24 are not explained.
	+30 are due to transport of goods.	+75 are due to amount and distance. -5 are due to means of transport. -40 are unexplained.
	+40 are due to household heating/conditioning	+30 are due to size of households +30 are due to means of heating/conditioning -20 are due to climate
	+100 are due to Industry	-200 are due to structure of industrial sectors +300 are due to techniques utilized.
	+186 are due to unexplained factors.	

for the origin of this discrepancy in the difference both in sectorial structures of the economy and in the technological factors which have an impact on each of the sectors.

The results are presented in Table 1.II [1.27].

The negative sign explains a most favourable situation of the USA compared to Europe regarding the factors considered. For example, for transport of goods the role of pipeline networks within the USA gives an advantage to the USA due to the fact that per t·km of goods transported this means is less energy-consuming than other ways.

A recent study of the French Institut économique et juridique de l'énergie (IEJE) [1.28] trying to analyse the diminution of energy consumption in France since 1978, shed some light on the evolution in some other highly industrialized countries. Figure 1.14 displays the % evolution of GNP and primary energy consumption between 1972 and 1981 in the USA, Federal Republic of Germany, United Kingdom, France, Italy and Japan. Interestingly enough, the curves of energy consumption all show their minimum in 1975 and their maximum in 1978, and then all continued to decline. The GNPs

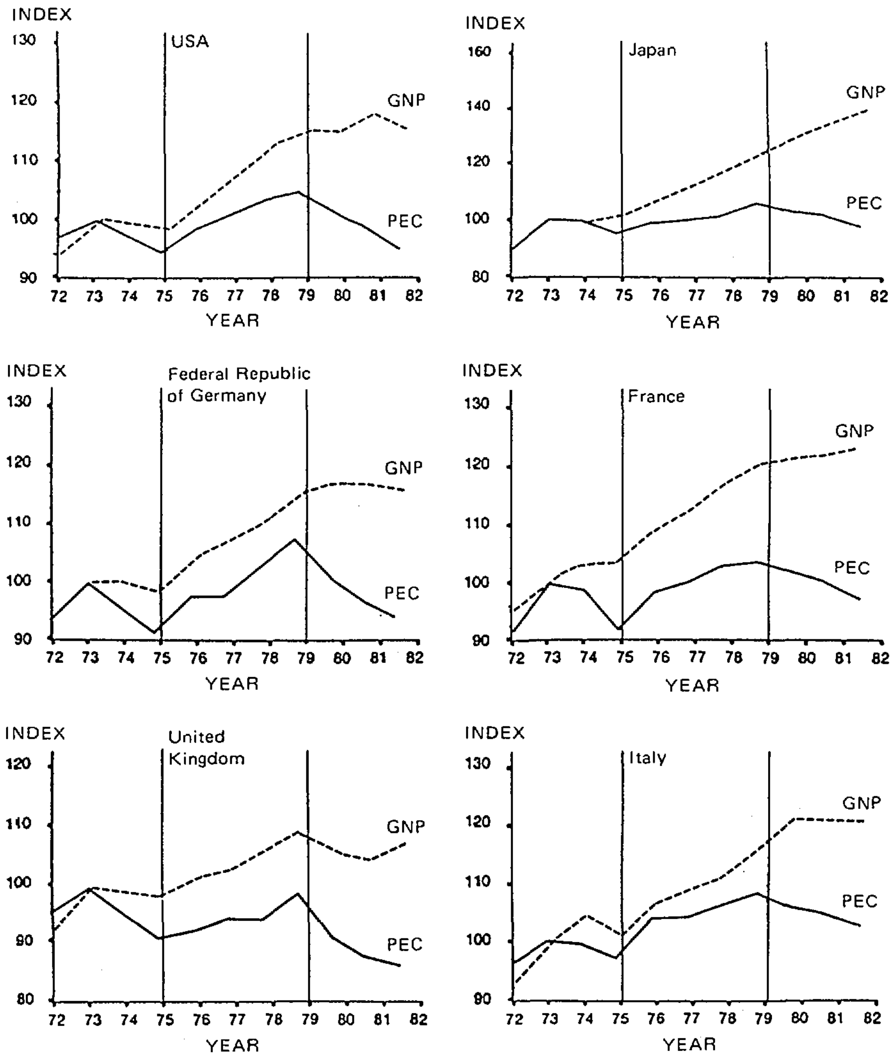


FIG.1.14. Evolution of GNP and primary energy consumption in some highly industrialized countries between 1972 and 1981 in % [1.28].

TABLE 1.III. EVOLUTION OF ENERGY CONTENT OF GNP IN SOME HIGHLY INDUSTRIALIZED COUNTRIES [1.28]

	1973	1975	1979	1982
USA	100	95	90	81
Japan	100	93	85	70
Fed. Rep. of Germany	100	92	93	81
France	100	88	86	78
United Kingdom	100	92	90	80
Italy	100	96	93	84

TABLE 1.IV. ENERGY CONTENT OF GNP IN 1972 [1.26 and 1.28]

Country	toe/10^6 US$ (1972)	Index
USA	1 480	100
Canada	1 772	120
Netherlands	1 272	86
United Kingdom	1 121	76
Sweden	1 072	72
Fed. Rep. of Germany	1 031	70
Italy	951	62
Japan	849	57
France	795	54

show in contrast, with some slight exceptions, a growing tendency. It could not be a better demonstration of the decoupling effect between economic growth and primary energy consumption [1.27].

As far as the energy content of GNP is concerned, Table 1.III shows a general tendency to decline, on average from 100% in 1973 to 70–80% in 1982. The absolute figures, a year before the reference year 1973, are shown in Table 1.IV for a few more countries. Striking is the index proportion France 54, Federal Republic of Germany 70, USA 100 and Canada 120.

TABLE 1.V. GDP AND ELECTRICITY CONSUMPTION PER HEAD [1.30]

COUNTRY		1970	1975	1980
USA	GDP	4835	7173	11319
	kWh	8015	9408	10469
NORWAY	GDP	2881	7095	14009
	kWh	14643	17935	20327
GERMANY, FED. REP.	GDP	3066	6797	13358
	kWh	4124	5008	6082
JAPAN	GDP	1962	4471	8627 (1979)
	kWh	3509	4264	5089 (1979)
KENYA	GDP	143	242	394 (1979)
	kWh	74	91	113 (1979)
BRAZIL	GDP	490	1169	1809 (1979)
	kWh	491	756	1047 (1979)
INDIA	GDP	99	145	184 (1978)
	kWh	114	143	169 (1978)
SINGAPORE	GDP	906	2507	3817 (1979)
	kWh	1063	1856	2729 (1979)
KOREA, REP.	GDP	267	583	1549
	kWh	298	592	1047

US$ and kW·h per head (rounded).

1.2.2.3. Electricity/economic growth relationship

Equally interesting is in parallel the relationship of electricity consumption to economic growth. As a matter of fact this relationship was studied for electrical energy systems very early on, long before interest in the global energy system materialized.

Table 1.V displays the GDP and electricity consumption per head figures for a series of characteristic countries in 1970, 1975 and 1980.

In turn, Fig.1.15 displays for a series of developed and developing countries 1981 data for electricity production per head versus electricity production per unit GNP [1.22]. With some exceptions, the higher the per head electricity production, the higher its content in the GNP.

Finally, Fig.1.16 displays comparatively the energy and electricity intensity index in the USA between 1946 and 1982, expressed as the energy and electricity consumption content of GNP in 1972 constant US$. While the

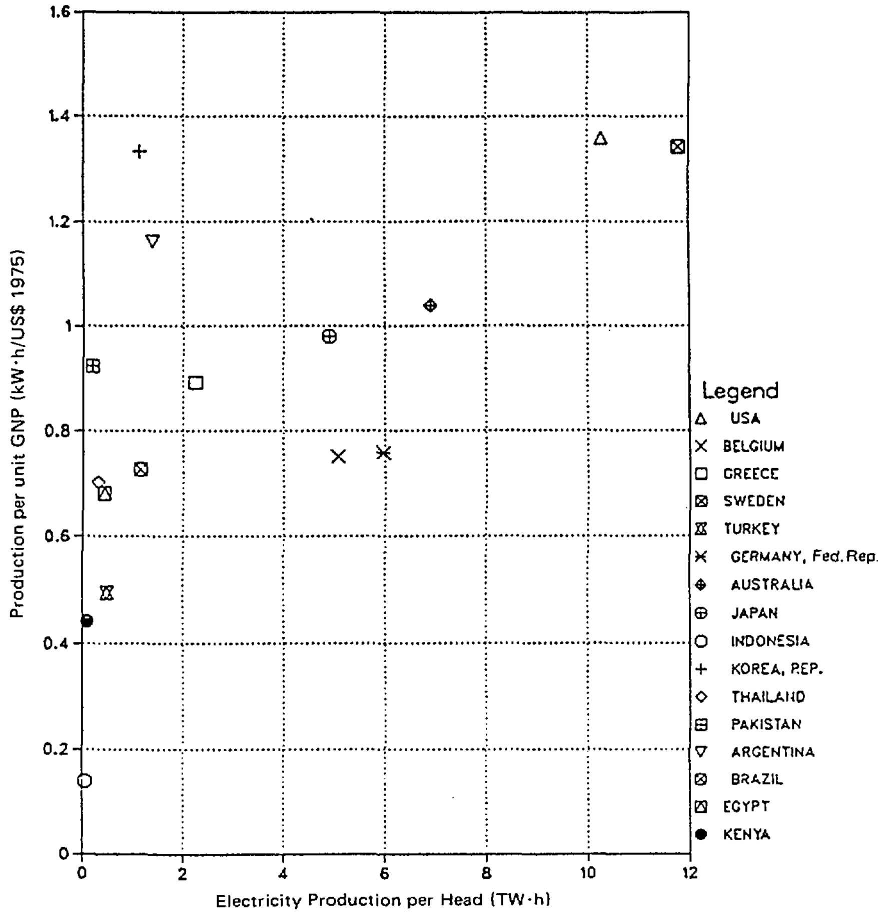


FIG. 1.15. Electricity production per head versus electricity production per unit GNP 1981 [*1.22*].

electricity index increased up to almost 220 (1950 = 100), the energy index declined to 75 in 1982, confirming the general trend that higher electrification reduces the total energy consumption per unit of GNP.

1.2.2.4. A provisional conclusion

The above considerations regarding the relationship between energy and economic development had a triple objective:

(1) First, to show that undoubtedly a certain relationship exists between energy consumption and economic growth. However, it is complex, variable and

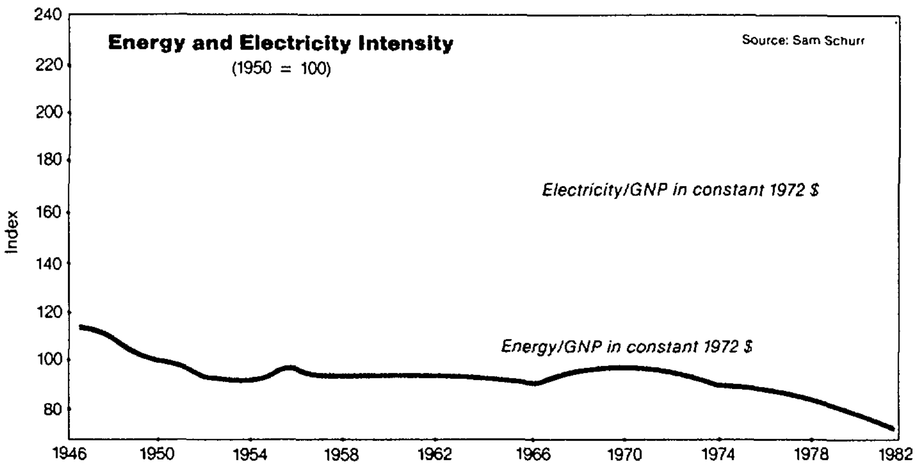


FIG.1.16. Energy and electricity intensity in the USA [1.31].

conditioned by many exogenous and endogenous factors and acts both ways, i.e. a strong feedback coupling effect is exercised by energy on economic growth as well.

(2) Second, to contribute to fighting the myth of simple mechanisms or equations able to describe this relationship, which, even if proven acceptable for certain periods in the past, are definitely superseded and even misleading now.

(3) Since economic growth is a basic issue of development and an important planning parameter, an approach is needed to relate energy planning to its figures, in a less empirical and more objective way.

The energy planning considerations presented in the next subchapter and the planning techniques dealt with in chapter 17 appear for the time being the best approach and methodology that could be offered to these purposes. They integrate economic growth trends and subsectoral analysis to elaborate scenarios of future energy demand, which if well managed, and if efficiency were improved, might result in the best possible output options of the energy system.

1.2.3. Internal economic aspects of the energy system

In addition to the external aspects of the energy system, there are, inside the system, crucial economic issues, related to costs, prices, tariffs, economic calculations, discounted and present value figures, investment, depreciation and last but not least financial aspects which can only be enumerated in this introductory overview. It was preferred to leave them for later discussion when sufficient technical background has accumulated to recognize, each time they come into the picture, the physical energy system structure referred to or generating the problems.

1.3. Planning issues

Due to the long lead time of energy projects, there has always been some concern for planning in the energy sector. This related, however, to individual production and transport projects meant to start operating in the future, when a need for increased energy supply was expected. It was only in the electrical energy sector, and this because of its physical structure, that real extension planning appeared, first for the short term and later to progressively longer time horizons. Triggered by the electricity subsector to answer questions referring to longer-term availability of supply of primary energy resources such as coal, petroleum, natural gas, etc., the producing subsectors started some planning of their own. A phase of unco-ordinated subsectoral energy planning prevailed for some time, originating a certain amount of data and limited planning expertise.

Factors that have gradually led to an universally accepted basic concept of energy planning, however, with some variated approaches in the detailed methodology have been (a) over 40 years of integrated energy planning in the centrally planned economy (CPE) countries in Eastern Europe, (b) first concern with energy planning in the West as part of the reconstruction efforts launched by the European countries at the end of World War II, (c) increasing progress of energy planning activities in the developed western countries and, more recently, in a series of more advanced developing countries.

1.3.1. The energy master plan (EMP)

The aforementioned situation resulted in the decision to start elaborating energy master plans (EMPs). The main objective of an EMP is to ensure the availability of energy at the lowest possible total economic, financial and social cost, consistent with the pursuit of other national development goals.

Because of limited resources, energy options must be selected so as to achieve balanced development throughout the economy, i.e. energy strategy and policy must represent an integrated part of overall socio-economic development. Accordingly, the success of an energy policy is measured by its effect on growth, employment, balance of payment, inflation and income distribution as well as on aspects less readily quantifiable in monetary terms, for example quality of life, environment and strategic considerations [1.32].

In this concept, energy planning is a part, an essential one, of overall economic planning and should be carried out and implemented in close consideration with the latter. On the other hand, the principal emphasis is on the detailed and disaggregate analysis of the energy sector with due regard for the main interactions

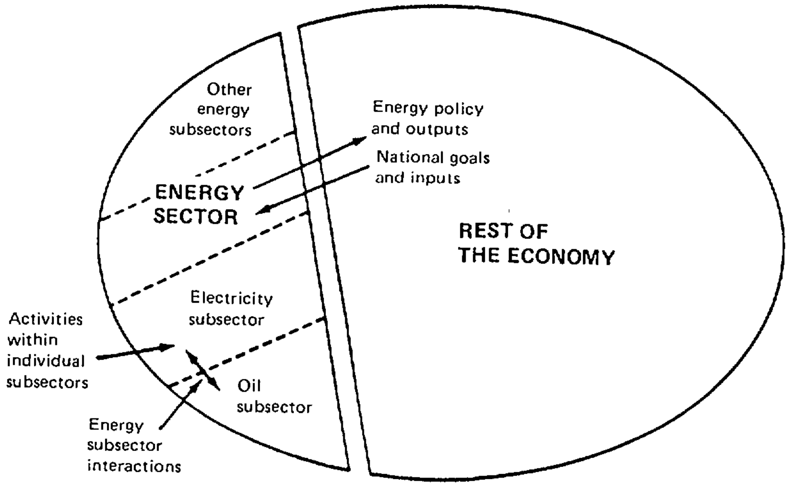


FIG.1.17. Hierarchy of interactions in integrated national energy planning (INEP) [1.20].

within the sector itself, as well as with the rest of the economy. This analysis has to address three interrelated facets: energy demand, energy supply and pricing, to be dealt with as interactions, at four different levels. Figure 1.17 illustrates the hierarchy of interactions in the described approach of integrated national energy planning (INEP) [1.20].

As with all planning exercises, energy planning starts with a diagnosis of the existing status and a critical analysis of the past evolution. The existing status is the reference base and its analysis has to include all items and issues of relevance and reference for the further planning. Especially for the aforementioned three interrelated facets, energy demand, energy supply and pricing, the point of departure must be very well defined [1.33].

After a few years of experience, methodological recommendations for energy diagnosis are now quite well established. The Commission of the European Communities – General Direction for Development issued a guide, elaborated by the Institut économique et juridique de l'énergie (IEJE) Grenoble regarding the collection and processing of data [1.34], the Argonne National Laboratory has a brochure based on its international energy development programme studies [1.35] and further articles [1.33 and 1.35] bring additional recommendations.

The planning process is described in detail in chapter 17. The following are a few highlights for a first insight:

Energy demand projection can be carried out either in a macro (economic) or in a micro (structural) approach. The macro approach is top-down: total energy demand is forecast according to one of the methods described in chapter 17, and shares of this demand are apportioned by end-use energy. The micro approach is bottom-up: separate forecasts are made for each final consumption sector and these are then added to obtain the total energy demand.

As far as developing countries are concerned, a special difficulty, generated by their rural-urban dichotomy, has to be faced, i.e. separate projections have to be made for the demand for non-commercial and commercial energy resources.

Energy supply projections are based on studies of possible development of domestic primary energy resources and resulting import necessities. Again difficulties appear in relation to non-commercial primary energy resources – fuelwood and charcoal – for the most part supplied by a vast number of individual consumers themselves, operating at a subsistence level.

Energy pricing is the third key element of energy planning which has a major role in stimulating energy efficiency and interfuel substitution and in mobilizing the financial resources to implement the plan. They should correctly reflect the cost of supply. Similar difficulties appear for the non-commercial resources, especially when substitution actions are intended to reduce deforestation.

The above three interrelated facets have further to be dealt with at the four significant levels:

At the highest and most aggregate level the energy sector has to be viewed as part of the whole economy and the impact of investment, price and import decisions related to energy on other sectors of the economy has to be considered and the policies and programmes in the energy sector have to be oriented, as aforementioned, towards the achievement of overall national economic goals [1.37].

Therefore, energy planning requires analysis of the links between the energy sector and the rest of the economy. Such links include the input requirements of the energy sector such as capital, labour and raw materials as well as energy outputs such as electricity, petroleum products, woodfuel and so on, and the impact on the economy of policies concerning availability of supply, energy prices, taxes and so on, in relation to national objectives. Since energy permeates the whole economy, the energy sector is much more extensive than other sectors such as agriculture or industry. In this respect, the energy sector is like the 'financial sector', with energy acting as the physical counterpart of money [1.19].

As an example, it is at this level of integration that criteria for energy investment and the ranking of supply/demand projects have to be established. For example, for petroleum-importing developing countries – and not only for developing ones – from the balance of payments standpoint a priority ranking could be considered that would specially promote: projects that save (through more efficient use) or displace petroleum (through interfuel substitution) in large quantities; projects that can yield these results in the shortest time; and projects meeting the same results at the least cost, i.e. projects that give the highest economic and financial returns when based on a reasonable range of oil price assumptions [1.38].

At the second level, the energy sector is treated as a separate entity composed of subsectors such as electricity, petroleum products and so on. This permits detailed analysis of the sector with special emphasis on interactions among the different energy subsectors, substitution possibilities, and the resolution of any resulting policy conflicts, such as competition between kerosene and electricity for lighting, or woodfuel and kerosene for cooking. At this level, the balance supply/demand of the energy system is optimized. To this purpose alternative solutions and scenarios are formulated and ranges of acceptable options computed. Depending on the size and structure of the energy system, the period of time involved, the nature of constraints and the optimization criteria, adequate modelling and computer programs would present the alternatives ranged in various hierarchical options. In general, the first ranking should display the possible and/or acceptable options according to their least present value costs as reference alternatives, and compared with other constrained or desirable policy (strategic) alternatives.

At the third level – end-use energy demand of the final consuming sectors – the shares of total demand are apportioned insofar as the total demand has not been determined in a structural approach and for each sector a further suboptimization checked in relation to possible supply alternatives.

The fourth and most disaggregate level pertains to planning within each of the energy subsectors. Thus, for example, the electricity subsector must determine its own demand forecast and long-term investment programme, the woodfuel subsector must develop consumption projections and detailed plans for reforestation, harvesting of timber, and so on.

Although having an already defined mix, the supply sectors have to be finally checked in relation with the effective chains to the end-use energy demand.

A successful optimization should offer not only the best option for a given final year, possibly including some intermediate years, but the best solution for a given period of time, if possible in the sequence short, medium and long-term analysis. Theoretically, the best solution is an integrated life alternative for the energy system, in which for example the optimal solution for the first five years has not necessarily to coincide with the overall long-term optimum. However, in order to achieve such a result, the input data must be very reliable and even in such a case the more and more aleatory character of the system behaviour in the very distant future makes it a most difficult exercise. Nevertheless, with sensitivity analysis possible variation ranges may be identified and at least an intelligent guess may be possible.

1.3.2. Elaboration of EMP

After the brief description of goals and content of EMP, a few hints regarding the main aspects of its elaboration might prove useful to round off the desired overview on energy planning.

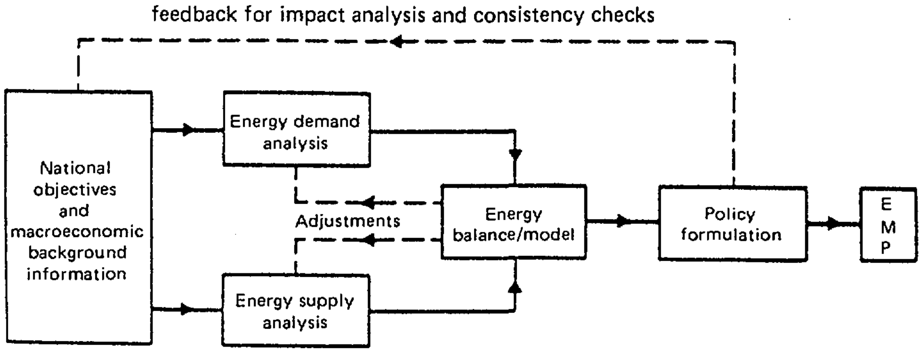


FIG.1.18. Basic steps for implementing INEP [1.20].

1.3.2.1. Planning horizons and uncertainty

The envisageable planning horizons are: short term (about one year), medium term (2 to 10 years) and long term (at least 10 to 20 years). In the short term, national energy planning is most useful for supply/demand decisions to meet unforeseen problems. In the medium term, energy planning is more flexible because there is sufficient time to make significant policy changes. The long-term planning horizons involve the most fundamental strategies of all, for example greater or lesser energy-intensive patterns of economic development, gradual change-over from dependence on some energy sources to others, etc.

All forms of planning must deal with the problem of uncertainty and have alternatives at hand [1.39].

1.3.2.2. Basic steps, data base and manpower for EMP

The basic steps in the elaboration of EMP are shown in Fig.1.18. The presentation is self-explanatory after the foregoing discussion, with the exception of the energy balance/model phase.

Supply/demand balancing consists basically of assigning specific energy sources to corresponding uses. Subsection 17.2.5 deals in detail with energy balances. At this point a simple look at Fig.17.3 would provide the necessary general information on this issue.

Regarding energy models, dealt with in detail in subsection 17.4.2, at this stage only an early warning: these are excellent planning tools, but the (energy) planner is responsible for planning.

An adequate and reliable data base is of paramount importance for the energy planning process and deserves attention. The same applies to the manpower base, which is even more difficult to provide and maintain. Both problems are dealt with in the final chapters of this book.

1.3.2.3. Institutional framework

A problem also of great importance and very differently approached is the institutional framework in which EMPs are elaborated and then implemented. This is further dealt with in chapter 17.

1.3.3. Provisional conclusion on energy planning

Although the basic concept of goals and correlations of national energy planning is similar, volume and depth, structure and sections, elaborating and implementing institutions, etc., are different in the three categories of countries: industrialized countries, centrally planned economies and developing countries.

Centrally planned economy countries have by their economic structure well-defined development goals and hence clear energy demand figures, established planning institutions and co-ordinating authorities. Energy planning results, therefore, in a rather routine exercise, although due to its terms of reference not always flexible enough. However, by its gigantic dimensions and diversification of primary energy resources, this exercise remains in the USSR, for example, a permanently growing challenge.

Industrialized countries have a very diversified approach to energy planning, both as to its content and to its compulsoriness. However, under the pressure of the common agreed energy strategy and policies, discussed in detail in chapter 14, and the co-ordination work of IEA, substantial progress has been achieved also in the energy planning sector. The yearly IEA review of the energy policies and programmes of the member countries and special sessions, for example the November 1983 workshop on methods of formulating energy policy [1.40], offer very interesting information in this respect.

Developing countries, corresponding to their size and structure, display a great diversity in their approach and achievements as regards energy planning. In order to provide an image in this respect, Table 1.VI presents a classification of the oil-importing developing countries (OIDC) established in relation to their capacity to formulate and implement energy strategies and investment plans [1.41]. Three groups of countries are defined in the scheme:– Group A: developing countries with a national planning and policy analysis capability and which already possess energy investment plans; Group B: developing countries that have some institutional structure (even though this is invariably weak) for energy planning and implementation but which need strengthening with outside technical support; and Group C: those developing countries (the majority in number but the least in population) which lack effective national planning

TABLE 1.VI. CLASSIFICATION OF DEVELOPING COUNTRIES ACCORDING TO THEIR LOCAL ENERGY PLANNING AND POLICY ANALYSIS CAPABILITIES [1.41]

Group A	*Group B*	*Group B*	*Group C*	*Group C*
Argentina	Bahamas	Kenya	Afghanistan*	Malawi*
Brazil*	Bangladesh*	Lebanon	Angola*	Mali*
Chile	Barbados	Liberia	Benin	Maldives
Colombia*	Bolivia*	Madagascar*	Bhutan	Mauritius
Gabon	Brunei Darussalam	Malta	Botswana*	Mozambique*
India*	Burma*	Mauritania*	Burundi*	Nepal*
Korea, Republic of	Cameroon*	Morocco	Cape Verde	Nicaragua
Malaysia	Congo*	Nigeria*	Central African Republic*	Niger*
Pakistan*	Costa Rica*	Panama*	Chad*	Papua New Guinea
Peru*	Cyprus	Paraguay*	Comoros	Rwanda*
Turkey	Dominican Republic	Philippines*	Democratic Kampuchea	Sao Tome & Principe
	Ecuador	Sri Lanka*	Democratic Yemen	Senegal*
	Egypt	Suriname	Djibouti*	Seychelles
	Ghana*	Syrian Arab Republic	Dominica*	Sierra Leone*
	Guatemala*	Tanzania*	El Salvador*	Solomon Islands
	Guyana	Thailand*	Equatorial Guinea*	Somalia*
	Indonesia*	Trinidad & Tobago	Ethiopia*	St. Lucia
	Ivory Coast	Tunisia*	Fiji	St. Vincent and the Grenadines
	Jamaica	Uruguay	Gambia*	Sudan*
	Jordan	Viet Nam*	Grenada*	Swaziland
			Guinea*	Togo*
			Haiti*	Uganda*
			Honduras*	Upper Volta*
			Laos	Yemen
			Lesotho*	Zaire
				Zambia*

* Includes two categories of countries – those where rural population faces serious and immediate problems regarding the availability of traditional energy sources, and those in which at least 33% of energy demand is met by traditional energy sources.

and implementation capability and for which direct technical and financial assistance is needed.

However, this assistance should not consist of a transfer of historically obsolete methods, either from Western or Eastern countries, but rather of background support helping the developing countries to forge their own approach for planning on their own conditions [1.41]. Experience shows in such cases, that even the first version of an EMP, based on rather poor data, could be very useful. It provides the first consistent and comprehensive planning approach

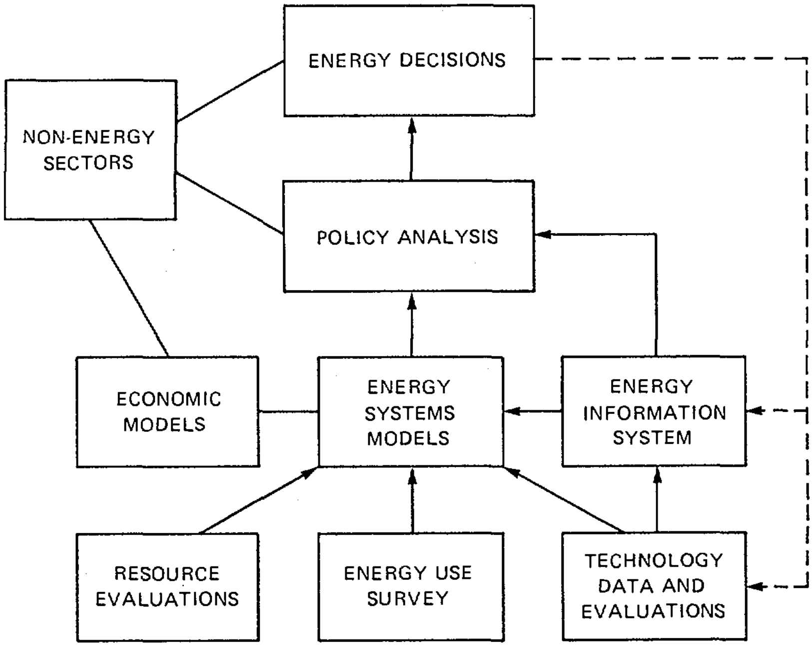


FIG.1.19. A characteristic basic structure of national energy planning [*1.38*].

to a sector with no previous co-ordinated activity, it identifies areas where information is poor, manpower insufficient and salient needs exist. Once first experience is gained, much progress could be ensured.

Last but not least, the comprehensive, pervasive, analytical and synthetic exercise of energy planning is also the best approach to identify the role of nuclear energy in an overall energy system and once its usefulness has been recognized, to promote its introduction 'embedded' in the optimized development of the integrated energy system.

1.3.4. Energy policy and strategies

Figure 1.19 might best synthesize the previous considerations on the energy system as an integrated part of the national economy and interest in its integrated planned development. The process started with the analysis of past energy consumption and the current status and continued with controlled forecasting reflections over shorter and medium-term time intervals, with some further thoughts and investigations on longer time periods. It offered herewith elements to think about in order to establish convenient energy policies. These obviously should be integrated in an adequate energy strategy, which for elaboration needs in addition to the Energy Master Plan (EMP) and the master plans of other economic sectors as basic support documents, some major guidance elements, which, typically for long-term ventures, lie in the no-man's-land between objective documentation and professional best guess.

In Ref.[1.43], M.G. Ussher, an Argentinian lecturer at the IAEA courses, describes the link between political decisions and energy planning and the importance of the ongoing activities at the interface frontiers. For the longer term, however, one must rely on the guided guess and also work with alternative scenarios.

For example, put over-simply, it is likely that 1980–2000 will not be a 'remake' of 1960–1980, and European advanced countries will probably never reach the same per head energy consumption level as that of the present-day USA [1.44]. First, because they are currently doing quite well with substantially lower specific energy consumption, and secondly, apart from the explanation displayed in Table 1.II, because of a basic better energy husbandry now, which under the new circumstances has a substantial chance even to progress.

In fact, similar rates of economic growth may conceal very diverse social and economic realities; within these, the structure of economic activities and the land-use pattern have a great influence upon energy demand.

The changes in the economic structures of OECD industrialized countries will be dominated in the next decades by the continuation of the decline of the primary sector (agriculture, mines) and by the increasing importance of the tertiary sector (services). These developments and the changed position of industry in the post-industrial societies, the fact that household equipment and car ownership will gradually reach saturation level and the consequence of these developments upon goods traffic, will result in energy demand growing comparatively more slowly than the economy [1.44].

In the developing countries, the long-range energy strategy may well take advantage of the tunnel effect advocated by N.E. Berrah [1.24] and result in energy development patterns, both less commercial-energy-intensive and better utilizing their own resources, without jeopardizing both the rhythm of socio-economic development and the improvement of life standards.

After having discussed planning up to the highest national policy decision level and even speculated about the very long-term strategies, we may mention a new sub-phase of energy planning deserving mention. In a series of countries, but particularly in the Federal Republic of Germany, government-financed projects for developing local and regional energy supply concepts are being embarked on [1.45]. It seems that by this sort of micro-energy planning, national overall planning is gaining a series of feedback responses which could be only beneficial for the broad national picture as well as effective for a decentralized approach and implementation of energy policy.

Part I

ENERGY DEMAND AND RATIONAL ENERGY SUPPLY

Chapter 2

ENERGY DEMAND AND DEMAND MANAGEMENT

Energy demand is dealt with in the present chapter and again in chapter 17, but from another aspect. Chapter 17 considers the quantitative structure of energy demand which must be analysed in order to forecast future evolution and to prepare an adequate energy supply within an optimized overall energy system. Chapter 2 seeks to examine the relationship between needs for services and for useful energy, the relationship between useful energy and end-use energy consumption, i.e. demand for energy and how the ratio can be optimized through effective energy demand management.

2.1. Nature and structure of energy demand

2.1.1. Useful energy

Useful energy is an essential input for satisfaction of the primary needs of human beings for food, shelter, mechanical work, transportation and communication. Heat and cold are used for space-conditioning, food preparation and domestic warm water or industrial purposes; mechanical energy for industrial work, domestic appliances and transportation, radiant energy for lighting and telecommunications.

The need for useful energy depends basically on the nature of the energy-consuming services or processes but could vary widely depending on how energy-intensive these are in design and operation. Within certain limits, the energy intensiveness of the process is a consumer's option. It has, however, important repercussions outside his own sphere of action, as will be commented on later.

Experience shows that the need for useful energy decisively depends on the level of socio-economic development and rapidly increases with the sophistication of the society one lives and works in [2.1 and 2.2].

Figure 2.1 displays the wide range of daily energy consumption (MJ/inh. day) for food, households, industry and agriculture, and transportation per inhabitant living in increasingly developed societies. The figures vary from the mere needs of the primitive human being for food and shelter to the high average daily per head consumption of 11 tce yearly of a highly technological society, as for example the USA.

With a minimum of 1.90 GJ (65 kgce) per head yearly energy consumption, the last developed countries, with hardly 5.45 MJ (1300 kcal) daily, are found at the bottom of the curves of Fig.2.1, below any subsistence limit, but for the contribution of non-commercial energy resources.

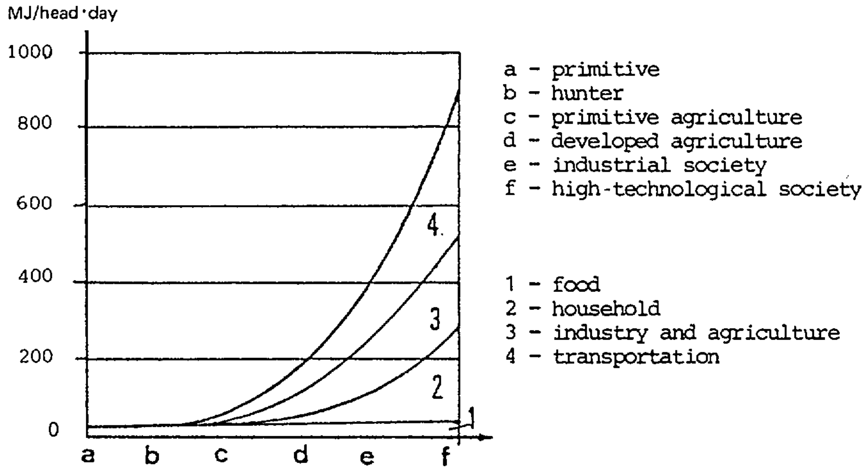


FIG.2.1. Historical evolution of per head daily energy consumption [2.2].

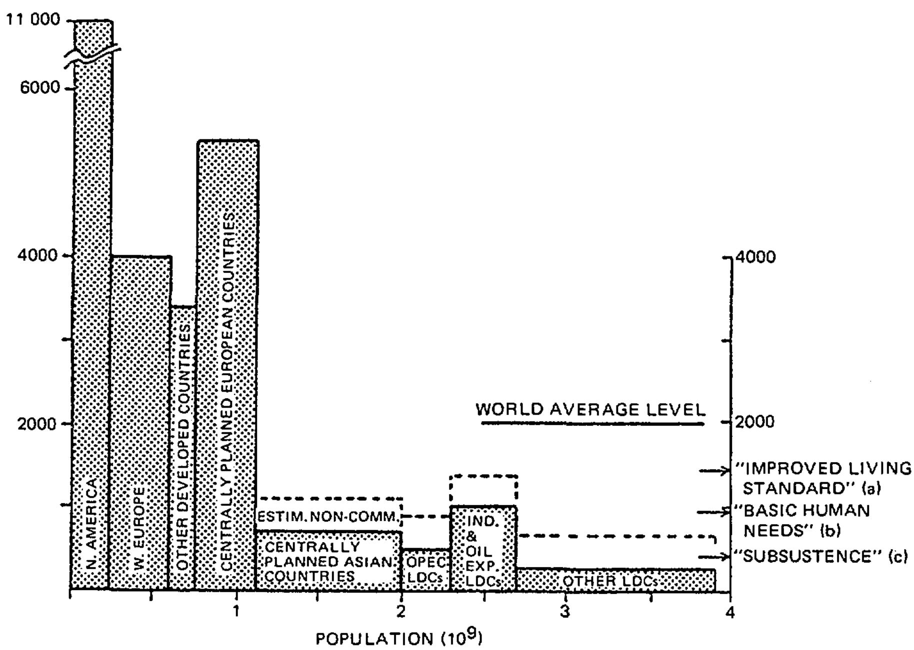


FIG.2.2. Distribution of world commercial energy consumption in 1974. Annual per head consumption vs total population (area gives total energy) [2.3].

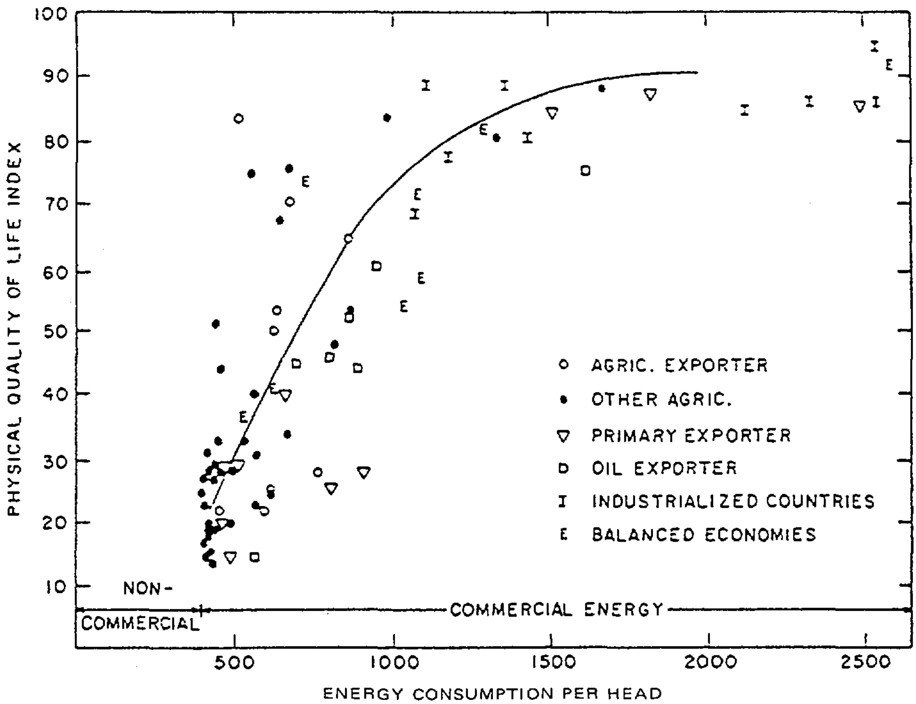


FIG.2.3. Relationship between physical quality of life index (PQLI) and energy consumption per head [2.2].

Figure 2.2 gives more detailed information additional to that contained in Tables 13.I, 13.IV, and 13.V, i.e. in some other structure and with indications of subsistence levels depending on per head energy consumption [2.3].

According to Fig. 2.2, nearly 75% of the world population lives at or below a level (b) which provides "basic human needs", even when non-commercial energy is taken into account. From a number of studies, an approximate figure of 8800–11700 MJ (300–400 kgce) per head per year has emerged as the minimum energy input needed to provide a subsistence level (c) of food and shelter in a rural agrarian area. For an improved living standard (a), a per head energy consumption of around 44000 MJ (1500 kgce) would be required.

Figure 2.3 displays the dependence of the physical quality life index (PQLI) – an index which combines the socio-cultural values and groups them on a scale 0 to 100 – on the per head energy consumption, marking the relative position of countries at different stages of socio-economic development [2.3]. Another relationship, dependence of PQLI on the gross domestic product (GDP), is illustrated in Table 2.I [2.4].

TABLE 2.I. RELATIONSHIP BETWEEN THE PHYSICAL QUALITY OF LIFE INDEX (PQLI) AND GDP PER HEAD [2.4]

Income groups	Average GDP US $/inh.a	PQLI
Low	152	39
(Example: India)	(140)	(41)
Medium-low	338	59
(Example: Malaysia)	(680)	(59)
Medium-high	1091	67
(Example: Taiwan)	(810)	(88)
High	4361	95
(Example: USA)	(6670)	(96)

There are four levels of GDP per head: low, medium-low, medium-high and high, for which representative PQLI figures are: 39, 59, 67 and 95. For example, India ranks at 41, Malaysia at 59, Taiwan at 88 and the USA at 96.

Although undoubtedly a certain correlation exists between standard of living and per head GDP and energy consumption, caution has to be exercised when comparing indicators from developed countries with those from developing ones. Apart from the latter having no energy consumption for space heating, absolute figures will in the future be lower since, owing to energy conservation efforts, similar levels of living standards might be obtained with less expenditure of primary energy.

At this point a remark may be made concerning Figs 2.1 to 2.3 and Table 2.I. The diversity of specific energy consumption figures is certainly bound to the increasing needs for energy when society develops higher standards. However, the question arises, are at certain levels of development the needs for useful energy always satisfied? Apparently not, unless they appear as energy demand, and they do so only if the consumer can afford to pay for their satisfaction – in cash or in kind, the latter for example in collecting firewood. If need exists but the demand for energy is suppressed, it is probable that the demand would surge as soon as this becomes possible. That means that especially for developing countries a backlog of suppressed demand could suddenly accelerate normal demand evolution.

Another imbalance between energy needs and supply can occur, and it often does so, when demand is not met because of insufficient availability of supply capacity.

Reality shows, therefore, that for different reasons, needs for energy do not always correspond to energy demand. However, having made this point, such situations will be left for discussion in chapter 17 as energy planning issues, and in the present chapter a normal balance between energy needs, demand for and supply of energy is assumed.

The need for useful energy should be minimized – or optimized by what will be explained as demand management. Ideally, by avoiding any wastage, the demand for final usable energy should be equal to the need for useful energy. In this sense, the output of the consumer conversion devices will be considered equal to the useful energy, i.e. no wastage.

The conviction is becoming increasingly strong that total output of useful energy of an energy system bears a more stable relationship to the economic variables (incomes and output) than would the total of delivered energy or primary energy inputs. Unfortunately, consumption of useful energy can only seldom be directly measured, and it is usually determined from the energy supplied to the customer multiplied by an estimate of the average efficiency of the energy-using equipment.

2.2. End-use energy

According to the above considerations, there are three quite different levels at which demand for energy can be contemplated:

(1) Demand for useful energy (= output of consumer conversion devices, and which by no wastage = needs for useful energy);
(2) Demand for end-use energy, i.e. for input energy to the consumer conversion devices (= energy delivered and billed for by a supplier), and
(3) Demand for primary energy, which is the consumed input of primary energy resources into the energy system.

From the scale: primary energy, end-use energy (delivered net of conversion losses in the production of intermediate energy forms, as petroleum derivatives, electricity, district heat, etc.) and useful energy (net of appliance losses) each can represent a demand for energy supply. However, since useful energy cannot be statistically directly followed, the end-use energy is the one selected to serve as reference base for energy demand. It offers as such the following advantages:

(1) Although biased by the effect of very different appliance efficiencies, it still permits, when presented as aggregate figures for the various end-sectors, a fair idea of the structure of the last consuming stage of the energy systems.
(2) It separates two conceptually different sections of the energy system: the consumption section and the production/supply section.

However, although the end-use energy level separates conceptually the main compartments of the energy systems, physically it links them together and accordingly regulates the energy flows.

2.3. Formation and management of energy demand

The conceptual separation of the energy system into the demand and supply sides also helps us to understand and manage its development and operation according to the different level of professional energy knowledge and mentality on each of the two sides.

Indeed, on the suppliers' side, improving energy husbandry is the daily task of competent energy professionals, carried out carefully on a large scale and in a concentrated manner, while on the consumption side action relies on individual contributions of thousands and thousands of consumers, less professionally informed and acting randomly by interest or by slowly increasing motivation.

Progress in energy husbandry lies in the hands of these two so basically different parties, in their ability to concur in an energy demand best shaped for an efficient supply but also satisfactory as regards its service and amenities. In other words, energy demand should be so managed that it benefits everybody in the system. The key issue is not to minimize but to optimize energy demand, not to curtail but to optimize energy supply, and this in relation to the final services expected from a rational energy output.

The concept and denomination of demand management originate from the electrical power utilities, which in their endeavour to improve the daily and annual electrical load curves, began long ago to offer better tariff conditions to consumers voluntarily consenting to shift their demand from, or reduce it during, the electrical peak hours.

As the overall energy system concept developed, the sphere of demand management gradually expanded and soon became one of the main tools for optimizing design and operation of the full energy system.

The tasks of demand management in an overall energy system may be briefly outlined as follows:

(1) Reduce demand for final usable energy, matching it as closely as possible to the need for useful energy by eliminating wastage.
(2) Optimize the need for useful energy by partly replacing active energy consumption by passive arrangements able to achieve the same productivity and/or amenities.
(3) Improve efficiency of end-use energy conversion into useful energy.
(4) Move the demand for end-use energy to off-peak periods, without disorganizing production or affecting living conditions.
(5) Reduce peak demand for end-use energy by extending the same total energy demand over a longer time period.

TABLE 2.II. TYPICAL USEFUL ENERGY DEMAND CATEGORIES [2.5]

Sector	Typical useful energy demand categories	Comments
Industry	Indirect heat	Boilers providing steam
	Direct heat Using any fuel Using clean fuel High temperature Medium temperature Low temperature	Furnaces, kilns, dryers, etc. Clean fuel use required by some processes to prevent product contamination. Temperature differences allow for analysis of possible solar system penetration.
	Process electricity	Certain processes where electricity must be used (electric arc furnaces, aluminium smelting, etc.).
	Other electricity	Lights, motors, pumps
	Motive power	Heavy machinery (internal combustion, electric)
	Feedstocks	
	Vehicles	Off-road industrial vehicles
Agriculture	Similar distribution as in industry	
Residential/ Commercial	Space heating/air conditioning Water heating Cooking Lighting	 Can be electric or direct fuel
	Electromechanical	Appliances
Transportation	Passenger travel Car Bus Rail Air	 Intra- and inter-city Domestic, international
	Freight travel Truck Rail Marine Air	

(6) Reduce the rigid link of demand and supply in the last consuming stage by storage in the input energy supply line and thus more conveniently meet the demand for usable final energy, with less stress and effort in the previous intermediate conversion stages.

Each and all the above described actions are geared to optimize the design of the involved consuming and converting equipment, i.e. to reduce the nominal installed capacity and the subsequent investment costs and to improve at the same time operating conditions under higher load factors and efficiencies.

The formulation of the basic principles of energy demand management appears easier than their implementation. It has to be constantly recalled that action and reaction are most individual and governed by personal, economic and behavioural considerations on the demand side. Doubtless the demand side is alert to market signals, especially as regards energy prices, but in addition a considerable public relations effort and a rich basket of government incentives would be needed to redirect energy utilization towards energy saving and petroleum substitution patterns.

In fact, if the end-consumers have to decide on how energy-intensive their living and working styles should be and hence decide on the level of demand for end-use energy, an enormous number of consumers must be taken into account. These include many small private consumers, the residential and commercial sector, a great part of the transportation sector, agriculture and small industries. In addition, a tremendous, decentralized and diversified decision power is located on the output side of the energy system since it can select preferentially between different end-use energy carriers. Therefore, the optimization of the whole energy system can only succeed in close co-operation with the demand side. The latter should also gradually acquire knowledge and interest for the common endeavour, since more economic supply needs better consumption conditions and demand can obtain better supply conditions by better management of its requirements. The essence of the new approach of demand management is in this reciprocal give-and-take process, at the interface level of end-use energy demand and delivery.

Complicated cases for demand management action arise when the same useful energy demand could be met by a series of alternative end-use energy forms, for example heat for space heating. Expressing demand in terms of end-use energy would mean precluding alternatives, which could possibly strongly bias the optimization of the entire energy system. In such cases, the analysis should go back to the useful energy requirements, and consider all practical available alternatives of end-use energy supply. On the other hand, however, no alternatives to electricity exist for the end-use energy supply for television and radio sets.

Table 2.II displays the typical useful energy demand categories encountered in the four main consuming sectors: industry, agriculture, residential/commercial and transportation, with some additional explanatory comments [2.5]. In fact they all represent variations of the basic forms: heat, mechanical energy and light.

2.4. Optimization of demand for useful and end-use energy

2.4.1. General considerations

It is basic to all considerations on energy demand that all related optimization or management action should in no way curtail or jeopardize the quantity and quality of the services expected from the sources of energy inputs. Such action should only aim at achieving a lower requirement of useful energy or a more favourable distribution over time. As already mentioned, the ideal approach in this respect is not simply to try to minimize demand, but to optimize it for all concerned parties. This does not exclude that often the minimum is also the optimum. However, sometimes, the minimum useful energy input can involve unbearable direct and social costs for additional capital and labour investment.

A second premise, also previously mentioned, is the assumption that no waste of useful energy is incurred, i.e. the useful energy consumed is that really needed for the purpose. For instance, final usable energy can be consumed without being usefully required, i.e. serving human needs or production, when lights are left on in unoccupied rooms, buildings are overheated, machinery runs idle, extremely hot water tapped, etc.

Under these premises, it is both legitimate and recommendable to try to optimize the demand for end-use energy by taking action on: first, the need for useful energy itself and secondly, the efficiency of the devices converting the supplied end-use energy into useful energy. It will be with this dual approach that energy demand formation and optimization (management) will be commented on in the further analysis of the main consuming final sectors.

However, before entering into this detailed analysis, a strategic view might better round the perspective.

In addition to unavoidable general climatic conditions, the geographical location of human settlements, their density and transportation distances might have a great impact on the residential and working needs on the one hand and the transportation needs on the other. New energy conditions represent for land-use [2.6] and urban planning [2.7] an additional and important variable if not a constraint, to be considered in new projects or when changing existing situations.

Although still slow, new moves can be recorded in this direction, which together with progressive architectural concepts and new building materials may lead to less energy-intensive solutions, which by no means should result in less comfort and fewer amenities.

The third important main end energy consuming sector, industry and agriculture, is also very much influenced in its energy needs by its national distribution and structure. Industrial energy demand can favourably be geographically concentrated so as to offer better local energy supply conditions, for example by co-generated heat and electricity.

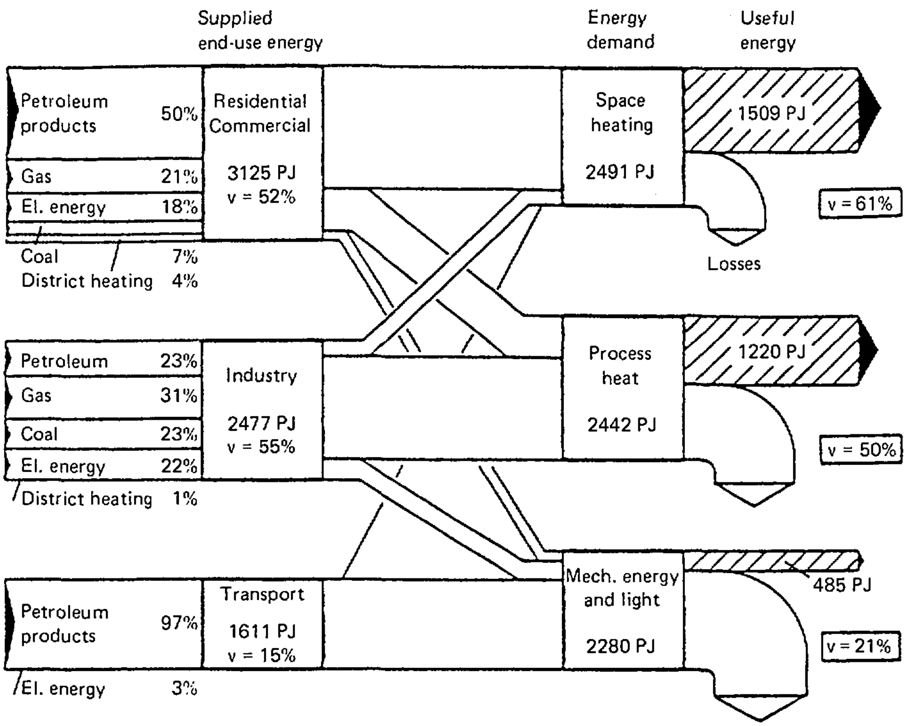


FIG.2.4. Energy flow chart of the Federal Republic of Germany (1981): end-use and useful energy [*2.8*].

To the above strategic effects of energy demand management on volume and structure of useful energy requirements, technology adds a multiplier effect through the relatively low efficiency of its conversion processes, which leads to a substantial increase of the demanded end-use energy supply. Although conversion devices are rather energy supply features, by some tacit understanding, those operating in the end consuming areas are included in the sphere of action of demand management, since effectively the energy demand of end-use energy very much depends on the selection and operating performance of such devices. Another reason is that their selection is a consumer choice and out of the hands of the energy supplier.

The strategic influence of technology on energy demand is illustrated in Fig.2.4, showing the last consuming stage of the overall energy balance of the Federal Republic of Germany in 1981. The demand for end-use energy input for the three useful energy forms is almost the same, 2491 PJ for space heating, 2442 PJ for process heat and 2280 PJ for mechanical energy and light. The output of useful energy is, however, very different, since the efficiencies

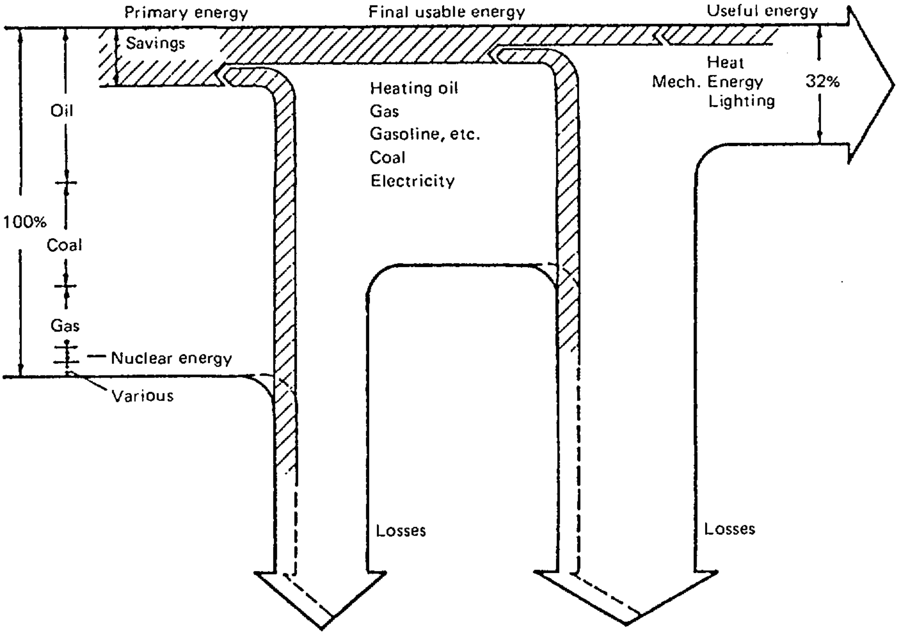


FIG.2.5. Effect of demand management in the final consumption stage on the input side of an energy system (status 1978) [2.9].

of the technological end-conversion processes are respectively 61%, 50% and 21%. The very low average efficiency of 21% in the transportation sector dramatically increases the demand for the most critical end-use energy carriers, petroleum derivatives.

The latter figures demonstrate what a strong impact a managed demand in the transportation sector – obtained both by more rational requirements for useful energy and higher end-conversion efficiency – could exert on the petroleum imports and global energy balance of a country.

While the quantitative effects of improved efficiencies in the various possible energy supply chains will be commented on later in chapters 8 and 16, which take a more integrated quantitative view, Fig.2.5 is intended to display graphically the snowball effect demand management in the final consuming stage can have in rolling back energy input throughout the energy system [2.8]. As explicitly shown in Fig. 2.5, a small reduction in the useful energy output additionally reduces losses in the end-conversion stage and hence in all previous energy conversion and transport stages. With the indicated global efficiency of 32%, 1 toe less useful energy saves an input of 3.1 toe primary energy, possibly imported petroleum.

In conclusion, demand management represents a very efficient tool for optimizing the energy requirements of the last consumption stage. It could affect both basic components of energy demand at this stage: the fixed one depending on the design of the consuming (and converting) devices, on which the user can exert no influence once it has been established, and the second, variable one influenced by the consumer's habits and his choice of a more wasteful or more efficient pattern of energy usage. For favourably exercising its influence on the first component, demand management should be 'built in' early, in the design phase of the future energy consumer. The second component might be managed in the operating phase.

In the next subsections the main issues of optimization of energy demand by demand management, both of useful energy requirements as well as of end-conversion processes, will be followed through separately for the main consuming sectors: residential and commercial, industry and transportation. Agriculture will, as often in statistics, be included in the industrial sector, since a continuously increasing part of its energy consumption originates from agro-industrial activities.

2.4.2. Energy demand in the residential and commercial sector

Notably in industrialized countries, in spite of their high industrial energy consumption, the residential and commercial sector participate with a substantial share in the end-use energy demand balance – see subsection 2.4.5. This situation is due (in addition to a high number of home and commercial appliances) to the high space heating requirements in their generally cooler or colder climatic zones, or, if located in warmer regions, to the high air-conditioning needs. On the contrary, developing countries, located with a few exceptions in warm or tropical geographical regions, have practically no heating requirements and have hardly embarked yet on air-conditioning, although in many cases this is definitely needed.

Because of the above basic differences and the important role played by the consumption of non-commercial energy resources in the housing sector in the developing countries, the energy demand of industrialized and developing countries will be dealt with separately in the following analysis.

2.4.2.1. Industrialized countries

In industrialized countries the residential and commercial sector needs useful energy and implicitly end-use energy for four main uses: space heating and cooling, domestic warm water, cooking, and lighting and appliances.

2.4.2.1.1. Space heating

The useful heat energy for maintaining a building at a given inside temperature corresponds to the total heat flowing out of the building in a given period of

TABLE 2.III. SOME EXAMPLES OF HEATING EFFICIENCIES [2.10]

Usage		Thermal efficiency at the point of time of conversion (%)
Burning of wood or coal in fireplaces		20
Space heating with:	– coal	45
	– oil	63
	– natural gas	75
	– electricity	95
Cooking with gas		37
Cooking with electricity (excluding generation and transmission losses)		75
Heating of water in a natural gas appliance		62
Heat pumps		85[a]

[a] But 200–250% if gains from recycling are included.

time minus a possible free heat contribution from human presence or appliances' operation or an influx or direct solar radiation. The amount will depend on the building's general level of thermal insulation, as initially determined by its construction and, of course, will vary as a function of the outside air temperature. As a result, for the same functional service offered by buildings, the need for useful heat could differ considerably.

Preventing a part of the useful heat from diffusion reduces the need for heat inflow, i.e. exchanges better insulation for a part of the heat supply. Energy is saved by a higher investment cost; the process has an optimum, which leads to the optimized demand for useful energy. This should be realized in spite of the often still persisting first-cost syndrome.

The demand for end-use energy will depend on the nature and efficiency of the supplying energy carrier or heat-producing device. The assessment of average efficiencies of heating appliances is notoriously difficult. Any figure used will be met with scepticism, justified under certain conditions. In order to preserve cohesion, the figures of Ref.[2.10] are reproduced in Table 2.III. They are not fully up-to-date, and in the meantime, under the pressure of conservation interests, substantial progress has been made. For example, Fig.2.6 shows the efficiency curve of oil-fired heating boilers, which for conventional design is already high, but could be even more improved by modern design, and given a more favourable partial load operation.

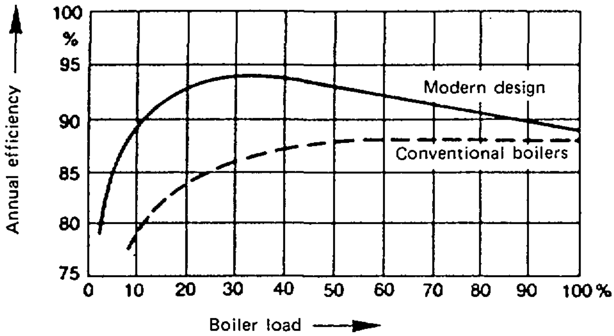


FIG.2.6. Efficiency curves of oil-fired heating boilers [2.11].

As another example, the end-use energy demand to heat an appartment of 67 m^2, well insulated (0.9 W/m^3 °C) in the Paris area with a need for useful energy of 5800 kW·h is compared using different end-use energy carriers. The energy requirements and efficiencies are as follows [2.30]:

	kW·h	Efficiency
electric heating	6100	95%
district heating	6700	86%
central heating with gas (700 mc)	8060	72%
central heating with fuel oil (0.75t)	8660	67%
direct heating with coal (1.5t)	11600	50%

The importance of high efficiencies of heating systems led in the Federal Republic of Germany to official regulations for these devices, in addition to mandatory thermal insulation measures. Since they depend on many factors, it is difficult and risky to indicate even average figures for energy consumption for space heating. However, a general idea can be gained from Table 2.IV, which displays average figures for a series of industrialized countries. The degree-day indications refer to the duration of the heating season in each country [2.12]. The consumption figures are from 1972–1976, i.e. before energy conservation measures were taken, both as regards better building insulation and higher efficiency of heating devices. Therefore, there was substantial scope for demand management action.

Generally, it is considered, that in relation to 1973 levels, specific space heating consumption in the industrialized countries could be reduced by up to 50%. A comprehensive UN-ECE study [2.13] concluded that for the total of the 17 industrialized countries of Europe and North America considered, the energy consumption of buildings could be lowered through modest energy conservation measures by 27% compared to the 1975 level – for more details see Ref. [2.14].

In addition to the enumerated, classical energy conservation measures, two newer approaches could manage to reduce the space heating demand for non-renewable end-use energy carriers. These are (a) covering a part of the need for useful energy for space heating with ambient heat by a heat pump and/or (b) by passive or active application of solar energy.

First, a brief description of the heat pump: the heat pump runs on an evaporation/condensation cycle, just like traditional air conditioners and refrigerators, but in reverse. It can gather free low-grade heat (anergy) that is always present in the environment, increase its temperature by incorporation of exergy and deliver the upgraded heat indoors for warmth and human comfort. Similarly, it can upgrade waste or process heat to the higher temperatures needed by industrial consumers. However, its best application remains in ambient anergy upgrading.

Heat pumps are typically classified by type of heat source and sink, and by the heating/cooling distribution fluid used. On this basis, heat pumps are designated air/air, water/air, air/water, water/water, earth/air, earth/water. The heating/cooling changeover may occur in the refrigerant circuit, but sometimes the switching is accomplished via the air or water circuits in air/air and water/water heat pumps, respectively.

Figure 2.7 show the basic structure and the heating and cooling cycle of an air/air heat pump, as commonly found in unitary applications. In this type of unit, the direction of the refrigeration cycle is reversed by the operation of valves, and the roles played by the heat exchangers (condenser and evaporator) are interchanged when the interior spaces switch from heating to cooling or vice versa.

The heat pump's efficiency in relation to its design heating (or cooling) requirement is measured by its coefficient of performance (COP), the ratio of heat output to work input. In relation to its actual operation, the so-called seasonal performance factor (SPF), i.e. the ratio between the total output during a given heating season to the total work input by the heat pump and all auxiliary equipment, is the decisive indicator. Whereas the COP of a heat pump can be three or more, a winter SPF in the conditions of a northern climate can only range between 1.5 and 2.1.

With respect to the primary energy consumption, Fig.2.8 compares the inputs of different heating systems for an output of 100% space heating usable energy demand. Central heating by a boiler of 85% efficiency requires a primary energy input of 118%; an electrically driven heat pump with a COP of three necessitates with 33% electricity consumption a primary energy input of 100% (given a thermal efficiency of the power plant of 33%), a heat pump with a gas-driven compressor needs only 56% primary energy, while a heat pump with an absorption cycle needs 77%.

Fig.2.7 is also an excellent example of the value of energy flow diagrams even for simple, single energy conversion processes. Not only can the resulting

TABLE 2.IV. AVERAGE ENERGY CONSUMPTION FOR SPACE HEATING [2.12]

	Final energy[a] GJ/dwelling (1975)	Reference year	Useful energy GJ/dwelling Individual houses	Flats	GJ/m^2 Individual houses	Flats	$MJ/m^2 \cdot$degree-day[b] Individual houses	Flats	References in [2.10]
France	61	1976	61	41	0.73	0.67	0.30	0.28	[2, 35]
Fed. Rep. Germany	74	1974	62	45	0.75	0.75	0.25	0.25	[1, 51]
Denmark	88 (1976)	1976	70	40	0.7	0.67	0.26	0.23	[17, 52]
UK	51	1975	40	18	0.5	0.31	0.21	0.13	[25, 53]
Netherlands	91 (1972)	1972	67	56	0.57	0.62	0.31	0.34	[13, 54]
USA	125 (1977)	1972	90	52	0.75	0.58	0.30	0.23	[49, 56]
Sweden	104	1975	89	58	0.90	0.95	0.24	0.26	[48]
Italy	49	1974	–	–	–	–	–	–	[14]

[a] Average for the dwelling stock.

[b] Number of degree-days: France 2400; Fed. Rep. Germany 3000; Denmark 2900; UK 2400; Netherlands 2700; USA 2500; Sweden 3700.

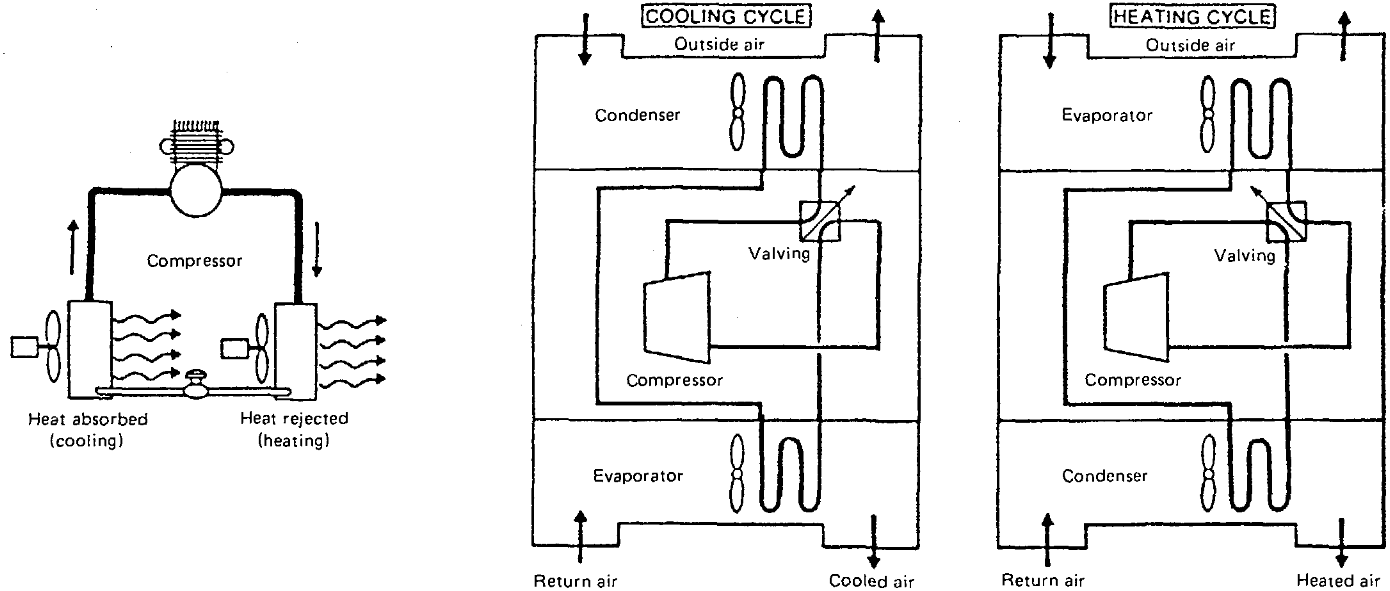


FIG. 2.7. Basic structure and heating and cooling cycle of an air/air heat pump [2.15].

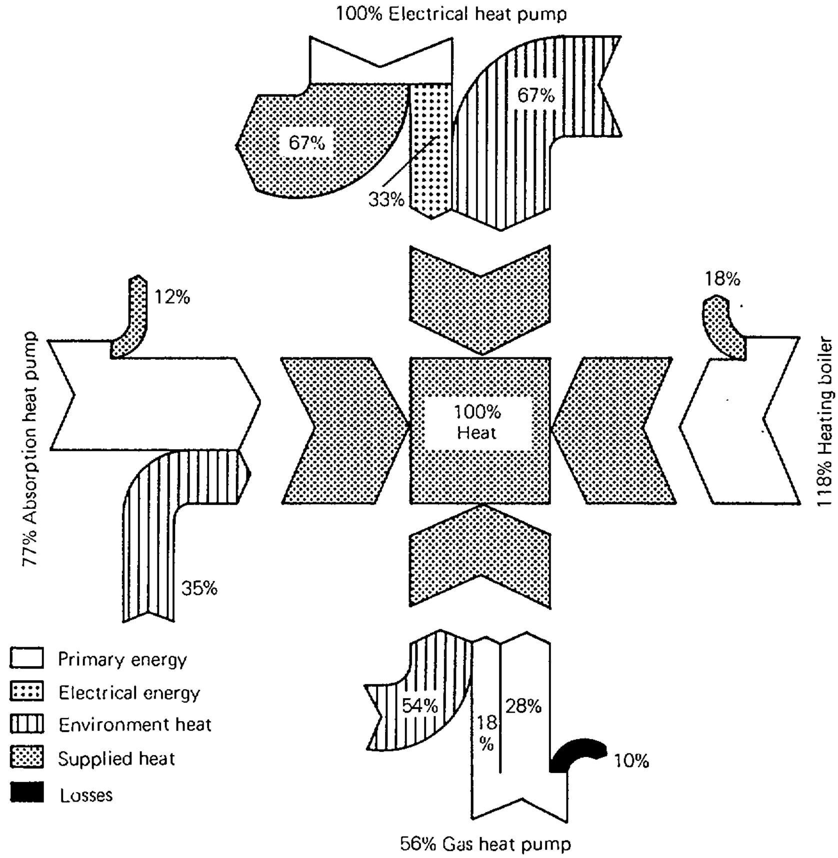


FIG.2.8. Primary energy requirements of different heating systems [2.16]

efficiencies be easily compared, but also the different ratios between added exergy and upgraded anergy are explicitly displayed.

In spite of their spectacular performances, heat pumps have also clear limitations. The COP of the heat pump is very dependent on the temperature difference between the cold source (outdoor air) and the warm source (temperature of the heating carrier). This temperature difference increases fast when the outdoor temperature falls, because simultaneously the temperature of the heating carrier has to rise. The temperature difference increases, therefore, at both ends and the operation of the heat pumps deteriorates rapidly. A complementary heat source has to intervene, either a fossil-fuel-fired boiler or electric heating. A bivalent heating system is therefore necessary. However, since normally the heat pump can operate alone from some 5°C outdoor temperature and, combined with the boiler, down to 0°C, it covers a quite

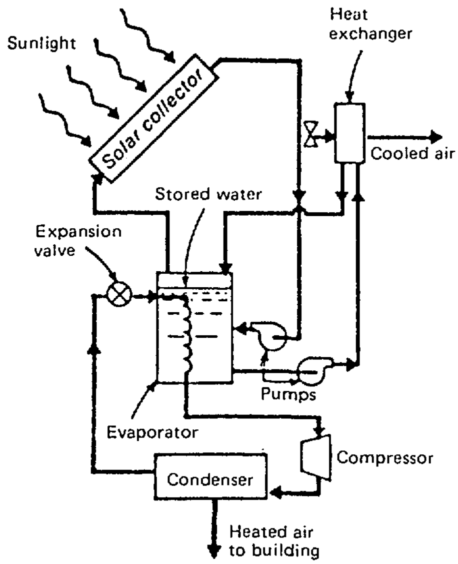


FIG.2.9. Solar-assisted heat pump [2.15].

respectable share of the annual heat requirements. Reference [2.17] analyses in detail such solutions of bi-energy, which are another good example of demand management.

The use of solar energy for reducing the need for useful energy for space heating could be either passive, i.e. through direct insulation, or active, via a solar collector. A more complicated combination is shown in Fig.2.9, where the heat pump operates with solar-heated water, stored in order to bridge the periods without sunshine. During the heating cycle, solar energy is used to increase the temperature of the storage medium, thus reducing the amount of compression work necessary to increase the temperature of the working fluid. As a result, the COP in solar-assisted systems may increase by as much as 50%, typically from 2 to 3 during winter months [2.15].

Space heating can also be based on heat delivery from a public district-heating system, preferably supplied with heat produced in co-generation with electricity in a process of very high common efficiency – see subsection 8.2.1. Another approach could be combinations of district heating with heat pump systems [2.18].

2.4.2.1.2. Space cooling

Air conditioning of residential and commercial buildings is highly developed in the USA, in Europe very much less so. Similar to space heating, there are central air conditioning and room air conditioning (window air conditioner).

TABLE 2.V. OWNERSHIP LEVEL FOR HOUSEHOLD ELECTRICAL APPLIANCES, IN % [2.12]

	Refrigerator			Freezer			Washing machine[a]			Dishwasher			References
	1960	1970	1978	1960	1970	1978	1960	1970	1978	1960	1970	1978	in [2.12]
USA	98	100	100	23	31	44 (1975)	55	62	75	7	27	38 (1975)	[69]
UK	18	59	88	–	3	24	36	63	75	–	1	3	[60]
Fed. Rep. Germany	41	85	93	–	22	47			89	–		16	[63, 68]
France	25	77	93	–	7 (1972)	21	24	54	76	–	2	21	[70]

[a] Electric washing machines only for the USA.

The efficiency of an air conditioner is also expressed by a coefficient of performance (COP), as the ratio between the useful energy supplied to homes and the electricity consumed. The average value of COP is at present around 2. Heat pumps operating as air conditioners have a slightly lower COP, 5% less than electric air conditioners.

The average annual electricity consumption for air conditioning in the USA is estimated around 3600 kW·h per dwelling by central air conditioning systems and 2000 kW·h per room by window air conditioners. The weighted average lies around 2500 kW·h [2.12].

Air conditioning for homes developed very fast in the USA, increasing from some 13% in 1960 to 51% in 1976. The share is much higher for commercial buildings. For many states in the USA it moved the yearly electric peak load from winter to summer.

Similar to district heating, a district-cooling system can be operated with a central chiller preparing the chilled water for distribution. Systems with heat pumps can be advantageously used, permitting even simultaneous distribution of heated and chilled water, which could often be required in larger communities [2.18].

2.4.2.1.3. Domestic warm water supply

Domestic warm water is needed for cooking, bathing (baths and showers) and washing up. The needs very much depend on the standard of living, habits, etc. With modern bath- and shower-equipped homes – in the European Economic Community 30–40% of homes in 1960, and 75–95% in 1975 – the use of warm water increased very fast. Modern baths and showers account for some 60% of domestic warm water consumption.

Few survey and statistical data exist on the quantity and the seasonal variation of warm water consumption. The problem became even more complicated with the development of dishwashers and washing machines for which the water is heated directly in the appliances themselves.

With efficiencies of hot water systems varying between 0.5–0.65 for fuel oil, 0.5–0.75 for gas, 0.8–0.9 for electricity and 0.3–0.45 for coal, average figures for annual demand for end-use energy in GJ per appliance are 3.5–6 (16) for electricity, 11–19 (28–32) for gas and 17.3 (France) for fuel-oil. The figures in brackets are for the USA, where the warm water consumption for washing machines and dishwashers, and there are many of them, is included [2.12].

Heat for warm water supply can also come from district heating systems as well as from heat pumps [2.19].

2.4.2.1.4. Cooking

Energy needs for cooking are rather small compared to the total household energy needs, i.e. 1.5 to 5%. In general they concentrate on gas and electricity, the latter showing a very fast development in recent decades in the USA, the UK, and the Federal Republic of Germany. In this latter the share of households with electric cookers rose from 20% in 1953 to 68% in 1975.

Annual end-use energy demand for cooking (GJ/household) varies from 1.8 to 4 for electricity and 3.5 to 14 for gas. The average electricity demand for Europe is 1000 kW·h/a (3.6 GJ/a), with the exception of the FRG where it is about 5000 kW·h/a [2.20]. For gas the European average of 4 GJ/a is very much lower than the USA figures (14.4 GJ/a), which are partly explained by the voracious pilot lights used there (these alone consume some 4.3 GJ/a).

2.4.2.1.5. Lighting and appliances

In addition to electric lighting, household electricity demand exists for large appliances (refrigerators, washing machines, freezers, dishwashers and television sets) and miscellaneous electrical and electronic appliances (irons, vacuum cleaners, hi-fi sets).

The demand for electricity as end-use energy for household appliances depends on how well a household is equipped with such appliances, which in turn depends on the household's income. In addition, the size and the technical features of the appliances are important in this respect.

Table 2.V presents an overview on the ownership level for household electrical appliances and the evolution between 1960 and 1978. In general, interest in the USA for, and the development of the use of, electrical appliances started earlier, but European countries followed quite rapidly. 1982 statistics in the Federal Republic of Germany show that the evolution has continued since 1978, although a certain saturation is appearing.

Table 2.VI *displays average figures for the specific electricity consumption* of household appliances for some industrialized countries. The high figures for the USA are mainly due to the large size of the appliances (as of cars) usual in that country. Since the figures refer to 1970–1976 they are partly obsolete, because under the pressure of energy conservation measures, the specific consumption of many electrical household appliances has been reduced. For example, the 1980 statistical data for the Federal Republic of Germany [2.21] indicate the following lower specific electricity consumption figures for an average household of 2–3 persons, in kW·h/a per household: lighting 250, refrigerator 340, freezer 640, washing machine 340, dishwasher 660, drying machine 430, electric cooker 490, television and hifi 170, warm water heater 1500, iron 60, vacuum cleaner 30, etc.

Finally, Table 2.VII presents a comparative percentage structure of the household electricity consumption in four characteristic countries. Interestingly enough, the accent in the Federal Republic of Germany is on large electrical appliances while the UK prefers rather lighter appliances.

TABLE 2.VI. SPECIFIC CONSUMPTION OF HOUSEHOLD ELECTRICAL APPLIANCES (IN kW·h/a PER HOUSEHOLD) [2.12]

	UK 1960	UK 1978	France 1976	USA 1970	Denmark 1975	Fed. Rep. Germany 1975
Refrigerator	375	350	290	1300	485–550	380–430
Freezer		1000	800	1380	750–800	580–815
Washing machine	80	200	450	360	575–700	330–410
Dishwasher		500	1000	360	650–665	565–725
Television	250	365	180	410	200	
Lighting	220	330	260	750	750	
Miscellaneous	235	450	160			
References in [2.12]	[60]	[60, 61]	[2, 62]	[67]	[61, 95]	[6, 68, 76]

TABLE 2.VII. BREAKDOWN OF SPECIFIC HOUSEHOLD ELECTRICITY CONSUMPTION ACCORDING TO MAJOR HEADINGS, IN % [2.12]

	Fed. Rep. Germany 1977	France 1976	USA 1972	UK 1978
Large electrical appliances	67.5	59	45.5	38
refrigerators	(22.5)	(19.5)	(28.5)	(17)
freezers	(18)	(11.5)	(9.5)	(13)
washing-machines	(19.5)	(22.5)	(5.5)	(8)
dishwashers	(7.5)	(5.5)	(2)	–
Lighting	13	18	16.5	18
Miscellaneous	19.5	23	38	44
television		(11.5)	(11)	(19)
Average consumption per dwelling (kW·h)	1550	1400	4600	1700
References in [2.12]	[64]	[2]	[67]	[60]

As far as the consumption per household is concerned, the average figures are not comparable since they refer to different years. The consistent specific data for 1981 are the following (net kW·h/a per head): Fed. Rep. Germany: 1409, France: 1190, USA: 3210, UK: 1510. Further, Denmark: 1440, Italy: 690, Greece: 605 [2.21]. In Norway in 1979 the comparable figure was 5392 kW·h/a per head, due also to the fact that 90% of households have electric heating, partly as an auxiliary heating system. In 1980 the Swedish figure was 2733 kW·h/a per head and the Swiss figure for 1981 was 1568 kW·h/a per head. Lighting has made in addition to quality, comfort and security, great progress as regards specific energy consumption. At present the global utilization factor for lighting with fluorescent lamps is around 0.09 [2.22] while when electric lighting was first introduced around 1870, the figure was 0.001 (a paraffin wax candle reaches 0.0015).

A breakdown of the percentage structure of total end-use energy demand of a household would show the following shares for 1981 in the Federal Republic of Germany: space heating 79%, warm water 10%, appliances 10% and lighting 1%.

Although demand management in the residential and commercial sector relies on space heating as the area of largest impact, the other components are also worth promotion. Reference [2.23], for example, makes a comprehensive analysis of all possibilities for improving the efficiency of domestic electricity use – excluding water heaters and space heaters – by redesign of the electric appliances and lighting involved. The conclusion, based on convincing figures, is that all three levels of demand management studied – moderate, strong and radical – resulting in reductions of up to 35, 50 and 80% of the electricity demand, are applicable without affecting the service and comfort expected. The calculations are based on Danish behaviour patterns and appliances sold in Denmark, but the results should be checked also in other countries.

In view of the complex structure and high level energy demand has reached in the residential and commercial sector of industrialized countries – the two towers of the World Trade Center in New York alone require 80 MW of electricity supply – a more systematic approach is needed for its study and determination. Accordingly, large buildings are studied in an integrated energy system approach, with adequate optimization of both, energy (managed) demand and supply.

2.4.2.2. Developing countries

The household sector accounts for a small proportion of total commercial energy used in developing countries – typically less than 10% in the poorer countries and between 10 and 20% in the middle-income countries. However, these statistics are somewhat misleading because they exclude fuelwood, which is the principal fuel for households in developing countries. Including fuelwood and agricultural and animal residues in the national energy balance makes the household sector the largest energy user in most developing countries, accounting for almost half of the total energy used in most of these countries and up to 90% in some of them (for example Burundi, Malawi, Nepal and Rwanda).

A partial explanation is that there are only few developing countries which need space heating; in the northern hemisphere Turkey, the Republic of Korea, the northern part of China; and in the southern hemisphere part of Chile and Argentina and the Alti Plano settlements in South America. While advanced solutions of district heating based on co-generation of heat and power are considered and implemented in the Republic of Korea, the demand for space heating in the other countries is met classically and estimated as such. The same considerations of demand management, i.e. thermal insulation of buildings, etc., are valid as discussed previously for industrialized countries.

The problems with the tropical developing countries consist in space cooling, i.e. air conditioning. While a clear trend exists towards air conditioning in commercial buildings, this is less the case with residential buildings.

Nevertheless, in spite of more suitable architechtural design, better natural ventilation and electric-driven fans, air conditioning represents a substantial amount of suppressed demand in these countries.

The warm water needed should be provided by solar energy. Ownership of household appliances is still at a very low level. However, the key problem in the household sector remains the energy requirements for cooking.

In this respect it is a tragic dilemma that with deforestation advancing as a terrible menace to all the rural developing world, demand management is not succeeding in at least halving the demand for firewood by utilization of cooking stoves of better efficiency. In fact, such stoves have been widely promoted as a means of cutting down on domestic energy consumption. However, their actual performance has fallen far short of those tested in the laboratories. This is partly because the conditions in the developing countries are different from those assumed and also because many of the proposed cooking stoves are made – in view of low or zero cost – of materials with low durability such as mixtures of sand and mud, and deteriorate rapidly. After a year or so, such a stove is likely to have a thermal behaviour which is hardly different from that of an open fire [2.24].

In conclusion, while the energy demand of the residential and commercial sectors in developing countries has in urban centres a similar structure to that in industrialized countries, – making allowances for less space heating and more air conditioning, and being at a substantially lower level – the conditions are totally different in rural areas. The latter, mostly at the economic limit of a subsistence fuel economy, can evolve in the domestic sector only to a very low energy demand, which is then met mostly with non-commercial energy resources. The situation in such areas is in general so precarious that no general indicators can be used and detailed surveys and studies are necessary to estimate end-use energy demand in close relation to the degree in which it satisfies the real needs for useful energy.

TABLE 2.VIII. % SHARES OF LIGHT AND HEAVY INDUSTRY IN TOTAL MANUFACTURING [2.25]

	1955		1965		1976	
	Light industry[a]	Heavy industry[a]	Light industry	Heavy industry	Light industry	Heavy industry
World	41.2	58.8	37.0	63.0	32.3	67.7
Centrally planned economies	49.3	50.7	36.0	64.0	28.2	71.8
Developed market economies	36.5	63.5	35.2	64.8	32.4	67.6
Developing countries[b]	67.3	32.7	56.8	43.2	48.9	51.1
Asia	–	–	61.6	38.4	55.0	45.0
Latin America	–	–	52.3	47.7	42.5	57.5

Source: *UNIDO, 1979.*

[a] Specifically, light industry includes: food, beverages and tobacco; textiles, wearing apparel and leather; wood and wood products including furniture; printing, publishing and allied industries; rubber products; plastic products; and other manufactures. Heavy includes: paper and paper products; industrial chemicals and other chemical products; petroleum refineries; miscellaneous products of petroleum and coal; basic metals; and fabricated metal products, machinery and equipment.

[b] Although the totals for developing countries include certain African countries, precise figures for the region of Africa cannot be derived.

2.4.3. *Energy demand in the industrial sector*

Energy is needed in the industrial sector primarily as an essential technological input for the production process and secondly for creating and maintaining the necessary conditions and ambience for the working manpower. Since the latter energy input is related to similar uses, i.e. space heating and cooling, warm water supply and lighting as discussed in subsection 2.4.2, the present subsection concentrates exclusively on the energy demand for technological processes.

It is not possible to deal here in detail with specific aspects of energy demand in the many branches of existing industries nor are systematic presentations available which could provide a rapid insight into the subject as is the case for the residential and commercial sector discussed in the previous subsection. However, it is hoped that a few essential statistical data and the basic presentation of the subject will offer sufficient general information and the necessary background to permit further investigations by the reader when necessary.

In favour of this approach is the fact that the demand of industrial processes for useful energy is in general close to the real needs, since wastage is somewhat controlled in this end-stage by the operational conditions of the manufacturing process itself. Energy intensiveness varies more widely in this field than in all other consuming sectors and is generally determined by technological conditions or the economic optimization of the industrial process itself.

A reduction of the needs for useful energy in industry depends, therefore, on progress in the technology of the respective processes and important achievements in this respect could be mentioned.

Industrial demand for end-use energy could sometimes easily be modified so as to reduce demand at peak periods and to move demand to off-peak periods. For example, doubling the number of mills and providing adequate storage could result in the same daily output but using off-peak energy only.

Industrial energy consumers can be classified into two groups. The first group comprises the energy-intensive industries in which energy costs represent a large share of total production costs (between 15 and 50% and occasionally even higher). These include iron and steel, cement, pulp and paper, chemicals, fertilizer, aluminium and petroleum refining. The second group of industrial users comprises a multitude of medium-sized and small energy consumers.

The first group of industries consume, on average, two or three times more energy per unit of value added than those of the second group, such as textile or food industries or the producers of electrical household or industrial appliances.

Table 2.VIII presents the evolution of the percentage shares of heavy and light industry between 1955 and 1976 in the world, the developed market economies, the centrally planned economies (CPE) and in the developing countries, including a breakdown for the latter in Asia and Latin America. As expected, the developed market economies and the CPE have higher shares of heavy industry,

but also in the developing countries this share increased rapidly, from 32.7% in 1955 to 51.1% in 1976.

An overview on the 'heaviness' of the different industry branches is offered by Table 2.IX which displays the ranking of United States industries according to the direct energy coefficient, i.e. the direct input of energy in US \$ – coming from four groups of industries – needed for each dollar of industry output [2.25].

The useful energy needed for industrial production processes is heat and mechanical energy in an average proportion of 85% and 15% respectively. The breakdown of the heat requirements is approximately 50% at temperatures higher than 400°C, 20% at 120–250°C and 30% under 120°C. Of the mechanical energy, 75% originates from electricity.

The average specific energy consumption in industry in the seven largest OECD member countries, after a slight increase between 1960 and 1970, has decreased continuously since. Table 2.X displays the evolution of the energy consumption per unit of industrial output for the seven OECD countries and the average figures [2.26]. Spectacular figures are for example: the specific consumption in the aluminium industry, down in France from 30 kW·h/kg in 1940 to 14 kW·h/kg at present; and in the USA from 26.5 kW·h/kg down to 17.5 kW·h/kg for the same period. Another example is that of blast furnaces where the coke rate – specific consumption of coke per tonne of pig-iron – decreased in Japan from 716 kg/t in 1955 to 479 kg/t in 1977 and in France from 1019 kg/t to 585 kg/t for the same reference year [2.12].

The recent experience of industrialized countries has shown in general that demand management and improved monitoring and control systems can further reduce the specific energy consumption per unit of industrial output and the share of petroleum fuels. For example, the latter declined between 1973 and 1980 from 60 to 57% in Japan, 52 to 43% in the Federal Republic of Germany and from 54 to 41% in the United Kingdom, due to increasing substitution of natural gas, coal, lignite and electric power [2.27].

A first step in realizing such savings is to carry out 'energy audits' for each of the major industrial energy users to analyse their existing pattern of energy use and to identify the areas for improving efficiency. Follow-up training and technical assistance is generally necessary for implementation. Special financial support may also be required. Possibilities for reducing energy intensity and substituting cheaper energy forms for petroleum in the energy-intensive industries have been identified in virtually every country. Table 2.XI shows for example that in developing countries, too, a substantial potential for reducing the specific consumption in industry exists and that even with small investments, mainly of a housekeeping nature, substantial energy savings are possible and paybacks are extremely fast. To realize the bulk of the potential savings would require larger investments and the replacement of inefficient equipment, but the payback period of such undertakings is still generally less than five years, and they earn

TABLE 2.IX. ENERGY COEFFICIENTS FOR SELECTED US INDUSTRIES [2.25]

Energy industries		Other fabricated metal products	0.017
Petroleum refining and related industries	0.572	Metalworking machinery and equipment	0.017
Electric, gas, water and sanitary services	0.374	General industrial machinery and equipment	0.017
Coal mining	0.155	Electrical industrial equipment and apparatus	0.015
Crude petroleum and natural gas	0.050		
Extractive industries		*Light industries*	
Chemical and fertilizer mineral mining	0.107	Plastic and synthetic materials	0.035
Iron and ferro-alloy ores mining	0.080	Lumber and wood products except containers	0.025
Stone and clay mining	0.068	Rubber and miscellaneous plastic products	0.019
Non-ferrous metal ores mining	0.045	Broad and narrow fabrics, yarns and thread mills	0.018
Heavy industries		Miscellaneous textile goods	0.016
Chemicals and selected chemical products	0.068	Wood containers	0.015
Primary iron and steel manufacturing	0.059	Food and kindred products	0.013
Stone and clay products	0.048		
Paper and allied products, except containers	0.046		
Glass and glass products	0.044		
Primary non-ferrous metals manufacturing	0.031		
Miscellaneous machinery, except electrical	0.024		
Paints and allied products	0.022		

TABLE 2.X. ENERGY PER UNIT OF INDUSTRIAL OUTPUT [2.26]

	1960	1970	1974	1975	1976	1977	1978	1979	1980
USA	119	118	94	94	92	86	83	86	85
Japan	111	106	100	101	105	100	95	91	79
Fed. Rep. Germany	85	101	103	92	89	83	84	85	80
France	112	117	100	91	89	88	89	94	87
UK	112	99	83	88	89	85	82	81	75
Italy	78	98	98	96	91	88	89	85	81
Canada	115	105	102	100	96	97	93	91	92
Average	105	111	96	94	94	89	86	87	82

1973 = 100

TABLE 2.XI. POTENTIAL ENERGY SAVINGS IN SELECTED INDUSTRIES IN THE DEVELOPING COUNTRIES [2.27]

Industry	Total developing countries' commercial energy consumption (10^6 toe/a)	Potential savings (%)	
		Category A[a]	Category B[b]
Iron and steel	109.0	3	15 – 20
Petroleum refining	54.0	7	15 – 25
Cement	52.0	11	18 – 28
Chemicals (ammonia)	19.0	2	20 – 25
Pulp and paper	15.0	11	12 – 15
Aluminium	13.0	2	10 – 15

Source: World Bank estimates based on consultant studies.

[a] Small investments, consisting mostly of combustion efficiency improvements, insulation, steam system efficiency improvements and other housekeeping measures; paybacks within 10–20 months.

[b] Large investments in retrofitting existing plants and additions to facilities, including waste heat recovery, combined heat and power generation, increased use of waste fuels, simple process changes and controls and replacement of inefficient equipment; payback in two to five years. Savings in categories A and B are not necessarily additive in specific plants.

economic returns of 17 to 50% a year. This type of investment also helps to remove plant bottlenecks and permits increased output, as well as reducing energy costs.

While with small investments up to 11% energy savings can be achieved, larger investments could increase the savings to up to 20–25%. However, the best thing developing countries can do for their further industrial development is to design from the very beginning the industrial energy supply in an integrated system concept, laid out at an optimized energy intensity.

Since industry is not only a large energy consumer, but also a producer of energy equipment and often an autoproducer of electricity in co-generation with heat, there are many possibilities to improve its energy husbandry. These are repeatedly suggested and described in the following chapters and bibliographies.

As initially mentioned, agriculture is often included in the industrial sector and indeed in some industrialized countries, especially in the USA, it has developed to the status of an agro-industry. With its high energy inputs in the form of fertilizers, mechanization of all activities and its downstream crop conditioning and food production, modern agriculture justifies this approach. Accordingly, its energy demand and energy husbandry in general may be dealt with similarly, both as methodology and basic problems.

However, at the other extreme, in the least developed countries where the balance of life can be hardly maintained, the dynamics of energy and nutrition are closely interwoven [2.28]. The problem is how to depart from the balance: daily need for nutrition equals food production, and the answer is 'only via energy'.

Between the two extremes are many intermediate situations and different energy intensities of agriculture imply different approaches. This is especially the case when agriculture becomes a producer of fuel, for example ethanol.

Taking a global view, it is worth recalling that food is a highly refined form of energy and absolutely essential to survival. The yearly consumption for human nutrition in the world exceeds 3×10^9 t and corresponds to about 5000 TW·h. This is only some 6–7% of the total energy consumption, but the energy used in its production, distribution and preparation is several times higher. In fact, the food chain is the most important single consumer of energy and one that can only increase in volume.

The limited agricultural area which is available for growing food for a rapidly increasing population makes it necessary to adopt ever more energy-intensive farming practices: use of more fertilizer, pesticide, irrigation, etc. A satisfactory diet also requires more of the energy-intensive animal products than are presently available in many developing countries. A more extensive system of conservation and international exchange will also add to the energy requirement. All in all, it is quite clear that the energy consumption necessary to maintain food supplies on a par with needs will continue to increase markedly in the years to come [2.31].

All these considerations lead to the conclusion that the agriculture of the future will develop more and more into a gigantic agro-industry.

2.4.4. Energy demand in the transportation sector

The transportation sector has had a particularly dynamic evolution in the last thirty years, favoured by initially cheap and abundant petroleum products, development of adequate road systems, general economic growth permitting a rapid spread of car ownership, conducive to more intensive business and tourist travel and a very consistent evolution of the automobile industry, one of the locomotives of industrial and economic development. Table 2.XII displaying the per head energy consumption of the transportation sector confirms this evolution, with the USA as the leading consumer country. This position is due to its early embarking on the automobile as the main vehicle for transportation, to the special relationship developed to its use which determined new housing and living conditions, and not least to the size and gasoline voracity of the large cars predominating in the 1970s.

The transportation modes fall into the following categories: road, rail, water-borne systems (barges, ships, tankers), air and pipelines. Transported are passengers and goods (freight) in public or private vehicles [2.29].

TABLE 2.XII. PER HEAD ANNUAL ENERGY CONSUMPTION OF THE TRANSPORTATION SECTOR IN GJ/a·inh. [2.12]

	1950	1960	1970	1975	1978
USA	52	55	72	81	84
France	9	11	17	23	24
Fed. Rep. Germany	9	13	20	23	26
UK	14	17	21	22	24
Italy	3	6	13	15	16
Netherlands	7	11	21	23	25
Denmark	7	12	26	29	29
Belgium	10	13	20	22	24
Sweden	9	19	27	29	31
Japan	3	5	13	16	17

1 GJ is approximately equivalent to 30 litres of gasoline.

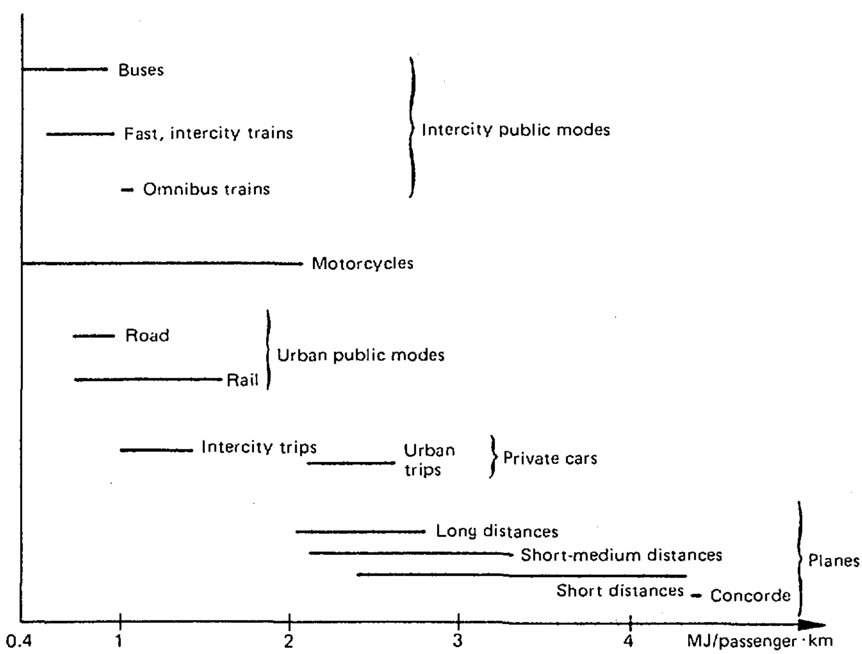


FIG.2.10. Specific energy consumption of passenger transportation modes [2.12].

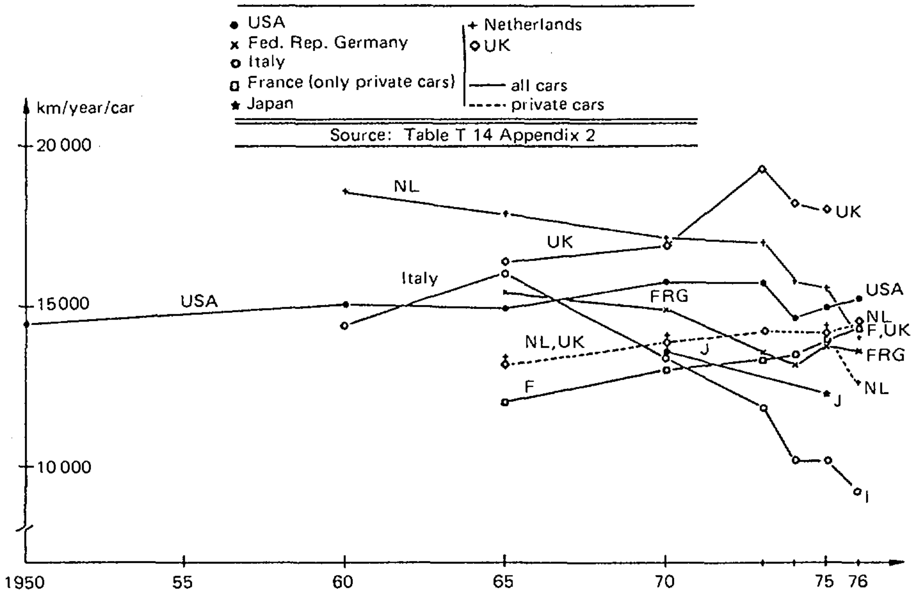


FIG.2.11. Average annual distance travelled per car (1950–1976) [2.12].

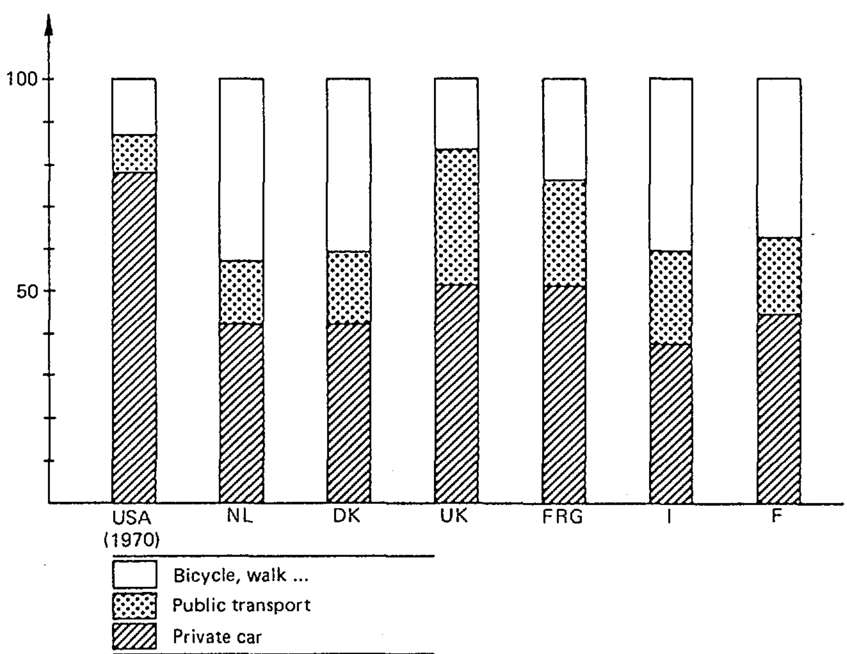


FIG.2.12. Distribution of home/work trips by mode in 1975 [2.12].

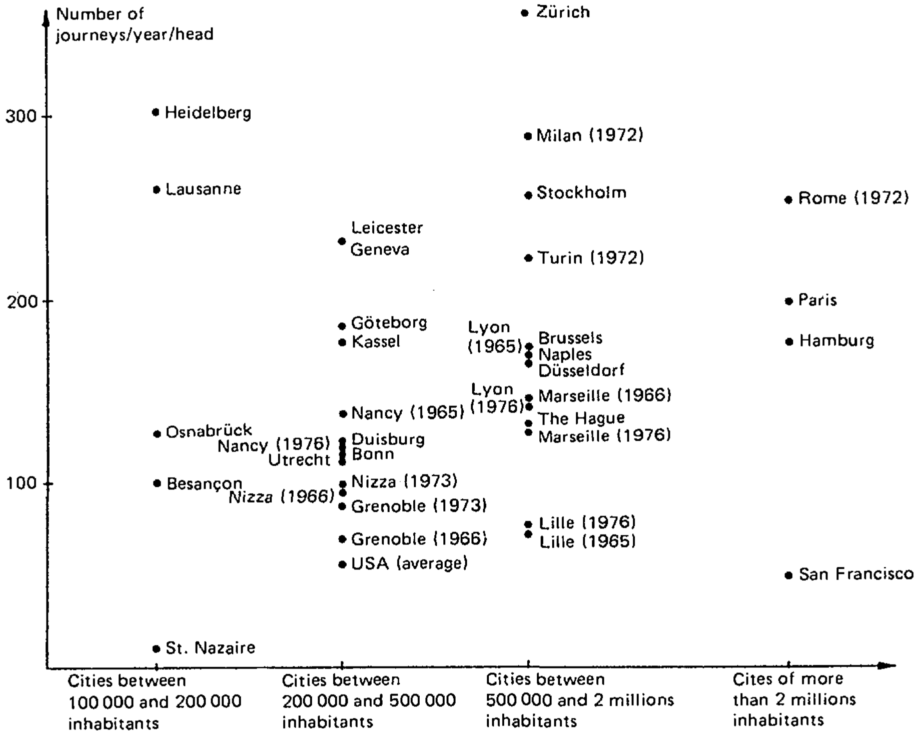


FIG.2.13. Per head mobility by public modes of transport in large cities (1971) [2.12].

A direct assessment of the needs for useful energy in the transportation sector is almost impossible, since in addition to a great many material factors, habits and emotional influences are deeply involved. Even the standard of living, although doubtless an important influencing factor, offers no significant correlation since a population's way of living and working exercises its own impact.

In the absence of any possibility of directly assessing what could be called a reasonable need for useful energy demand in this sector, the only practicable way to reach an acceptable judgement is to analyse multilaterally effective consumption figures in relation to all significant factors and influences. Gradually a general image will emerge, with structural indications concerning the order of magnitude of excessive energy wastage, exaggerated comfort demand, and real needs, but also avoidable demand for energy which depends upon the possibilities of changing demand-inducing patterns of behaviour.

Reference [2.12] offers a great amount of statistical data in relation to the transportation sector. However, it is related only to industrialized countries.

Nevertheless, it constitutes a reliable basis on which to start one's own investigations, adding pertinent information on developing countries as needed [2.32]. The following comments reflect selected information on salient aspects.

Figure 2.10 presents comparatively the specific energy consumption of passenger transportation in MJ/passenger-km of the different transportation modes. As might be expected, the lowest figures appear for public transportation, the highest for air travel.

In industrialized countries the private car has a particularly high importance and utilization. Figure 2.11 displays for a series of countries the evolution of the yearly travelled distance between 1950 and 1976. It ranges between 13 000 and 14 000 km, with a dispersion of 7%, except for the USA where the average was around 15 000 km. In most countries the average has gone down in the last ten years.

The importance of the private car also appears in its high share in the distribution of home/work trips with at least 35%, and up to 78%, compared with public transportation (varying between 10 and 30%), cycling, walking, etc. (15–40%) – see Fig.2.12.

Mobility in cities and especially in large cities or conurbations, both in industrialized and in developing countries, is one of the major aspects in their economic activities. Fig.2.13 displays some examples of the public transport intensities in a series of cities of different size in the world. It would be very interesting to add similar figures for the large conurbations in developing countries.

With the exception of hydroelectric-driven trains, all transport modes get their needed useful mechanical energy via thermal conversion processes based on the second law of thermodynamics, i.e. with a relatively low efficiency. Further, when the higher losses of part load operation are added, the average annual efficiency becomes even lower [2.33]. For ships, trains, i.e. large transporters, the efficiency could average 25–30%, for small private cars the annual average could lie as low as 12–15%. If the latter were supplied with gasoline gained from coal, instead of natural gasoline, the overall efficiency would be around only 4.5 to 6.5%, with methanol from coal at some 7%, and with hydrogen from coal about 7.5%. Electric cars would reach around 12% [2.22]. A diesel-driven car has a better efficiency, around 15%.

These low efficiencies, the lowest of all final consumption sectors, are unfortunately encountered in a sector which with few exceptions is completely based on petroleum products. Therefore, demand management in transportation is of paramount importance. There should be not only a long-term strategy for a better orientation of the whole sector but also medium- and short-term strategies. With respect to the latter, the successful compaign to reduce the specific gasoline consumption per km in the IEA member countries deserves special mention – see Tables 8.VIII and 8.IX and Ref. [2.34].

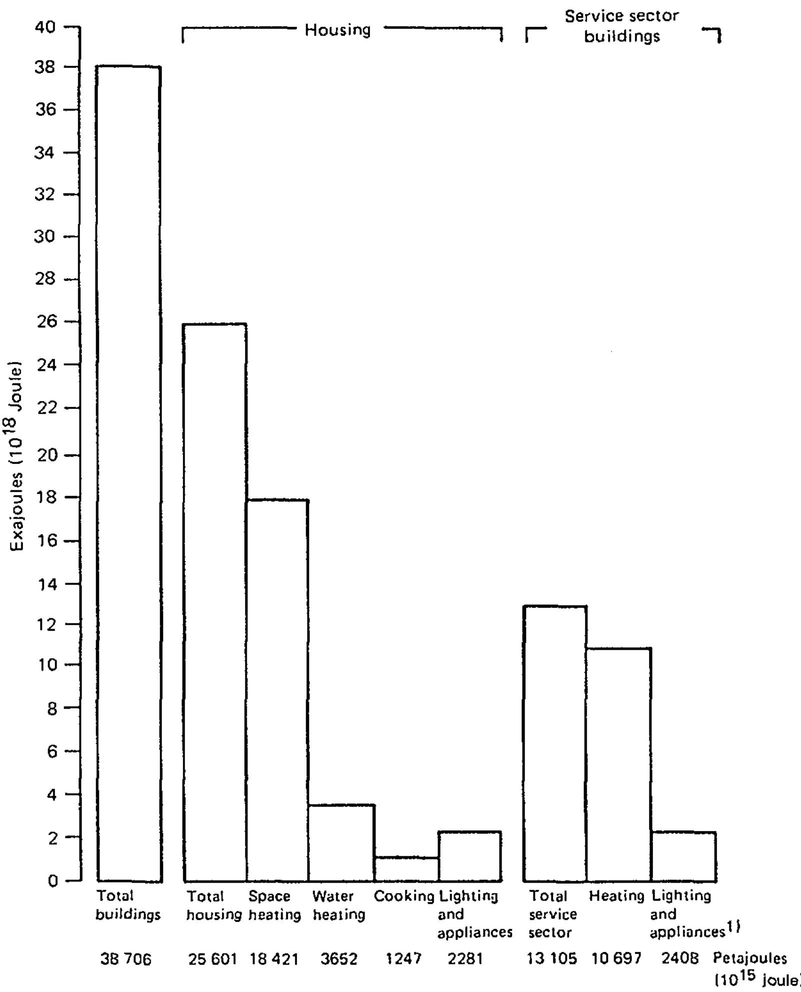


FIG.2.14. Total 1975 end-use energy demand in buildings, broken down by end-uses for seventeen ECE countries [2.14].

There are opportunities for improved energy efficiency of other modes of transport as well. Trains in North America and Europe have been modified to consume 3–10% less diesel fuel; ships and aircraft can also be made more fuel-efficient, initially through improved maintenance and operation, and subsequently through replacement by more fuel-efficient models.

As far as freight transport is concerned see once more Ref. [2.12].

Transportation has specific, possibly dramatic aspects in developing countries, especially in the petroleum-importing countries, because in many of these countries road transport is the only existing mode of transportation. Therefore, it is likely that with all demand management efforts such as training of truck and bus drivers and supervision of their driving performance, better vehicle maintenance, reducing empty backhauls, better selection of truck sizes and design, replacing the old gas-guzzling vehicles by new more advanced models, etc., which could bring savings of 20–30%, the total consumption of petroleum products of the sector will continuously increase, as general economic development progresses. It is particularly in this direction that petroleum saving and substitution in the industrialized countries could contribute to liberate a higher share of petroleum products for the developing countries.

Some of the latter have made good progress in gasoline substitution, e.g. by ethanol in Brazil, by liquefied petroleum gas (LPG) in Thailand, by compressed natural gas in Bangladesh or accelerated railway electrification, as in India.

2.4.5. Sectoral structure of end-use energy demand

In addition to the absolute figures of the end-use energy demand, its structure is important for the organization and optimization of its supply from the energy system. Of special interest is also the share of obligatory energy carriers and how far substitution or fuel switches are acceptable or desired. A few examples might illustrate the overall picture or provide insight into special situations:

(1) Buildings. Figure 2.14 displays the total end-use energy demand in buildings broken down by the end-uses for the seventeen Economic Commission for Europe (ECE) countries studied in [2.14]. The total demand of 38.7 EJ is first broken down into 25.6 EJ, i.e. 66.1% for housing (residential) buildings and 13.1 EJ, i.e. 33.9% for service (commercial) buildings. In the housing group 72% represent demand for space heating, 14.1% for domestic warm water, 4.8% for cooking and 9.1% for lighting and appliances. The percentage shares for commercial buildings are 82% for heating and 18% for lighting and appliances, including air conditioning.

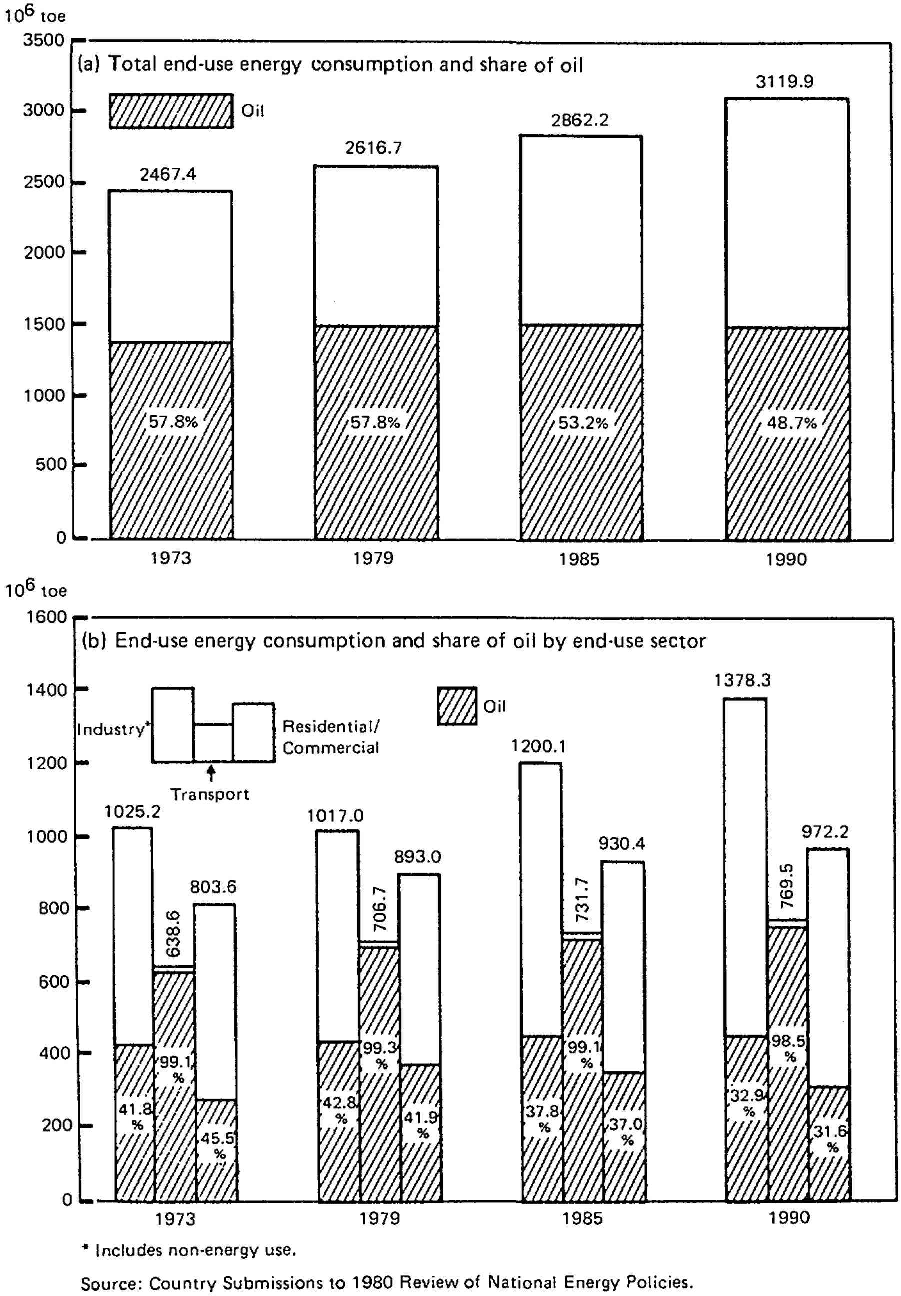


FIG.2.15. Trends in end-use energy and oil consumption in the IEA member countries (1973–1990) [2.34].

TABLE 2.XIII. % SHARE OF THE END-USE SECTORS IN THE TOTAL END-USE ENERGY DEMAND 1973–1990 [2.34]

End-use sector	1973	1979	1985	1990
Residential/commercial	32.6	34.1	32.5	31.2
Industry	41.6	38.9	41.9	44.2
Transportation	25.8	27.0	25.6	24.6

(2) IEA member countries. Figure 2.15 shows under (a) the evolution of total end-use energy and petroleum consumption 1973–1990 for the IEA member countries and under (b) the structure of the total by end-use sectors. As shown in Table 2.XIII the share of the residential/commercial end-use sectors varies between 32.6% in 1973 and 31.2% in 1990, the share of industry increases from 41.6% to 44.2% and the share of transportation decreases from 25.8% to 24.6% for the same interval.

(3) Country. Figure 2.16 displays the structure of the end-use energy consumption in the Federal Republic of Germany in 1982, both by end-use sectors and end-use needs. Regarding end-users, heat delivery reached 65.5% (33.5% for space heating and 32% process heating) and light 1% and mechanical energy 33.5%: 22% for transportation, 5% for industry and 1.5% for domestic, commercial and other needs.

(4) Household. In Japan, the structure of the household consumption was in 1973 as follows: space heating 41.4%, warm water supply 29.2%, cooking 14.8%, lighting 6.4%, electrical appliances 6.4%, air conditioning 1.2%, others 0.6% [2.36].

(5) Household with car. A family of 2.5 persons consumed in 1981 in the FRG the equivalent of 35 000 kW·h, with the following structure: space heating 18 000 kW·h (52%), car transport 12 000 kW·h (34%), warm water 2500 kW·h (7%), cooking 500 kW·h (1.5%), electrical appliances 1500 kW·h (4.5%) and light 250 kW·h (1%).

The comparison of the structural diversity of the examples presented shows a concurring general tendency but sufficient diversity to require in each concrete case a careful examination of the local conditions.

2.4.6. Electricity demand

Demand and supply of electrical energy and its handling within the electricity system is much better understood than the system handling of all other forms of energy. The recent IAEA handbook on expansion planning for electrical

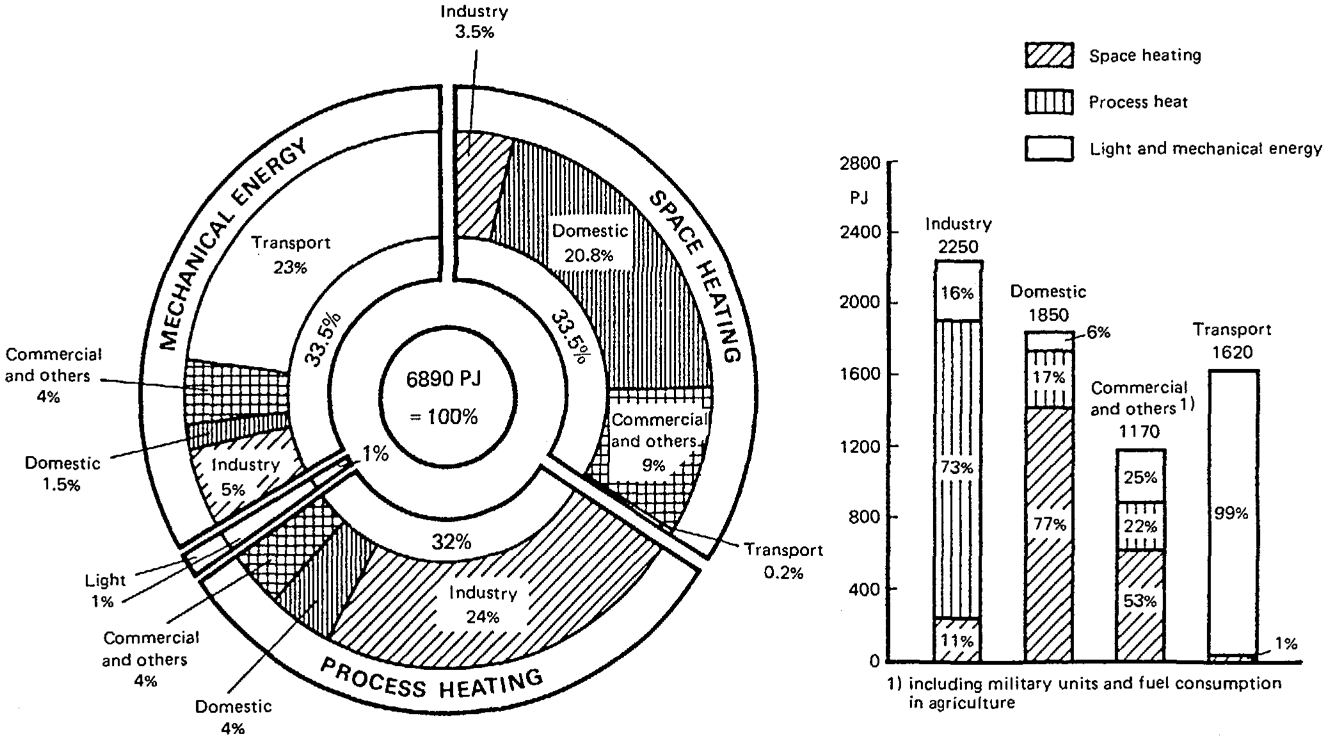


FIG.2.16. End-use energy demand in the Federal Republic of Germany in 1975 [2.35].

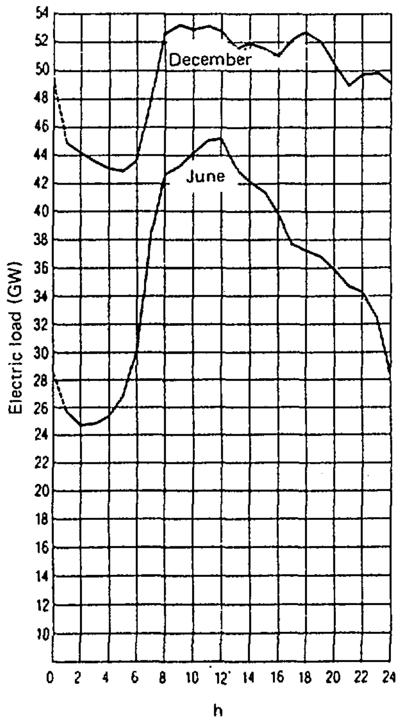


FIG.2.17. A summer and winter daily electric load curve.

generating systems [2.37], other IAEA guidebooks and chapters 6 and 17 of this book provide a large amount of information on this valuable and versatile intermediate form. However, no comprehensive analysis of the formation of demand for electricity is readily available. This is because electricity does not represent a final useful energy form attached to a certain need nor is it bound exclusively to a given end-use supply. Due to its versatility, electricity can supply any end-use demand and can be generated by any primary resource. Therefore, demand for and supply of electricity is very flexible, insistently required and gladly delivered. However, it must be technically and economically optimized. All the related problems are dealt with further on in this book with the exception of the technical aspects of electric demand management pertaining to this chapter.

Electricity demand is first dealt with as a usual end-use energy supply, i.e. aimed at high efficiency. Its supply efficiency depends, however, on the timing of demand, since electricity, not being storable, has to be produced at the time it is required. That means that demand for electricity should be moved, i.e. managed, to occur at favourable time periods. This is not feasible nor is it

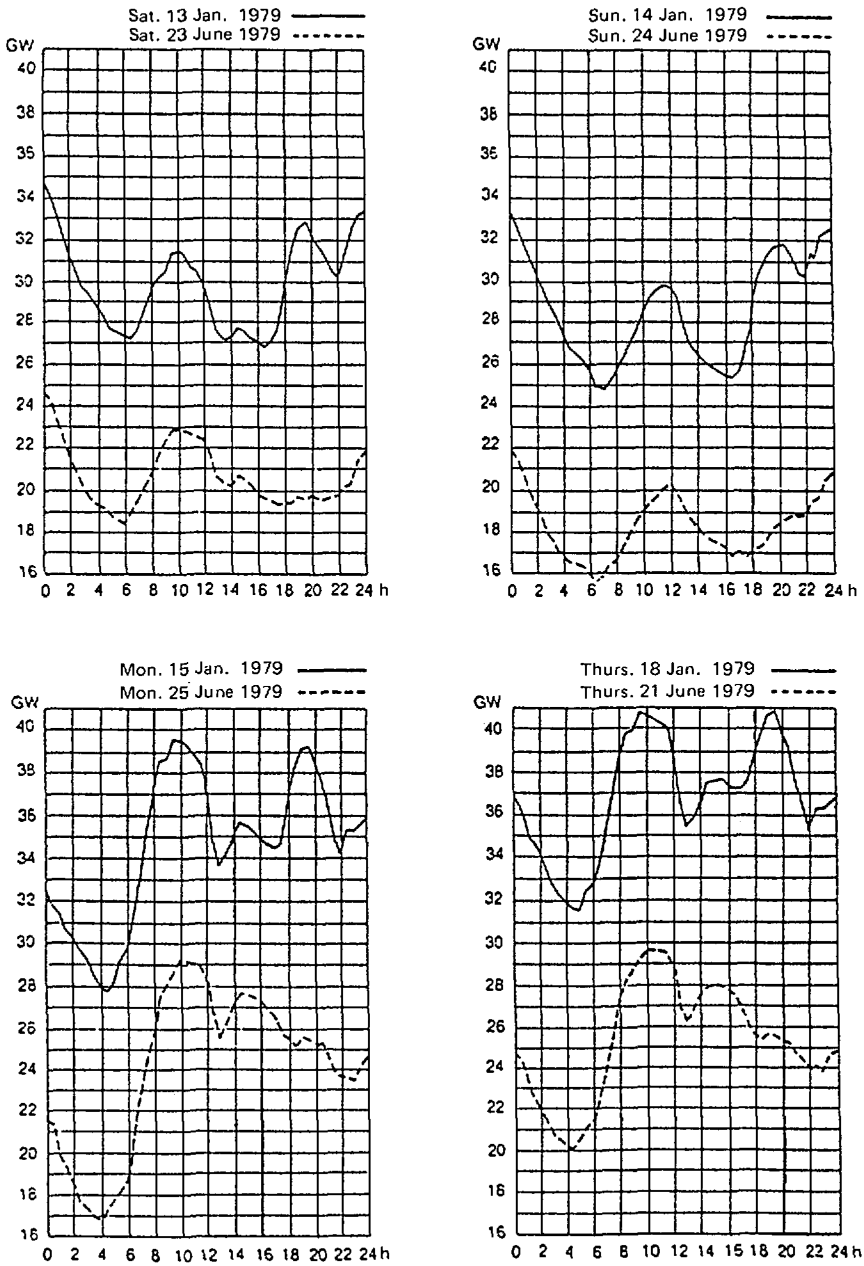


FIG.2.18. Characteristic daily electric load curves [2.38].

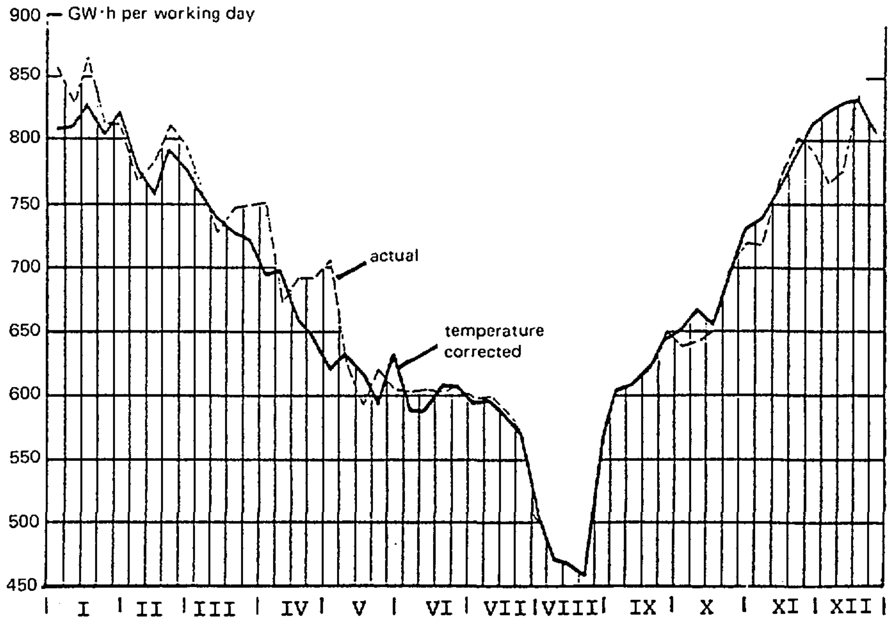


FIG.2.19. Yearly evolution of electrical demand [2.38].

necessary for all electricity production; but it could be of great help if this were partly the case, resulting in positive global effects.

Electricity demand and supply vary all the time, but it is sufficient for economic issues to relate to the hourly, daily, weekly, monthly and seasonal variations. Figure 2.17 presents for example the variation of the load curve of the electrical system of the Federal Republic of Germany on a summer and a winter working day. The load is in general lower in June and in addition there is a very reduced night load in summer.

Figure 2.18 illustrates the difference in electricity demand on a working day, on Saturday and Sunday in summer and winter [2.38, 2.39].

Figure 2.19 presents the yearly evolution of electricity demand in France, with a typical deep low in August possibly reflecting the vacation period.

A more systematic overview on the yearly variation of the electrical system load is offered by the yearly load duration curve. This curve shows the number of hours in the year during which the load was equal to or greater than any particular value. The area enclosed beneath the annual load duration curve represents the yearly energy consumption. Figure 6.3 presents as an example a projected annual electrical load duration curve in France (1985–1986) and the structure of its supply. The duration curves are particularly well suited for calculations and optimization operations and are used, expressed in appropriate equations, in computer programs.

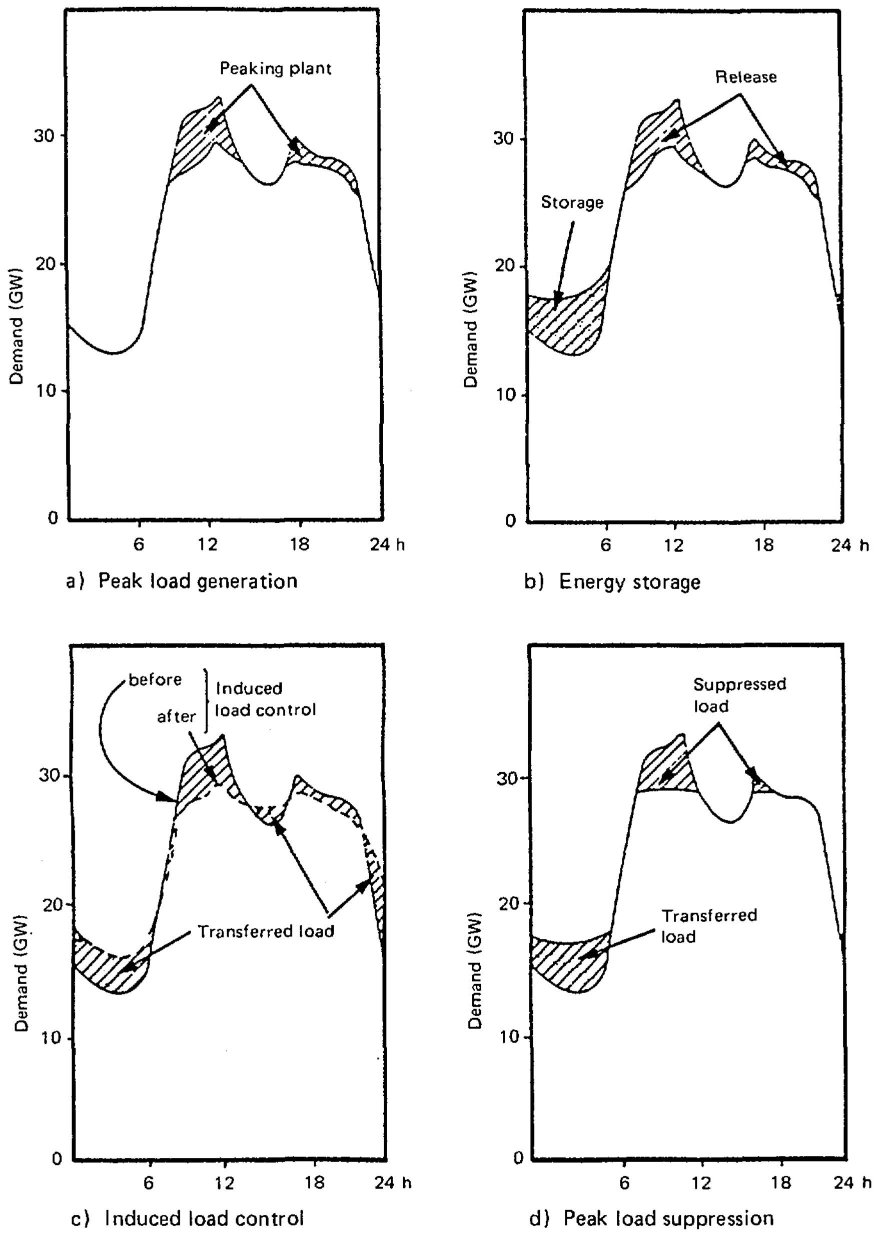


FIG.2.20. Methods of handling the peak load problem [2.40].

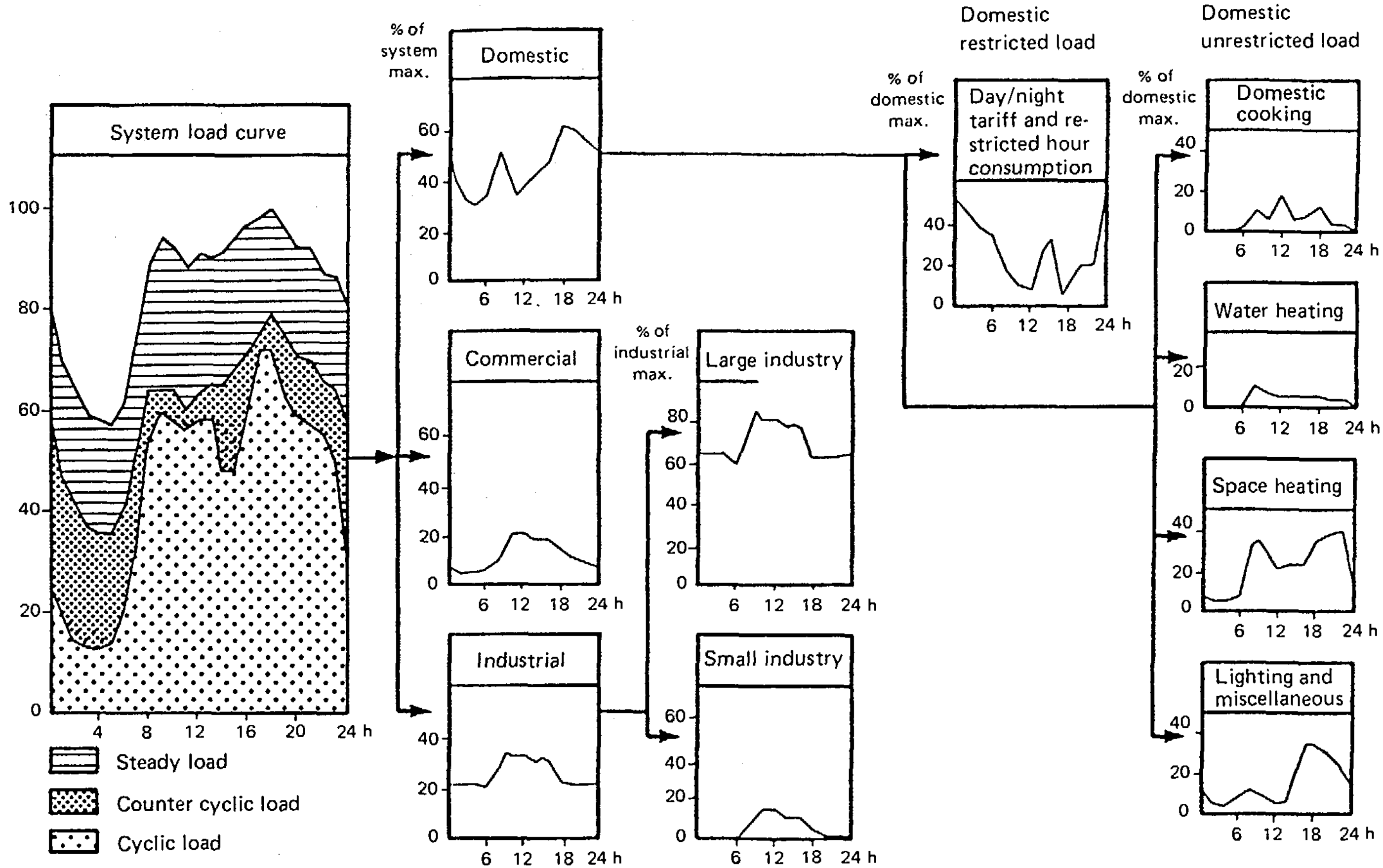


FIG.2.21. Composition of a typical winter daily electric load curve [2.40].

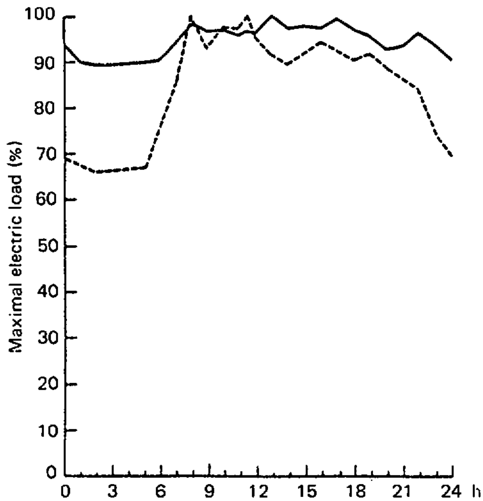


FIG.2.22. Daily electric load curves of the RWE system [2.41].

The essence of electric energy demand management is illustrated in Fig.2.20. The conventional way of meeting the load peak is to use old and inefficient generating plant or to install special peaking plants and operating them only during peak hours, leaving them idle for the rest of the time, Fig.2.20 (a). The cost of producing the peak loads is high and in general it is wasteful to supply an unrestricted peak load. Fig.2.20 (b) illustrates an energy storage method. This effectively changes the shape of the daily load curve by filling in the night trough with pumping load and supplying the peak demand by releasing the stored energy at this peak period. The economic merit of this solution depends on the capital investment required and the efficiency of the energy storage process.

Figure 2.20 (c) shows the possible effect of induced load management which is achieved by time-of-day pricing of electricity. In order to diversify the peak load, the tariff offered to the consumers gives financial incentives for off-peak electricity consumption and applies penalties for on-peak consumption. If successful, this method would lower the peak demand and increase consumption during the off-peak periods.

Figure 2.20 (d) shows the effect on the system load curve of imposed load control, where the supply to certain loads is restricted during the peak demand period. The corresponding amount of energy is then consumed off-peak.

Figure 2.21 shows how a very much improved, better shaped daily electric load curve could be managed through integration of the cyclically varying loads (such as domestic unrestricted loads, commercial and small industrial loads which vary thoughout the day), of the steady loads (such as large industrial loads which continue fairly uniformly throughout the day), and the counter-cyclically

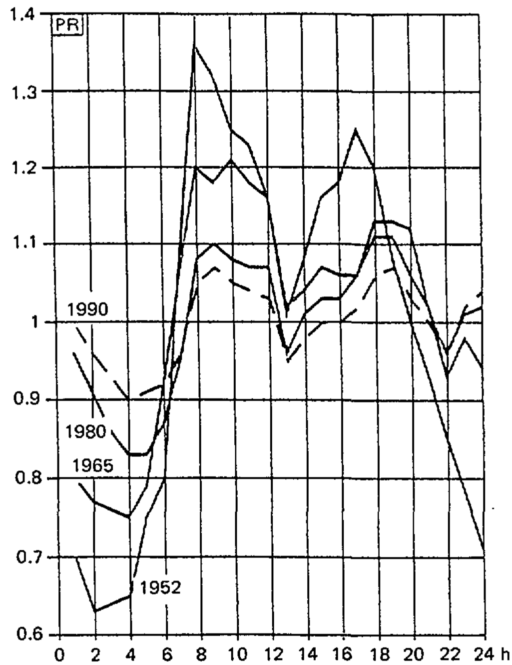


FIG.2.23. Evolution of the daily electric load of EdF (1952–1990) [2.38].

varying loads (such as domestic restricted loads, which through load management have fallen out of step with the overall system load pattern).

Figures 2.22 and 2.23 illustrate the successful implementation of demand management in the largest Federal German (RWE) and the National French electricity system.

As shown in Fig.2.22, through systematic load management, especially due to off-peak storage electric heating, between 10 December 1963 and the same date in 1980, the daily curve of the RWE system increased its daily load factor from 0.82 to 0.946, i.e. by 15.4%.

Similarly, as illustrated in Fig.2.23, the national EdF system improved considerably the shape of its daily electric load curve between 1952 and 1980 and foresees further progress until 1990.

Even more impressive are the results of the interconnection of the already nationally demand-managed electrical systems of East and West Europe. Figure 2.24 shows the individual daily electric load curves in 1963 and 1982 in the national power systems of Bulgaria, Czechoslovakia, the German Democratic Republic, Hungary, Poland, Romania and the USSR – Southern grid and the interconnected system.

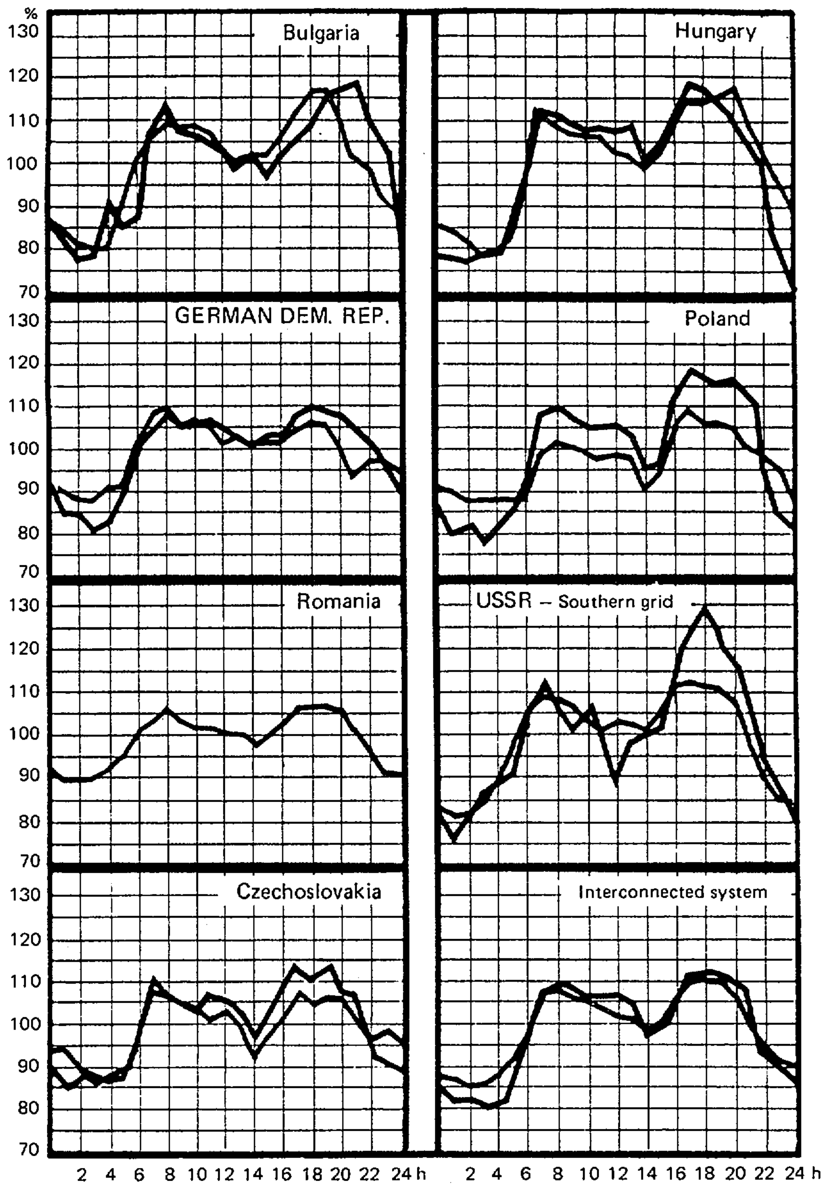
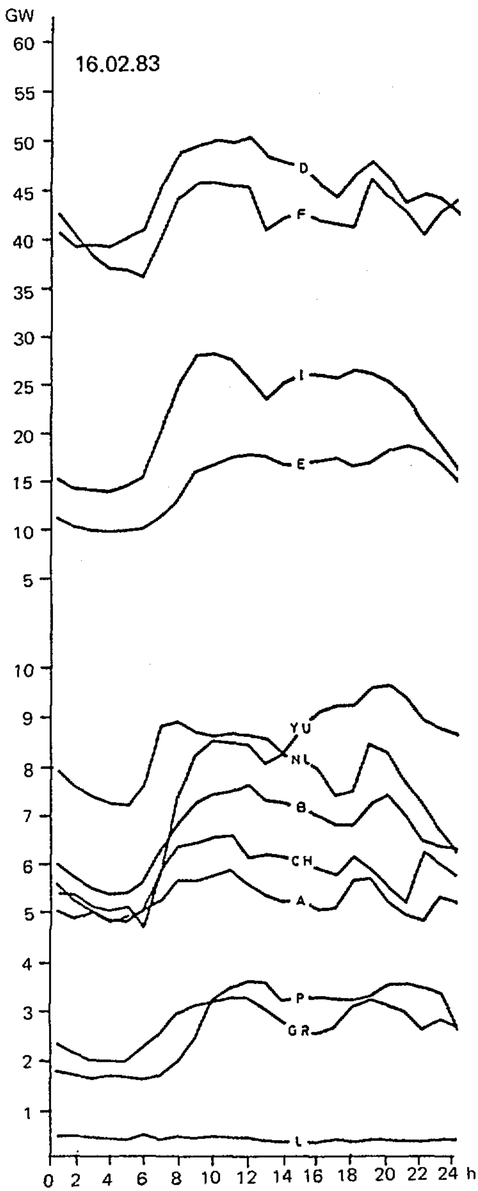


FIG.2.24. Daily electric load curves of the Eastern European national power systems on the third Wednesday of December 1963 and 1982 [2.42].



Interconnected load as % of total national load

Belgium	100 %
Fed. Rep. Germany	86 %
France	98.5%
Italy	90 %
Luxembourg	96 %
Netherlands	91 %
Austria	100 %
Switzerland	100 %
Spain	94.6%
Portugal	95 %
Yugoslavia	90 %
Greece	95 %

FIG.2.25. Daily national electric load curves in the West European interconnected electrical system [2.43].

Figure 2.25 shows the daily national electric load curves in the West European interconnected electrical system on 16 February 1983. The percentage indicated on the right side of the figure represents the share of the participating interconnected load in relation to the total load of the country.

A detailed description of the Eastern and Western European systems is given in subsection 7.6.1, where their projected interconnection is also commented on.

2.4.7. Means and measures for energy demand management

Though its effect is important, demand management is neither easy to promote not to implement. Four broad categories of measures have been identified which could help to achieve its goals:

- energy pricing policies
- taxation and other fiscal incentives
- direct capital allocation
- technical assistance, training programmes, regulations, promotional and educational programmes.

All the above measures are further elaborated in the following chapters, as gradually the volume of knowledge increases. However, one cannot insist too much or too soon that energy prices should reflect costs to the economy and serve as an essential instrument of energy demand management, i.e. of national energy policy and strategy.

Chapter 3

PRIMARY ENERGY RESOURCES

Inventory, reserves and production potential

This chapter will deal in two separate main subsections with non-renewable and renewable primary energy resources, as defined in chapter 1. However, for the purpose of background information and without entering into the major debate on definitions still in progress, one may understand that:

(a) The term 'energy resources' defines the global aggregate of energy which exists in non-renewable forms and is assumed to be ultimately recoverable, plus that existing in such renewable forms as solar, etc.
(b) The term 'reserves' refers to that fraction of energy resources which can be recovered by reasonable extension of today's technologies at costs which are expected to be economic.

For renewable energy forms, the resources might represent the ultimate annual production obtainable, while the reserves would correspond to the yearly production technically and economically achievable at a certain date.

Figure 3.1 displays graphically the primary energy classification system used in the United States of America known as the McKelvey diagram [3.1] with is two axes: increasing degree of geological assurance and increasing degree of economic feasibility.

Because of limited space, the presentation of the primary energy resources will focus more on the less known and newer forms, which by no means implies any qualitative judgement. The order selected for the presentation is that adopted in chapter 1.

3.1. Non-renewable primary energy resources

Estimates of the world's non-renewable energy resources and reserves as well as of annual production potential differ widely, depending on the available information at the time of their elaboration, the amount and quality of guesswork needed for filling the gaps, the threshold of techniques and costs selected for defining the reserves and their subcategories, and the envisaged progress in management and manpower input for production development. Therefore, it is hardly possible to present unequivocal figures. The quantitative differences should, in the present framework, not be regarded as disturbing because of their lack of precision as much as enlightening because of the scope for judgement.

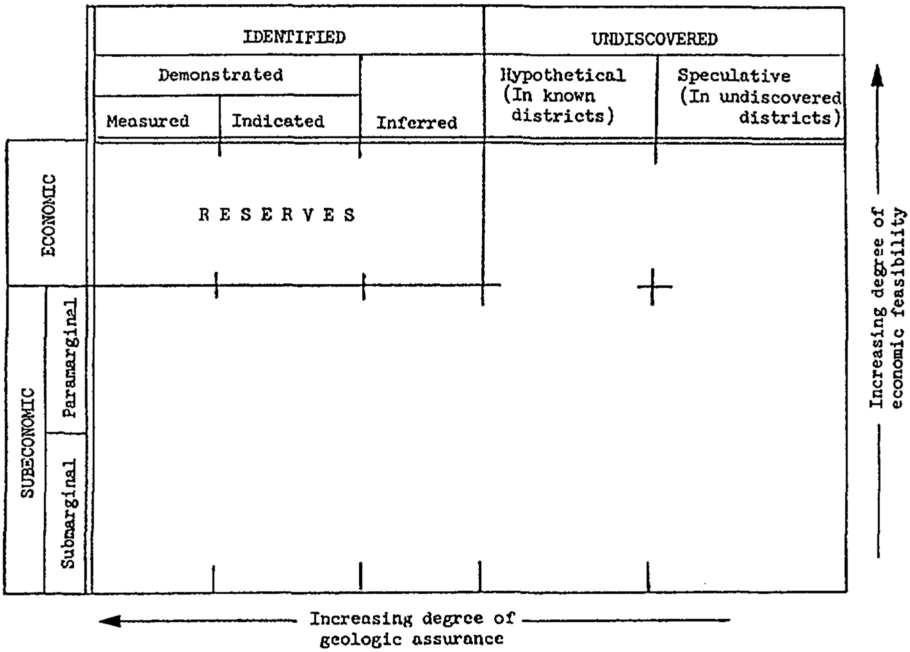


FIG.3.1. United States Department of the Interior classification system for primary energy [3.1].

3.1.1. Coal

Under the heading Coal, the following categories are distinguished: hard coal (anthracite, bituminous coal, sub-bituminous coal), lignite (including the better varieties also designated as brown coal), and relatively young formations of peat.

Rising estimates of the world coal resources and reserves have been published in the last decades [3.2–3.13]. One of the most recent publications, the WEC-1983 Survey of Energy Resources [3.3], presents the following updated figures concerning the proved reserves in place and proved recoverable coal reserves:

	Proved amount in place (10^9t)	Proved recoverable reserves (10^9t)
Bituminous coal (including anthracite)	920	515
Sub-bituminous coal	260	166
Lignite	340	265

Over 90% of the proved recoverable reserves of bituminous coal and anthracite are concentrated in a few countries namely, in the USA (125×10^9t), the USSR (108×10^9t), the People's Republic of China (99×10^9t), South Africa (52×10^9t), the Federal Republic of Germany (30×10^9t), Australia (27×10^9t), and Poland (27×10^9t) (see Fig. 3.2 and Ref.[3.4]). Most reserves, including those of India, have a high percentage of coking coal.

The currently economically recoverable reserves of sub-bituminous coal mainly lie in the USA (100×10^9t) and the USSR (42×10^9t).

The recoverable reserves of lignite are concentrated mainly in the USSR (89×10^9t), Australia (36×10^9t), the Federal Republic of Germany (35×10^9t), the German Democratic Republic, the USA (32×10^9t), Yugoslavia (15×10^9t), Romania and Poland (12×10^9t). In addition to the aforementioned proved recoverable reserves of coal, estimates exist of additional resources (in place and recoverable). The following figures [3.3] reflect the order of magnitude of the additional coal resources in place:

	$t \times 10^9$
– Bituminous coal and anthracite:	
USSR	1710
People's Republic of China	1325
Australia	507
USA	472
Federal Republic of Germany	186
UK	185
India	85
Poland	84
– Sub-bituminous coal:	
USSR	1650
USA	275
Australia	100
Canada	27
– Lignite:	
USSR	759
USA	394
Australia	87
People's Republic of China	40
Poland	24
Indonesia	14

TABLE 3.I. WORLD COAL RESOURCES AND RESERVES, COMPARISON OF ESTIMATES [3.8]

	Geological resources				Technically and economically recoverable reserves			
	WEC[a]		WOCOL[b]		WEC[a]		WOCOL[b]	
	(10^9 tce)	(%)	(10^9 tce)	(%)	(10^9 tce)	(%)	(10^9 tce)	(%)
USA	2570	25.4	2570	23.9	177	27.8	167	25.2
USSR	4860	48.0	4860	45.2	110	17.3	110	16.6
People's Republic of China	1438	14.2	1438	13.4	99	15.5	99	14.9
United Kingdom	164	1.6	190	1.8	45	7.1	45	6.8
Germany, Fed. Rep.	247	2.4	247	2.3	35	5.5	34	5.1
India	57	0.6	81	0.7	33	5.2	12	1.8
Republic of South Africa	58	0.6	72	0.7	27	4.2	43	6.5
Australia	262	2.6	600	5.6	27	4.2	33	5.0
Poland	126	1.2	140	1.3	21	3.3	60	9.0
Canada	115	1.1	323	3.0	10	1.6	4	0.6
Others	230	2.3	229	2.1	53	8.3	56	8.5
TOTAL	10127	100.0	10750	100.0	637	100.0	663	100.0
Largest five countries	9377	92.6	9791	91.1	466	73.2	481	72.5
Largest ten countries	9897	97.7	10521	97.9	584	91.7	607	91.5

[a] Estimates by World Energy Conference 1978.
[b] Estimates by World Coal Study in 1980.

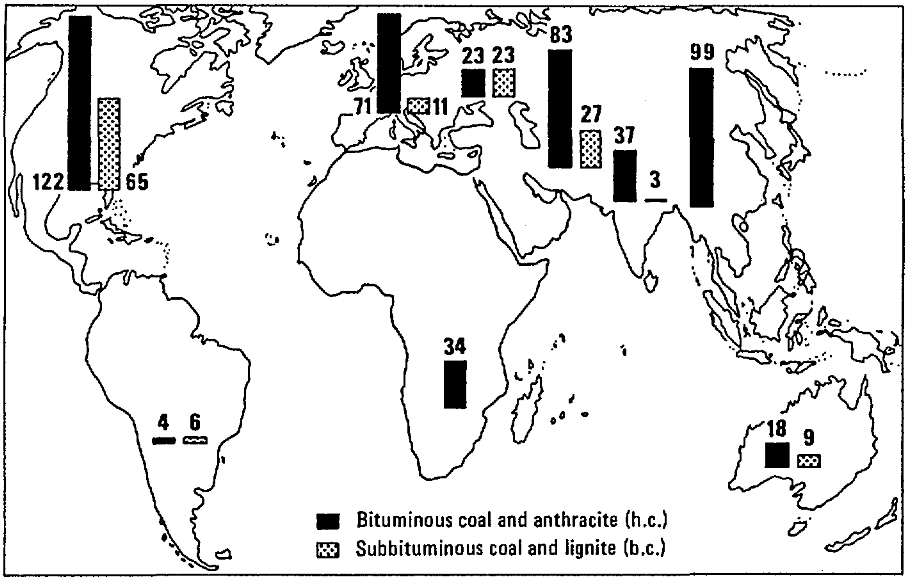


FIG.3.2. Distribution of technically and economically recoverable coal reserves in 10^9t [3.4].

Although not representing the most recent status, Table 3.I displays an overview on the total world coal resources and reserves and the division of these between the most endowed countries [3.8]. The figures – in 10^9tce – from the two sources, the World Energy Conference and the World Coal Study (1980) show, with a few exceptions, quite good agreement.

The production of bituminous coal and anthracite amounted in 1978 to 2.54×10^9t, of sub-bituminous coal and lignite to 1.078×10^9t and of peat to 48.4×10^6t.

In 1981 the world hard coal (bituminous coal and anthracite) production reached 2750×10^6t and had the following regional structure (in 10^6t) [3.14]:

OECD countries	1097.9
Asia	782.2
USSR	510.0
East Europe	202.6
Africa	136.9
Central and South America	20.6
	2750.2

The main producing countries (in 10^6t) were:

USA	698.1
People's Republic of China	593.0
USSR	510.0
Poland	163.0
South Africa	131.2
UK	125.3
India	123.1
Federal Republic of Germany	95.5
Australia	92.1

It was thought that world coal production might reach 3.9×10^9tce in 1985, 5.8×10^9tce in the year 2000 and possibly 8.8×10^9tce in 2020. Figure 3.3 illustrates such an evolution [3.4]. However, more recent studies have reduced the estimates in the light of the general evolution in the past few years to $4–4.6 \times 10^9$tce in the year 2000 and $6.3–8.4 \times 10^9$ tce in 2020 [3.6, 3.7].

However, such an increase in world coal production could only be reached if coal could be transported to large consumers worldwide. While the transport aspects are dealt with in chapter 7, it is worth mentioning that world coal trade – for metallurgical and steam coal – increased from 173×10^6t in 1973 to 273.4×10^6t in 1982 [3.14]. It appears to have good prospects for a further increase, provided that the necessary transport infrastructure becomes available in time, that the environmental aspects involved are solved, and that substantial progress is made in the coal extraction and preparation phases [3.15].

As far as coal extraction is concerned, interest in a high recovery factor is obvious, both for lowering global production costs and from the conservation point of view.

Recovery factors for underground coal mining are quoted in most cases between 25 and 75%, according to the mining conditions and to the kind of estimate. In open-cast mining, recovery factors are substantially higher, mostly between 75 and 90% [3.16].

Further recent data on coal resources and reserves as well as on the coal production of different countries can be found in Ref. [3.3], where coal composition and heat values are also indicated.

An example of the wide field of variation of the calorific value of lignite depending on the moisture and ash content is given in Fig. 3.4 [3.17]. The example chosen illustrates the difficult conditions sometimes encountered when operating lignite power plants and emphasizes the importance of an adequate fuel supply.

In addition to the general considerations relating to the energetic utilization of coal, its importance as raw material must be equally stressed. In particular, coal can serve as a basic input for the manufacture of carbon-containing chemical compounds and their derivatives [3.9]. Even lignite, a younger coal, is considered a suitable raw material for a series of chemical products [3.18].

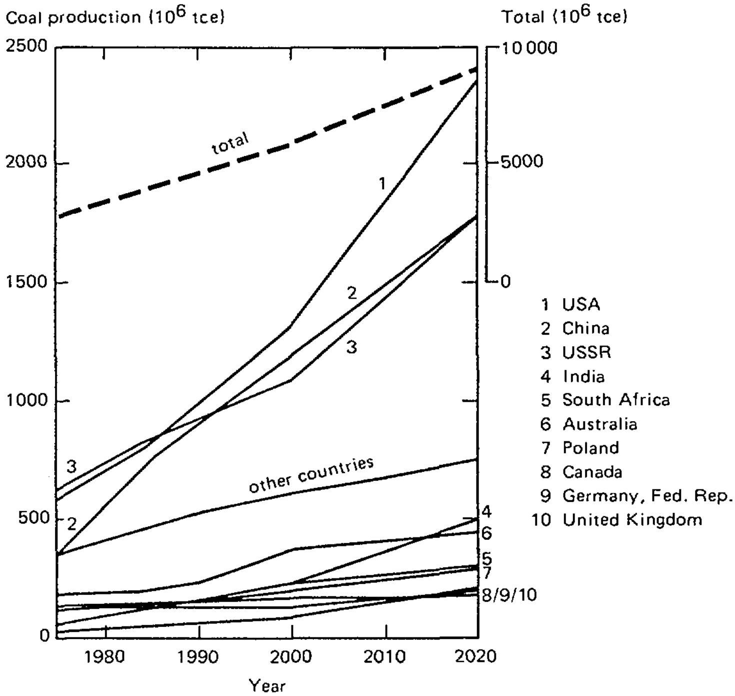


FIG.3.3. Estimated future coal production trends [3.4].

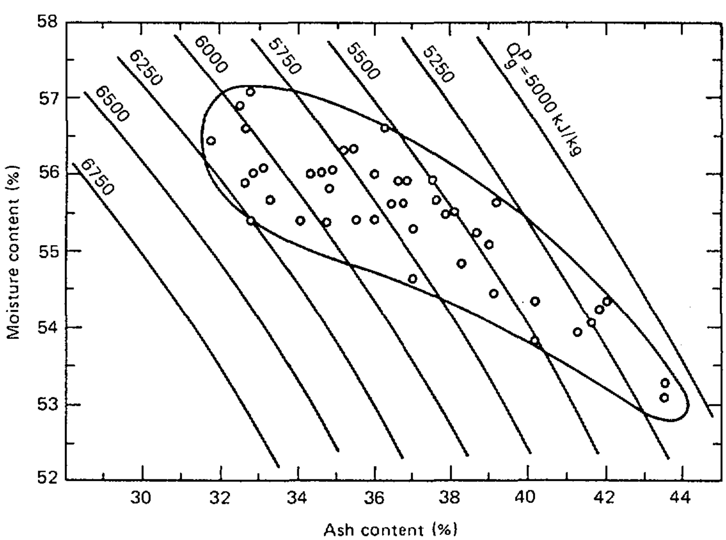


FIG.3.4. Correlation between the moisture and ash content and the heat value of lignite in the Maritza – Ext. 3 power plant (Bulgaria) [3.17].

TABLE 3.II. CUMULATIVE PRODUCTION, RESERVES, RESOURCES AND ULTIMATE RECOVERY FOR PETROLEUM ACCORDING TO REGION [3.2]

Region	Cumul. prod. 1-1-1979		Proved recoverable reserves 1-1-1979		Estimated add. recoverable resources		Ultimate recovery	
	(10^6t)	(%)	(10^6t)	(%)	(10^6t)	(%)	(10^6t)	(%)
Africa	3 750	7	8 040	9	34 000	16	45 790	13
North America	17 520	33	4 480	5	24 000	11	46 000	13
Latin America	7 040	14	7 770	9	12 000	6	26 810	8
Far East/Pacific	1 720	3	2 390	3	12 000	6	16 110	4
Middle East	14 680	20	51 050	57	52 000	24	117 730	33
Western Europe	560	1	2 710	3	10 000	5	13 270	4
USSR, China, Eastern Europe	7 530	14	12 700	14	64 000	30	84 230	24
Antarctic					4 000	2	4 000	1
Total	52 800	100	89140	100	212 000	100	353 940	100

Peat is a heterogeneous mixture of partially decomposed organic matter (plant material) and inorganic minerals that have accumulated in a water-saturated environment. Such an environment inhibits active biological decomposition of the plant material and promotes the retention of carbon that would normally be released as a gaseous product of the biological activity. Consequently, there is an accumulation of organic material known as peat.

The formation of peat and peatlands occurs in swamps, bogs and salt water and fresh water marshes that can be found worldwide. However, the formation process is extremely slow. Estimates for European peat formation are of the order of 20–80 cm per 1000 years. Because it is formed so slowly and formation stops once fuel peat production has been started, peat cannot be considered a renewable resource.

In geological terms, peat is regarded as young coal. It has a lower calorific value, varying from 8 to 18 MJ/kg. Reduction of the moisture content from 90% in excavated peat to 30% in air-dried peat is the most demanding task in fuel-peat production. One estimate [3.2] of the total amount of peat in the world is around 122×10^9tce (318×10^9t) of which 20.7×10^9tce are proved reserves and 101×10^9tce additional resources. Only 5.8×10^9tce (16×10^9t) are considered to be economically recoverable. In a more recent publication [3.19] total world peat resources are indicated as 143×10^9tce. At least 40 to 50 countries are known to have peat resources and several other countries are also believed to possess such resources. Peat may be found in every continent.

Peat is thus a realistic, under many conditions competitive, energy alternative [3.20]. Therefore the present world production of 35.7×10^6tce might rapidly develop by the year 2000 to $42.8–5.7 \times 10^6$tce in developed countries and $14.2–28.4 \times 10^6$tce in developing countries. The ultimate potential is higher.

3.1.2. Petroleum

The presentation under this heading will deal separately with conventional and unconventional forms of petroleum, the latter comprising: deep water basins, heavy oil, tar sands and oil shale. However, the available statistical material is in some cases deficient.

3.1.2.1. Conventional petroleum

Over the years, a great number of estimates have been published concerning the total amount of recoverable petroleum (cumulative production, proved recoverable reserves and additional recoverable resources). Beginning with 82×10^9t estimated in 1942, the figures have shown a trend to increasingly higher estimates [3.2].

The last comprehensive estimate, published by the WEC in 1980 [3.2], put the total quantity of recoverable petroleum at 354×10^9t, out of which

TABLE 3.III. PROVEN RECOVERABLE PETROLEUM RESERVES (10^6 t)[a] [3.8]
(as of 1 January)

	1950	1960	1970	1973	1976	1977	1978	1979	1980	1981	Reserve/production ratio 1979	Reserve/production ratio 1980
USA	3521	4786	5280	5023	4503	4270	4025	3888	3615	3602	8.4	7.4
Canada	172	655	1198	1392	968	846	818	819	928	873	12.6	10.6
TOTAL North America[c]	3693	5441	6478	6415	5471	5116	4843	4707	4543	4475	9.0	7.9
Venezuela	1357	2571	2012	1869	2415	2435	2483	2456	2438	2449	21.0	21.7
Mexico	–	–	819	382	1297	955	1910	2183	4263	6003	57.5	54.6
TOTAL Latin America[c]	1629	3491	3981	4448	4826	4039	5507	5627	7704	9480	29.4	31.9
Abu Dhabi	–	40	2182	2833	4024	3956	4229	4093	3820	3956	52.9	60.9
Saudi Arabia[b]	1386	7143	19987	19918	20710	21500	20886	23048	22712	22923	47.9	46.3
Iraq	750	3571	3752	3957	4680	4638	4707	4379	4229	4093	25.2	29.7
Iran	1000	5000	7503	8868	8799	8595	8458	8049	7913	7844	54.8	106.0
Kuwait[b]	1571	8857	10164	9945	9713	9625	9563	9473	9349	9268	75.4	107.8
Oman	–	–	682	682	805	791	771	341	327	319	22.7	22.5
Qatar	143	340	750	955	798	778	765	546	513	489	21.5	21.4
TOTAL Middle East[b]	4679	25919	46181	49257	50793	50842	50289	50913	49379	49396	46.8	51.6
Indonesia	157	1285	1228	1365	1910	1433	1364	1391	1310	1296	16.4	16.7
India	–	100	98	114	125	409	409	396	355	352	29.7	35.2
Australia	–	–	341	289	232	188	273	287	291	322	13.3	17.2
TOTAL Asia-Pacific[b]	259	1561	1792	2036	2897	2646	2694	2730	2641	2678	18.3	19.8

	1950	1960	1970	1973	1976	1977	1978	1979	1980	1981	Reserve/ production ratio 1979	1980
Algeria	–	714	1091	1528	1006	928	900	859	1151	1119	18.6	24.9
Gabon	–	21	68	104	106	80	74	65	68	61	7.1	6.0
Libya	–	214	4775	4148	3561	3479	3411	3315	3206	3138	31.4	36.7
Nigeria	–	21	682	2046	2756	2660	2551	2483	2374	2278	20.1	22.6
TOTAL Africa[b]	29	1039	6778	8922	8348	7997	7742	7461	7786	7524	23.3	28.8
United Kingdom	–	–	1	682	2183	2292	2592	2183	2101	2019	26.9	25.2
Norway	–	–	–	273	955	772	819	805	784	750	40.4	31.6
TOTAL Western Europe[b]	101	412	243	1648	3477	3348	3665	3270	3203	3149	29.7	27.0
USSR	614	4000	6139	10232	10969	10655	10232	9686	9140	8595	15.7	14.2
China	–	–	2047	2660	2728	2729	2729	2729	2729	2797	26.1	26.4
TOTAL CPEs[b]	614	4000	8186	13370	14051	13793	13370	12824	12278	11774	17.4	16.1
TOTAL World	11004	41863	73369	86096	89863	87781	88110	87532	87534	86475	28.1	28.9

[a] One metric ton = 7.33 barrels from 1970 onwards. Before 1970 one metric ton = 7 barrels.

[b] Includes one half of neutral zone.

[c] Totals include all other.

Source: Oil and Gas Journal.

TABLE 3.IV. WORLD PETROLEUM RESOURCES (10^9 t) [3.8]

	Proven reserves (1980)	Estimated additional recoverable resources [a]	Total expected recovery	Delphi poll
North America	4.5	20-24	24.5 - 28.5	28.8
Latin America	9.5	12-23	21.5 - 32.5	23.4
Middle East	49.4	18-52	67.4 -101.4	109.2[b]
Asia-Pacific	2.7	12-18	14.7 - 20.7	15.6
Africa	7.5	12-34	19.5 - 41.5	11.7
Western Europe	3.1	2-10	5.1 - 13.1	11.7
CPEs	11.8	48-64	59.8 - 75.8	59.8
Antarctica	--	3-4	3 - 4	--
TOTAL World	88.5	127-229	215.5-317.5	260.0

[a] Including ultimate recovery from known fields

[b] Includes North Africa

Sources: various sources such as Moody, Halbouty, World Energy Conference 1980, etc.

53×10^9t (i.e. 15%) had already been recovered. On 1 Jan. 1979, the proven recoverable reserves were approximately 89×10^9t (i.e. 25%), and the additional recoverable resources were around 212×10^9t, i.e. 60%. Table 3.II presents the cumulative production, reserves, resources and ultimate recovery for conventional petroleum by the main world regions. It includes resource figures for the Antarctic region (4×10^9t), which is usually considered in the unconventional petroleum category.

Reference [3.3], the WEC survey of 1983, gives updated figures by country on proved petroleum reserves in place and recoverable, on additional petroleum resources as well as on recent annual production. It does not, however, give total figures, except for the proved recoverable reserves, for which a rounded figure of 84×10^9t is quoted. As per 1 January 1983 the equivalent figure was 91.4×10^9t. In addition to the petroleum tables, Ref. [3.3] presents a table with the data on reserves, resources and annual production for natural gas liquids, i.e. hydrocarbons in natural gas reservoirs which are separated from the natural gas as liquids. The highest figure is for Mexico, with a production of 11.86×10^6t in 1981.

Another recent reference [3.21] presents an evolution of the figures for the world proven recoverable petroleum reserves at the end of the year, as follows:

Year		1973	1975	1978	1980	1981
World	(10^9t)	84.5	88.6	86.3	87.3	90.3
Arab countries	(10^9t)	43.7	45.0	46.7	45.8	45.9
Arab countries	(%)	51.8	50.8	54.0	52.5	50.8

In general, proven world petroleum reserves are tending to level off at around 90×10^9t, with a lifetime of 33.5 years, against only 27 years at the beginning of 1980.

The countries with the largest proven recoverable reserves [3.3] are, in 10^9t:

Saudi Arabia	22.5
Kuwait	8.8
Iran	7.8
Mexico	6.9
Indonesia	6.7
United Arab Emirates	4.4
Iraq	4.1
USA	4.0
Libya	3.1
People's Republic of China	2.7
Nigeria	2.3
United Kingdom	1.0
Venezuela	0.9
Canada	0.9

For the USSR, which has very important petroleum reserves, no data were included. However, according to other sources, and especially to Table 3.III, the USSR's recoverable petroleum reserves of some 9×10^9t rank second to Saudi Arabia and ahead of Kuwait. Table 3.III displays a good general picture on the proven recoverable petroleum reserves by regions and countries in the period 1950–1981 and also presents the reserve production ratio in 1979 and 1980 [3.8].

In contrast to the well-developed interest in the reserves, interest in the resources estimation is more recent. The figures are becoming increasingly reliable, and have been backed by scientific methods and analysis.

Table 3.IV presents a recent synthesis of the world petroleum resources, adding to the proven recoverable reserves the estimated additional recoverable resources to consolidate the total expected recovery. The last column shows the average figures collected in a WEC Delphi poll in 1977, which are in line with both ranges and the orders of magnitude obtained from other sources.

The quantity of petroleum which can be actually extracted from a reservoir depends on the factor of recovery, which for example at its ultimate limits represents the ratio between recoverable proven reserves and the proven reserves in place.

Enhanced recovery means stretching the production from a given petroleum reserve or resource, i.e. a better utilization of the reservoir's capacity; it leaves a smaller percentage of petroleum in the deposit. The percentage not used represents a reserve loss from the point of view of the enlarged overall energy balance, since it has to be replaced marginally (like any loss in the balance) by an opportunity primary resource, the same or another for which additional costs of exploration and production are involved.

The evolution of the recovery factor has a long technical and economic history. The first stage of crude oil exploitation (starting in the 1860s and lasting up to the first decade of the twentieth century) was that of primary recovery. The recovery factor reached only 10–15% because after the natural pressure of underground water or gas mixed with oil dissipated, tremendous quantities of oil were left underground.

In the second stage, extending to the end of the 1930s, the recovery factory reached 15–20% in industrialized, oil-producing countries, but still remained very low in the other regions.

The third stage – 1940 to the end of the 1950s – was characterized by the accelerated introduction of secondary recovery through artificial water flooding of reservoirs, which brought the recovery factor to 30–40%. At this stage, increased attention was given to natural gas recovery when associated with petroleum deposits.

The fourth and present stage started at the end of the 1960s and is characterized by a considerable broadening of recovery methods used and their highly scientific combination and integration in new, complex approaches. Thermal drive, which includes steam and hot water injection for local and area stimulation, in situ combustion, fire, flood, etc., appeared and the injection of gaseous agents, e.g. carbon dioxide, now seems very promising.

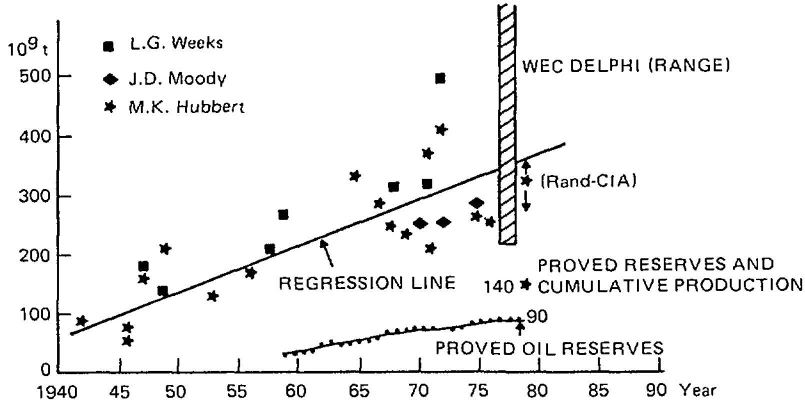


FIG.3.5. Estimates of world petroleum resources [3.8].

With new secondary and tertiary recovery methods, the ECE region (grouping the European countries and the USA) considers increases in the recovery factor from the present 35% for on-shore and 40% for off-shore operation, to up to 45% as feasible and up to 60% as the maximum possible for the 1990s. However, such high anticipated figures, which involve considerable technical efforts and new investments, could only be realized if the additional extraction remains competitive in the then prevailing conditions of the petroleum world market.

With the above described concept of the recovery factor, it is interesting to turn back and summarize the world petroleum resources status and prospects as follows [3.22]:

(1) Cumulative petroleum consumption to the end of 1979 was 60×10^9t, which include the 1979 consumption of almost 3.2×10^9t and 44×10^9t, i.e. 73% of total consumption, in the period 1960–1979;

(2) Existing proven reserves can be mobilized with an average recovery factor of 25%: of 90×10^9t 75% is in developing countries (including 69% in OPEC countries), 15% in countries with centrally planned economies, and 10% in industrialized countries (although they consume 65% of the world's petroleum production);

(3) Future discoveries of new petroleum deposits presumed to be mobilized with the same recovery factor of 25% may amount to 120×10^9t, most of it under the oceans;

(4) Increasing the average world recovery factor from 25 to 40% would augment the recoverable reserves by 90×10^9t, an amount equivalent to the existing proven reserves!

(5) Altogether, ultimate reserves of conventional petroleum should be around 300×10^9t, as displayed in Table 3.IV and Fig.3.5, including 40–45% off shore.

TABLE 3.V. LARGEST PETROLEUM PRODUCERS IN 1980 AND 1982 (10^6 t)

Country	1980	1982	Country	1980	1982
USSR	603	612	United Arab Emirates	83	60
Saudi Arabia	495	325	Canada	82	73
USA	485	480	U K	80	103
Irak	138	48	Indonesia	78	65
Venezuela	113	100	Iran	74	98
Mexico	110	148	Algeria	45	32
People's Rep. China	106	102	Argentina		25
Nigeria	101	64	World	3066	2756
Kuwait	86	42			
Libya	85	55			

TABLE 3.VI. LARGEST PETROLEUM CONSUMER COUNTRIES (10^6 t)

	1979	1980
USA	874	800
USSR	440	438
Japan	265	255
Federal Republic of Germany	147	131
France	119	113
Italy	102	103
UK	96	
People's Republic of China	90	
Canada	88	
Spain	52	
Western industrialized countries	1990	1720 (in 1981)

Accordingly, the evolution of future world petroleum supply would depend both on the discovery of new petroleum fields and on the degree of improvement in the recovery factors in known fields and in reservoirs still to be discovered.

An interesting move in new directions may be noted in recent years, i.e. enhanced and improved operation of small petroleum fields. According to an expert from the Rand Corporation, some 29 000 fields (95 per cent of the

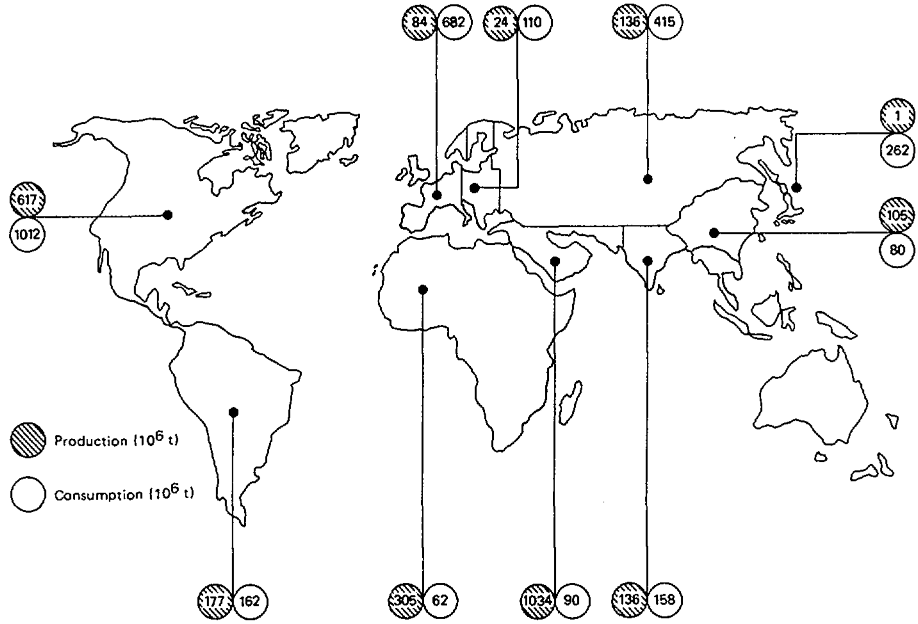


FIG.3.6. Production and consumption of petroleum in the world [3.24].

world total of fields so far discovered) each hold 6.7 × 10^9t or less of recoverable oil, or in aggregate the equivalent of just 10 × 10^9t of hydrocarbons, i.e. only 7% of the world total. More than 26 000 of them are in the USA, while outside North America there are only 1500 small fields, which contribute 2 × 10^6t equivalent or 3% of the total there. Because the USA is the most intensely drilled area of the world, it has a greater share of its reserves in non-giant fields. An intensive drilling effort in other places could have similar results. In many countries small fields will continue to be found for many years to come. Their cumulative impact could be great, and their contribution to the economies of the petroleum-importing developing countries could be especially significant [3.23].

However, it is only slowly that this awareness is growing outside the USA, and a campaign to promote it rapidly and efficiently would be more than welcome for all future petroleum consumers over the world.

The world production of petroleum increased till 1973 very rapidly, more than doubling between 1950 and 1960 and 1960 and 1970 [3.8]:

	1950	*1960*	*1970*	*1973*
World production (10^6t):	525	1051	2336	2845

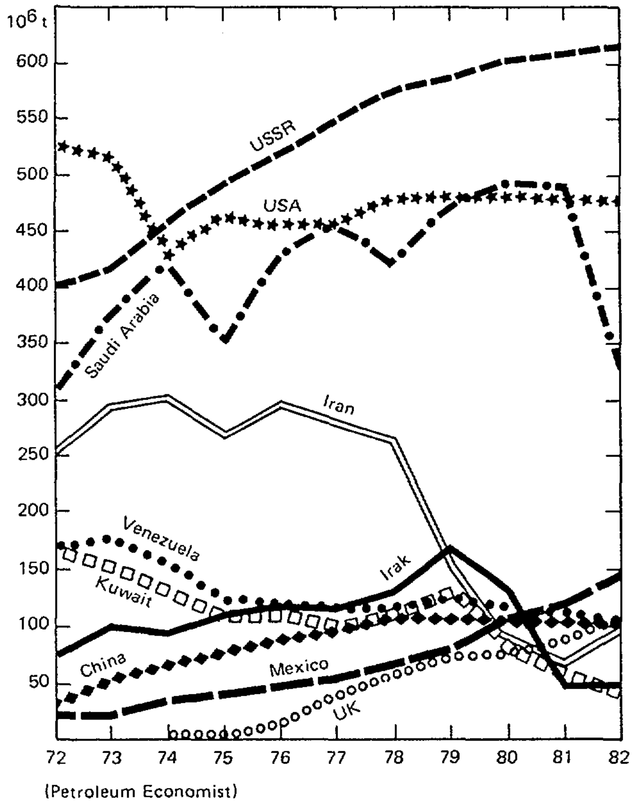


FIG.3.7. Evolution of petroleum between 1972 and 1982 (10^6 t).

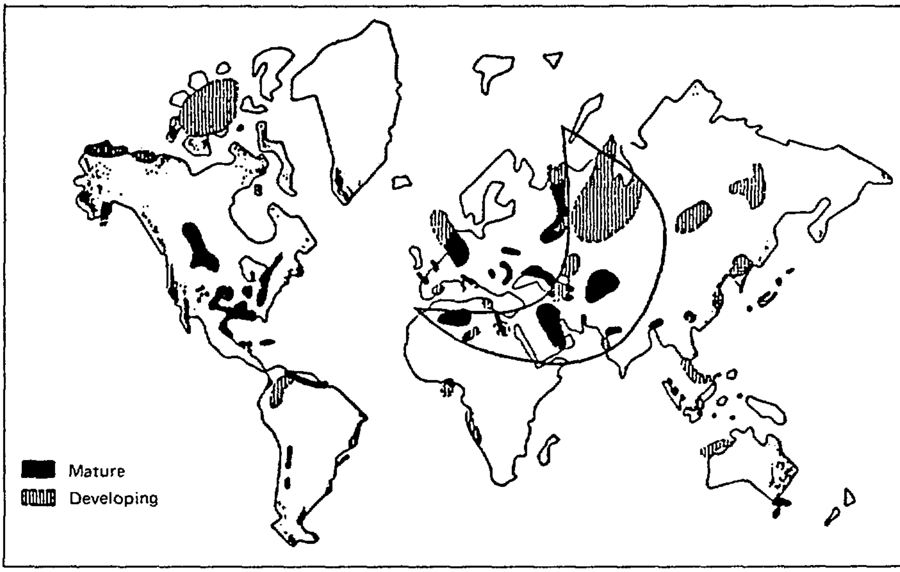
and showing over the first 23 years an average yearly growth rate of approximately 7.5%. For well known reasons, the growth rate after 1973 was broken and the world production evaluated quite differently:

	1974	*1975*	*1976*	*1977*	*1978*	*1979*	*1980*	*1981*	*1982*
World production (10^6t):	2849	2717	2947	3052	3098	3189	3066	2859	2756

Table 3.V shows the largest petroleum-producing countries while Table 3.VI presents the largest petroleum consumers.

Figure 3.6 illustrates the great discrepancies between domestic petroleum production and consumption in the main regions of the world and herewith the basic dilemma of petroleum supply politics [3.24].

The rate of petroleum reserves depletion varies widely. In addition to the information of Table 3.III, the following figures are self-explanatory: in 1979 Latin America had already extracted 47% of the proven recoverable reserves,



Source: M.T. Halbouty, 1980

FIG.3.8. Main world petroleum productive areas [3.8].

the USA 81%, the Middle East only 24%, Eastern Europe and the People's Republic of China 44%, Africa 34% and Western Europe 14%.

Figure 3.7 illustrates the evolution of petroleum production between 1972 and 1982 and Fig.3.8 the worldwide location of the main productive areas. Almost 60% of the world's giant petroleum fields are within the crescent shown on the map.

After the peak of almost 3.2×10^9t in 1979, world petroleum production decreased steadily, the OPEC countries being mainly affected by this trend. Their contribution decreased from 1.46×10^9t in 1979 to 1.05×10^9t in 1981 and to a low of some 0.75×10^9t in 1983.

The petroleum consumption of the western industrialized countries declined (10^9t) from 1.96 in 1973 to 1.79 in 1975, recovered to 1.95 in 1977 and after a peak of 1.99 in 1979 declined continuously to 1.72 in 1981 and to some 1.58 in 1983. Among other factors, the sharp petroleum price rise after 1973 contributed strongly to this evolution. In fact, a correlation can be observed with the evolution of the average posted price of a barrel of crude oil, which increased from US $3.40 in 1973 to US $11.30 in 1974, to $12.90 in 1978, to $18.70 in 1979 and $30.10 in 1980 to peak at $34.50 in 1981. It was averaging $30.50 in 1983, with an OPEC basic price of Arabian light crude oil of $29/barrel.

To illustrate the strong position petroleum has acquired in modern life, it may be mentioned that in 1980, the world – excluding countries with centrally planned economies – consumed 91 700 litres of petroleum derivatives every second of which 26 000 were heating fuel and 21 000 gasoline and light fuels. That corresponds to a consumption of 76 t/s.

Regarding future petroleum production capabilities two interesting estimation approaches may be mentioned:

(a) A tentative synthesis of recent surveys, and
(b) A hypothetical profile of petroleum production and resource depletion.

A tentative synthesis based on the world energy outlook and the petroleum requirements between now and the end of the century is presented in Ref.[3.25], based on six recent surveys carried out by six major organizations: Standard Oil Company of California, Chevron (1982), Exxon (1981), Shell (1982), Institut Français du Pétrole (IFP), (1983), Chase Manhattan Bank (1983) and the International Energy Agency (IEA), (1982).

While the methodologies, economic growth rates and elasticity factors which led to the energy demand forecasts have been discussed in chapter 2, it should be retained that quite good convergence emerged in relation to the demand for petroleum in the years 1990 and 2000. This varies within rather narrow limits (10^9t):

Study	*1990*	*2000*
Chevron	3.26	3.65
Exxon	3.40	3.70
Shell	3.05–3.29	3.37–3.78
IFP	2.96–3.05	3.00–3.57
Chase	3.20	3.52

No IEA figures are presented, since this study mainly refers to the OECD area.

The most recent WEC estimates are 2.8–3.4 × 10^9 in the year 2000 and 2.4–3.6 × 10^9 in 2020, depending on how successfully petroleum substitution develops [3.6].

While the studies referred to relate to a medium-term development and have a very practical character, the second approach refers to a very long time period (year 2100) and has a theoretical, hypothetical structure, extrapolating, however, from an initial, firm past evolution [3.8].

On the basis of total estimated remaining and recoverable conventional petroleum resources of 200 to 300 × 10^9 t as of January 1980, a hypothetical world and production profile was drawn, see Fig.3.9. This profile, which includes past production records, is based upon a totally hypothetical cumulative oil consumption of 261 × 10^9t from 1980 to 2100. Output is assumed to peak in 1990 at some 3.3 × 10^9t and to remain at that level until 2020 following a normal production profile. At the end of 1980, 62.8 × 10^9t of petroleum had been produced over a period of 120 years. According to the assumed profile, present proven reserves of 88 × 10^9t will have been produced before 2010 over a

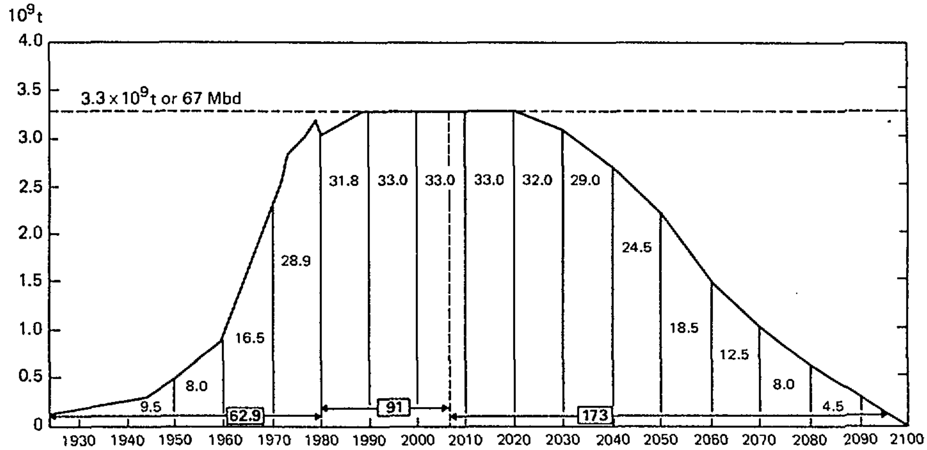


FIG.3.9. Hypothetical petroleum production profile and resource depletion [3.8].

period of less than 30 years. Based on the above estimate of the world petroleum resource base, reserve additions would allow petroleum production to continue but at a declining rate for another 90 years. This assumption does not take into consideration the very large potential from unconventional liquid hydrocarbon resources such as shale oil, tar sands, the Orinoco petroleum belt and liquids from coal.

The hypothetical world petroleum production curve does not represent in any way a likely production profile. It simply shows that, based on current resource and reserve additions, large volumes of petroleum could be produced for decades to come. At the same time, however, the curve indicates that petroleum output worldwide appears to be close to peaking, suggesting the need for the development of alternative energy sources, including liquids from unconventional petroleum resources.

3.1.2.2. Unconventional petroleum

Unconventional petroleum is generally defined to include petroleum in deepwater basins and polar regions, heavy oil deposits, tar sand and oil shale resources.

3.1.2.2.1. Deep off-shore and polar regions petroleum

The seas cover almost 70% of the earth's surface, and about 80% of this amount is in the realm of deep ocean. There the sedimentary layer is very thin and covers in general a basaltic crust where the presence of petroleum is highly unlikely.

The remaining 20% of the ocean's surface represent a submerged sedimentary area of the continental margins of the same order of magnitude as all on-shore sedimentary areas. Estimates of its petroleum resources range from 15% to 100% of the world's recoverable resources.

As far as polar regions are concerned, both the Arctic and the Antarctic, the resources, once discovered, will be difficult to exploit because of the extreme climatic conditions. Petroleum from deep-ocean basins would need much more research before this new resource could be commercially harnessed. In addition, there is the legal issue regarding the common heritage of resources beyond the sovereignty of coastal states, which is as yet unresolved.

3.1.2.2.2. Heavy oil

Heavy oil or heavy crude is essentially highly viscous petroleum which is arbitrarily distinguished from tar sands according to the viscosity as measured by API (American Petroleum Institute) gravity. Heavy oil varies from 10 to 25° API while tar sands components usually remain between 7 and 10° API [3.26]. Practically, a heavy crude will flow, while a tar sand will not.

Heavy crudes exist with a worldwide geographic distribution. They are concentrated, however, together with tar sands: 90% of the reserves are in only three countries: Canada, Venezuela and the USSR. The estimated reserve figures vary between large limits. The Orinoco Belt region in Venezuela for example is estimated to comprise alone some 100×10^9t heavy crude recoverable reserves, which is practically equal to the present proven recoverable world reserves of conventional petroleum. Newer figures for the same region are even ten times higher [3.27] or indicate more moderate figures, for example some 220×10^9t, as recoverable world reserves [3.28]. Without entering into more details on these reserves, it appears almost certain that they are several-fold those of conventional petroleum.

The sticky honey-like quality of heavy petroleum makes its extraction from under ground more difficult since no natural lifting mechanism exists and costly production techniques must be used.

However, a variety of technologies has been developed in recent years for the production of heavy crude and although heavy crude requires higher production costs and needs to be upgraded in order to make it equal to a barrel of light crude, it has become competitive at the present increased petroleum prices. It has even been affirmed that heavy oil technology is one of the best examples of how technical progress can speed up the development of a primary energy resource and bring it successfully to competitive market prices.

Present worldwide production of heavy oil and tar sands oil is running slightly in excess of 200×10^6t per year, of which the vast majority (195×10^6t) is heavy oil. Tar sands production only amounts to 90×10^6t, of which 80×10^6t comes from Canada [3.28].

Reference [3.28] has an excellent overview on the location of the world heavy crude resources, on its production and the downstream processes involved, and discusses environmental and marketing aspects as well.

3.1.2.2.3. Tar sands petroleum

The term 'tar sand' or 'oil or bituminous sand' comprises such deposits of sand and sandstone that contain a high concentration of bituminous hydrocarbons, from which petroleum can be recovered by a heating or other extraction process. Sometimes, when the above arbitrary distinction is not made, heavy oil and bitumen (asphalts) of higher density and viscosity are included under this denomination.

The only country presently operating large tar sands projects is Canada. Two such projects are in operation in the Athabasca region of Alberta, one with a capacity of 3×10^6t/year, operating since 1967, and another of 7×10^6t/year, operating since 1978. Currently petroleum from tar sands supplies about 8% of Canada's petroleum requirements of $85-90 \times 10^6$t/year [3.29].

The commercial tar sands operations employ variations of strip-mining technology to remove overburden and mine the tar sands. The Clark hot-water process is used to separate the tar from the sands. This process is simple, but it requires approximately equal volumes of water and tar sands as feed materials. It functions well only if the bitumen saturation exceeds 10% by weight and only if the sands are water wet. Large tailing ponds are required in order to settle finely divided clays before any water may be recycled [3.30].

The bitumen extracted from tar sands has limited acceptability for refining into the lighter liquid fuels most in demand today. As extracted, the bitumen is also difficult to transport by pipeline because of its relatively high viscosity. Upgrading of bitumen could be effected by simple vis-breaking, to produce a viscosity adjustment, by de-asphalting, or by a complete coking or hydro-cracking operation. In the more severe operations, all of the heavier ends are removed as a residue or converted to process fuels. The residue tends to be high in sulphur and may be difficult to dispose of. The naphtha and gas oil streams that result from upgrading operations are usually blended to form synthetic crude oil, suitable as feedstock in most existing refineries. This synthetic crude oil tends to be high in middle distillates and somewhat lower in gasoline yields than natural crude oil and is, accordingly, not perfectly substitutable in obtaining a particular petroleum product slate.

The characteristic data of the processing are:

(1) The material balance: from an input of 100 weight units bitumen (after separation from sand), 66% are won as crude, 13% consumed, 10% lost and 11% collected as by-products.
(2) The energy balance: from 95% bitumen plus 5% outside energy input, the average output is: 69% crude, 15% consumed in operations, 9% losses and 7% collected by-products [3.29].

(3) Out-of-pocket operating costs (excluding capital-related charges): mining 53%, extraction of bitumen 22% and upgrading 25%.

A research and development programme is under way to obtain increased bitumen recovery plus substantial energy savings.

However, the bulk of tar sands deposits throughout the world are located at depths which do not permit surface mining and require in situ methods of extraction. Various techniques have been tested through pilot-scale operations. Most have attempted to lower the oil viscosity by raising its temperature, thereby enabling flow to occur. A serious problem of in situ production is how to contact a sufficient volume of the essentially immobile deposit to effect adequate production. This problem may be overcome by utilizing pressures above overburden pressure and thereby parting (fracturing) the deposit.

The most widely tested method of obtaining in situ recovery of tar sands is cyclic steam injection, whereby steam is injected in slugs alternating with periods in which the condensed steam and oil are allowed to flow back. An advantage of cyclic steam injection is that it can be utilized with lower capital investment, the limiting case being a single-well test.

Drive technologies that endeavour to force oil from injection towards production wells offer the potential for higher recovery levels. Continuous steam displacement of oil can be attempted in tar sands following a number of cycles sufficient to enable communication between injection and production wells. Alternatively, air can be injected to sustain combustion in the deposit and thereby generate heat in situ. Water also may be injected to scavenge heat and thereby improve thermal efficiency.

In addition to its large tar sands projects in operation using surface mining and extraction, Canada has about 15 in situ pilot tests in progress in the Alberta tar sands.

3.1.2.2.4. Oil shale

The term 'oil shale' encompasses such shale deposits as possess a high concentration of organic materials (kerogenes) which can be converted to oil and gas by a heating process at a temperature of about 480°C.

However simple the concept appears, large-scale industrial production is complicated and expensive. Oil shale must be mined by underground or surface mining techniques, crushed and retorted using a heat supply. The resulting retort gas may be used either within the plant as fuel or for other heating processes on site. A serious problem emerges from the handling of huge quantities of mined rock and of spent shale, which after retorting increases in volume by almost 50–75%. In surface mining, the removal and disposal of the overburden further increases the volume involved.

Current production techniques require considerable quantities of water, amounting to approximately 3 litres of water for one litre of shale oil, two-thirds of it being needed to consolidate the spent shale. Many of these difficulties might be considerably reduced through in situ or underground oil extraction. In such a process, the shale is crushed by underground explosions inside cavities prepared by traditional mining techniques. Subsequent combustion of some of the shale provides the heat needed for the extraction of oil, which gathers at the bottom of the cavity and is pumped up to ground level. Several pilot test operations are successfully under way; however, substantial progress is still necessary in retorting. The ash could be used as a raw material in the cement industry and for reduction of soil acidity in agriculture [3.30].

The oil yield of oil shale varies between 40 and 550 litres of oil per ton of shale, with 40–100 litres for low grade shales and some 100–250 L/t for shales generally considered to be of good commercial interest.

The present information on world oil shale resources and recoverable reserves is summarized in the following figures [3.30]:

Area	Estimated resources in known deposits (10^9t)	Recoverable reserves under present conditions (10^9t)
Africa	14	1.5
Asia	15	3.5
Australia and New Zealand	0.1	–
Europe	11	4
North America	320	12
South America	115	7
TOTAL	475	29

The figures refer only to resources yielding more than 40 litres of oil per ton of oil shale.

As far as oil production from oil shale is concerned, the USSR states that in 1978 its production reached 37×10^6t, which represents 6% of the production of conventional petroleum. In China, a production higher than 10×10^6t of petroleum is assumed. Rich oil shale material, such as in the USSR with more than 200 litres of oil per ton, is used directly in large thermal power stations (up to 1600 MW). The balance is used for petrochemical feedstock.

The United States of America, which has over two-thirds of the known world oil shale resources and which alone [3.31] surpasses the petroleum reserves of the entire Arab world has not yet embarked on a firm oil shale development programme. Research and development is currently being carried out, but major decisions, once postponed, are apparently being kept in abeyance, in the light of world petroleum supply policies and evolution. In other countries, the utilization of oil shale for petroleum production is still in the research phase or is just beginning.

3.1.3. Natural gas

Several forms of natural gas are included under this heading:

(1) Natural gas, per se, coming from separate deposits and which represents by far the major part of the gaseous hydrocarbons of this group.
(2) The gas originating from the lighter hydrocarbons which are dissolved in the petroleum within the deposit when these, under released pressure, turn into gases in the above-ground installations. Such gases are called "oil or petroleum gas" or "associated gas" and have a similar composition to natural gas.
(3) Deep conventional natural gas from accumulations found at depths greater than 5000 m, and which, because of the high costs of seismic surveys and drilling, have been explored only to a very limited extent in the past.

In addition there are several forms of 'unconventional' natural gas:

(4) Gas dissolved in water, i.e. gas dissolved in underground water near a source of hydrostatic pressure, gas in geopressured zones and gas in lakes.
(5) Natural gas from coal-beds
(6) Natural gas from tight formations (tight sands)
(7) Gas from shales
(8) Gas hydrates.

In the following, the presentation will focus mainly on conventional natural gas, which constitutes the majority gas at present commercially exploited and will briefly consider the unconventional forms as possible sources of future supply.

3.1.3.1. Conventional natural gas

Natural gas at the well-head is a mix of different components, the proportion of which varies from field to field. At the well-head, the natural gas stream (wet gas) is separated from any associated crude oil (in the case of associated gas) and the non-hydrocarbon elements, and desulphurized. Then the gaseous mix is fractioned to separate methane, which constitutes 75% to 99% of the mix, liquefied petroleum gases (propane and butane) and condensate. Ethane will often be left within the methane component to enrich its calorific value but when economic circumstances are appropriate it may also be removed and used as feedstock for ethylene plants.

Gross production refers to wet gas production at the well-head. Marketed production refers to the proportion of gross production which is actually sold, i.e.

which is not lost, used as a pipeline fuel, reinjected or flared. The term dry natural gas refers to marketed gas with the liquefiable hydrocarbons extracted that are otherwise left in the gas stream.

Although natural gas use occurred in China hundreds of years B.C., and although use in western industrialized societies began in the 19th century, the modern era of natural gas as an energy source began only in 1925. That was the year in which high-pressure, large-volume welded steel pipeline became a commercial reality, making possible gas transmission over the hundreds of miles typically separating major producing regions and centres of population and industry. The cast iron pipes, bolted at the flanges or screwed together by couplings, that had been commonly used to that point, were subject to enormous losses through leakage at higher pressures. Once the transport difficulties and certain economic constraints had been overcome, natural gas developed worldwide and at a high rate.

The evolution of the proved natural gas reserves shown in Table 3.VII [3.32] confirms this situation. While in the USA and Canada, the increase after 1950 was only moderate and beginning with 1970 even a decline intervened, in all other regions of the world spectacularly increasing reserves have been registered. For the world as a whole, the proven reserves increased from $6.3 \times 10^{12}\,m^3$ in 1950 up to $69 \times 10^{12}\,m^3$ in 1980! According to these figures, the largest reserves are now in Eastern Europe and the USSR (35.5%), and in the Middle East (25.5%), which lead by far the other regions.

Table 3.VIII displays the figures of the world proven, potential and total remaining resources, as of 1 January 1981 [3.8].

Ref.[3.3] presents tables with the distribution by country of proved recoverable reserves, additional resources and recent annual production of conventional gas, including main gas constituents as per June 1982. Regarding the latter, a few countries show up with lower CH_4 contents, because of high figures for CO_2 and N inert components.

The top ranking twelve countries in the world proven conventional gas reserves hierarchy are according to Ref.[3.8] (in $10^{12}m^3$):

USSR	26.0	(34.9%)
Iran	13.7	(18.4%)
USA	5.4	(7.2%)
Algeria	3.7	(5.0%)
Saudi Arabia	3.1	(4.2%)
Canada	2.5	(3.3%)
Mexico	1.8	(2.4%)
Netherlands	1.75	(2.3%)
Qatar	1.7	(2.3%)
Norway, Venezuela, Nigeria	1.2	(1.6%)
Rest of the world	10.0	(15.2%)

TABLE 3.VII. PROVEN WORLD RESERVES OF NATURAL GAS AS OF 1 JANUARY (10^{12} m^3) [3.32]

Year	USA Canada	Latin America	Western Europe	USSR Eastern Europe	Middle East	Africa	Rest Asia	World Total
1950	5.3	0.6	0.1	0.3	-	-	-	6.3
1960	8.2	1.3	0.3	1.8	4.5	0.6	0.4	17.1
1965	9.2	1.7	1.6	3.1	5.9	1.9	0.8	24.2
1970	9.3	1.9	3.5	9.8	7.7	3.8	1.3	37.3
1975	8.3	2.2	3.9	20.4	16.3	5.4	2.8	59.3
1976	8.1	2.3	3.9	20.7	17.1	5.9	3.1	61.1
1977	7.8	2.6	3.9	22.7	17.5	5.7	3.5	63.7
1978	7.6	3.1	3.7	22.7	17.4	5.7	4.1	64.3
1979	7.5	4.0	3.5	23.8	17.5	5.9	4.9	67.1
1980	7.5	4.5	3.7	24.5	17.5	6.0	5.5	69.0

TABLE 3.VIII. WORLD CONVENTIONAL GAS RESOURCES BY REGION AS OF 1 JANUARY 1981 (10^9 m^3) [3.8]

	Proved Reserves	(%)	Reserves	(%)	Total remaining Reserves	(%)
Western Hemisphere	13 018	(17)	51 311	(27)	64 329	(24)
Western Europe	4 246	(5)	5 223	(3)	9 469	(4)
Middle East	18 396	(24)	29 332	(16)	47 728	(18)
Africa	5 906	(8)	26 253	(14)	32 159	(12)
Asia-Pacific	4 259	(5)	10 264	(5)	14 253	(5)
Antarctic	--	--	3 200	(2)	3 200	(1)
CPEs	31 752	(41)	63 011	(33)	94 763	(36)
TOTAL	77 577	(100)	188 594	(100)	266 171	(100)

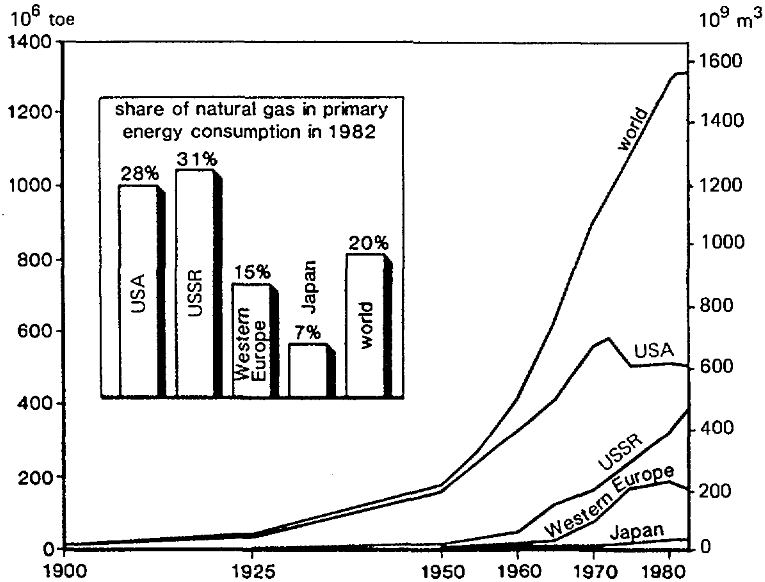


FIG.3.10. Natural gas consumption 1900–1982 [3.33].

As far as yearly production of conventional gas is concerned, the ranking in 1981 was the following (in $10^9 m^3$):

USA	530	Indonesia	31.8
USSR	465	Norway	25.2
Netherlands	85.7	China	20
Canada	66.7	Fed. Rep. Germany	18.5
Algeria	65	Italy	14
Mexico	41.9	Argentina	13.6
UK	37.4	Australia	12.3
Romania	37.0	France	10.2.
Venezuela	34.7		

Fig. 3.10 displays the evolution of natural gas consumption between 1900 and 1982 in different regions and the share of natural gas of primary energy consumption in 1982 [3.33].

Table 3.IX presents the reserves-to-production ratios and estimated resources-to-production ratios for the various regions of the world, related to the 1980 production figures. Although relatively lower for Western Europe and the OECD, the ratios indicate much longer duration than is the case for petroleum.

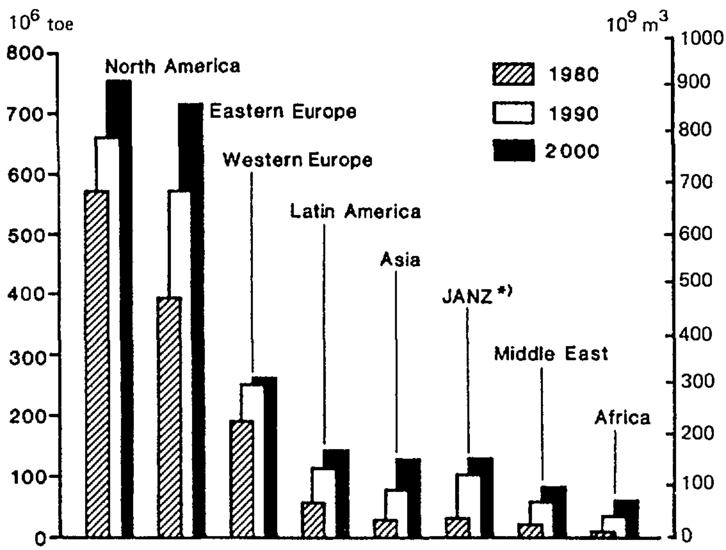
TABLE 3.IX. RATIOS OF PROVEN RESERVES AND RESOURCES OF NATURAL GAS TO 1980 PRODUCTION [3.8]

	1980 Production		Ratio of proven reserves to production	Ratio of total remaining resources to 1980 production
	$10^9 m^3$	(%)	(years)	(years)
Western Hemisphere	720.6	(43)	18	89
Western Europe	202.0	(12)	21	47
Middle East	121.9	(7)	151	392
Africa	71.7	(4)	82	449
Asia-Pacific	71.9	(4)	59	202
CPEs	507.6	(30)	63	187
TOTAL	1695.7	(100)	46	157
of which				
OECD	849.7	(50)	16	74

TABLE 3.X. COMMERCIALIZED NATURAL GAS PRODUCTION 1950–2000 (10^9 m^3/a) [3.32]

	1950	1960	1970	1978	1990	2000
North America	180	375	685	613	550–620	520–650
Latin America	3	12	36	62	140–170	160–220
West Europe	1	12	77	185	200–230	170–220
East Europe - USSR	10	57	235	427	750–840	900–1070
Middle East				48	120–170	180–290
Africa				21	100–140	150–230
Other Regions				69	150–210	220–300
World Total	194	465	1085	1425	2000–2400	2300–3000

The evolution of commercial natural gas production in the world since 1950 and estimates to the year 2000 are presented in Table 3.X. It is anticipated that the yearly world production will increase from 194 billion m^3 in 1950, to 1085 $\times$ $10^9 m^3$ in 1970 and 1425 $\times$ $10^9 m^3$ in 1978 to around 2000–2400 billion in 1990 and to some 2300–3000 billion m^3 in the year 2000 [3.32].



*) Japan, Australia, New Zealand

Source for data: World Gas Supply and Demand Study 1980–2020, International Gas Union, Report of Task Force II, Table 1-2-a, Moderate Oil Price Case

FIG.3.11. Demand for natural gas by regions in 1990 and 2000 [3.34].

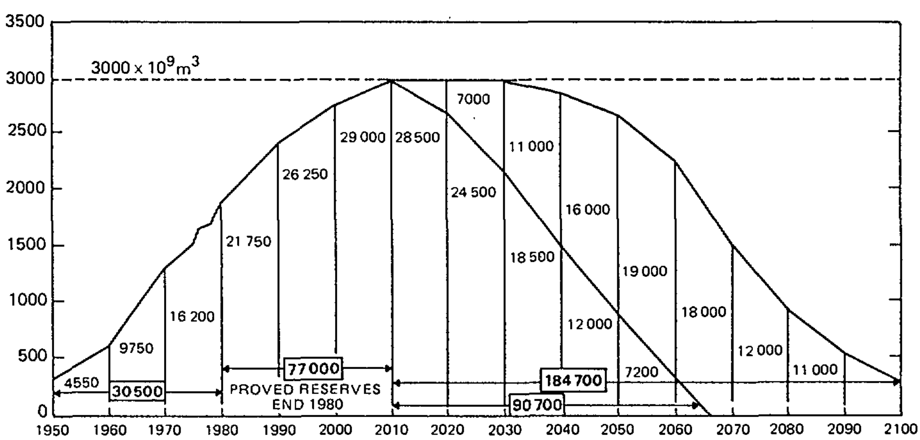


FIG.3.12. Natural gas; hypothetical production profiles and reserve consumption in 10^9 m^3 [3.8].

The last WEC study estimates an increase of the world natural gas production to 2160–2640 billion m^3 in the year 2000 and 2880–3840 billion m^3 in 2020 [3.6].

Figure 3.11 displays the projected demand for conventional natural gas by regions in 1990 and 2000, based on more recent data [3.34].

Similarly as for the long-term supply of petroleum, Fig.3.12 illustrates hypothetical scenarios for future supply of conventional natural gas on the basis of total proven and potential reserves of between $168 \times 10^{12} m^3$ and $262 \times 10^{12} m^3$, to cover a reasonable range of uncertainty [3.8]. At an annual average growth rate of production of 1.6%, which is in line with recent industry estimates, gross world production is assumed to peak at $3000 \times 10^9 m^3$ in 2010 and depending on actual resources, either to remain stable for a couple of decades or to decline rapidly. The graph also shows natural gas depletion for ten-year periods, peaking at $29\,000 \times 10^9 m^3$ in the period 2000–2010. Current proven reserves would be almost exhausted just before 2010 in these scenarios, with output after 2010 coming from resources yet to be proven. Conventional gas resources would be consumed around 2050 in the pessimistic scenario and around 2090 in the optimistic one. These scenarios, which are based on a detailed production assessment through 1990 and on hypothetical developments thereafter, indicate that gas reserves are large enough to allow this energy source to make a substantial additional contribution to the world energy supply well into the next century. Unconventional gas resources were not included in this hypothetical production scenario.

The worldwide reserves of associated gas can only be very roughly estimated since the volume of gas arising from the volume of oil extracted – the so-called GOR (gas-oil relationship) – varies from a few m^3 gas per m^3 oil to several hundred. However, based on an average GOR value of 160 m^3 gas/m^3 oil, which represents the average GOR values from 19 countries accounting for 45% of the world petroleum production, the WEC survey [3.2] determined according to the 1978 petroleum production a world availability of associated natural gas of approximately $570 \times 10^9 m^3$. This corresponds to about 40% of the conventional natural gas production in that year. Unfortunately, some 55% of the world associated gas production was flared or in the best cases reinjected. In the meantime, the situation has improved, part of the associated gas being treated and exported as butane and propane on the world LPG markets.

In terms of reserves, Ref. [3.32] estimates the world reserves of associated gas at approximately $21\,000 \times 10^9 m^3$, with more than half – $11\,500 \times 10^9 m^3$ – in the Middle East.

3.1.3.2. Unconventional natural gas

(a) Gas dissolved in underground water near a source of hydrostatic pressure, is produced today in Japan, the USA and Italy. Significant resources undoubtedly exist in many parts of the world, but little exploration has yet taken place. While unable to compete with conventional natural gas if more readily available, it could easily compete with imported gas.

(b) Geopressured gas is known to exist in geopressured zones at pressures significantly in excess of hydrostatic. At this time the only active programme in exploration and development of geopressured resources is taking place in the USA. Nevertheless, it is believed that the potential of this type of gas is enormous and as such it represents a major energy source in the future.

(c) Gas is produced in lakes and in marshes as methane but no systematic exploration has taken place so far, except for the gas from lake Kivu, which is shared by Zaire and Rwanda, and which probably represents a large reserve in a lake.

(d) Methane occurring naturally in coal-beds, held by absorption in the coal and in the interfaces with strata above and below the beds. With 6–8 m^3 associated with a ton of coal, it could be extracted from the underground coal mines and used commercially while also reducing the risk of gas explosions in the mines.

(e) Large quantities of methane also lie trapped in and beneath thick layers of shale, especially black, sevonian shales. Similarly, gas is found in large quantities in tight sandstones, which are low permeability structures requiring fracturing of the host rock to allow the gas to flow freely to the well-bore. Almost 5% of the total conventional gas production of the USA is produced from tight sandstones [3.23].

(f) Gas hydrates, i.e. natural gas hydrates are one of the most significant and least-known new sources of gas occurring in nature. They were first discovered by Soviet petroleum geologists in 1970. Natural gas hydrates are natural gas, in a frozen state in ice. In this state large quantities of natural gas can be contained in a cubic metre of ice. Since the 1970 discovery, it has been found that natural gas hydrates can exist at temperatures above freezing provided the pressures are high; therefore, the pressure/temperature relationship is crucial for the existence of natural gas hydrates. Considerable indications of gas hydrates have been found not only on land but also off-shore and apparently some of the first quantitative estimates of the potential of gas hydrates off-shore are very high. Very little has been published on the characteristics, resource conditions, variety of types, and reserves, on the extraction methods and the probable cost of extraction of such unconventional natural gas.

In general, the resource of each of the unconventional gas sources is huge. Unfortunately, the production costs of most of them generally require a sale price that may not be borne by natural gas markets without subsidy for many years, depending on the development of gas demand and conventional supply. When in the next century, however, worldwide conventional supply. When in the next century, however, worldwide conventional resources begin to decline, the resulting price increases may increasingly justify a resort to these vast and as yet untapped, but less economic gas fuel resources.

3.1.3.3. Natural gas trade

Before 1970 natural gas was traded almost exclusively between Canada and the USA and between the USSR and Eastern Europe. With the development of a natural gas industry in Western Europe and the emergence of LNG technology, gas trade quadrupled in the 1970s but still represented only 3% of total world gas consumption, i.e. 10.5% pipeline gas and 2.5% LNG [3.8].

In 1982, West European natural gas production covered – with trade between the respective countries – 82% of the year's consumption of the region. Imports of 13.4% from the USSR, 4.2% from Algeria and 0.4% from Libya covered the balance [3.34].

3.1.4. Nuclear energy resources

The nuclear resources for the production of energy by nuclear fission are uranium and thorium, and for controlled nuclear fusion, a series of light elements such as isotopes of hydrogen (H), helium (He), lithium (Li) and boron (B).

For practical purposes this subsection will concentrate on the nuclear resources for production of energy by nuclear fission. However, due to its paramount importance as a long-term energy option, a short presentation of the prospects of controlled nuclear fusion will help to define its eventual resources requirements.

3.1.4.1. Controlled nuclear fusion – prospects

Modest but continuous progress is reported in the fusion research programmes, although even the most optimistic estimates as to when a commercial power-producing fusion plant will become available do not envision the attainment of this goal in less than 40 years [3.35]. It is therefore, a farsighted attitude that some US \$2 $\times$ 10^9 are spent yearly on fusion work in the world, and also that smaller countries at least follow closely the scientific information generated on the subject. The interest is evident since fusion energy promises a reliance on an essentially inexhaustible, uniformly distributed, and comparatively cheap fuel source. In addition, it involves fewer safety and environmental problems than nuclear fission technologies. It thus constitutes one of the main long-term energy alternatives known at this time.

Several different fuel cycles could be employed in fusion reactors, but whichever is chosen the reactions will take place in a very hot plasma – at temperatures of the order of a hundred million °K. Because it gives the highest yield at the lowest temperature, the reaction between deuterium and tritium, two isotopes of hydrogen, will probably fuel the first fusion reactors. The reserves of deuterium which can be separated from water are virtually inexhaustible, the water of the earth containing approx. 46 $\times$ 10^9t of deuterium [3.2]. The tritium which is necessary in the fusion process must be produced in the reactor through a breeding process in which lithium absorbs fast neutrons to create tritium. However, lithium is a relatively rare element, the world's recoverable reserves and resources being estimated at about 10×10^6t, exclusive of the lithium dissolved in the oceans. With these additional resources, lithium would become available in immense quantities. On the other hand, alternative fuel cycles, such as D-D, might completely eliminate any requirements for lithium.

With this suggestion as to possible input elements, the short considerations on fusion energy will close with the recommendation that in spite of the long lead time expected, the progress in this area deserves the early and increasing attention of anybody involved in long-term energy planning – see Ref. [3.36], the further indicated bibliography and the annual IAEA reports on the subject.

3.1.4.2. Uranium resources

A close co-operation exists in the area of uranium resources, production and demand between the IAEA and the Nuclear Energy Agency of the OECD. The following presentation is mainly based on their common work and publications [3.37].

3.1.4.2.1. Definitions of uranium resources categories

According to recent definitions, uranium resources are classified in the NEA/IAEA scheme into the following categories.

(1) Reasonably assured resources (RAR) refer to uranium that occurs in known mineral deposits of such size, grade and configuration that it could be recovered within the given production cost ranges, with currently proven mining and processing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of deposit characteristics. Reasonably assured resources have a high assurance of existence and in the cost category below US \$80/kg U are considered as 'reserves'.

(2) Estimated additional resources – category I (EAR-I) refer to uranium in addition to RAR that is expected to occur, mostly on the basis of direct geological evidence, in extensions of well explored deposits, and in deposits in which geological continuity has been established but where specific data and measurements of the deposits and knowledge of the deposits' characteristics are considered to be inadequate to classify the resource as RAR. Such deposits can be delineated and the uranium subsequently recovered, all within the given cost ranges. Estimates of tonnage and grade are based on such sampling as is available and on knowledge of the deposit characteristics as determined in the best known parts of the deposit or in similar deposits. Less reliance can be placed on the estimates in this category than on those for RAR.

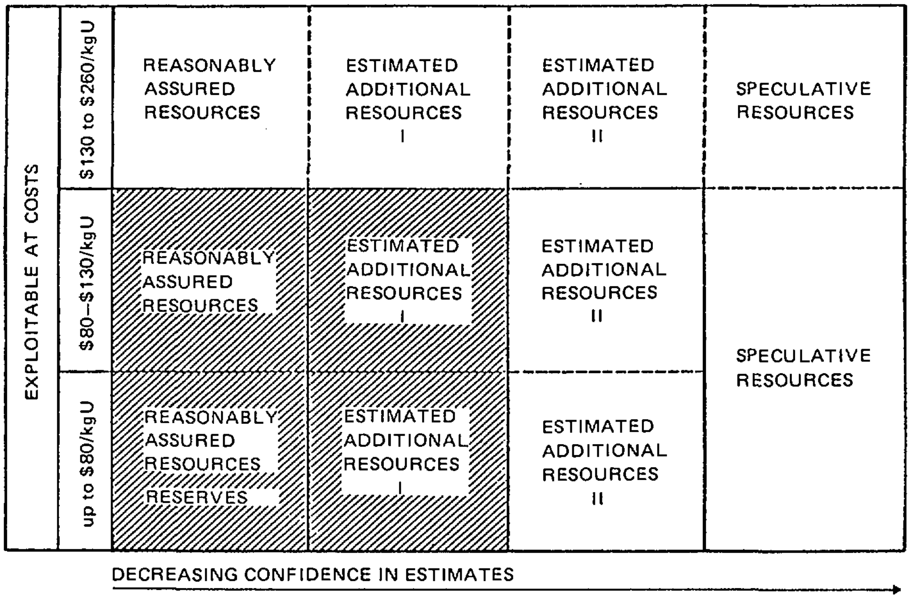


FIG.3.13. NEA/IAEA classification scheme for uranium resources [3.37].

(3) Estimated additional resources – category II (EAR-II) refers to uranium in addition to EAR-I that is expected to occur in deposits believed to exist in well-defined geological trends or areas of mineralization with known deposits. Such deposits can be discovered, delineated and the uranium subsequently recovered, all within the given cost ranges. Estimates of tonnage and grade are based primarily on knowledge of deposits' characteristics in known deposits within the respective trends or areas and on such sampling, geological, geophysical or geochemical evidence as may be available. Less reliance can be placed on the estimates in this category than on those for EAR-I.

(4) Speculative resources (SR) refer to uranium, in addition to estimated additional resources – category II, that is thought to exist mostly on the basis of indirect evidence and geological techniques. The location of deposits envisaged in this category could generally be specified only as being somewhere within a given region or geological area. As the term implies, the existence and size of such resources are highly speculative.

Figure 3.13 shows as a block diagram the different quantities of uranium recoverable after due allowance for ore dilution and for mining and milling. The horizontal axis corresponds to a decreasing degree of assurance of the actual information (tonnage and grades), while the vertical axis expresses the range of technological/economic feasibility of exploitation at estimated recovery costs.

TABLE 3.XI. REASONABLY ASSURED RESOURCES OF URANIUM [3.37] (10^3 tU)

Countries	Cost range	$80/kg U reserves	$80–130/kg U	Total
Algeria[b,e]		26	–	26
Argentina[b]		18.8	4.5	23.3
Australia		314	22	336
Austria[e]		0	0.3	0.3
Brazil[a]		163.3	–	163.3
Cameroon, Republic of		0	0	0
Canada		176	9	185
Central African Republic[a,d]		18	–	18
Chile[*,a]		0	2.3	2.3
Denmark		0	27	27
Egypt		0	0	0
Finland[a]		0	3.4	3.4
France		56.2	11.3	67.5
Gabon[b,e]		19.4	2.2	21.6
Germany, Federal Republic of		0.85	4.2	5.05
Greece		1.4	4.0	5.4
India[b,e]		32	–	32
Italy		2.85	–	2.85
Japan		7.7	–	7.7
Korea, Republic of		0	10	10
Mexico[a]		2.9	–	2.9
Namibia[e]		119	16	135
Niger[b,c]		160	–	160
Peru[a]		0.5	–	0.5
Portugal		6.7	1.5	8.2
Somalia[a,d]		0	6.6	6.6
South Africa		191	122	313
Spain		15.65	4.5	20.15
Sweden[f]			37	39
Turkey[a]		2.5	2.1	4.6
United States of America		131.3	275.9	407.2
Zaire[b,c]		1.8	–	1.8
Total (rounded)		1 455.8	587.8	2 043.6
Total (recoverable)[g]		1 410	585	1 995

TABLE 3.XI (cont.)

Data available as of 1 January 1983.
Reported tonnages refer to quantities of uranium recoverable from mineable ore, except where noted.

- * Assigned to cost category by Secretariat.
- [a] Uranium contained in situ.
- [b] Uranium contained in mineable ore.
- [c] OECD (NEA)/IAEA: Uranium Resources, Production and Demand, Paris (1977).
- [d] OECD (NEA)/IAEA: Uranium Resources, Production and Demand, Paris (1979).
- [e] OECD (NEA)/IAEA: Uranium Resources, Production and Demand, Paris (1982).
- [f] Includes 35 000 tonnes U in the Ranstad deposit from which no uranium production is allowed due to a veto by local authorities for environmental reasons.
- [g] Mining and milling losses deducted by the Working Party.

3.1.4.2.2. Data on world uranium reserves and resources

The data displayed in the following tables do not include the corresponding figures for the countries with planned economies, since the latter are not available. Therefore, when speaking of world uranium resources in fact one refers only to WOCA countries (i.e. world outside centrally planned economies areas). However, in addition to the tables, some estimates are given to round up the actual world figures.

Table 3.XI presents by country the figures of the reasonably assured uranium resources – in 10^3t U – as reserves in the cost range up to US $80/kg U, as resonably assured resources in the cost range of US $80–130/kg U and as total figures. The leading countries in the uranium reserves category are:

Australia	314 000 t	USA	131 300 t
South Africa	191 000 t	Namibia	119 000 t
Canada	176 000 t	France	56 200 t
Brazil	163 300 t	India	32 000 t
Nigeria	160 000 t		

The total of the reserves category is 1 410 000 tU.

In the higher cost range, the resources hierarchy changes, the USA with 275 900 tU and South Africa with 122 000 tU being the leaders. The total of the reasonably assured resources category amounts to 1 995 000 tU.

The estimated additional resources – category I, amount to 865 000 tU in the cost range up to US $80/kgU and 305 000 tU in the higher range, for a total of 1 170 000 tU. The more endowed countries (up to US $80/kgU range) are:

Australia	369 000 t	Nigeria	53 000 t
Canada	181 000 t	USA	30 400 t
South Africa	99 000 t	Namibia	30 000 t
Brazil	92 400 t	France	26 600 t.

TABLE 3.XII. IUREP SPECULATIVE RESOURCES OF URANIUM [3.37]

Continent	Number of countries	Speculative resources 10^6 tU			
		Full range		Most likely range	
		Low	High	Low	High
Africa	51	1.3	4.6	2.6	3.5
America, North	3	1.8	2.9	2.1	2.4
America, South and Central	41	0.7	1.8	1.0	1.3
Asia and Far East[a]	41	0.3	1.6	0.5	0.8
Australia and Oceania	18	2.0	4.0	3.0	3.5
Western Europe	22	0.3	1.1	0.4	0.6
TOTAL WOCA[b]	176	6.3	16.2	9.6	12.1
CPEA[c,d]	9	3.3	8.4	5.2	6.5

[a] Excluding People's Republic of China and eastern part of USSR.
[b] World outside centrally planned economies area.
[c] The potential shown here is 'Estimated Total Potential' and includes an element for 'Reasonably Assured Resources' and 'Estimated Additional Resources' although those data were not available to the Steering Group.
[d] CPEA – centrally planned economies area.

For category II of the estimated additional uranium resources only a few countries are cited. Leading are the USA with 470 600 t in the cost range up to US $80/kg U and 338 500 t in the higher range, i.e. totalling 809 100 t uranium contained in mineable ore. Canada follows with 179 000 + 102 000 = 281 000 t uranium contained in situ.

As far as uranium resources in the planned economy countries are concerned, Ref. [3.37] mentions the estimates of the 1980 WEC Survey of Energy Resources [3.2]: 450 000 – 500 000 t as reasonably assured resources, out of which there are 160 000 t each for the USSR and the People's Republic of China, 60 000 t for the German Democratic Republic (GDR), 25 000 t for Czechoslovakia and 20 000 t for Romania. In the estimated additional resources are some 1 500 000 t, with the main part in the USSR and the GDR, and not including the People's Republic of China.

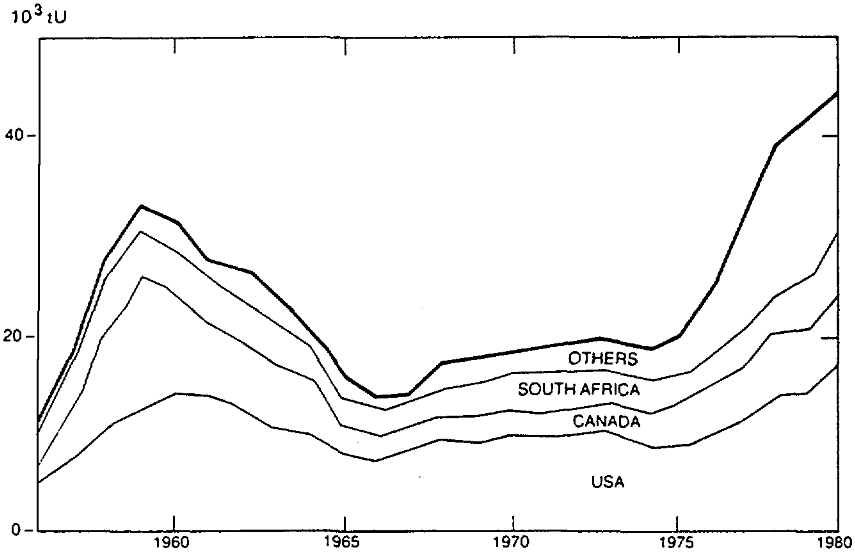


FIG.3.14. Historical uranium production of WOCA 1981–1983 [*3.38*].

In the speculative uranium resources category the leading countries are Australia (2 600 000 t), South Africa (1 351 000 t), Canada (1 200 000 t), USA (691 000 t) and Argentina (368 000 t). The other countries have under 15 000 tU.

To obtain actual worldwide data on uranium resources available and to promote uranium prospecting, the NEA and IAEA launched in 1976 an international co-operation programme entitled IUREP (International Uranium Resources Evolution Programme). Table 3.XII displays the most recent data on IUREP speculative uranium resources. In addition to the 176 WOCA countries it includes estimates of total uranium resources in nine countries with planned economies. The potential of the latter amounts roughly to half of the WOCA countries' resources.

3.1.4.2.3. Uranium production

Figure 3.14 illustrates the evolution of WOCA uranium production between 1955 and 1980, in total figures as well as showing the contribution of its main suppliers.

Table 3-XIII continues the presentation with more details on uranium production by country. The more important producing countries have been: USA, Canada, South Africa, France, Australia, Nigeria and Namibia.

TABLE 3.XIII. WOCA URANIUM PRODUCTION (tU) [3.37]

	1981	1982	1983[b]
Argentina	123	155	200
Australia	2 860	4 453	3 700
Belgium[c]	40	40	40
Brazil	4	290	300
Canada	7 720	8 080	7 500
France	2 553	2 859	3 200
Gabon	1 020[e]	970[e]	n.a.
Germany, Federal Republic of	36	34	40
Japan	3	5[a]	7
Namibia	3 971	3 776	3 800
Niger	4 360[e]	4 259[e]	n.a.
Portugal	102	113	100
South Africa	6 131	5 815	5 800
Spain	178	150	150
United States of America	14 793	10 331	7 900[d]
Total	43 894	41 220	32 737

[a] Provisional.
[b] Estimated.
[c] From phosphates.
[d] Production in the USA in 1983 is expected to fall between 7500 and 8300 tonnes.
[e] CEA-Rapport Annuel (1981, 1982).
n.a. not available.

To summarize, the WOCA uranium production evolved as follows, in 10^3t:

cumulated till 1977	1977	1978	1979	1980	1981	1982
472.2	28.3	33.9	38.1	44.0	43.9	41.3

The theoretical production capacities are estimated [3.37] to reach some 68 000 tU in 1984, peaking at 78 000 tU in 1986 and slightly decline to some 70 000 tU in 1990. The essential part of this production would originate from deposits with costs ranging under US \$80/kgU, i.e. US \$30/lb U_3O_8.

This development would, however, depend on there being suitable market conditions, with favourable demand and a favourable economic climate, and there being sufficient lead time for the extension of the mining and processing operations.

3.1.4.2.4. Thorium resources

For the time being, the thorium market is not important since the industrial applications of thorium are rather limited. However, research is under way for using thorium as nuclear fuel. It could be used for example in heavy-water reactors, in high-temperature gas-cooled reactors and breeder reactors. So far it is effectively being used in research reactors and prototypes.

The world thorium resources are not well known, little prospecting having been done. Estimates run for resources recoverable at costs less than US $80/kg Th at some 700 000 t as RAR and 2–3 000 000 t as estimated additional resources [3.37]. The largest known thorium reserves are occurrences of the heavy mineral monazite in beach sands of Australia, Egypt, India, Liberia and in parts of Brazil and the USA.

Currently Australia, the USA, Malaysia and Thailand produce monazite, from which thorium could be extracted. The production is several thousand tonnes and the thorium content a few hundred tonnes.

However, it is considered that even if reactors or fuel cycles using thorium were adopted extensively in the post-2000 period and demand for thorium expanded greatly, the cumulative requirements to 2025 for thorium are likely to be less than the possible production, based on current estimates of the RAR and EAR of thorium.

3.1.5. Geothermal energy resources

Geothermal energy is continuously generated by the flow of heat from the earth's core. It could, therefore, be regarded as a renewable energy resource. However, except for geothermal energy from the highly active magmatic zones, the flow which is harnessed is usually greater than the input flow of heat. The heat stored in the subsoil is then gradually used. The process could be, therefore, regarded as the harnessing of a finite reservoir, i.e. a utilization for a limited period of time followed by a variable period required to replenish the reservoir. With such a long renewal period, compared to the short renewal periods of the other renewable energy resources, geothermal energy seems to belong rather to the non-renewable energy resources, and it will be treated, therefore, accordingly.

Technically, geothermal energy resources can be divided into the following six basic groups: dry steam fields, hot-water (wet steam) fields, low-temperature fields, hot dry rocks, geopressured zones and magma energy.

Dry steam geothermal fields deliver dry steam at the well-head which can be directly used in steam turbines for electricity generation or supplied as process steam to industries or other heating processes.

Hot water fields consist of hot water deposits existing under high hydrostatic pressure which prevents in situ boiling. During production, the hot water travels to the surface through a production well with a reduction of hydrostatic

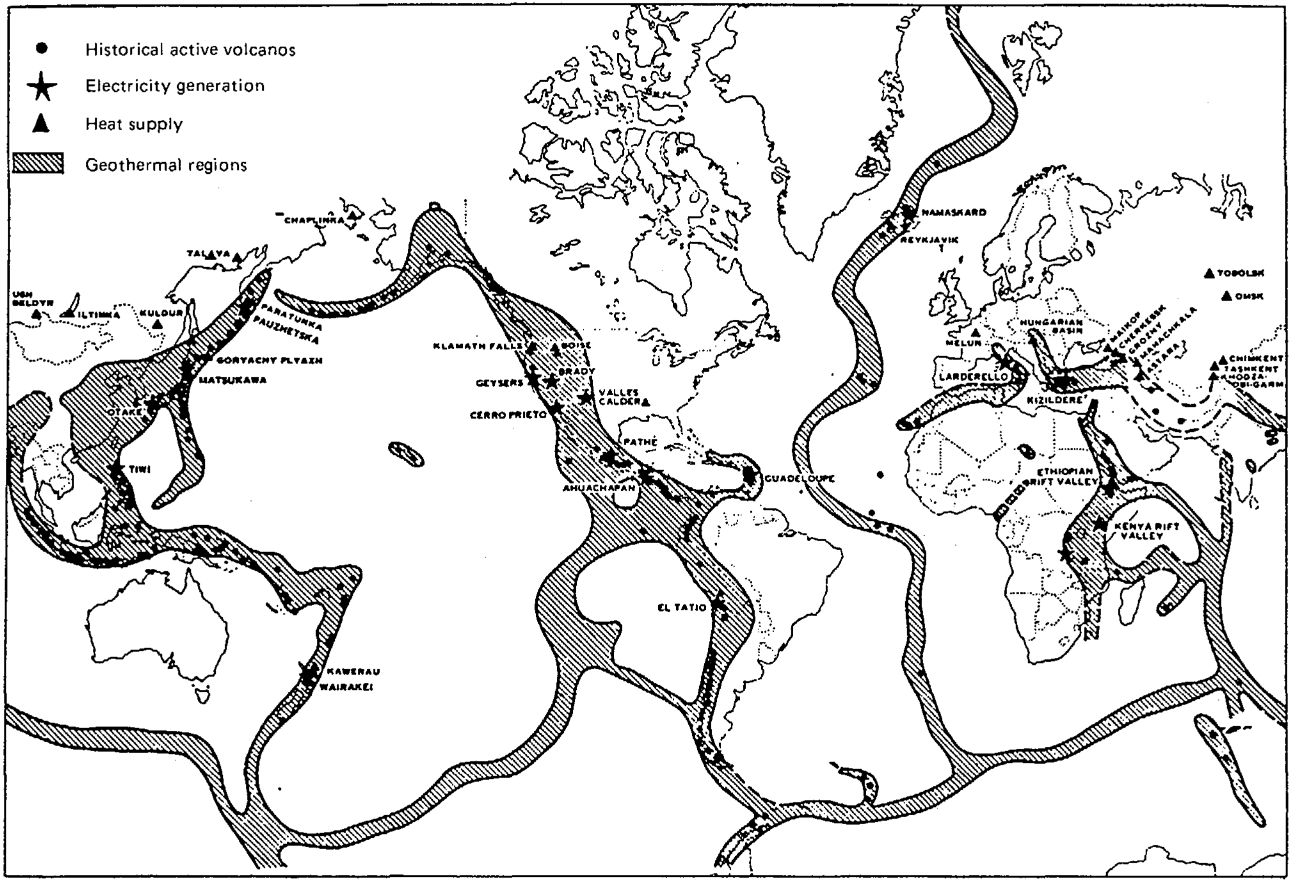


FIG.3.15. World geothermal zones [3.42].

pressure as its depth decreases. When the pressure reaches a level which allows the hot water to boil, flashing takes place, and a mixture of water and wet steam issues from the well.

Low-temperature geothermal field wells deliver warm or hot water with temperatures under 100°C or up to 130°C.

Geopressured geothermal fields are hot water deposits at pressures significantly in excess of hydrostatic. They have an additional energy potential, often increased by natural gas components [3.39].

Geothermal energy of hot dry rocks, i.e. of regions where steam or water is not naturally present as a means of bringing the heat to the surface, may be exploited by injecting water down one well in a fractured structure and recovering steam from a second one.

Magma chambers are underground structures of molten rock in the range of 700–1200°C, which in many areas around the world lie within 10 000 m of the surface. They represent a very large source of thermal energy. Research has overcome many of the problems involved in drilling into such material, but the initial stage of investigation has not been yet completed [3.40].

The theoretical geothermal resources of the earth are estimated at 30 000 000 MW and the heat stored in the first 2000 m of the crust is several thousand times larger than the fossil fuel resources of the globe [3.41]. However, available sites for geothermal power are mainly limited to tectonic regions – see Fig. 3.15 [3.42] – and on that basis, only a modest capacity expansion of what might be called conventional geothermal resources – dry steam, wet steam and low-temperature water – is expected by the year 2000, i.e. from 2500 MW in 1980 up to 17 000 MW for electricity generation. The use of geothermal energy for heating and industrial purposes could be about three times greater.

The extraction of power from hot dry rock, which is a more widespread resource, from magma and geopressured zones is in the initial research stage and major developments are not foreseen before the year 2000.

3.2. Renewable primary energy resources

The group of renewable primary energy resources as defined in chapter 1 originates from the three main natural energy sources: solar, geothermal and gravitational energy. Solar energy is generated by the nuclear fusion processes in the sun and gravitational energy is a result of planetary motion. The origin of geothermal energy is natural fission of radioactive isotopes, which creates a natural heat flow towards the earth's surface, almost everywhere constant around 63 kW/km^2, and a temperature gradient by heating the rocks, averaging 3 K/100 m. In some places the gradient may vary between 1 and 5 K/100 m. In addition to the general heat flow, volcanoes, hot wells, etc., may bring to the earth's surface stored geothermal heat, when the upper rock formations are favourable to such activities.

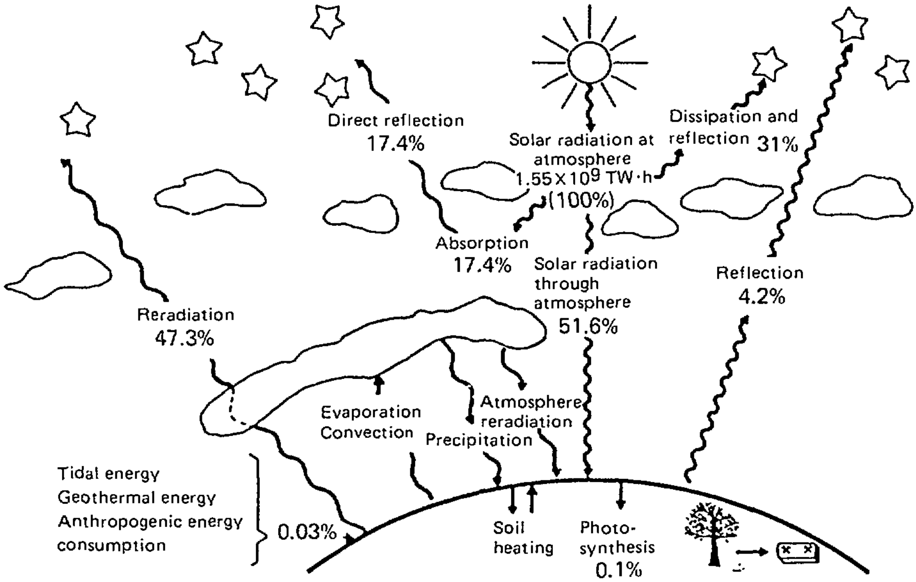


FIG.3.16. % balance of the solar radiation on earth [3.44].

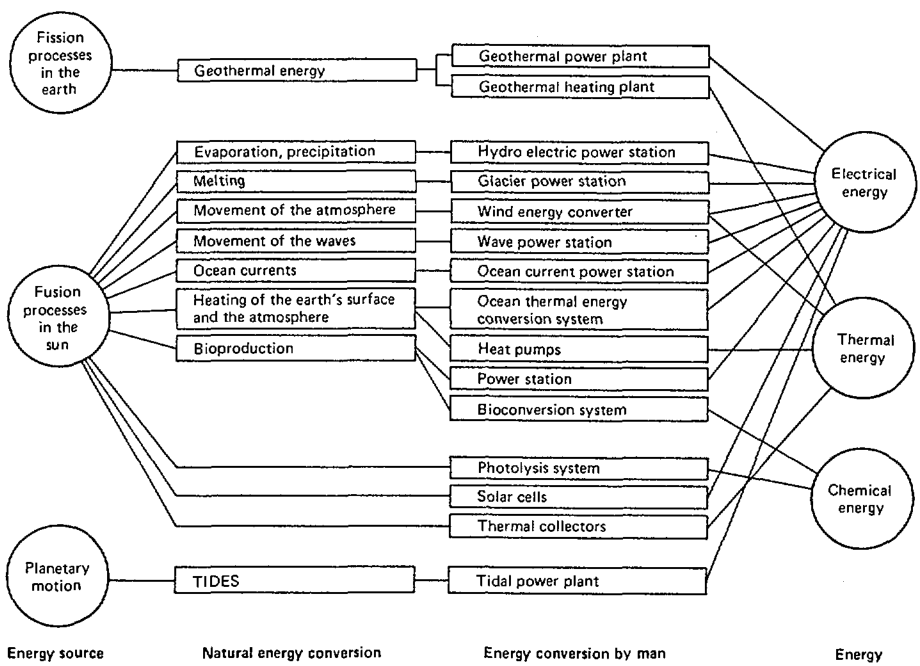


FIG.3.17. Natural and anthropogenic conversion of renewable energy sources [3.43 and 3.45].

The contributions of the three basic sources differ, however, by several orders of magnitude: solar radiation carries annually a flux of 5.61×10^6 EJ/a (i.e. 178 000 TW·a) to the atmosphere of the earth, the geothermal heat flow of approximately 1000 EJ/a is about five thousand times smaller, while the theoretical tidal energy potential with some 100 EJ/a is another order of magnitude behind [3.43].

Figure 3.16 presents a percentage energy balance of the solar radiation reaching the earth's atmosphere. On the left side the contribution of the other two natural energy sources, tidal and geothermal energy, has been marked, including the anthropogenic consumption of non-renewable energy resources.

It appears most striking that less than one tenth of a percent of the solar radiation is needed to grow all the plants and animals of the world and that the world fossil and nuclear fuel consumption represented in 1982 only 0.005%, or taken together with the other non-solar energy resources, only 0.04% of the radiated solar energy on Earth.

Figure 3.17 displays a chart of the natural conversion processes of the three main energy sources into renewable primary energy resources and the next anthropogenic conversion stage, when, harnessed by man's action, these resources are converted into intermediate energy forms able to supply the end-use energy required.

Although discussed in more detail in chapters 15–17, the contribution of the renewable primary energy resources in the overall energy world balance deserves an overview comment, before entering into their particular presentation.

In fact, in the history of world energy development, the renewable energy resources, hydro, wind, wood and agricultural waste, played an important role (in the centuries before 1900, even an almost exclusive role) in the energy supply of mankind. It is only in recent decades that petroleum and natural gas appeared and rapidly strengthened their shares of consumption. However, in spite of the changed world picture, in a great number of developing countries, the share of renewable energy consumption has remained preponderant.

Currently, a change in the future evolution of world energy supply is anticipated, with an increased role for the renewable primary energy resources, which, together with nuclear energy, would gradually take over the diminishing market shares of petroleum and natural gas resources [3.46].

Similar to the presentation of the non-renewable primary energy sources in subsection 3.1, this subsection will concentrate on a short review of the total and harnessable potential of the renewable primary energy resources, leaving for the next chapters more detailed comments on technical aspects and future development.

3.2.1. Hydraulic energy resources

By some mutual and tacit agreement in the world, this denomination has been reserved for the energy that can be gained from converting the kinetic energy of

TABLE 3.XIV. THEORETICAL (GROSS) AND TECHNICALLY HARNESSABLE HYDRO-ELECTRIC POTENTIAL IN THE WORLD [3.47]

Geographical Zone	Hydro-electric potential (1) gross	(2) technically harnessable	Share (2)/(1)
	(TW·h)		(%)
Europe (without USSR)	3400	700	21
USSR	4000	1100	28
North America	6100	1300	21
Japan - China	9000	1450	16
Central and South America	5400	1850	34
Africa	6300	2000	32
Rest of Asia	-	1200	-
Oceania	1500	200	13
Antarctic	200	-	-
Total	40 700	9800	27

flowing water into mechanical and then eventually into electrical energy. Subsequently, tidal and wave energy are considered under the separate heading of sea and ocean energy.

3.2.1.1. Conventional hydraulic energy resources

Hydro-energy, as defined above, is a renewable source of energy, and its theoretical global potential may be considered constant and self-renewing on a yearly cycle basis.

The theoretical annual hydraulic energy potential of a river basin depends on the precipitation it receives annually in its catchment area and the quantity of water remaining on the earth's surface and running down from its altitude to sea level. Since certain portions of the river cannot technically be harnessed, the technical, usable potential is lower, usually about 50% of the theoretical potential. This corresponds to a technical recovery factor of the same order of magnitude. However, the economic harnessable potential is the actual, real recovery factor, since it determines, depending on the competitive level of the opportunity cost of alternative thermal or nuclear power stations, the level of installable hydro capacity at a certain moment. With the increase of prices of petroleum and other alternative energy resources, the threshold of hydro power competitiveness

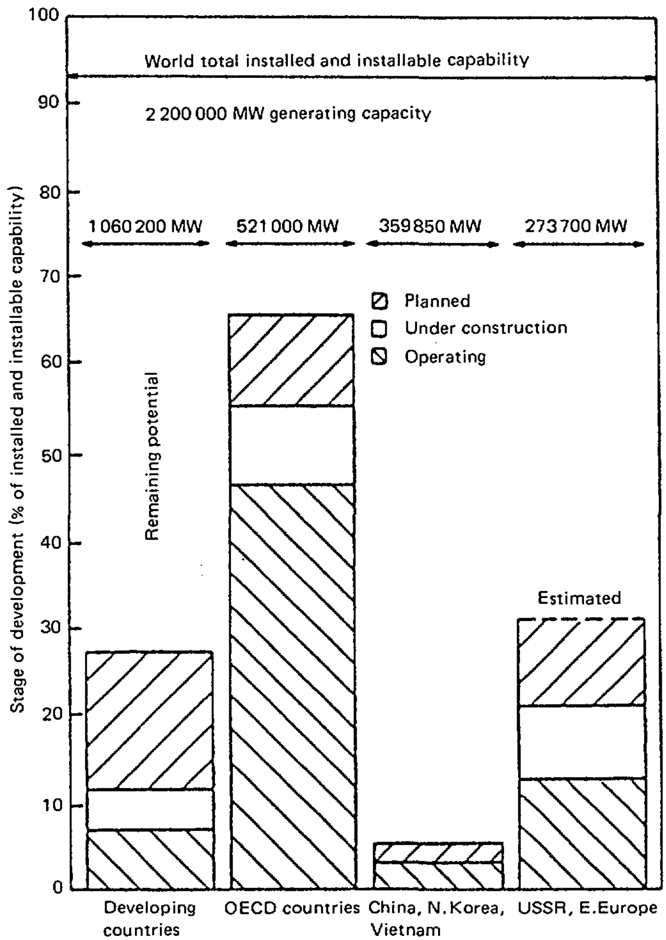


FIG.3.18. World total installed and installable hydraulic capability [3.4].

rose substantially in the last decade, bringing the economic harnessable potential increasingly closer to the technically harnessable one, and raising herewith considerably the figures of the economic recovery factor to 70–80% and more of the technical ceiling. But even the latter is moving constantly upwards due to continuously improving construction concepts and techniques.

With all the caution that must be applied to worldwide estimates, Table 3.XIV displays the distribution of the theoretical and the technically harnessable hydro potential in the world and the percentage share of the latter.

While Table 3.XIV presents the yearly production potential (TW·h) of world hydro-electric power, Fig.3.18 displays the installable and installed electric

TABLE 3.XV. COUNTRIES WITH MAJOR HYDRO-ELECTRIC POTENTIAL [3.47]

	Harnessable potential (1)	Harnessed potential in 1974 (2)	(2)/(1)
	TW.h	TW.h	%
1. Peoples' Rep. of China	1 320	35	2.6
2. USSR	1 095	132	12
3. USA	701.5	304	44
4. Zaire	660	3.85	0.6
5. Canada	535.2	210	39
6. Brazil	519.3	67	13
7. Malaysia	320	1.2	0.37
8. Colombia	300	8.2	2.73
9. India	280	27.4	9.78
10. Birmania	225	0.4	0.17
11. Vietnam and Laos	192	0.4	0.20
12. Argentina	191	4.82	2.52
13. Indonesia	150	1.55	1.03
14. Japan	130	82.3	63.53
15. Ecuador	126	0.44	0.34
16. New Guinea	121.7	0.17	0.82
17. Norway	121	76.5	63.22
18. Cameroon	114.8	1.07	0.93
19. Peru	109.2	5.58	5.10
20. Pakistan	105	4.85	4.85
21. Sweden	100.3	57.3	57.12
22. Mexico	99.4	16.9	17
23. Venezuela	98	7.3	7.44
24. Chile	88.6	6	6.77
25. Gabon	87.6	0.007	0.008
26. Spain	67.5	30.7	45.48
27. France	65	56.8	87.38
28. Yugoslavia	63.6	20.7	32.54
	7 986.7 (81.5 %)	1 162.3	14.5
Other countries	1 815.7 (18.5 %)	264.2	14.5
World total	9 802.4	1 426.5	14.5

capacity (MW) [3.4]. The technically utilizable potential amounts to 2 200 000 MW. Against this potential, the following changes have been reported [3.3]:

	1978	1983	Change %
Operating capacity (MW)	314 563	371 457	+18
Under construction (MW)	110 059	102 223	−7.1
Planned (MW)	181 204	247 106	+36

The remarkable increase of 36% in the planned capacity suggests the future outlook is favourable.

Shares of the world hydraulic energy potential are: OECD countries 24%, centrally planned economies 28% and developed countries 48%. While in the OECD countries 46% of their potential is now utilized, in the developing countries the figure is only 7% at present. The latter therefore possess the greatest potential for development.

Table 3.XV presents in a decreasing sequence in its first column the harnessable hydro potential of the best endowed countries in the world. The second column, referring to the real harnessed potential, is rather obsolete (1974). The third column shows the discrepancies in the degree to which the different countries were using their hydro power potential Ten years ago France had already reached over 87%, Japan 63.5% and Norway 63%.

However, it is supposed that the proportion will improve, increasing from a world-wide average of 14.5% in 1974, to some 22% in 1985, 36% in 1990 and 80% in the year 2020. Table 3.XVI shows accordingly a scenario with a particularly strong emphasis on the developing countries [3.2].

TABLE 3.XVI. PROBABLE WORLD HYDRO-ELECTRIC DEVELOPMENT [3.2]

	(annual electrical energy in TW.h)			
Country grouping	1976	1985	2000	2020
OECD-countries	1050	1250	1490	2020
Planned economies	200	330	800	2400
Developing countries	325	550	1250	3330
T O T A L	1575	2130	3540	7870

Assuming that by the year 2020 about 80% of the total harnessable hydro-electric potential is developed and operating at an average capacity factor of 50%, the world yearly production potential of electrical energy would reach some 7870 TW·h.

A definite new tendency is making itself felt in the world, due to the substantially increased competitiveness of hydro power in the light of the evolution of petroleum prices. On the one hand giant hydro power plants emerge where the electricity market can absorb the bulk capacity additions, on the other hand, existing older hydro power plants designed according to the concepts and techniques of the first 50 years of electricity supply are being modernized, both in design and equipment, and their installed capacity and annual productivity have substantially increased.

Some examples of giant hydro power plants in operation or under construction are the following:

	Installed capacity (MW)	Yearly generation (TW·h)
Itaipu (Brazil – Paraguay)	12 870 (21 500)	70
Grand Coulee (I-II-III) (USA)	6 480 (10 230)	20.3
Sayan (USSR)	6 360	23.8
Krasnoyarsk (USSR)	6 000	20.4
Churchill Falls (Canada)	5 225	34.4
Cabora-Bassa (Mozambique)	2 040	16.5
Iron Gates (Romania-Yugoslavia)	2 000	10.5

The advantages of hydro power are: a continually renewable energy resource with a year as the hydrological cycle; it is nonpolluting and extremely flexible and reliable for electricity generation, permitting the storage of large amounts of energy and optimal schemes for multi-purpose utilization – irrigation, electricity generation, flood control, navigation, drinking water supply, fish and wildlife, recreation, etc. Thus, hydraulic resources have a considerable role to play in the future socio-economic development of the globe. Some trade-offs may be required to optimize the overall benefits, but hydro-electric generation, accepting sometimes certain limitations, can substantially contribute to make multi-purpose water utilization economically possible and electrically advantageous [3.48, 3.49].

3.2.1.2. Non-conventional hydraulic energy resources

3.2.1.2.1. Micro and minihydro power plants

Triggered by the new competitive conditions of hydro power on the energy market, an old traditional area of hydro power techniques which has been. almost forgotten since the petroleum era, i.e. small hydro power plants, was suddenly revitalized and entered a phase of great interest and accomplishments. The installed capacity of these new hydro power plants is small compared to the normal or giant capacity of conventional hydro units, so by contrast and possibly also for commercial reasons, they have been ranged in a new category, that of micro and mini hydro plants.

For their possible implementation also in very simple conditions of construction and equipment in remote areas, these units allow harnessing the energy potential of small rivers not normally included in the official hydro potential figures since the statistical bases do not go below 1, 2 or 5 MW. Therefore, the consensus is increasingly to regard this additional hydro potential as non-conventional.

However, a new era has opened for the micro and mini hydro power plants, with impressive progress in design and equipment and acceptable unit costs since they are no longer conceived as down-scaled conventional plants, but products of an independent optimized approach. The latter also includes multilateral activities extending or establishing the necessary statistical basis to compound an updated inventory and advanced basic project designs. These activities are carried on both in developed and developing countries although for different reasons and purposes, since this additional hydro potential must be known and well studied. It possibly could represent a substantial, even a considerable figure.

Consequently, thousands of micro and mini hydro power stations are being built in the world, with installed capacity between 20–500 kW, which seems the range most accepted. However, the range is extendible at both ends, from portable 5 kW units up to 1000 kW normally, and even to 2–10 MW under special conditions.

For example, the People's Republic of China has more than 150 000 micro and mini power plants in operation, with installed capacity ranging from 5 kW to 12 MW. The majority are connected with irrigation plants and located in remote areas which will not be reached by the public network in the next 10–20 years, or even later.

3.2.1.2.2. Non-conventional hydro power projects

An example of a non-conventional hydro power project is the artificial creation of a water flow from a higher located natural water source to a lower reception area, able to receive large quantities of water and either conduct them further or dispose of them by evaporation into the atmosphere.

Such projects have been in existence for many years, but not one has been implemented so far. An example is the Qattara project, proposed some 70 years ago and continuously improved since then. The project envisages to channel Mediterranean sea water to a depression 134 m below sea level in the western desert of Egypt and to form a vast lake till its level reaches 60 m below sea level. Depending on the alternative chosen, a base load power plant would supply 670 MW, and a peak load station another 600 MW. By further pumped storage the peak power could be raised to 8000 or even 10 000 MW.

Another project exists for a 300 MW power plant using the water channelled through a pressure tunnel of 70 km to the Dead Sea using the height difference from the Mediterranean Sea (see the Bibliography).

Although working with artificially created waterflows, the pumped storage hydro power plants – see chapter 6 – do not fall into the above described category, since they do not directly use a primary energy resource, the water being pumped to the upper reservoir, and not existing there in nature.

Another real non-conventional yet not used hydro power potential is that of the huge melting water quantities flowing down from the ice mountains in the polar regions. Stored in ice reservoirs closed by ice dams, it could serve for electricity generation in glacier power plants as does melting ice water in conventional hydro power plants – see Fig. 3.17.

3.2.2. Sea and ocean energy

Under this heading tidal power, wave energy and ocean thermal energy conversion (OTEC) will be presented in more detail. Ocean currents and salinity gradients are only mentioned for completeness, since no commercial development can be expected before the year 2000, whereas marine biomass and off-shore wind energy will be included in the following two subsections.

3.2.2.1. Tidal energy

Unlike most of the other 'new' energies, ocean or land based, tidal energy has already shown with the French tidal plant of La Rance of 240 MW [3.50], 18 years of reliable commercial operation. However, this plant remains unique, except for the experimental micro power plant of 400 kW located at Kisbaya Guba near Murmansk in the USSR (1968).

The global world potential of tidal energy amounts to some 30 000 TW·h yearly [3.51] and strongly depends on the availability of favourable sites. Some 40 sites in the world meet the conditions: favourable geographical conditions in order to minimize engineering work, an average tide of 5–12 m, possible linkage of a grid in order to accommodate the variable but calculable electrical output, and favourable socio-economic and ecological conditions. Half of the sites allow an installed capacity of over 1000 MW, the others allow at least capacities of 2000 MW [3.52]. With some exceptions, the sites are located in developed countries.

Of the studies pursued by Canada, India, the Republic of Korea and the United Kingdom, the Canadian project to harness the giant 17 m high tides of Fundy Bay is the most advanced. A pilot turbine of 20 MW should become operational in 1984, while for the full project with an installed capacity of 4864 MW commissioning is expected by the mid-1990s [3.53].

In the United Kingdom and France it is considered that a tidal power plant could produce electricity at a cost comparable to that of coal and lower than that of oil. However, this applies at present only to sites with high tidal range and the cost cannot compete with nuclear power [3.50].

Small tidal plants in the range of a few MW would lead to excessively high kW·h costs for average 5 m tides, unless erected as part of a larger aquacultural and coastal area management programme.

3.2.2.2. Wave energy

The waves arise from the effect of solar and wind action on seas and oceans and carry an enormous amount of kinetic energy, estimated at some 10^6 MW or around 91 kW/m waveline [3.48]. There are already proposals for harnessing this energy, both off-shore and when the waves break against a shoreline [3.54]. In some locations it may provide energy from storms and winds occurring thousands of miles away, favourably supplementing the local winds to provide a greater availability of power output.

Wave energy technology is at an early but rapidly changing state of development. Present designs assume that wave energy devices are to be placed in a vigorous wave climate (45–50 kW/m mean annual value), such as found predominantly beyond 30°N and 30°S, with the exception of the West African coast between the equator and 20°S.

However, despite a very large number of design concepts [3.55] – over 350 patents have been registered – the results are disappointing, the projects leading to excessively high kW·h costs. Therefore, competitive generation of electricity – except for specialized very small-scale applications, as in maritime buoys – is not expected before the year 2000 [3.54].

3.2.2.3. Ocean thermal energy conversion (OTEC)

The oceans and seas represent a huge heat storage exploitable when temperature differentials are present. Under the effect of solar radiation and sometimes of warm currents in some areas, a thermal gradient may exist between the warmer water found at the surface of tropical seas and the cooler water existing at considerable depths. Claude, as early as 1930 in Cuba, tried to take advantage of this temperature difference by using the thermodynamic process named after him. The very small thermodynamic limits and high investment costs of the process prevented further development [3.53].

However, with increasing fuel prices and the possibility of applying less expensive technology, a considerable interest resurged for OTEC. Extensive investigation of adequate sites and possible progress of the technology involved as well as an impressive number of case studies have very much promoted the prospects of OTEC [3.52, 3.56].

A total of 99 nations and territories, having direct access to an OTEC thermal resource with an average monthly Δt exceeding 20°C within their exclusive economic zones – 200 nautical miles – have been identified. Of this total, 62 are developing countries. Twenty-five of the latter are projected to have installed capacities greater than 1000 MW by 2010. For the other 27, a great potential exists for smaller-scale plants – less than 100 MW – which could become competitive with diesel-powered plants in many locations.

Estimates of global installed OTEC capacity range from 10 000 to 100 000 MW; a realistic figure probably lies closer to the lower end of that range. However, in the USA, a goal of 10 000 MW of OTEC capacity by the year 2000 has been established by law [3.52] and two pilot plants are to produce 100 MW by 1986.

As far as technological experience is concerned, no land-based OTEC plant has ever been operated, with the exception of the 22 kW plant built by Claude in Cuba in 1930. A 50 kW floating plant was an extremely successful experiment for a few months in 1979.

However, some of the major parts of the OTEC system are well tested, reliable and should be amenable to normal engineering scaling. These include the heat exchangers, turbines and generators, platforms and pumps. A few major components which require development work include the cold water pipe – this could be 1000 m long with a diameter of 10 m for a 40 MW plant –, underwater electrical cables and floating platform mooring. The heat exchangers use ammonia as a working fluid and titanium as preferred material because of its resistance to ammonia corrosion and its long life in contact with sea water. The turbines required are larger than any yet built because of the small enthalpy drop and the large inflow involved.

Small-scale OTEC plants in the 1–10 MW range now appear to be competitive with diesel generators on remote islands [3.57].

OTEC plants could also provide potable water as a by-product. Also, 'grazing' mode operation of OTEC ships in international waters to produce energy-intensive products such as liquid ammonia for fertilizer is under study [3.54].

In conclusion, prospects for OTEC utilization are very favourable. The major impediments relate to the lack of demonstrated reliability at full scale and the need for greater awareness and understanding of the benefits that can be realized especially by developing countries.

3.2.3. Wind energy

The energy in the wind is derived from the differential heating of the atmosphere by the sun, the rotation of the earth and the irregularities of the earth's surface, which result in gradients of temperature and pressure [3.58].

The total annual kinetic energy of the world's winds is estimated to be about 30×10^6 TW·h/a, i.e. about 2% of the solar radiation reaching the globe [3.58]. The technically usable potential is assumed to be limited to theoretically 30×10^3 TW·h/a [3.2]. However, nature concentrates this energy in certain regions, such that the average wind energy flux or energy density in many locations can be equal to or greater than the average solar energy flux.

The power of a wind flux is proportional to the cube of its speed (v) and its density (ρ), and the power P can be calculated:

$$P = \frac{1}{2} \rho \cdot A v^3 C p$$

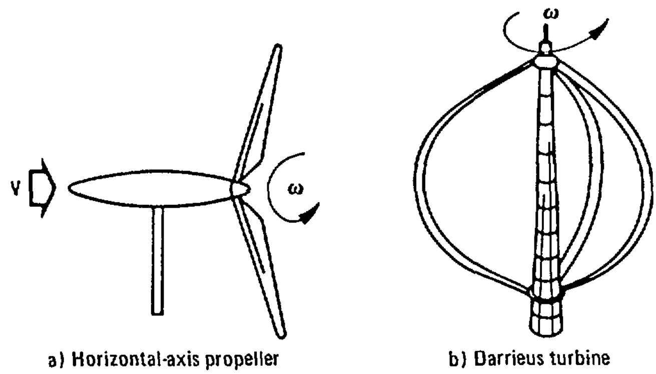


FIG.3.19. Two basic types of wind energy converters [3.59].

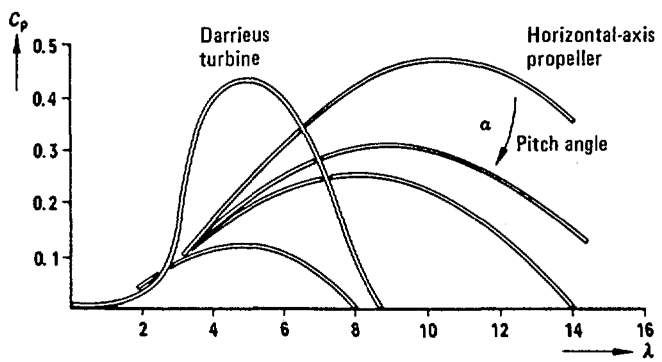


FIG.3.20. Variation of power coefficient C_p with velocity ratio λ [3.59].

where A = swept area of turbine, and Cp is a power coefficient depending on the nature and quality of the technology involved, $Cp \leqslant 0.5926$ [3.59].

Figure 3.19 presents two basic types of wind energy converters: the horizontal-axis propeller and the Darrieus turbine with vertical axis [3.59].

Figure 3.20 shows the variation of the power coefficient Cp with the velocity ratio $\lambda = u/v$ where u is the blade-tip speed [3.59].

As for hydro energy, wind energy has:

(1) A theoretical potential which is equal to the kinetic energy transported by air.
(2) A technically harnessable potential, which is the maximum share of the theoretical potential that can be converted into usable energy. The ceiling value is 59.26% (Betz coefficient).
(3) An economic potential, which represents the share of the technically harnessable energy economically acceptable.

The wind energy resource is quite variable in both time and location. The variability with time occurs during intervals of seconds (gusts), minutes (power variations), hours (diurnal cycles) and months (seasonal variations). This variability implies that wind energy is best utilized in three situations [3.60]:

(1) Interconnected with other power plants, ranging from a small diesel to a large utility grid. The output of the windmill is then used to save conventional fuels; however, in utility applications some capacity credit is also achieved.
(2) Utilized in connection with some form of energy storage such as batteries or pumped hydro-electric systems. In this case, firm power can be supplied, but the additional costs and losses associated with the storage system must be accommodated.
(3) Utilized in applications where the energy end-use is relatively independent of time, has a time constant which can allow for the fluctuations in the wind or where an end-product can be stored. Examples of these types of applications include some types of irrigation, pumping and desalination of water and heating, drying and cooling of agricultural products.

In addition, there are applications and localities where there is a potentially beneficial correlation or matching, on a statistical basis, of the availability of the wind and the need for energy. In many localities, the winds tend to blow in the afternoons and evenings, which are also the most usual times of peak energy demands.

Figure 3.21 displays the mean annual wind speed distribution over the continents in m/s for four velocity classes: between 5.6 and 8 m/s, between 4.5 and 5.6 m/s, between 3.6 and 4.5 m/s and under 3.6 m/s [3.2].

Figure 3.22 refers to the annual energy yields obtainable from wind in different world regions, these depending on the combined effect of wind speed and duration. The numbers indicate annual outputs in kW·h/kW obtained by a 1250 kW turbine, 55 m in diameter; continuous annual operation at 100% capacity would mean 8760 kW·h/kW [3.2].

Since the wind off-shore is stronger than on the adjacent land -- hilltops aside – off-shore wind units should be capable of providing greater output than on-shore ones.

Wind systems can be constructed in sizes ranging from a few watts up to 1 MW or more. For larger amounts of power, additional units can be added whether in 'farms' or clusters or spread more randomly based on the terrain.

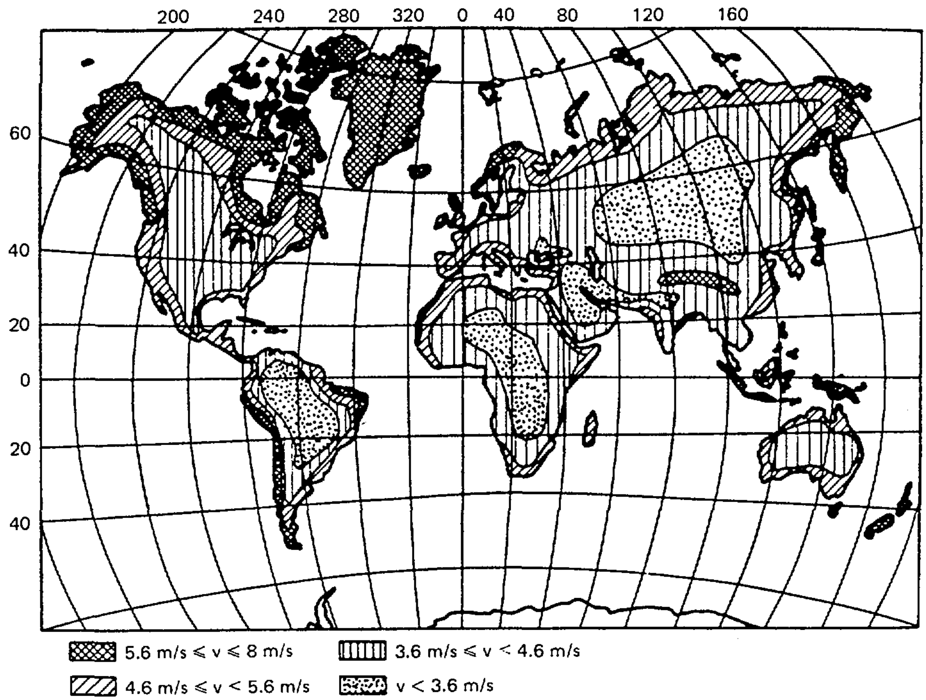


FIG.3.21. Mean annual wind velocities over continents in m/s [3.2].

Practical wind systems can be constructed across a wide spectrum of materials and technological levels ranging from the individual craftsman or community level using local materials through the higher technology high-speed systems manufactured in quantity. Across this spectrum, however, advances in the understanding of the wind and the design of wind systems have increased their capability and practicability and the lack of thermodynamic losses means that relatively highly efficient systems can be obtained.

The shaft power from the wind turbine can be utilized for a wide variety of purposes, including electricity, direct pumping, direct mechanical work (grinding, sawing, extracting food oils) and direct heating, although the design of the wind turbines may be different for different applications.

Wind energy has been one of the few forms of renewable energy which traditionally has been cost-effective and practical during numerous previous eras. The question is whether the combination of improved knowledge of the wind and wind systems combined with the rising cost and economic penalties associated with fossil fuels can again lead to a wide-scale contribution of energy from the wind. Recent experiments and assessments suggest this is probable [3.61].

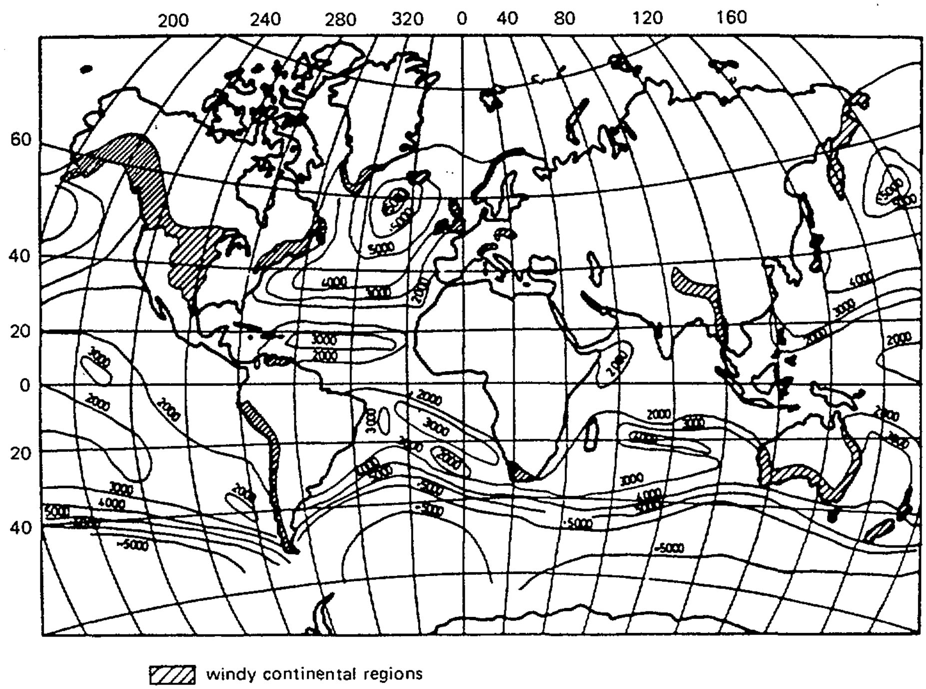


FIG.3.22. Annual yields from the wind [3.2].

3.2.4. Biomass energy resources

Biomass is defined as plant and animal matter and its derivatives which can be converted into energy. It includes trees, shrubs, other woody vegetation, grasses, other herbaceous plants, energy crops, algae, aquatic plants, agricultural residues, forest residues, manures, solid wastes, industrial, municipal and domestic wastes, waste water and human wastes [3.62].

Biomass is a product of photosynthesis arising from the capability of the chlorophyll of plants to absorb the electromagnetic energy of light and to use it for producing from the carbon dioxide of the air, sugar and carbohydrates with the release of O_2. The reaction represented as

$$CO_2 + H_2O \longrightarrow (CH_2O) + O_2$$

is in reality a very complicated process, consisting of a series of individual subprocesses, not yet scientifically completely understood [3.63].

The photosynthetic efficiency, defined as the chemical energy fixed in biomass related to the incident solar energy, varies between 0.24 for continents and 0.06 for the ocean, leading to 0.11–0.16 as a global average.

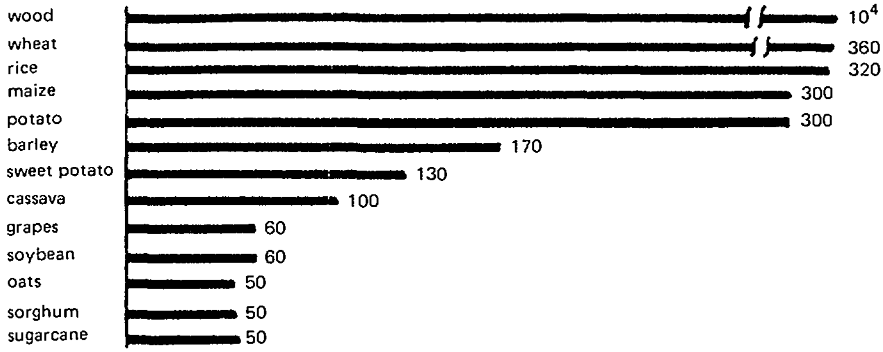


FIG.3.23. Annual production of main biomass types, in 10^6 t [3.2].

Biomass-producing plants (bioms) can be classified into three main groups:

(1) Cellulose bioms, e.g. trees and bushes and their fruits and leaves
(2) Herbaceous and agricultural, e.g. crops
(3) Aquatic bioms, e.g. algae (in marine and fresh water).

Another classification of biomass, depending on its origins, is the following:

(1) Primary biomass is produced by the photosynthesis of plants, i.e. the organic matter formed by plants.
(2) Secondary biomass is the biomass produced by animals fed with primary biomass, for example, the meat produced by herbivorous animals. Because of the low efficiency (10 to 20%) of the conversion of primary into secondary biomass, the latter is not of interest for exclusive energy use.
(3) Residual biomass as a result of human activities, both of primary origin – straw for example – or of secondary or even tertiary origin, as for example waste meat, urban waste, dung, etc.

In fact a fourth and very important category exists, the fossil biomass, i.e. petroleum, coal, natural gas, which, originating from a biological process, has been exposed for a long time afterwards to various transformations. However, this category will not be considered in this subsection.

The annual production of biomass corresponds to the effect of a solar power component of some 40 TW and includes as main useful components of the yearly production of some $100-140 \times 10^9$t [3.45] the biomass types singled out in Fig.3.23. Their energy content (hydrocarbons such as cellulose and wood) ranges around 5 kW·h/kg.

The distribution of biomass production rate is illustrated in Fig.3.24. Almost half of production (47.3%) is concentrated in the equatorial zone, up and down

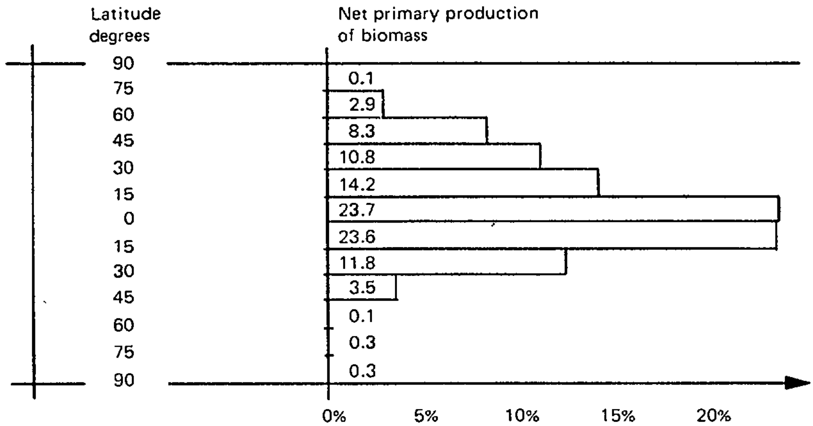


FIG.3.24. Distribution of biomass production rate versus latitude [3.2].

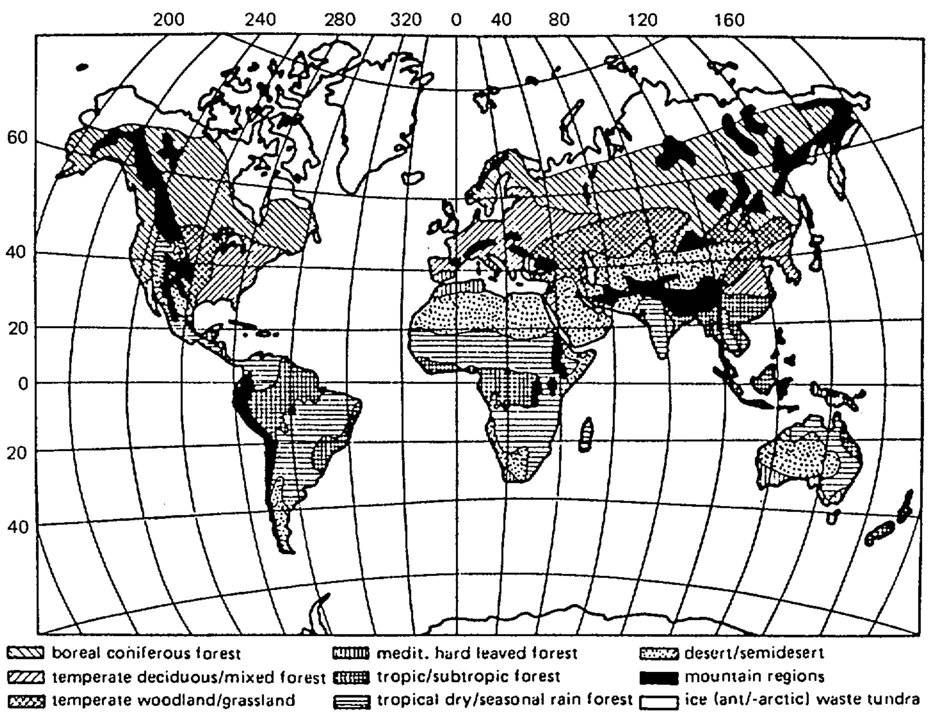


FIG.3.25. Global distribution of main types of vegetation [3.2].

to 15 degrees latitude, with another quarter (26%) between the latitudes 15° and 30° north and south [3.2].

Figure 3.25 shows the distribution of the main types of vegetation around the globe and herewith the main types of biomass sources [3.2].

Concerning the utilization of biomass, the comments in this subsection will be confined to its direct consumption. Its conversion to gaseous and liquid fuels will be commented on later, in chapter 5.

Fuelwood, by far the most important biomass form, is the fourth largest contributor to world energy supply after petroleum, coal and natural gas.

Until roughly the middle of the nineteenth century, wood was everywhere the principal fuel, even in North America and Europe. Since that time it has been steadily replaced in industrialized countries by cheaper, more efficient and more convenient sources of energy – first coal, and later oil and gas and electricity, the substitution taking place first in industrial and later in household use. It was probably only after the turn of the present century that wood lost its place as the main fuel in the rural areas of most industrialized countries, but since then its decline has been rapid and continuous. During the third quarter of the century total wood fuel (firewood and charcoal) use in Europe fell by more than a half, and in the USA by more than three-quarters, although it has been predicted that fuelwood use in the USA is now likely to level off because of a growing demand for fireplace wood [3.64].

As shown in Table 3.XVII, in 1974 consumption of fuelwood in the developed world is estimated to have been about 155 million m^3. As such, it accounted for less than one per cent of total energy use in these countries, and not much more than one-tenth of all the wood they used. In the same year consumption of fuelwood in developing countries is believed to have been roughly 1200 million m^3, accounting probably for about one quarter of their total energy use (excluding energy from agricultural and animal residue, human energy and animal power) and nearly nine-tenths of their total wood use.

Most of developing countries' consumption takes place in rural areas. In nearly all developing countries wood fuel is the dominant rural source of energy. It is the principal source of fuel at the household level for cooking the daily food and maintaining warmth in the home.

As shown in Table 3.XVII, wood fuel accounts for nearly three-fifths of the total of commercial energy and energy from fuelwood used in Africa, for more than two-fifths in the Far East (excluding China), for one-fifth in Latin America and for 14% in the Near East. In some individual countries the share of wood fuels is in excess of 90%.

In the rural areas of most developing countries, the dependence on wood is often almost total. Where it is not used, the principal fuels are usually other locally available organic materials: animal dung and crop residues. It was recently estimated that animal dung used as fuel provides energy equivalent to around 13% of the energy being used in the form of wood fuel, and that energy from crop

TABLE 3.XVII. FUELWOOD AND ROUNDWOOD CONSUMPTION AND FUELWOOD ENERGY, 1974 [3.64]

Region	Fuelwood	Total roundwood	Fuelwood as % of roundwood	Energy[a] from fuelwood	Commercial energy	Fuelwood as % of fuelwood and commercial energy
	(x 10⁶ mc)	(x 10⁶ mc)	(%)	(x 10¹⁵ J)	(x 10¹⁵ J)	(%)
Developed Market Economies	54.9	790.6	6.9	531	140 449	0.4
North America	17.6	474.7	3.7	170	77 763	0.2
Western Europe	32.3	240.8	13.4	312	45 161	0.7
Oceania	2.5	21.5	11.6	25	2 654	0.9
Eastern Europe and the USSR	99.7	462.1	21.6	964	54 267	1.8
Total developed countries	154.6	1 252.7	12.3	1 495	194 716	0.8
Developing Market Economies	1 145.3	1 336.1	85.7	11 074	22 038	33.4
Africa	268.3	299.6	89.5	2 594	1 848	58.4
Latin America	243.9	298.0	81.8	2 358	9 383	20.1
Far East	577.0	667.9	86.4	5 579	7 577	42.4
Near East	56.1	70.6	79.4	543	3 230	14.4
Asian centrally planned economies	153.5	205.7	74.6	1 485	16 790	8.1
Total developing countries	1 298.8	1 541.8	84.2	12 559	38 828	24.4
World	1 453.4	2 794.5	52.0	14 054	233 544	5.7

Source: 'Energy in agriculture,' *The State of Food and Agriculture 1976* (FAO, Rome 1977).[a] Assuming 1 m^3 of fuelwood contains 9.67×10^9 J of energy.

TABLE 3.XVIII. COUNTRIES WHERE FUELWOOD ACCOUNTS FOR OVER TWO-THIRDS OF TOTAL ENERGY CONSUMPTION IN 1980 [3.65]

Country	GNP/inhabitant US $/year	Fuelwood use m^3 per head/year	Energy consumption (GJ per head/year) Firewood	Total	% fuelwood of total energy consumption
Afghanistan		0.42	3.95	5.71	69
Angola	470	1.05	9.87	14.09	70
Benin	310	1.00	9.40	11.00	85
Burma	170	0.67	6.30	8.20	77
Burundi	200	0.17	1.59	2.00	79
Cameroon	670	0.92	8.65	11.94	72
Central African Republic	300	1.08	10.15	11.38	
Chad	120	1.62	15.22	15.85	96
Congo Rep. Popul.	900	0.90	8.46	11.06	76
Ethiopia	140	0.74	6.96	7.79	89
Gambia		1.42	13.35	17.10	78
Guinea	290	0.60	5.64	7.93	71
Haiti	270	0.82	7.70	9.24	83
Honduras	560	1.14	10.72	16.41	65
Lao		0.89	8.36	10.33	81
Madagascar	350	0.61	5.73	7.79	73
Malawi	230	1.59	14.95	16.33	91
Mali	190	4.20	39.48	40.33	98
Nepal	140	0.91	8.55	8.87	96
Niger	330	0.52	4.89	6.39	76
Nigeria	1 010	1.19	11.18	15.41	72
Rwanda	200	1.02	9.59	9.70	99
Sudan	410	1.79	16.82	19.42	87
Tanzania	280	1.89	17.76	19.31	92
Uganda	300	0.33	3.10	3.96	78
Upper Volta	210	0.88	8.27	9.23	89

residues is equivalent to about 16% of the energy produced from animal dung. In aggregate, wood fuels, therefore, probably account for about 85% of all non-commercial energy in developing countries, other than human and animal energy.

Table 3.XVIII displays the list of the developing countries where fuelwood accounted for over two-thirds of their total energy consumption in 1980 [3.65].

The demand for fuelwood has grown far faster than supply. Many developing countries are, therefore, facing a second energy crisis which affects particularly the rural sector of their economies. This crisis is very acute: the forests of the developing countries at the moment are being consumed at a rate of 1.4% of the

TABLE 3.XIX. POPULATIONS (IN MILLIONS) WITH A FUELWOOD DEFICIT[a] [3.65]

Region	1980						2000	
	Acute scarcity		Deficit		Potential deficit		Acute scarcity or deficit 2000	
	Total population	Rural population	Total population	Rural population	Total population	Rural population	Total population	Rural population
Africa	55	49	146	131	112	102	535	464
Near East and North Africa			104	69			268	158
Asia and Pacific	31	29	832	710	161	148	1 671	1 434
Latin America	26	18	201	143	50	30	512	342
Total	112	96	1 283	1 052	323	280	2 986	2 398

[a] Total population and population with essentially rural type of energy consumption (total population less population of urban centres with over 100 000 inhabitants) in regions where the firewood situation has been categorized.

total forest area, or 10–15 million hectares a year. As fuelwood supplies are exhausted, animal and crop residues are burned, thus often depriving the soil of valuable nutrients and organic conditioning material.

In many places where population growth and urbanization are rapid, forest resources have been heavily depleted, bringing adverse environmental consequences as well as a serious shortage of fuelwood. Deforestation is most serious in semi-arid or mountainous areas, where urgent problems of erosion, siltation and desertification are arising. Preliminary results of an evaluation study concerning fuelwood supply and needs indicate that about 100 million people in the rural areas and another 150 million people in urban areas of developing countries suffer already from an acute shortage of fuelwood. About another 1000 million are in deficit situations, where they are able to meet their minimum fuelwood requirements only by cutting in excess of sustainable supply. Under current trends of population growth, of fuelwood demand and of depletion of those resources, over 2300 million rural people in developing countries will need, within two decades, large supplies of alternative fuels.

Table 3.XIX presents in more detail the described situation, i.e. the 1980 existing populations in the different world regions affected by an acute fuelwood scarcity or deficit and the probable situation in the year 2000. The rapid increase of population strongly aggravates the evolution, especially in the rural areas.

Because large-scale substitution of fuelwood by other renewable or non-renewable energy sources is highly unlikely in view of the technical, organizational and socio-cultural difficulties involved, the United Nations Conference on New and Renewable Sources of Energy, held in Nairobi in 1981, recommended as desirable the pursuit of the following policies:

(1) Intensification of the productivity of existing fuelwood resources.
(2) Creation of new forest resources. These are required to supply fuelwood either as a main product or as a by-product particularly in village community woodlots, in large-scale plantations, or in forestry integrated with agricultural practices.
(3) Pre-processing of fuels, especially the twigs, branches, and (dried) leaves that result from logging operations but are seldom used because of their rapid and different burning rates.
(4) Organization of fuelwood distribution, based on adequate transport facilities.
(5) Development and introduction of stoves. This might possibly double traditional firewood combustion efficiency values.

In addition to meeting domestic cooking and heating energy demand, as previously described, fuelwood can also serve for small-scale electricity generation and industrial heat supply. However, in order not to aggravate the already existing deficit, in the last decade proposals have been made for meeting such additional requirements with fire- and fuelwood originating from special energy plantations, with fast-growing trees.

An important project, the dendrothermal programme, has been started for such a purpose in the Republic of the Philippines. It involves the participation of farmer associations in charge of growing, harnessing and supplying adequate quantities of wood, of power plant corporations for the electricity generation and of rural electric co-operatives to purchase the electricity and distribute it to consumers.

The plantations will grow ipil-ipil (Leucaena leucocephala), a species of fast-growing tree, occupying some 1500 ha for a 3 MW electric plant. The project target is to cover in the late 1980s an electricity demand of 676 MW (51%) by dendrothermal power plants, with the balance up to 1324 MW, to be supplied by small-scale hydro power (480 MW, i.e. 35%) and 13% purchased from the National Power Corporation [3.66].

3.2.5. Direct solar energy

Direct solar energy is the earliest primary source of energy; it is clean, renewable, abundant and available all over the globe. Unfortunately, although at its origin concentrated and of extremely high temperature (about 6000 K), it reaches the earth with a rather low energy density and temperature.

Solar energy is essentially black-body radiation, having at the upper limit of the Earth's atmosphere a mean value of about 1.37 kW/m^2 on a surface normal to solar incidence, with small seasonal variations of $\pm 3.5\%$. On horizontal surfaces it varies, depending on latitude, and diminishes because of atmospheric effects to 1.0 kW/m^2 [3.68].

Global solar radiation on the Earth's surface comprises direct or beam radiation and diffuse radiation from all over the sky.

The average annual radiation on the Earth's surface varies roughly between 2000 and 2500 $kW \cdot h/m^2 \cdot a$ in arid zones and between 1000 and 1500 $kW \cdot h/m^2 \cdot a$ in higher latitudes. Besides hourly variations, solar radiation on the Earth's surface has seasonal variations which can be 1:2 in the arid zones and up to 1:10 in the higher latitudes. Solar energy, unlike fossil fuels, is more or less evenly distributed over the globe, see Fig.3.26.

Figure 3.27 displays the worldwide distribution of the average annual sunshine hours.

Complementing the per cent chart of the solar radiation contribution to the earth's energy balance shown in chapter 1, Fig.3.28 presents in absolute figures (EJ/a) and in % the energy flux diagram of the solar radiation on the Earth and the balance of the incoming short-wave and the outgoing long-wave radiation energy.

Although the flow diagram is self-explanatory, some main aspects deserve special mention:

From the conversion of matter into energy, in the fusion process inside the sun, some 3.5×10^{27} $kW \cdot h$ are radiated annually into the universe. Of this tremendous amount of energy less than half of a billionth part, i.e. 1.55×10^{18} $kW \cdot h$, reaches

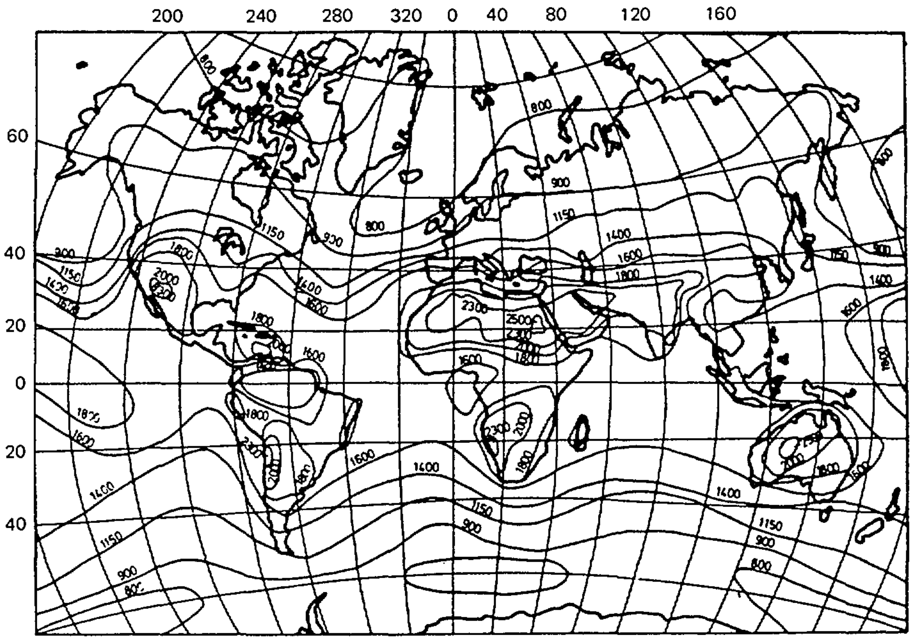


FIG.3.26. Regional distribution of the annual solar radiation in kW·h/m² [3.2].

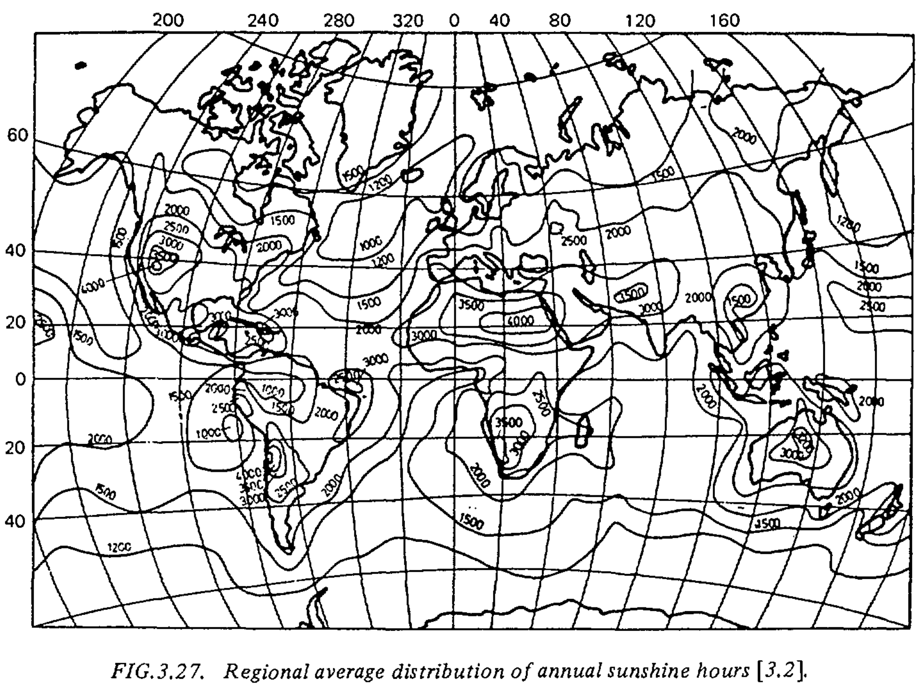


FIG.3.27. Regional average distribution of annual sunshine hours [3.2].

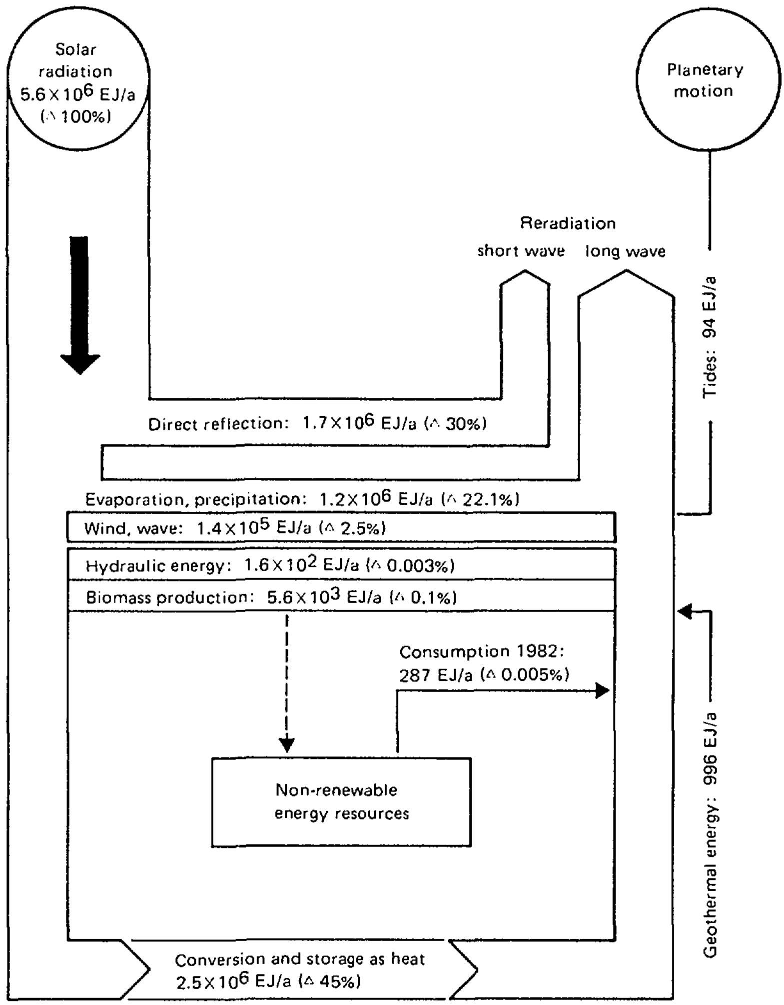


FIG.3.28. Energy flux chart of solar radiation on the Earth [3.29].

annually the part of Earth facing the sun. These 1.55 X 10^9 TW·h annually, i.e. 5.6 X 10^6 EJ/a, determine the following energy balance of the earth:

(1) From the incoming radiation 1.7 X 10^6 EJ/a, i.e. 30%, is reflected as direct or diffuse reflection to the universe;

(2) A further 22.1%, i.e. 1.2 X 10^6 EJ/a of the incoming radiation, is absorbed in the atmosphere.

(3) The balance of 47.6% reaches the earth's surface and produces 1.4×10^5 EJ/a, i.e. 2.5% of wind, wave and marine current energy and 1.6×10^2 EJ/a, i.e. 0.003% hydraulic energy.
(4) Only 0.1%, i.e. 5.6×10^3 EJ/a, is taken over by plants through photosynthesis.
(5) To the above input comes the contribution of tidal energy of 0.002%, of the Earth's heat 0.02% and 0.006% of the world's primary energy consumption from non-renewable sources.
(6) Finally the Earth's balance is closed by the long-wave radiation of the low-temperature heat back into the universe, with the exception of the small amount stored in the Earth's outer crust and in the lower part of the atmosphere as what is called environmental heat.

In spite of its continuous growth, the world consumption from non-renewable primary energy resources remains immensely small compared to the annual incoming solar radiation on the Earth. Harnessing the latter on a rapidly increasing scale, remains one of the most difficult and challenging tasks in the field of energy, and it will take decades to accomplish it on a satisfactory and rewarding level.

Chapter 4

DEVELOPMENT OF SOME NEWER AND RENEWABLE PRIMARY ENERGY RESOURCES

While for most of the primary energy resources presented in chapter 3, their conversion into intermediate energy carriers appears as an obvious next link of the energy chain, it was felt that additional preparatory information is needed on the following newer and renewable primary energy resources: nuclear energy, geothermal energy and solar energy.

For keeping the next chapter, dealing with intermediate energy carriers, to a manageable size, the additional information is presented in this separate, auxiliary chapter 4. In addition to an adequate linkage to chapter 5, this chapter allows a consolidated presentation of the specific characteristics of the three most recently developed energy resources, which otherwise would have been less happily divided between two separate chapters.

4.1. Nuclear energy resources[1]

The preparation of the nuclear fuel to an adequate form for 'burning', i.e. for the first conversion into an intermediate energy form, is more complicated than for all other primary energy carriers utilized for production of heat and electricity. However, once processed it offers an extremely highly concentrated input.

This special feature of nuclear energy and the subsequent presentation of the current types of nuclear reactors involved in the conversion process, constitute the additional preparatory information, referred to in the above introduction, as far as nuclear energy resources are concerned.

4.1.1. Elements of the nuclear fuel cycle

Since nuclear fusion energy is still in the research stage, the following considerations will concentrate on nuclear fission energy, the main energy carrier used being uranium. Due mention will be made of thorium where this is significant.

Uranium contains the fissile (with thermal neutrons) isotope ^{235}U (0.7%) and also the more abundant isotope ^{238}U (99.3%) which is the 'fertile' material for the production of fissile plutonium-239 (^{239}Pu). Both isotopes have their role in the utilization of nuclear energy, but changing for certain purposes

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[1] This subsection has been selectively extracted from the IAEA Guidebook on the Introduction of Nuclear Power [4.1], from the Summary of the IAEA International Conference on Nuclear Power Experience [4.2], and from the Report on Status and Trends of Nuclear Power Worldwide [4.3].

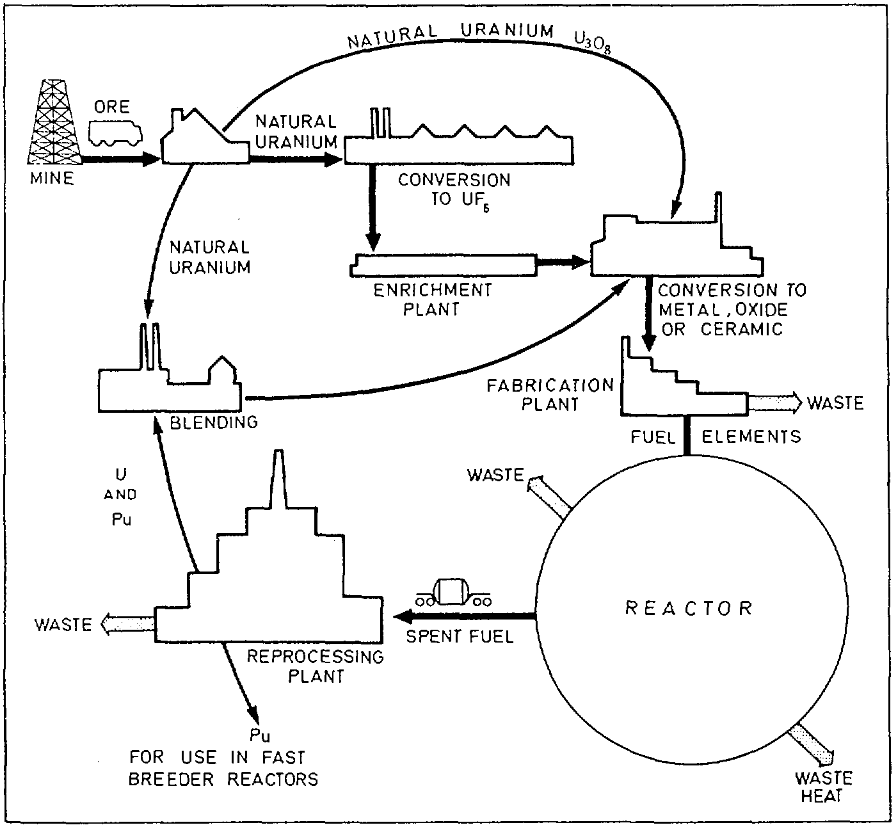

FIG.4.1. The nuclear fuel cycle.

this natural relationship (enrichment of ^{235}U content) brings additional complications in the nuclear fuel cycle.

The fuel cycle begins with the extraction of the uranium-bearing ore from the earth and, after certain recycling, ends with radioactive waste which must be disposed of adequately. It could be considered as consisting of three characteristic stages:

(a) A first stage preceding the neutronic irradiation of the nuclear fuel in the nuclear reactor (front-end)
(b) The stage of neutronic irradiation of the nuclear fuel (nuclear energy production in the reactor) and
(c) The post-irradiation stage (back-end).

All three stages have their characteristic technical aspects. The principal elements of the nuclear fuel cycle are shown in Fig.4.1.

4.1.1.1. The front end of the nuclear fuel cycle

The first stage, which is directly related to production and preparation of the primary energy form and as such is called the front end of the fuel cycle, includes the following activities [4.3]:

(1) Mining – open cast or underground – of the uranium-bearing ore, which in the present (richer) mines has an average content of uranium of 2.5%
(2) Physical and chemical treatment of the ore in order to obtain a concentrate, the yellow cake with a U_3O_8 content of 75–85%
(3) Treatment of the concentrate for obtaining UO_3, uranium oxide of high quality
(4) Conversion of the UO_3 into UF_6 (uranium hexafluoride) if the reactor fuel has to be enriched
(5) Enrichment or isotopic separation [4.4], and finally
(6) Manufacture of the fuel elements.

The technology and equipment for exploration, mining and milling of uranium is not difficult to acquire. The mining techniques are similar to those applied in conventional mining operations, except for the special features and precautions associated with radioactivity [4.5].

Current technologies use ores having a recoverable uranium concentration in the range of 0.02% to 0.2%, but recently, rich deposits were discovered having ores with up to 3% U. Following the removal of uranium ore from the mine, it is physically prepared and chemically processed or milled to produce a commercial product, yellow cake, a concentrate of uranates containing about 80% U_3O_8. Uranium milling is based primarily on hydrometallurgical operations such as leaching, solvent extraction or ion-exchange, and precipitation. Separation based on physical properties, such as specific gravity or magnetic susceptibility, is impractical for almost all uranium ores.

The conversion (to UF_6) and enrichment processes are only required if the reactor is fuelled by enriched uranium. Prior to enrichment, the yellow cake concentrate is purified and converted to uranium hexafluoride, UF_6, which is a solid uranium compound at room temperature but vaporizes at a rather low temperature of about 60°C. With this process a gaseous uranium compound is obtained, which is necessary for all subsequent processes used for the enrichment of uranium in the isotope ^{235}U.

Uranium conversion to UF_6 has been a normal commercial enterprise for many years. Conversion plants are basically chemical processing plants.

Through the enrichment process, the concentration of ^{235}U in natural uranium (0.7%) is increased to the required degree, which varies from 2 to 4% ^{235}U for light-water power reactors, up to high enrichments of 20 to 90% for fast breeders and some types of research and test reactors.

For separating the lighter ^{235}U from the heavier ^{238}U molecules of the UF_6 gas, it is necessary to perform physical work, named 'separative work'. The enrichment service price is based on the amount of separative work needed for the enrichment operation, multiplied by the price of the 'separative work unit' (commonly abbreviated SWU and expressed in mass units). It is necessary to add to this price the price of the feed material used in the operation, the feed amount being a function of the ^{235}U content of the depleted uranium left after the process (tails assay).

Because uranium enrichment provides a direct route to the production of nuclear-weapons-grade fissile material, enrichment technology still remains a highly classified area of nuclear technology.

There are five basic methods of current interest for the enrichment process, namely gaseous diffusion, gas centrifuge, aerodynamic, chemical and laser techniques.

The gaseous diffusion process has been developed and used for almost all of the uranium enrichment which has been performed for reactor fuel. The enrichment process is effected by passing gaseous uranium hexafluoride (UF_6) through a porous barrier. The lighter UF_6 molecules containing ^{235}U pass through at a faster rate than do the heavier UF_6 molecules containing ^{238}U. The amount of separation accomplished in a single stage is rather small, and hence a large number of stages are required to achieve enrichments of practical interest. Starting with natural UF_6, enrichment to a level of 3% ^{235}U requires some 1200 stages.

Gaseous diffusion plants have been constructed and operated in the USA, the United Kingdom, the USSR, France and China. While the process is known to require large amounts of electrical energy and is subject to very large economies of scale, it is technically possible to build diffusion plants of any desired output.

In the gas centrifuge process the UF_6 gas is constrained to rotate at high speed in a centrifuge. The stabilized centrifuge forces separate the lighter UF_6 molecules containing ^{235}U from the heavier ones containing ^{238}U. It requires fewer stages (each of them formed by several centrifuges) and consumes less electrical energy than the gaseous diffusion process, but the investment cost per unit capacity is larger.

The basic research and development of the centrifuge process was carried out in the Federal Republic of Germany. Pilot plants have been constructed and successfully operated, and plants are now being constructed on a commercial scale. A consortium of the United Kingdom, the Federal Republic of Germany and the Netherlands – known as URENCO – has two plants now in operation and has started the construction of larger commercial facilities.

Several aerodynamic methods have been used to separate uranium isotopes. The best known among these is the 'jet nozzle process' developed in the Federal Republic of Germany, in which a gaseous mixture of UF_6 and hydrogen is forced to flow through a nozzle and expands in a space limited by a curved wall. The centrifugal forces separate the heavier molecules from the lighter ones. The stream is thus divided into two fractions, one of them being richer in ^{235}U than the other.

The jet nozzle process has been demonstrated in the Federal Republic of Germany and a plant is to be constructed in Brazil, under its co-operation agreement with the Federal Republic of Germany. The South African enrichment process is believed to be based on the same principle.

In the chemical enrichment process developed by the French CEA the separation effect results from differences which occur in reaction equilibrium between the isotopic species of interacting uranium compounds. The nature of the chemical compounds made to react has not been divulged.

The use of laser technology for uranium enrichment is still at the laboratory research stage. The process is based on using lasers to exploit the slight differences in excitation energies of ^{235}U and ^{238}U atoms or molecules. In principle, the laser process could achieve a large degree of separation in a single stage while consuming relatively small amounts of energy. The most striking advantage of this process is that it could virtually eliminate the waste of ^{235}U remaining in the depleted uranium tails after enrichment. Hence, it would provide means of recovering the ^{235}U in the huge stockpiles of depleted uranium tails which are available from the enrichment plants in operation. These depleted tails contain about 35% of the ^{235}U originally fed to the enrichment facilities and this could provide additional substantial amounts of ^{235}U.

It is too early to predict the future development of the laser technology for the enrichment process, but if it is successful, it will make a significant contribution to the world's energy resources through the 'mining' of the large tails stockpiles available from the enrichment plants using other technologies.

The uranium enrichment supply situation is similar to that of natural uranium – overcapacity and oversupply. Existing and planned enrichment capacity can meet future requirements for enriched fuel for many years ahead. Large-scale enrichment of uranium has now been carried out for 40 years. The gaseous diffusion process deployed in four countries continues to provide the major source of enriched uranium, but centrifuges are now also in production in four countries.

The US gaseous diffusion plants have been the base-load plants for most of the world's enrichment supply. The plants are currently operating successfully at only 35% of the present capacity of 17.2 million SWU per year. The improvement and uprating projects will bring the plant capacity to 27.3 million SWU per year. The first two units of the centrifuge plant under construction at Portsmouth, Ohio are scheduled for startup in 1988–1989 at 2.2 million SWU per year capacity. With 20 years of development and 2000 machine years of experience, centrifuge performance and reliability are well established.

The EURODIF project is in production and the Tricastin gaseous diffusion plant has been completed with the planned capacity of 10.8 million SWU per year. This is a significant achievement which positions EURODIF as a major enrichment supplier and achieves considerable European enrichment supply independence. The URENCO tripartite project has also progressed well with centrifuge plants in operation in the Netherlands and the United Kingdom, and a third planned in the Federal Republic of Germany. URENCO plans an expansion to two million SWU capacity in the late 1980s. The tripartite arrangement has worked well and provides a model of a successful multinational nuclear project involving government and industry.

The process of fabrication of fuel elements starts with either the conversion of enriched uranium hexafluoride into uranium dioxide powder (UO_2) or the conversion of natural uranium into UO_2, for all water-cooled power reactors. The basic component of the fuel elements is small cylindrical pellets which are composed of uranium dioxide powder that is compacted by cold pressing and then sintered to attain the required density and structural stability.

The uranium dioxide pellets are inserted into a thin tube made of a suitable cladding material, such as zirconium alloy, to form the fuel rods. In contrast to enrichment technology, fuel element fabrication plants are available on a commercial basis from manufacturing companies.

4.1.1.2. Fuel management at the power plant

Starting with the reception of fresh fuel at the power plant and ending with the removal of the spent fuel from the plant fuel cooling ponds, a series of activities are performed. Fuel is inspected, stored, loaded into the reactor, burned, removed when spent and temporarily stored awaiting transport away from the power plant. In-core fuel management includes the long-term fuel cycle planning, development of the refuelling schedule, operational monitoring and guidance and the economic optimization of the fuel cycle. To perform these functions, sophisticated computer models and reactor analysis techniques are applied.

This is the main productive phase of the fuel cycle, since here energy is produced from the nuclear fuel.

4.1.1.3. The back-end of the nuclear fuel cycle

The back end of the fuel cycle starts with the transport of highly radioactive spent fuel away from the power plant site. This is a well-established activity. Thousands of shipments have been made in specially designed containers with few minor incidents, which did not represent any danger to the public.

The temporary storage of spent fuel at the power plant can cover a period of a few months to several years. Afterwards, depending on the fuel cycle strategy adopted for ultimate disposal of the spent fuel or reprocessing, the fuel will be removed from the temporary cooling ponds to away-from-reactor storage (interim or permanent) or to a reprocessing facility.

While the spent fuel is highly radioactive, it is stored under water in specially constructed ponds provided with a cooling system to remove the heat generated by radioactive decay. Later, dry storage is possible. Spent fuel storage technology has been well developed; however, large central away-from-reactor storage facilities have not yet been built, except where such facilities are part of a reprocessing plant.

Following a cooling-down period of about one year in the temporary storage pool, during which the most intense short-lived and intermediate half-life radioactive fission products have decayed, spent fuel can be transferred to a reprocessing plant. The reprocessing operations involve a series of mechanical and chemical steps to be carried out in specially designed facilities, comprising hot cells, remotely operated equipment inside the hot cells and instrumentation for control and protection against radiation hazards of the highly radioactive materials to be handled. After treatment of the spent fuel, the remaining uranium and the plutonium produced are separated from the fission products by solvent extraction. Recovered uranium, which might still contain up to 1% ^{235}U or more, can be recycled. Recovered plutonium is converted into plutonium dioxide (PuO_2) providing the fissile material for the degree of enrichment required instead of uranium-235. The fission products constituting the radioactive waste have to be treated and disposed of.

At present a large portion of spent fuel is being stored in water pools at reactors. A small part of spent fuel is in storage pools at reprocessing plants or in away-from-reactor storage. Only a small part of the spent fuel has been reprocessed.

Even with full operation of planned reprocessing plants a large portion of spent fuel arisings will not be reprocessed for some time and will have to be stored. For example, through 1990 no more than 6500 Mt U of oxide fuel can be reprocessed in Europe and an inventory of some 10 800 Mt U of unreprocessed fuel will be stored at the reprocessing plants by that time. Enough storage pool capacity is being planned at the reprocessing plants for this accumulation. However, a majority of utilities will, in addition, need to expand their storage capacities at reactor sites to provide a buffer against possible delays in shipment from the plant. Some countries are also considering the possibility of construction of centralized storage facilities. Much work is being done to develop dry storage technology and a significant dry storage capacity may be operating before the end of this century. The expansion of on-site storage and reprocessing capacities as well as the provision of centralized storage facilities should prevent spent fuel overcrowding problems in the future.

In spite of proven reprocessing technology there still seems to be some uncertainty about the desirability of reprocessing spent thermal reactor fuel.

Prices for reprocessing appear to be high and there are no market prices for the plutonium produced, as thermal reactor recycling does not present a generally proven economic case and the need for the breeders has still not materialized on a large scale. It is notable that at least one country has adopted a policy for the medium term to store spent fuel in an intermediate storage, keeping the option open for ultimate disposal of spent fuel as waste. This policy may also be adopted by other countries in the future as long as reprocessing does not present economic benefits to the utilities operating the nuclear power plants.

Uranium enrichment and reprocessing of spent fuel are considered the most sensitive elements of the fuel cycle from the non-proliferation point of view. Fuel reprocessing is the process in which a nuclear-weapons-usable material, ^{239}Pu, is recovered. Transfer of technology and international co-operation in this field have, therefore, been very limited and subject to tight restrictions.

The last step of the back-end of the fuel cycle consists in the management and disposal of radioactive waste. It must be remembered that management and disposal of radioactive waste are always a national responsibility.

The objectives of waste management are:

(a) To perform safely and efficiently a series of operations leading from the collection of wastes arising from nuclear operations through waste conditioning and transport to storage and disposal; and
(b) To ensure that no unacceptable detriments to humans will occur at any time as a result of these waste management and disposal operations.

An integrated waste management system has three basic elements: effluent control, conditioning of retained radioactive materials to facilitate their handling, and storage and disposal.

There is now adequate knowledge and practical experience available for radioactive waste management as a result of extensive R&D work and engineering investigations. While there is practical operating experience of the application of such knowledge for the management of low- and intermediate-level wastes, further work needs to be carried out to demonstrate the overall practical feasibility and safe system performance for management of high-level wastes. These investigations, especially covering aspects of conditioning and deep underground disposal, are being pursued intensively in all countries faced with this task. It was stated that the past research and development activities "clearly show that workable technology is available and ready for demonstration".

Management of low- and intermediate-level radioactive wastes has developed into an industrial activity based on established and proven technology. There is considerable experience available from disposal of these wastes in underground repositories located in shallow ground as well as low-level wastes into the sea. These alternatives, including that for rock cavities disposal, are subjects of continuing investigations for the generation of further knowledge, necessary for many countries which are just establishing or developing a disposal system for their nuclear wastes. Those countries already having disposal repositories in operation are also developing new repository systems in order to get more capacity for their growing nuclear programmes.

Continuing research and development work on the management of uranium mill tailings is leading to a better understanding of the long-term radiological and related requirements to be satisfied for an acceptable solution to this problem, which has emerged as one of the most essential in normal fuel cycle operations. Planning work is being emphasized together with clear definition of the rehabilitation objectives and restoration programmes to be developed even before mining operations begin.

The principal waste from reprocessing is a high-level liquid containing essentially all the fission products and the remaining transuranium elements. This is the most radioactive waste in the entire nuclear fuel cycle and is of major importance in waste management.

It is widely recognized that high-level wastes from reprocessing plants will be managed sequentially with initial storage as liquids in steel tanks followed by solidification and storage of the solidified product for an adequate period for decay cooling. Underground disposal of such wastes in deep geological formations is the ultimate disposal option seen to be acceptable.

Several approaches have been developed for the immobilization of high-level waste, the most developed to date being the vitrification process. However, from the numerous approaches under development, only the French AVM process, which started full-scale industrial operations at Marcoule in 1978, is developed beyond the demonstration stage.

Improvements in volume reduction and immobilization of high-level wastes, necessary from the viewpoint of safety and economy for storage, transportation and final disposal are being achieved. Investigations are being made on new high-stability materials to be used for the inclusion of high-level wastes as well as on interim and ultimate storage conditions for solidified wastes of different activity levels. The small volume of the high-level wastes and the demonstrated satisfactory safety of their intermediate storage would tend to make their long-term disposal less urgent. However, it is considered that the highest standard of safety at the lowest cost, i.e. optimization, will only be attained by carrying the effort to the end, i.e., the commissioning and operation of an ultimate disposal facility.

For ultimate disposal there is no experience available, although it has been proved that disposal is feasible with the existing technology. Detailed investigations carried out in different geological formations such as salt and granite as well as in basalt and clay clearly indicate the validity of this.

There are two main reasons why a repository system for high-level waste has not yet been demonstrated. The first is that the present and projected volumes of commercial high-level wastes for tens of years are so small that the

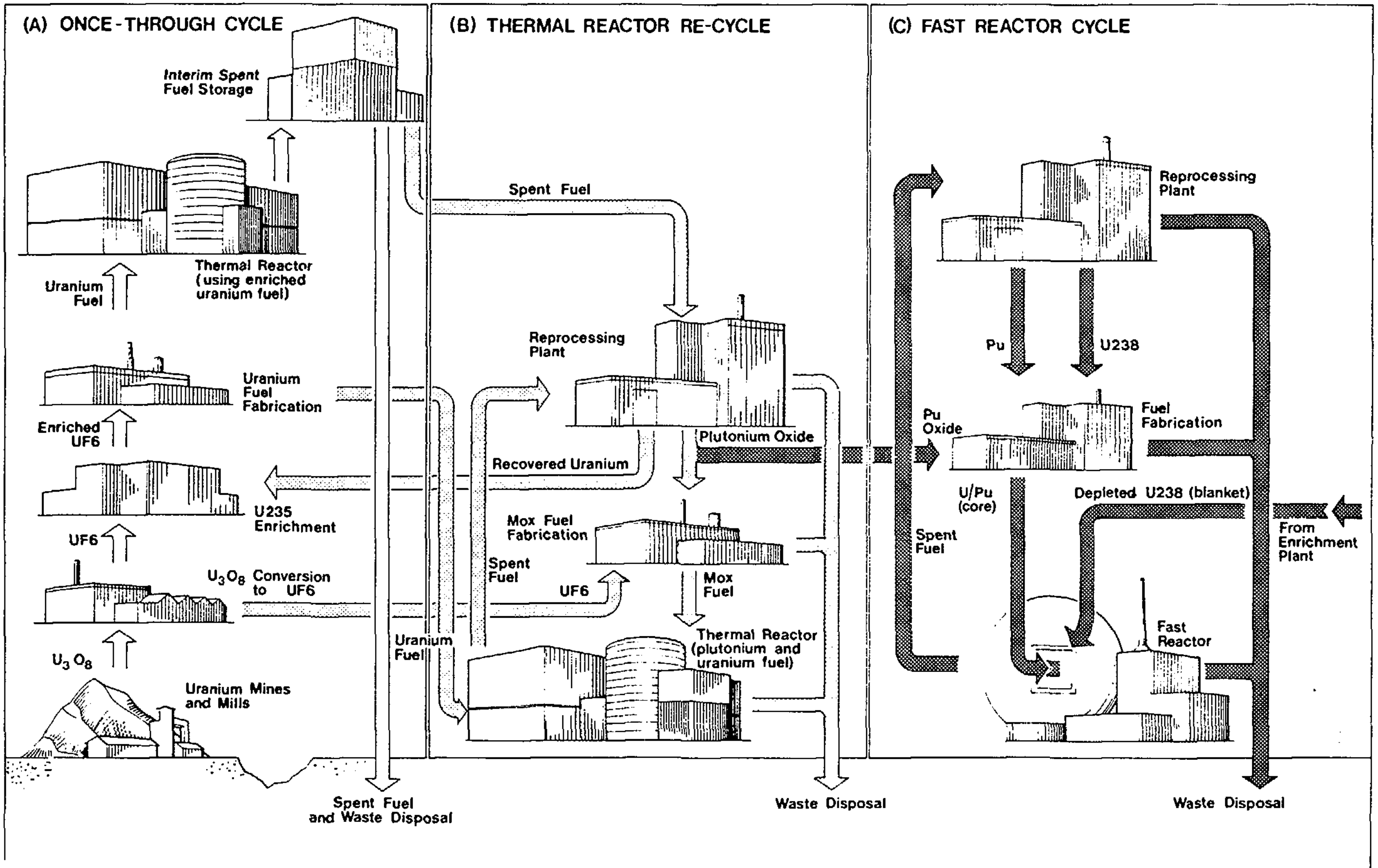

FIG.4.2. Nuclear fuel cycles for different power reactor systems.

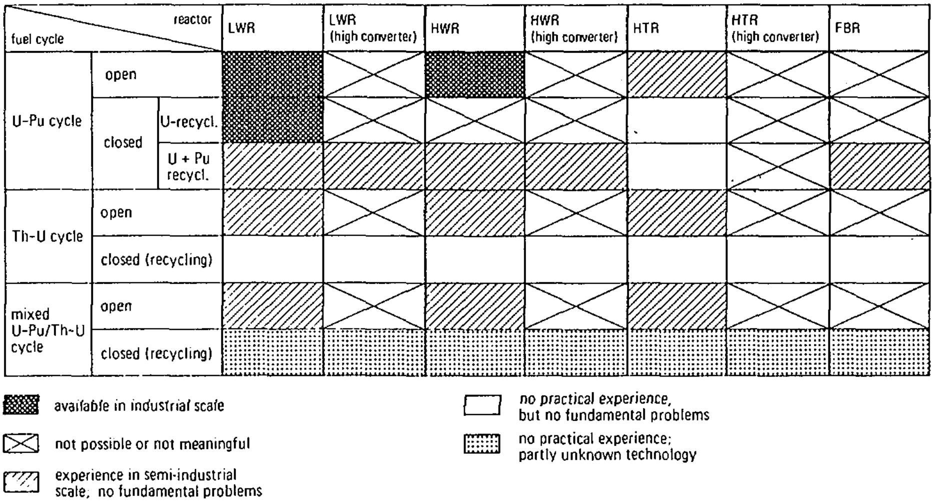

FIG.4.3. Status of experience with fuel cycles in various reactor types.

need does not yet exist. The second reason partly stems from the first. From a technical standpoint, the time is being used to perform research and development work in order to determine the best designs for a system. As a consequence, a final system design has not yet been completed. Some countries expect to initiate construction and operation of a waste repository in the next decade or two.

Nuclear waste disposal is perceived by some of the public as presenting insurmountable problems, perhaps because of a misinterpretation of the emphasis on safety, or because of the unique aspects of radioactive wastes. Most people knowledgeable about nuclear waste management consider that the technology for safe disposal of radioactive wastes is already available and the situation is really one of deciding which of several possible approaches should be selected and when to implement them.

4.1.2. Fuel cycles for different nuclear power reactor systems

Nuclear fuel cycles can be either open or closed. In an open (or once-through) fuel cycle strategy, the fuel passes through the reactor only once, while in a closed cycle, unburnt fissile material is recovered in a reprocessing plant and then recycled to fuel thermal or fast reactors. Figure 4.2 contains a schematic representation of these alternative fuel cycle strategies.

Fuel cycles are based on natural fissile (^{235}U) and fertile (^{232}Th, ^{238}U) materials and on man-made fissile materials (^{233}U, ^{239}Pu, ^{241}Pu). In accordance with the fissile and fertile materials used, fuel cycles may be classified into two main categories: the uranium-plutonium cycle and the thorium-uranium cycle. As long as a cycle does not sustain itself, i.e. as long as less fissile material is bred than is consumed, both cycles require an addition of the natural fissile material ^{235}U. A pure Th-U cycle exists only if highly enriched ^{235}U and ^{233}U are used as fuel.

The P-Pu and Th-U cycles can also be combined when employed in various reactors to form a mixed cycle. These strategies are indicated in Fig.4.3, which is a matrix diagram of the possible combinations of fuel cycles and types of reactors, showing also their technical status and feasibility. For reasons of brevity and clarity, the matrix has been limited to the most important types of reactors, leaving aside the more complicated combined cycles.[2]

It can be seen from the diagram that closed cycles can be operated with almost all types of reactors and that once-through or open cycles preclude the operation of high converting or breeding systems. The open U-Pu fuel cycle with LWRs and HWRs, and closed U-Pu with recycle in LWRs are available on an industrial basis.

4.1.2.1. Once-through or open fuel cycle strategy

In this strategy there is no reprocessing of the spent fuel and consequently no recycling of unused ^{235}U or of the ^{239}Pu which has been produced. Since spent fuel is stored and ultimately disposed of as waste, this cycle involves extended facilities for storage and ultimate disposal where spent fuel is to be removed from the temporary storage at the reactor site.

4.1.2.2. Closed cycle with fuel recycling strategy

This cycle involves the removal of spent fuel from the temporary storage to a reprocessing plant, where the spent fuel is reprocessed to separate and recover plutonium and uranium. The separated plutonium dioxide is used for fuel enrichment in fissile isotopes by combining it with natural or depleted uranium in mixed oxide (MOX) fuel pellets, which are then fabricated into mixed oxide fuel elements. The recovered uranium, which is still slightly enriched (LWR cycles) may then be re-enriched to the needed degree. New reactor core loadings would consist of a combination of mixed oxide fuel elements and enriched uranium elements.

The uranium and plutonium recycle fuel cycle strategy is technically feasible in both LWR systems and HWR systems and has been successfully used in some LWR nuclear power plants using mixed oxide fuel elements. However, at present, there is no unanimity concerning the economic benefits of reprocessing and recycling for thermal reactors.

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[2] The various types of nuclear power reactor systems are indicated in the diagram by their acronyms. These are fully explained in subsection 4.1.3.

4.1.2.3. Uranium-plutonium cycle

The annual make-up inventory of a 1000 MW(e) LWR is approximately 33 t of UO_2 with a ^{235}U enrichment of about 3%. After a burnup of 33 MW·d/kg, the ^{235}U content is reduced to some 0.8%. Most of the plutonium generated from ^{238}U is fissioned immediately, contributing some 35% to the energy production. In the spent fuel elements approximately 210 kg/GW(e)·a of plutonium is unloaded.

Heavy-water reactors operated on natural uranium or low-enriched uranium require an annual make-up charge of approximately 150 t of natural uranium per 1000 MW(e). After an average burnup of 7.5 MW·d/kg the amount of plutonium unloaded is approximately 360 kg/GW(e)·a.

In the HTGRs enrichment of about 8–10% is required. The annual make-up charge would be about 9 tonnes of uranium per 1000 MW(e). Because of the high burn-up of 100 MW·d/kg, most of the plutonium generated is burnt in the reactor so that the plutonium discharged is only some 70 kg/GW(e)·a.

All types of reactors mentioned so far can be operated both in the once-through or the closed cycles.

For the liquid metal fast breeder reactor, however, reprocessing and recycling are not optional but essential elements and integral parts of the closed fuel cycle. Present developments of fast breeder reactors are based on a plutonium cycle, although a Th-^{233}U cycle may also be feasible.

Initial loading of a fast breeder reactor would contain highly enriched uranium or plutonium recovered from spent fuel of LWRs and HWRs. Subsequently, the fuel used would be mainly provided by the plutonium produced in the breeding process. In the steady-state fuel cycle depleted uranium from enrichment tails or natural uranium is converted into uranium dioxide and combined with recovered plutonium dioxide and recovered uranium dioxide to fabricate mixed-oxide fuel. Spent fuel is reprocessed after exposure in the reactor to separate plutonium and uranium from the highly radioactive fission products. Radioactive wastes are processed into suitable forms for permanent disposal.

Fast breeder reactors use U-Pu fuel elements. The annual make-up core charge is about 12 t of ^{238}U with 14%, i.e. 1.7 t of plutonium. At a breeding rate of 1.2 an excess of about 160 kg of plutonium would be produced per year.

4.1.2.4. Thorium-uranium cycle

In principle, all types of reactors referred to above can be run also in the Th-U cycle instead of the U-Pu cycle. This cycle involves using ^{232}Th, as a fertile material for the production of fissile ^{233}U, and reprocessing and recycling of the separated ^{233}U. The utilization of the ^{233}Th-^{233}U fuel cycle has long been considered attractive, owing to the excellent neutron characteristics of ^{233}U and the availability of vast thorium resources, but the technical problems to be overcome in implementing such a fuel cycle are substantial.

The use of thorium has been considered for some of the existing designs of thermal reactors. The most promising type for its application is the high-temperature gas-cooled, graphite-moderated reactor (HTGR) system. The use of thorium is also technically feasible for light-water and heavy-water reactor systems and for FBRs. In addition, some advanced reactor concepts for the development of a thorium thermal breeder have also been considered. The analysis reveals reduced uranium ore requirements in all cases. Nevertheless, none of these concepts have been developed to practical applications.

4.1.3. Current types of nuclear reactors of various sizes

Nuclear power reactors used in nuclear plants for the generation of electricity are designed, built and operated to produce heat through the fission chain reaction of ^{235}U and ^{239}Pu, the chain reaction which takes place in the reactor core being under control and automatically adjusted to supply the desired power output [4.6].

In addition to the cooling system servicing the heat transfer, other main elements of the reactor core are the moderator and the neutron-absorbing materials. The moderator has the function of slowing down the neutrons emitted in the fission process to the thermal energy range at which they are more effective in producing further fissions to maintain the chain reaction. In the case of fast reactor types, no moderator is required. The function of the neutron-absorbing materials, which are either in the form of movable rods inside the core, or chemical compounds dissolved in the coolant, is to regulate the fission chain reaction and control the power level of the reactor. A reflector surrounds the core, to prevent neutrons from escaping from the core and hence reduce fissile material requirements and improve the power distribution within the core.

The main elements of the reactor core are assembled according to the design of the reactor system, inside a tank or a pressure vessel. For safety reasons, the whole reactor circuit and reactor vessel are enclosed inside a leaktight containment building which provides a safety barrier against radioactive products release to the environment. The containment building may also provide protection to the nuclear reactor against outside hazards, such as an airplane crash.

The reactor system provides the heat source which replaces the furnace in a fossil-fuelled electrical generating station. The remaining conventional part of the plant consists of a steam/water circuit feeding steam to a turbine driving an electrical generator. Heat from the reactor is thus transferred by the coolant and used to generate steam. The steam/water circuit is adjusted to the steam conditions achievable with a nuclear heat source. The control of the reactor and of the conventional circuit is carried out from a control room.

4.1.3.1. Classification of nuclear power reactor systems

The original choices of nuclear thermal reactors and fuel cycles were largely determined by specific national circumstances and by experience and facilities acquired from defence-related programmes. Most of the countries with leading nuclear power programmes also saw the plutonium-fuelled fast reactor with its breeding potential, essential fuel reprocessing requirements and favoured waste management as the ultimate strategic target of optimum nuclear economy development [4.7]. Ensuing operational experience, world economic development and political factors determined, however, important changes in the real nuclear evolution.

Power reactor systems are broadly classified according to neutron energy into thermal (low neutron energy) and fast (high neutron energy) reactors. They are further classified according to the main elements in the reactor core, namely the fuel used (including its degree of enrichment in the isotope ^{235}U), the coolant and the moderator. Table 4.I contains a list of the main types of power reactor systems and their classification.

The types of power reactor systems[3] have been grouped into the following three main categories:

(a) Reactor types proven and commercially available for export;
(b) Other fully developed reactor types;
(c) Advanced and partially developed reactor types.

The first category includes three types of power reactor systems:

- PWR (pressurized light-water-moderated and -cooled reactors)
- BWR (boiling light-water-moderated and -cooled reactors)
- PHWR (pressurized heavy-water-moderated and -cooled reactors).

All of these have reached a level of technical and industrial development that allows them to be considered as proven and mature systems for use in large-scale commercial power plants.

The types of power reactor systems included in the second category are:

- GCR (gas-cooled, graphite-moderated reactors)
- AGR (advanced gas-cooled, graphite-moderated reactors)
- LWGR (light-water-cooled, graphite-moderated reactors).

[3] The list presented is confined to those types which have been developed and used in large-scale nuclear power plants, the design and technology of which have been successfully demonstrated and which have potential for further development and use in industrial commercial plants in the foreseeable future.

TABLE 4.I. CLASSIFICATION OF POWER REACTOR TYPES

Reactor type	Symbol	Neutron energy	Fuel: Fissile concentration	Fuel: Form	Coolant		Moderator
Pressurized light-water moderated and cooled	PWR	Thermal	Slightly enriched	UO_2	Water	Light water	Light water
Boiling light-water moderated and cooled	BWR	Thermal	Slightly enriched	UO_2	Water	Light water	Light water
Pressurized heavy-water moderated and cooled	PHWR	Thermal	Natural	UO_2	Water	Heavy water	Heavy water
Heavy-water moderated, boiling light-water cooled	HWLWR	Thermal	Natural	UO_2	Water	Light water	Heavy water
Steam-generating heavy water	SGHWR	Thermal	Slightly enriched	UO_2	Water	Light water	Heavy water
Light-water cooled, graphite moderated	LWGR	Thermal	Slightly enriched	U-metal or UO_2	Water	Light water	Graphite
Gas-cooled, graphite moderated	GCR	Thermal	Natural	U-metal	Gas	Carbon dioxide	Graphite
Advanced gas-cooled graphite moderated	AGR	Thermal	Slightly enriched	UO_2	Gas	Carbon dioxide	Graphite
High-temperature gas-cooled, graphite moderated	HTGR	Thermal	Highly enriched	$UO_2 + ThC_2$	Gas	Helium	Graphite
Heavy-water moderated, gas-cooled	HWGCR	Thermal	Natural	U-metal or UO_2	Gas	Carbon dioxide	Heavy water
Fast breeder	FBR	Fast	Highly enriched	$(U+Pu)O_2$ $(U+Pu)C$	Liquid metal	Liquid sodium	None

TABLE 4.II. NUCLEAR POWER REACTORS IN OPERATION OR UNDER CONSTRUCTION AT THE END OF 1983 [4.3]

Country	In operation		Under construction		Electricity supplied by nuclear power reactors in 1983	
	No. of units	Total MW(e)	No. of units	Total MW(e)	TW·h(e)	% of total
Argentina	2	935	1	692	2.4	(5)
Belgium	6	3 473	2	2 012	22.8	45.7
Brazil	1	626	1	1 245	0.7	
Bulgaria	4	1 632	2	1 906	12.3	32.3
Canada	15	8 303	8	5 925	46.3	12.9
China, P.R.			1	300		
Cuba			2	816		
Czechoslovakia	2	762	9	4 354	5.7	8.0
Finland	4	2 206			16.7	41.5
France	36	26 903	25	29 200	136.9	48.3
German Dem. Rep.	5	1 694			(11)	(12)
Germany, Fed. Rep.	16	11 110	11	11 908	62.4	17.8
Hungary	1	408	3	1 224	(2)	(10)
India	5	1 030	5	1 100		
Italy	3	1 232	3	1 999	5.6	3.2
Japan	28	19 023	10	10 022	106.5	(20)
Korea, Republic of	3	1 789	6	5 474	9.0	18.4
Mexico			2	1 308		
Netherlands	2	501			3.4	5.9
Pakistan	1	125			0.9	
Philippines			1	621		
Poland			2	880		
Romania			2	1 320		
South Africa			2	1 842		
Spain	6	3 760	9	8 369	10.2	9.1
Sweden	10	7 355	2	2 100	39.1	36.9
Switzerland	4	1 940	1	942	14.8	29.3
Taiwan, China	4	3 110	2	1 814	(18)	(36)
United Kingdom	35	8 304	7	4 252	43.9	17.0
USA	80	63 315	49	54 228	292.0	13.0
USSR	43	20 671	41	38 001	(113)	(8)
Yugoslavia	1	632			3.7	(6)
Total	317	190 839	209	193 854	(1000)	(12)

Source: IAEA Power Reactor Information System (PRIS).
Note: Values in parentheses are IAEA estimates.

TABLE 4.III. TYPES AND NET ELECTRICAL POWER OF NUCLEAR REACTORS CONNECTED TO GRID AS OF 31 DECEMBER 1983 [13–22]

Country	PWR		BWR		GCR		AGR		PHWR		LWGR		HTGR		FBR		Other		Total	
	No	MW(e)	No	MW(e)	No	MW(e)	No	MW(e)	No	MW(e)	No	MW(e)	No	MW(e)	No	MW(e)	No	MW(e)	No	MW(e)
ARGNTINA									2	935									2	935
BELGIUM	6	3473																	6	3473
BRAZIL	1	626																	1	626
BULGARIA	4	1632																	4	1632
CANADA									15	8303									15	8303
CZCHSLVK	2	762																	2	762
FINLAND	2	890	2	1316															4	2206
FRANCE	28	24550			6	2050									1	233	1	70	36	26903
GRMN.DR	5	1694																	5	1694
GRMNY FR	7	6609	6	4419					1	52			1	13	1	17			16	11110
HUNGARY	1	408																	1	408
INDIA			2	396					3	634									5	1030
ITALY	1	242	1	840	1	150													3	1232
JAPAN	12	8350	14	10366	1	159											1	148	28	19023
KOREA RP	2	1161							1	628									3	1789

TABLE 4.III. (cont.)

NETHLNDS	1	450	1	51															2	501
PAKISTAN									1	125									1	125
SPAIN	4	2840	1	440	1	480													6	3760
SWEDEN	3	2630	7	4725															10	7355
SWITZRLD	3	1620	1	320															4	1940
TAIWAN			4	3110															4	3110
UK					26	4090	7	3880							1	242	1	92	35	8304
USA	52	43156	27	19829									1	330					80	63315
USSR	13	6209	1	50							26	13716			3	696			43	20671
YUGOSLAV	1	632																	1	632
Totals	148	107934	67	45862	35	6929	7	3880	23	10677	26	13716	2	343	6	1188	3	310	317	190839

Note 1. During 1983, 25 reactors (20943 MW(e)) were newly connected to the grid.

Note 2. In addition, 1 reactor was shut down during 1983:
- US-133 HUMBOLDT BAY, 63 MW(e) BWR

The GCR, also known as the 'Magnox' system in the UK, has been fully developed to maturity in the UK and in France. Reactors of this type have also been exported to Japan, Italy and Spain. However, power plants using this system are no longer being built, nor have they been available for export for more than a decade. Recently, however, there have been indications of interest in offering this system for export in the SMPR (small and medium power reactor) range.

The AGR has been fully developed in the UK as a successor to the GCR. A series of units using this system have been and are being built, but it has never been exported from the UK nor is it currently available for export. It has the important advantage that owing to the higher fuel element temperature, the steam cycle can be designed with the high pressure and temperature which are currently used in the classic advanced steam power stations and performing, therefore, at a much higher thermal efficiency than the other power reactors could reach.

The LWGR is also a fully developed system. It has been developed in the USSR, where a series of units of this type are in operation, under construction and planned. However, it has never been exported nor is it commercially available for export.

The main types of reactor systems which may be included in the third category are:

– FBR (fast breeder reactor)
– HTGR (high-temperature gas-cooled, graphite-moderated reactor)
– HWLWR (heavy-water-moderated, boiling light-water-cooled reactor)
– SGHWR (steam-generating heavy-water reactor)
– HWGCR (heavy-water-moderated, gas-cooled reactor)

The design and technology of all these power reactor systems have been successfully demonstrated for the generation of electricity. However, they are not considered as competitive alternative nuclear power plant systems in the current commercial market, nor are any of them being offered for export. The FBR in particular and the HTGR to a lesser extent are objects of substantial development efforts in several countries owing to their promising future potential. The HWLWR, SGHWR and HWGCR have been brought to the stage of industrial-scale prototype operation, but further development efforts have either been stopped or are being maintained at a low level.

The number and electric output of the various power reactor systems in operation and under construction (as of 1 January 1982) belonging to the above three categories are summarized in Table 4.II. Table 4.III shows the nuclear power reactors – types and net electrical power – connected to the grid as of 31 December 1983 [13.22].

4.1.3.2. Reactor types proven and commercially available for export

A short presentation of the power reactor systems belonging to this first category will follow; for more details see Refs [4.1, 4.3].

4.1.3.2.1. PWR – pressurized light-water-moderated and -cooled reactors

This reactor system was first conceived as a naval propulsion unit and has been successfully operated for submarine applications in the USA since 1954 when the first nuclear submarine Nautilus was launched. The system was subsequently developed for civilian power application and led to the construction of the first prototype nuclear power plant of Shippingport with a net electrical output of 60 MW.

The reactor core is contained in a pressure vessel in which light water is used as coolant and moderator, circulating through a closed primary circuit. The water circulated through the primary circuit passes into a heat exchanger where steam is produced in a secondary circuit and used to drive a steam turbine-generator set for the generation of electrical power.

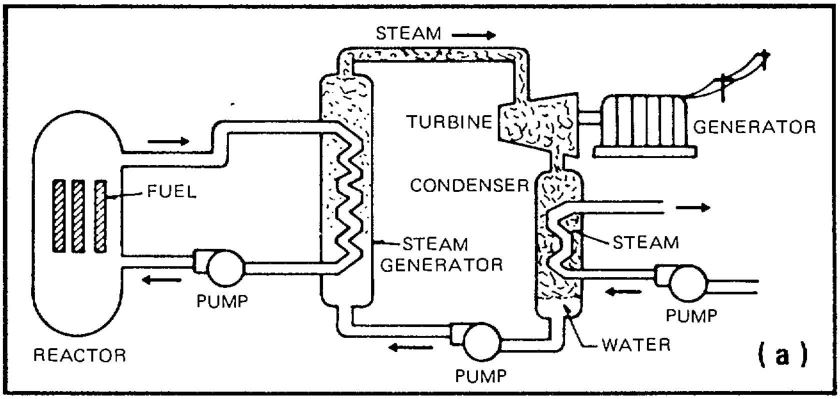
A simplified schematic representation of the system is shown in Fig.4.4(a). The operating pressure in the primary circuit is about 160 bar to prevent boiling. This requires a large and heavy reactor vessel weighing several hundred tons. Owing to the high pressure inside the primary coolant boundary, a strong containment is essential, since the potential release of energy in the event of a break in the pressure boundary would be very great. The steam inlet temperature is of the order of 280°C, and this requires turbine designs of larger size and lower efficiency than similar-size turbines in modern conventional plants.

The reactor is fuelled with slightly enriched uranium with an average enrichment between 2 to 3% of ^{235}U. Average discharge burnups of up to 33 MW·d/kg U have been obtained in operating reactors. Periodically (approximately once a year) the reactor has to be shut down for refuelling. The reactor has a strong negative temperature coefficient, which is one of its built-in safety features.

The PWR has been the most widely developed system among the proven types of reactors commercially available today. As of 31 December 1982, there were 137 PWRs in operation with a total capacity of about 97 700 MW(e) in 19 countries. There were also 139 PWR units with a total installed capacity of about 139 000 MW(e) under construction in 16 countries.

The operating experience with PWRs is extensive and it is certainly the most abundant of all available reactor systems. In operation, these plants are considered as reliable as fossil-fuelled thermal stations.

The initial unit capacity range of 200 to 300 MW(e) in plants designed and operated in the sixties has evolved to the range of 1200 to 1300 MW(e) for plants of current design.


STEAM
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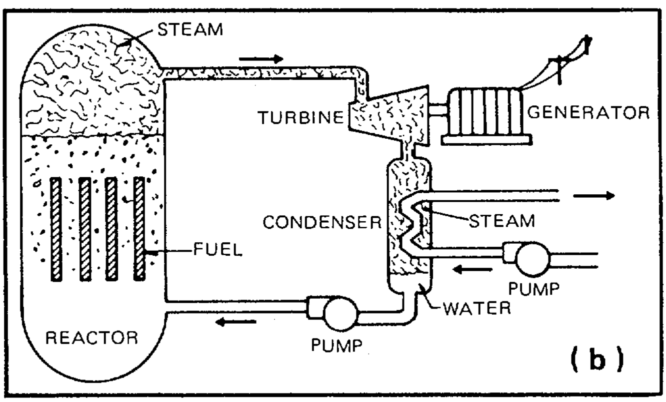
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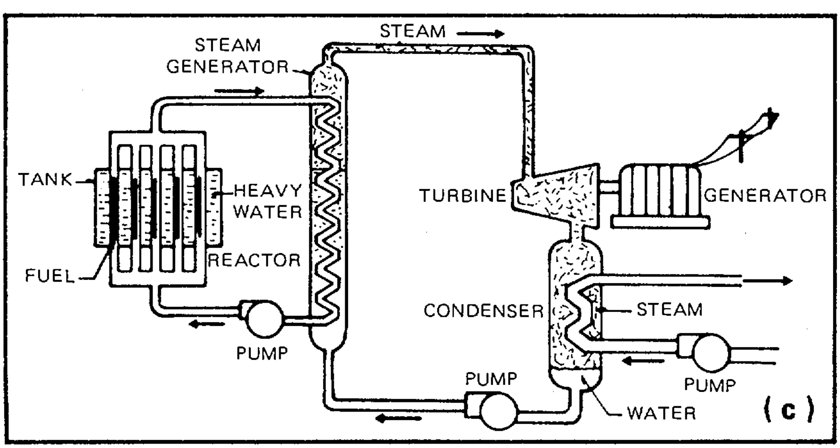
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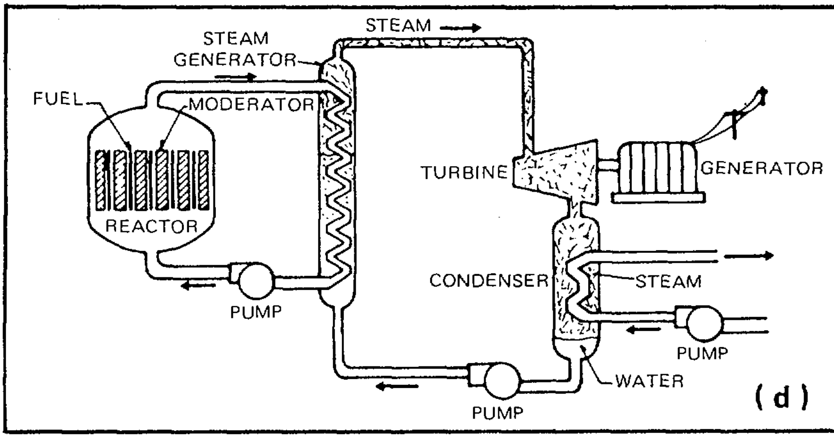
(c)



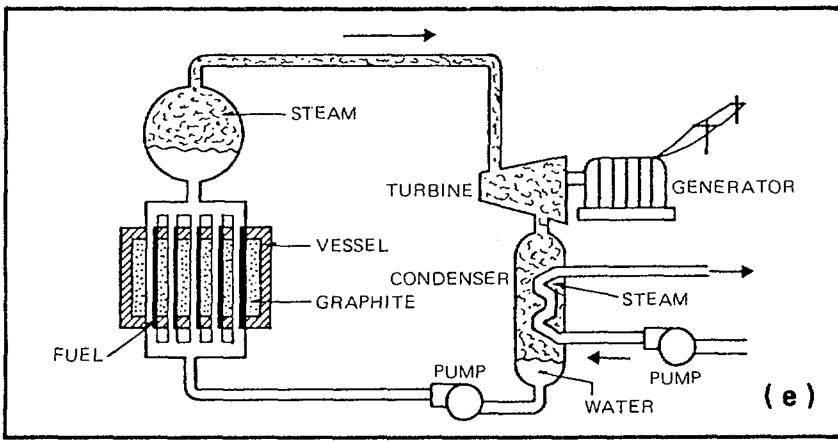


FIG.4.4. Schematic diagrams of power reactor types: (a) typical pressurized-water reactor (PWR); (b) typical boiling-water reactor (BWR); (c) typical heavy-water reactor (HWR); (d) typical gas-cooled reactor (GCR); (e) typical light-water graphite reactor (LGWR).

Regarding the export market, PWR plants have been exported and are available for export from France, the Federal Republic of Germany, the USA and USSR. The size range is 600 to 1300 MW(e), except in the case of the USSR, which exports the 420 MW(e) reactor (usually twin units).

4.1.3.2.2. BWR – boiling light-water-moderated and -cooled reactors

The development of the BWR was originally motivated by the desire to reduce costs and to avoid technological difficulties by eliminating the heat exchangers used in the PWR design. This led to the development and construction of the Dresden 1 BWR plant in 1960 with an electrical capacity of 200 MW(e).

The BWR direct-cycle system has many similarities to the PWR system, but differs from it in one important respect; it passes the steam directly from the reactor pressure vessel to the turbine without the use of an intermediate heat exchanger. The system is schematically represented in Fig.4.4(b). Since boiling is allowed in the system, the operating pressure inside the pressure vessel is much lower than for a PWR system (of the order of 70 bar).

Steam temperature, pressure and moisture conditions at the inlet to the turbine are similar to those in the PWR system and also a special turbine design is required. However, the thermal efficiency is somewhat higher than in the PWR system because steam passes directly to the turbine without temperature reduction in a heat exchanger. A significant difference arises from the fact that steam is carried directly from the reactor to the turbine and hence carries with it radioactivity. This radioactivity is primarily nitrogen-16, a very short-lived isotope (half-life 7 seconds), so that the radioactivity of the steam system exists only during power generation. Experience has demonstrated that shutdown maintenance of BWR turbine, condenser and feedwater components can be performed without excessive radiation exposures. Deposits of radioactive material will, of course, be formed in the turbine, making overhaul and maintenance more difficult. These difficulties will be increased if fuel element failures occur, releasing fission products into the coolant.

The reactor is fuelled with slightly enriched uranium. The average enrichment for the initial core is in the range of 1.6 to 2.2% ^{235}U. The reload fuel has slightly higher enrichment, with an average in the range of 2.4 to 2.8% ^{235}U. Average discharge burnups of over 30 MW·d/kg U have been achieved in operating plants. The reactor has to be shut down for refuelling.

An important feature of the BWR design is that, in addition to a negative temperature coefficient, the reactor has a negative void coefficient due to the internal boiling.

The BWR is the second most widely developed reactor system after the PWR. As of the end of 1982, there were 66 BWR power reactors in operation in 12 countries with a total capacity of 44 300 MW(e). There were also 38 units under construction in eight countries (seven of them have BWR plants in operation) with a total capacity of about 38 800 MW(e).

The countries most heavily engaged in BWR technology are the USA, Japan and Sweden. About 75% of all BWR plants in operation or under construction are in these three countries (50% in the USA alone). BWRs have been exported by the USA, Sweden and the Federal Republic of Germany.

In general, performance of the BWR plants has been satisfactory and similar load factors as for the PWR (about 70%) may be assumed for planning and economic studies. Technical and economic comparisons between the

PWR and BWR systems have shown that the differences between the two systems are marginal.

4.1.3.2.3. PHWR – pressurized heavy-water-moderated and -cooled reactors

The use of natural uranium as a fuel requires moderators with low neutron absorption characteristics. Graphite and heavy water (D_2O) are such materials. The development of PHWRs started approximately at the same time as development of the PWR, BWR and GCR began, but proceeded at a slower rate. The first PHWR prototype, NPD (22 MW(e)) was put into operation by Canada in 1962. With a somewhat different design, the prototype MZFR (52 MW(e)) was completed by the Federal Republic of Germany in 1966. Both designs were further developed by these countries and constitute today the two available versions of the PHWR. The Canadian version is also known as CANDU (CANada-Deuterium-Uranium), while the German version is often called the 'Atucha' type (the first commercial power plant of this design was installed in Atucha, Argentina).

The principal difference between the two versions of PHWR is the reactor design; pressure tubes in the CANDU and pressure vessel in the German version.

Both versions are fuelled with natural uranium in the form of uranium oxide clad in zirconium alloy. Heavy water is used as moderator, and in a separate circuit as coolant. The coolant must, as in a PWR, be maintained at high pressure to prevent boiling. The steam generators for both versions are similar to the steam generators of the PWRs.

The fuel of the CANDU is loaded into horizontal zirconium pressure tubes, which pass through a large tank – known as the calandria – filled with heavy water as moderator. The use of pressure tubes in the reactor core allows the coolant system to be pressurized without the need for massive steel pressure vessels.

Like the PWRs, the Atucha-type PHWR uses a steel pressure vessel. The moderator and the coolant circulate in separate systems. The moderator is separated from the coolant by the moderator tank as well as by the coolant channels and is under the same pressure as the coolant, but it is kept at a lower temperature level in order to improve the neutron balance.

For both versions, refuelling and fuel shuffling are performed while the power plant is under full load, without affecting operation. The average discharge burnup achieved is up to 7.5 MW·d/kgU.

A schematic representation of the CANDU type is shown in Fig.4.4(c), the representation of the PWR is basically valid for the 'Atucha' type. The steam conditions for PHWR are 250°C and 42 bar, which is somewhat lower than for light-water reactors. Owing to the cost and tritium content of the heavy water, the design criteria are for minimum leakage and recuperation of any losses that might occur.

As of end 1982, 19 PHWR reactors were in operation in six countries with a total output of 8500 MW(e). In addition, there were 17 reactors under construction with a total capacity of 9800 MW(e) in four countries (three of them have PHWRs in operation). The performance of the PHWR plants has been very satisfactory. Similar load factors as for LWRs may be assumed for planning and economic studies (65%).

PHWRs have been exported and are available for export from Canada and the Federal Republic of Germany. Canada is actively pursuing domestically the CANDU line and has exported reactors of this type to India (which subsequently has developed its own design as well as the capability of constructing the CANDU) and to Pakistan, Argentina, the Republic of Korea and recently to Romania. In the Federal Republic of Germany, there has been no domestic development of PHWRs after the MZFR, but two reactors have been exported to Argentina, the first one in operation since 1974, the second one currently under construction.

4.1.3.3. Reactor types fully developed but commercially not available for export

Three reactor systems (GCR, AGR and LWGR) have been included in this group.

The GCR ('Magnox' system) has been developed in the United Kingdom and in France. The choice of graphite as moderator allows the use of natural uranium and a relatively simple fuel cycle.

In the United Kingdom, the first GCR power plant to go into operation was Calder Hall (4 × 50 MW(e)) in 1956. In France, G-2 at Marcoule (39 MW(e)) went into operation in 1959. These were followed in both countries by a series of commercial GCR power plants, comprising a total of 26 units (4400 MW(e)) in the United Kingdom and 6 units (2100 MW(e)) in France. In addition, the United Kingdom exported two 150 MW(e) GCRs (to Japan and Italy) and France a 480 MW(e) unit to Spain. The last units of this type were put into operation in 1972. In spite of the extensive use of this system during the early period of nuclear power development the GCR line was discontinued.

Figure 4.4(d) brings a schematic representation of the GCR. The reactor is fuelled by natural uranium metal, the coolant is carbon dioxide gas (CO_2). Heat is transferred through heat exchangers producing steam to drive a turbine-generator for electricity production. The steel reactor pressure vessel of the early models was changed to prestressed concrete pressure vessels in the later ones. Fuelling is performed on load, and the discharge burnup achieved is of the order of 3.5–4 MW·d/kg U. Performance of the plants has been very satisfactory.

The AGR was developed in the United Kingdom as the successor of the GCR. The use of slightly enriched uranium (in UO_2 form) permitted a higher power density and better steam conditions and led to a smaller size reactor while retaining the graphite moderator and CO_2 gas coolant. On-load refuelling has also been retained as well as prestressed concrete pressure vessels. The prototype was put into operation at Windscale in 1963 (32 MW(e)), and shut down in 1981. The prototype was followed by 14 units (seven twin-unit stations, 2 × 600 MW(e)) in operation or under construction, all of them in the United Kingdom, which is the only country using this system. A shift towards PWRs is expected in the United Kingdom; the AGR is not being offered for export at present.

The LWGR was developed by the USSR. Figure 4.4(e) brings a schematic diagram. The first nuclear power plant, APS-1, which was put into operation at Obminsk in 1954, had a reactor of this type producing 5 MW(e). It was followed by units of 100, 200, 1000, and 1500 MW(e). There are 21 units with a total capacity of about 9000 MW(e) in operation and 8 more with 9000 MW(e) under construction – all of them in the USSR. The LWGR is on-load fuelled with slightly enriched uranium (1.8%), graphite-moderated and light-water-cooled (boiling). There are plans to install further LWGR units in the USSR, but it is not being offered for export.

4.1.3.4. Advanced and partially developed nuclear reactor types

The best assessments made indicate that between 2000 and 2020 the five million tonnes reasonably assured and additionally estimated uranium resources will be committed by the then operating nuclear reactors for their lifetimes. Thus considerable interest is devoted to the design of advanced reactors to provide a better utilization of the uranium or to use the much larger thorium resources.

Substantial progress is reported on major advanced reactor programmes in nine countries (Canada, France, the Federal Republic of Germany, Japan, India, Italy, USSR, UK, USA). These advanced programmes include the operation of test, demonstration and commercial prototype fast breeder reactors, development and demonstration of thermal reactors with high conversion ratios, and the closing of the fuel cycle for these plants, which is fundamental to the future ability of nuclear power to play a major role in helping to fulfil the world's long-term energy needs.

The introduction of fast breeders will provide this major step in the supply of world energy requirements, since the amount of energy which can be extracted from uranium resources by FBRs could be about 50 times or more than that obtained from present technology thermal reactor systems. This is due to the particular characteristic of the FBRs whereby they are able to provide energy while, at the same time, producing (breeding) more fuel than they consume.

The design of a fast breeder reactor is based on a chain reaction sustained by the fast neutrons released in the fission process of ^{235}U or ^{239}Pu. The excess neutrons accompanying fission are not moderated nor are they absorbed in medium-energy capture processes, so they can be more effectively used to transform fertile material (^{238}U or ^{232}Th) to fissile material (^{239}Th or ^{233}U). The design of a fast breeder reactor aims at maximizing the rate of production of fissile material compatible with power production and safe operation.

At present, the development of FBR technology is based on reactor designs using liquid sodium as a coolant and plutonium as fuel (LMFBRs – liquid metal fast breeder reactors).

Since the early fifties, extensive research and development programmes have been carried out in many countries and basic technical problems adequately solved. An advanced stage of technology has been reached with eight large demonstration and commercial prototype-size reactors planned to operate during the 1980s.

Extensive breeder operating experience has been gained in a number of countries. Four large demonstration plants have been in operation and one even up to 600 MW(e) (BN-600 in the USSR). Several test reactors for developing fuel and components have been brought into operation recently (KNK, FFTF, JOYO). A major step toward FBR commercialization is the construction in France of the 1200 MW(e) Super-Phénix which is expected to achieve criticality in 1984 [4.8].

Important gains have been made in the performance and safety of fast breeder reactors. Safety research and test demonstrations in the USSR and in the UK have affirmed that, even with failure of the primary heat sink, natural circulation cooling of an FBR core (PFR Dounreay in the UK) prevents fuel damage. Tests have also shown that the negative temperature coefficient of reactivity can assure stable operation.

It is important that breeder-produced plutonium has been successfully and routinely recycled after irradiation in the PFR and in Phénix in dedicated prototype fuel cycle plants and that the breeder cycle thus has been closed at least on a pilot scale. Mixed-oxide fuels have been fabricated on a near-industrial scale. Reprocessing of FBR fuel on a developmental or demonstration basis is being or will be carried out during this decade in six countries (Japan, USSR, India, Federal Republic of Germany, France, UK).

Breeder power costs will be controlled almost entirely by the capital costs of the reactor plant and fuel cycle facilities. For the power plants being constructed, the capital cost is notably higher than for the present generation of thermal power reactor plants. Consequently, reduced plant costs and serial production of large units are design objectives in the USSR and in France to obtain economic viability.

Although there have been delays and uncertainties in FBR development in some countries due to political or financial reasons, in other countries there has been an increased investment in the development of advanced reactors and fuel cycles. The principal directions for the future will be towards commercialization through reduction of capital cost, increased operating experience in large size plants and the closing of the fuel cycle.

The HTGR is another advanced reactor system under development. The main interest in this system lies in the possibility of achieving very high temperature using helium gas as a coolant and hence high thermal efficiencies. This system provides the possibility of being used for electricity generation and for the production of process heat with temperature of up to 1000°C, which could be of special interest for the gasification or liquefaction of coal [4.9]. The HTGR could be considered as a follow-up of the GCR and the AGR systems.

Prototypes have been designed and built in the Federal Republic of Germany and in the USA. Interest in the system also led to a co-operative experimental project of the European Community known as the 'Dragon' reactor which was built and operated in the United Kingdom. A 330 MW(e) prototype (Fort St. Vrain) is in operation in the USA and a 300 MW(e) prototype is under construction in the Federal Republic of Germany.

Several reactor concepts using heavy water as moderator but cooled by other materials have been developed to the stage of industrial prototypes. The interest in these types originated from the desire to reduce the heavy-water inventory and the risk of heavy-water losses.

Prototypes using light-water cooling have been developed in the United Kingdom (SGHWR, 92 MW(e)), Canada (Gentilly-1, 250 MW(e)), Japan (Fugen, 150 MW(e)) and Italy (Girene, 35 MW(e) under construction). Prototypes with gas cooling were built by Czechoslovakia (A-1 Bohunice, 110 MW(e), shut down), the Federal Republic of Germany (KKN Niederaichbach, 100 MW(e), shut down) and France (EL-4, 70 MW(e), in operation).

The original expectations regarding the potential advantages of these concepts have only partly been fulfilled, while experience with the PHWRs has shown that heavy-water losses can be maintained within reasonable limits. Though technical feasibility has been demonstrated, development work on the heavy-water-moderated and light-water or gas-cooled systems has been practically discontinued.

4.1.3.5. Status and prospects of small and medium nuclear power reactors — SMPRs

The present generation of nuclear power plants has been developed to satisfy principally the needs of the largest market for these plants, which corresponds to the industrialized countries with electric grids that admit the introduction of large units in the size range of 600 MW(e) to 1300 MW(e).

Currently, SMPRs are being thought of as power reactors of the order of 100 to 400 MW(e) and, as a definition, "less than 600 MW(e)" has been in use for some years. Applying this definition, more than half the operating reactors in the world would qualify as SMPRs. However, it should be noted that at the time when most of these plants were designed and built, they were certainly not considered as SMPRs, and would only qualify as such by today's accepted definition of the term.

Many countries have electrical grids that could only admit SMPRs (using the current accepted definition of the term), and therefore, there is a considerable interest in having such units available for export. There is a potential market and there are potential suppliers. No doubt, the relatively small role of nuclear power in meeting the needs for electric power in developing countries could be increased considerably by the economical deployment of SMPRs. Many countries could consider the nuclear option earlier instead of relying primarily on fossil resources which in most cases they do not possess.

Against this background, the commercial availability of SMPRs for export has been a constant issue and has motivated several meetings, market surveys as well as development efforts by potential manufacturers [4.10, 4.11].

Currently SMPRs are being built in India, which developed its own standard 200 MW(e) PHWR based on the CANDU design, and in the countries which are supplied by the USSR with the 420 MW(e) "Novo Voronezh" (PWR) units – Bulgaria, Czechoslovakia, Cuba, German Democratic Republic, Hungary and Poland. Although units of this type and size are still being built in the USSR, new domestic commitments in this country are in the 1000 MW(e) range. Except for the above-mentioned plants, all nuclear units contracted for since the late 1960s have been in the 600 MW(e) to 1300 MW(e) range. There have been plans for the acquisition of SMPRs in some countries and even formal enquiries were held, but no projects have yet materialized. Table 4.IV contains a list of the current available SMPR designs. They include well proven designs such as the Novo Voronezh PWR, the Magnox or the Indian plant, as well as submarine-based concepts, such as the proposals by Technicatome of France [4.12] and Rolls Royce in the UK. More novel BWR [4.13] and recently HTGR concepts are based on existing nuclear power plant technology and components. They are reviews of earlier designs, updated and modified by including new technical developments and special features to enhance their attractiveness in the SMPR range. If firm requests for bids should appear, both are expected to be available within a reasonably short period. A recent reference [4.14] describes in detail the new BWR design in the Federal Republic of Germany.

Practically all the SMPR designs mentioned could be applied for dual-purpose plants (co-generation of electricity and heat) supplying heat for industrial processes, space heating, domestic warm water or water desalination plants. For district heating even a factory-built, road-transportable heating reactor (70 MW) has been proposed [4.15].

TABLE 4.IV. RECENT SMPR CONCEPTS [4.3]

Country	Manufacturer	Reactor type	Fuel type	Unit size (MW(e))
Canada	AECL	PHWR	nat.	300
France	TECHNICATOME	PWR	enr.	325
Germany, Fed. Rep.	KWU	BWR	enr.	312
Germany, Fed. Rep.	KWU	PHWR	nat.	300
Germany, Fed. Rep.	KWU	HTGR (modular)	enr.	70/module
Germany, Fed. Rep.	HRB	HTGR	enr.	500
India	Power Projects Division	PHWR	nat.	220
Sweden	ASEA-ATOM	BWR	enr.	300
USSR	ATOMENERGO EXPORT	PWR	enr.	440
UK	NNC	GCR	nat.	300
UK	Rolls Royce	PWR	enr.	320

The principal factors favouring SMPRs are:

– Possibility of integration into relatively small or weak electrical grids
– Smaller overall investment requirements
– Ease of transport of equipment and components
– Possibility of extensive shop fabrication leading to shorter construction time and easier QA (quality assurance) and QC (quality control)
– Somewhat fewer national industrial infrastructure requirements as a consequence of the possibility of extensive foreign shop fabrication
– Early introduction of nuclear power, which would permit the accumulation of national experience in preparation for large follow-up projects.

The principal factors against the use of SMPRs are:

– Relatively high costs per kW(e) and per kW·h (economies of scale)
– Similar governmental, organizational, regulatory, educational, training and manpower requirements as for large nuclear plants, which imply proportionally larger efforts
– Possible lack of provenness and demonstrated licensability, especially for first-of-a-kind design
– Relatively small potential world market for SMPRs, as compared with the market for large nuclear power plants.

No doubt, each country with an interest in SMPRs has evaluated and will evaluate the advantages and disadvantages of implementing such a project, taking into account the above-mentioned factors, together with others that may apply to its particular situation.

However, a breakthrough seems to be needed. This might happen if a technically and economically very attractive design appeared on the market. It could also happen if several potential customers got together. A substantial firm demand for SMPRs would constitute an incentive for major development efforts by the potential manufacturers and would permit the distribution of the development costs among several projects. A third possibility for a breakthrough would be if a market for SMPRs would develop in the industrialized countries.

Given the strong interest SMPRs present for developing countries, and the previously described difficulties in inducing manufacturers to invest more effort in their promotion, the IAEA is steadily continuing its co-ordinating efforts, which in this area started as early as in the late sixties.

4.2. Geothermal energy resources

The utilization of geothermal energy for scattered, limited balneological warm water needs has a long history. After the beginning of this century practical industrial applications were introduced in Italy and then in 1930 in Iceland. The development gained momentum in the 1950s and has been in a very active phase since the 1970s. The growing interest to develop geothermal energy as a substitute for petroleum has been the main driving force behind this trend. This was fortunately complemented by adequate technological progress and experience maturing at that time.

In spite of its advantages, geothermal energy has also disadvantages which strongly limit its area of utilization. Unlike fossil and nuclear fuels, geothermal energy cannot be transported long distances to market areas in its primary form; either the heat energy must be used at its source or, like hydro power, converted to electricity for transmission to load centres. Like oil and gas, however, geothermal development involves a substantial investment risk. The combined disadvantages of non-transportability and the need for risk capital are unique to geothermal energy [4.16].

Given the relatively limited practical experience compared to that with other, conventional primary energy resources and the active research still under way [4.17], geothermal energy could be considered as a newer resource and included as such for more detailed comments in this chapter. These will be, however, restricted to the less known phase of exploration and, by analogy to the previous subsection on nuclear energy, to the geothermal power generation cycles. For all other aspects the interested reader is referred to Ref. [4.18], which in 299 papers deals in detail with all phases of geothermal development, i.e. geology, hydrology and geothermal systems, geochemical and geophysical techniques in exploration, environmental factors and waste disposal, drilling technology, production technology, reservoir engineering, electricity production, space and process heating, other single and multi-purpose developments, economic and financial aspects and legal and institutional aspects.

4.2.1. Exploration for geothermal energy resources

Exploration for hydrothermal systems [4.19], both of low and high temperature, is carried out using geological, geophysical (electrical resistivity, thermal gradient, magnetic) and geochemical methods. Seismic methods are useful in sedimentary areas, while remote sensing methods have proved effective in volcanic areas.

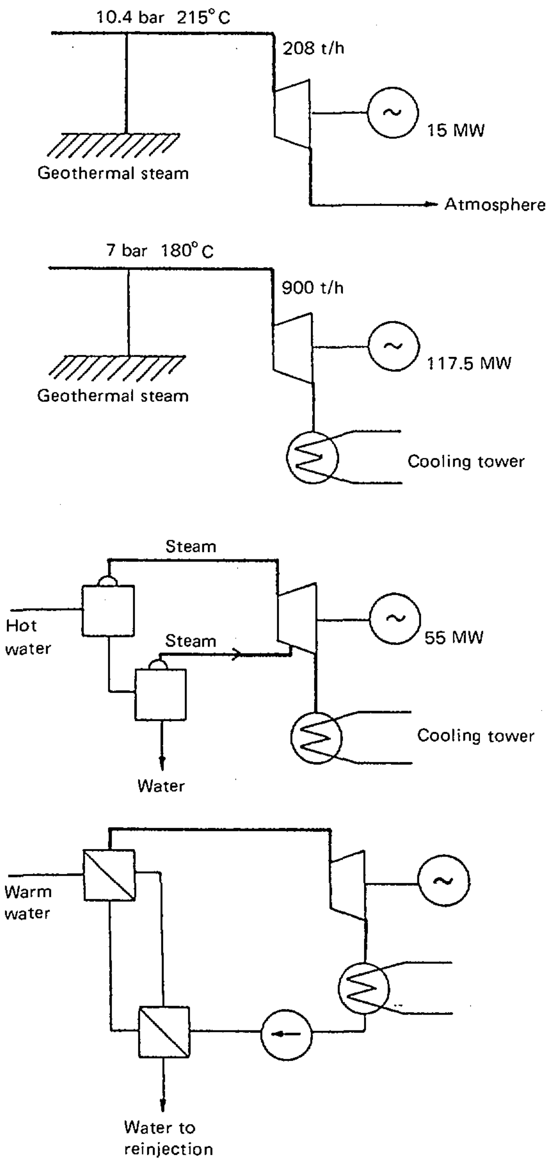
Exploration for a low-temperature geothermal reservoir not associated with vulcanism is very similar to oil exploration. The purpose is to find an underlying stratum formed of pervious rocks, filled with water and situated at such a depth that the geothermal gradient requires it to have a temperature above a specified threshold prescribed by technical and economic considerations.

Once the initial surface exploration has been completed, the inferred results must be proved by drilling. Only thus is it possible to ascertain temperature values, flow volume and composition of the fluids. The main risk of loss occurs at this point. If the measured parameters do not corroborate that exploitation of the reservoir is economic, exploration must be continued elsewhere. One drilling failure is never wholly useless since it adds to general knowledge of the subsoil. The financial risk it represents, on the other hand, can be prohibitive in a developing economy.

In sedimentary areas, geothermal exploration has often been preceded by petroleum exploration. These drill holes have thus permitted measurements of porosity, permeability, temperature and fluid composition for the area involved. However, while these data may exist, they may or may not be available to the geothermal community. When the law provides for information to be communicated to the government, this is very helpful in reducing the cost of hydrothermal exploration in sedimentary formations. The success ratio of geothermal drilling in that case is higher than without the information.

The success ratio in low-temperature volcanic hydrothermal areas varies greatly depending on geological structures and the number of boreholes that have been drilled.

Exploration technology for high-temperature hydrothermal systems is well developed, although new techniques are continually under investigation. The shallow nature of these fields usually results in a high surface heat flow, including several types of natural thermal manifestations such as geysers, hot springs, etc. In conjunction with or following the initial geological surveys,



(a) Geothermal superheated steam backpressure cycle in Italy

(b) Geothermal superheated steam condensing cycle for a future geothermal power station at Geysers (USA)

(c) Geothermal hot water condensing cycle

(d) Geothermal warm water condensing cycle with low-temperature boiling working fluid

FIG.4.5. Currently used geothermal power generation cycles.

early investigations will include geochemical surveys of the surface features and either then, or later, surface-heat-flow surveys.

Aerial infra-red surveys will provide useful information on high-temperature fields but require very close ground control. Satellite-mounted infra-red surveys are not at present capable of sufficiently high resolution to be of much use. Other geophysical techniques which have been used include resistivity, magnetic gravity and seismic surveying.

As for low-temperature geothermal reservoirs, on completion of all scientific work, the proof of the technical and economic viability of a field must be provided by drilling. Maximum drilling depths in high-temperature fields are currently of the order of 3000 m, although some investigation wells may be deeper. The drilling and well-completion technology to cope with the temperatures and depth encountered is available from the oil industry, although it is extremely important to note that oil-industry techniques cannot be applied indiscriminately to geothermal work.

Borehole temperatures and pressures can be obtained with mechanical-type instruments up to the maximum temperature of 365°C so far encountered. Commercially available electric logging is limited to temperatures of about 150°C.

4.2.2. Dry steam, mixed and hot water geothermal power generation cycle

According to the nature and temperature of the hydrothermal fluid, different geothermal power generation cycles come into application – also see Ref. [4.20]. Figure 4.5 shows the four basic possibilities.

Geothermal, superheated dry steam might be introduced directly in a steam turbine and expanded either to ambient pressure, freely blowing the expanded steam into the atmosphere (case (a) of Fig.4.5) or the expansion can be extended to the lower pressure obtainable in a condenser depending on the temperature of the available cooling water (river or cooling tower) (case (b)). In the first case, evidely less electric power can be obtained per tonne of steam introduced in the turbine. Both cycles correspond to actual installations: the first one to an early geothermal power station in operation in Italy, the second one to a recent plant erected at Geysers in the USA.

Case (c) of Fig.4.5 is applied for geothermal water of higher temperature (hot water). The hot water is introduced into an expander where it is expanded till it reaches a convenient (optimum selected) temperature, delivering by flashing steam which is fed to the steam turbine for electricity generation. The expanded water, now at lower temperature, is either disposed of or further expanded in a second stage, where by flashing it delivers steam of lower pressure which is introduced into the turbine at the corresponding expansion stage.

The latter cycle is the improved alternative currently applied in the more recent geothermal power plants in San Salvador and in a large series in the Philippines, for the 55 MW generation units. The advantages of the two-stage

TABLE 4.V. CUMULATIVE INSTALLED ELECTRIC GENERATION BASED ON GEOTHERMAL ENERGY

	Installed capacity (MW)				
Country	1980	1985	1990	1995	2000
Chile	–	–	15	15[a]	15[a]
Costa Rica	–	–	80	380	380[a]
El Salvador	95	150	260	425	535
Ethiopia	–	8	8	8	50
France	–	15	15[a]	15[a]	15[a]
Iceland	32	32	68	68[a]	68[a]
Indonesia	0.25	32	92	92[a]	92[a]
Italy	440	480	560	620	800
Japan	168	1000	3668	3668[a]	3668[a]
Kenya	–	30	30[a]	30[a]	30[a]
Mexico	150	620	1000	2000	4000
New Zealand	202	191	282	382	382[a]
Nicaragua	–	–	35	35	100
Philippines	446	558	1225	1225[a]	1225[a]
Turkey	0.5	0.5	100	100[a]	150
United States of America	923	1674	4374	4974	5824
Union of Soviet Socialist Republics	5	10	310	310[a]	310[a]
Totals	2462	4801	12122[a]	14347[a]	17644[a]

[a] Indicates that the figure is a minimum. Data based on information available end 1980.

flashing alternative are: about 10% higher electrical power output; i.e. a better utilization of the geothermal heat resource and a lower temperature of the used water to be disposed of.

Case (d) of the same figure represents the now usual solution applied for low-temperature geothermal water (warm water[4]). In this case, where a normal steam cycle would result – because of the very low flashing pressure (under atmospheric pressure) – in an extremely poor power output, an alternative

[4] Arbitrarily but possibly for more simplicity of language, 'hot' water describes water of more than 100°C temperature at normal ambient pressure, while 'warm' water refers to water below 100°C.

working fluid with low boiling temperature and accordingly higher power output is used. Naturally, the circuits of the heating and working carriers are here separated, the heat is transferred in a main surface heater while a second stage preheater for the working fluid further cools down the heat-spending geothermal water, before this is disposed of, for example by reinjection into the geothermal reservoir.

4.2.3. Range of utilization of geothermal energy

The first three previously described geothermal energy carriers, dry steam, hot and warm water, are technically and economically fully developed and commercially viable.

The range of utilization of low-temperature geothermal carriers normally encompasses heating processes between 20 and 70°C such as fish farming and cattle breeding, floor and swimming pool heating, between 80 and 120°C space heating and plant drying and in general warm water delivery for domestic, commercial and industrial purposes [4.21]. Via binary heat cycles, they can contribute to exclusive electricity generation or be combined in heat co-generation schemes.

High-temperature geothermal energy carriers, dry steam or hot water can be used for process steam supply, water desalination and/or electricity production in exclusive or co-generation plants.

In addition, geothermal carriers can be used for space cooling and refrigeration as well as for recovery of valuable chemical compounds and minerals, provided they contain them in economic conditions.

As regards possible and probable world-wide development of electricity generation from geothermal energy, Table 4.V displays an alternative evolution of the cumulative installed capacity to the year 2000 [4.19].

4.3. Solar energy

This subsection deals only with direct solar energy, the indirect forms, i.e. hydraulic, wave, OTEC and wind energy, having been commented upon in detail in chapter 3, both as regards their potential and characteristics as well as the main technological features and options involved.

Although the amount of solar energy available on the surface of the earth is very large, solar radiation as an energy resource has peculiar properties which have to be considered when applying it to meet specific needs. These properties are the following:

(1) Solar energy at the earth's surface has a very low density. It has to be collected and possibly concentrated in order to be technically usable and economically applicable. Therefore, in contrast to other energy carriers, solar energy technology involves, in general, equipment of larger dimensions.

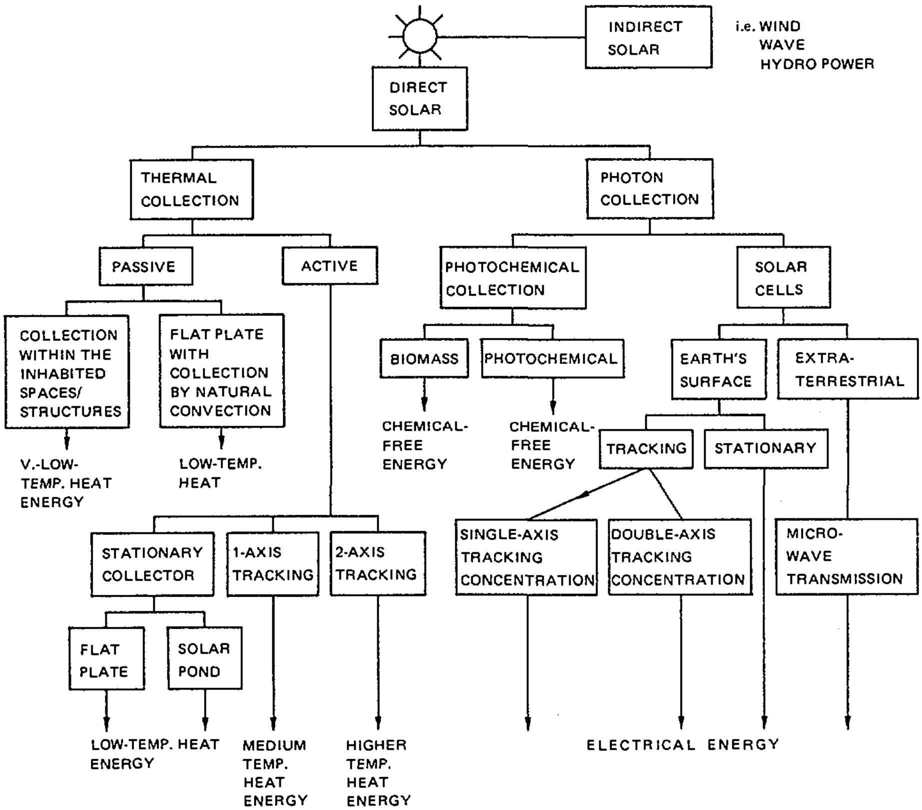


FIG.4.6. Direct solar energy collection and utilization options [*3.67*].

(2) Another difference consists in the fact that because of physical and technical limitations, the efficiencies in the collection and utilization of solar energy are substantially lower than for other energy resources. Although sufficient solar energy is usually available, the higher input leads to higher costs.

(3) Since the intensity of solar energy varies during the day and the year, proper storage often becomes necessary in the conversion/utilization cycle.

Direct solar energy collection and possible concentration options are illustrated in Fig.4.6 [3.67]. The two basic options, thermal and photon collection, offer different lines of development which can be followed in the tree-diagram down to the end-use energy carriers: low-, medium- and higher-temperature heat and electrical energy.

The type and level of the technology involved depend on the selected option. New techniques for thermal collection and concentration are solar pond technology, different constructions of collectors, and their sun tracking systems – one-axis and two-axis tracking – etc. Photovoltaic progress deserves special attention as the way to obtain electricity by photon collection from direct solar energy.

Solar energy technology is progressing at such a rapid pace that it is hardly possible to write about the present status without the risk that after a short time the overall image will be substantially obsolete. However, the speed of implementation of these new techniques is much lower, since for many reasons other than pure technique, the level of interest in solar energy among large groups of consumers is frustratingly low.

Nevertheless, Fig.4.6 and Table 4.VI provide an adequate background against which any progress or expectation may be validly projected and compared.

Specifically, the following areas of interest which deserve active attention.

4.3.1. Utilization of direct solar energy for heating and cooling purposes

As illustrated in Fig.4.6, direct thermal collection of solar energy can be passive or active.

Passive collection is the simplest and hence usually the most cost-effective way of gathering solar energy, and many of the techniques have been used for centuries; in new buildings of good design the solar contribution may cover 30–60% of the space heating load.

There are basically two approaches to the increasingly favoured passive utilization of solar radiation: the one preferring 'solar houses' or 'living greenhouses' i.e. buildings with very large glass surfaces which give the living space an artificial ambience and the other giving preference to 'low-energy homes' which, using especially strong insulation, realize a passive heat gain only through their windows. The first direction implies higher architectural requirements and a stronger change in living habits, the second represents a lighter line of approach.

Flat-plate collectors, which constitute by far the majority of stationary solar collectors, provide mainly active collection, as well as some which is passive.

Basically, a flat-plate collector comprises the following elements: transparent glass (or plastic) cover(s); an absorber; a working fluid insulation to ensure minimum heat loss from the absorber; and an enclosure – see Fig.4.7.

The solar radiation passes through the transparent glazing and is absorbed by the absorber plate below, which in turn transfers heat by convection and conduction to the working fluid – which could be water, air or some other special fluid.

TABLE 4.VI. AVAILABLE SOLAR TECHNOLOGIES AND THEIR APPLICATION [3.67]

Application	Thermal passive (low technology)	Thermal stationary (intermediate technology)	Solar ponds (inter-mediate technology)	Tracking collectors: 1-axis (Low-to-intermediate technology)	Tracking collectors 2-axis (High technology)	Photovoltaics (terrestrial) (High technology)	Satellite power systems (High technology)
Space heating: agriculture/building	X	X	X	X			
Water heating: agriculture/industry/building	X	X	X	X			
Refrigeration: building/industry/agriculture		X	X	X	X	X	
Space cooling: building/industry/agriculture	X	X	X	X	X	X	
Cooking: building/agriculture		X		X	X		
Water pumping: building/industry/agriculture		X	X	X	X	X	
Water purification: building/industry/agriculture		X	X	X	X		
Greenhouses: building/agriculture	X	X	X				
Timber and crop drying: agriculture	X	X					
Power production (electrical): building/industry/agriculture			X	X	X	X	X
Power production (mechanical): building/industry/agriculture			X	X	X	X	
Industrial process heating: industry		X	X	X	X		

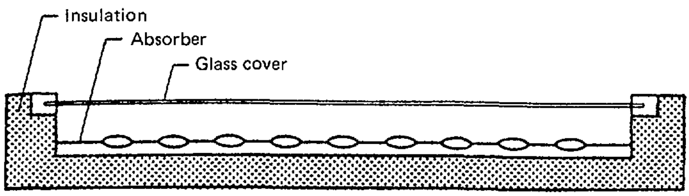


FIG.4.7. Flat plate solar collector [4.22].

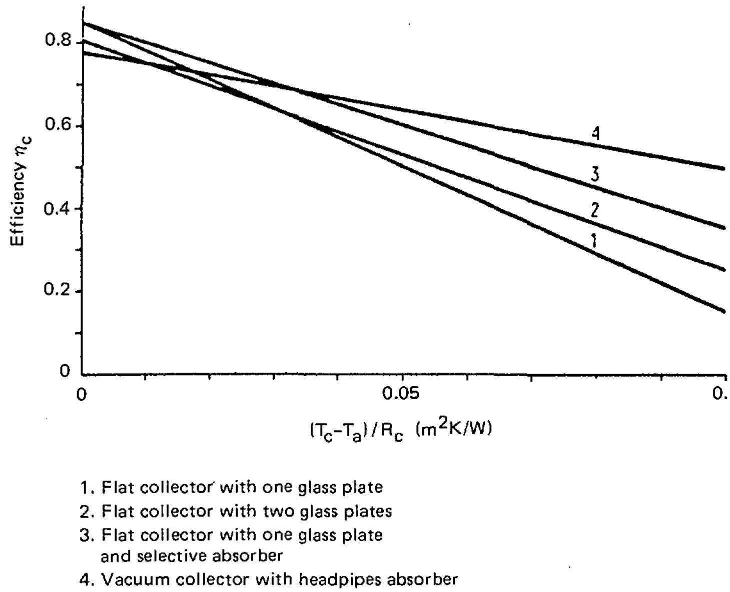


FIG.4.8. Efficiency curves of various solar collector types [4.22].

The efficiency of a solar collector is defined as

η_c = heat output/solar radiation input

and depends on its construction, the temperature difference $T_c - T_a$, where T_a is the ambient temperature, and on the intensity of the radiation R_c (W/m^2) on the collector's surface. η_c shows a direct dependence on $(T_c - T_a)/T_c$ for the different collector types as illustrated in Fig.4.8.

Figure 4.8 illustrates the efficiencies attainable by various types of construction, temperature differences and radiation intensity [4.22].

A wide variety of flat-plate collectors exist, differing from one another in their materials of manufacture, geometries, heat transfer properties, working temperatures and efficiencies, the proper choice of a unit being dependent on the economics, required reliability and specific application. Simple flat-plate collectors have been able to achieve temperatures of 40°–80°C with conversion efficiencies of between 40–60%. To achieve higher temperatures, the absorber is often covered with a special selective coating which, because of its physical properties, limits the emission of infra-red radiation from the absorber. For temperatures in excess of about 100°C, special constructions of stationary collectors such as the evacuated tube collectors have been designed and tested. Such collectors can operate effectively at temperatures of about 150°C.

Because flat-plate systems are mainly decentralized, the collector units can often be integrated unobtrusively into buildings. Also, experience shows that flat-plate collectors have been well accepted in those countries where they have been in use.

Constructed in a modular form (units 1–4 m^2), the flat-plate collectors can be coupled to make collector arrays of various sizes, depending on the application. However, there is a maximum size for collector arrays, owing to their thermal losses. It is, therefore, possible to design a heating facility for a block of houses, but it would be necessary to install several units for a whole agglomeration.

Solar ponds are water collectors, typically two or more metres deep. They are often stabilized in order to prevent convection – for instance, by the artificial creation of a salt gradient. The absence of convection means the upper layers of the water insulate the water layers below. The solar radiation absorbed in the water is converted into heat, and a slow build-up of temperature occurs in the depth of the pond, so that temperatures of around 90°C may be reached. The cost of constructing the pond per unit area is less than one-tenth the cost of constructing flat-plate collectors, so that the lowered collection efficiency – typically about 20% – is more than offset by the substantial reduction in capital costs.

The solar pond combines the advantages of cheap construction with very substantial thermal storage, so that energy can be extracted at a fairly constant rate, regardless of daily fluctuations in solar energy inputs.

The technology is now at an advanced stage of development, and techniques have evolved for dealing with the problems of vertical salt diffusion, dirt, and algal growth.

It is difficult to obtain fluid temperatures in excess of 150°C with the use of even the most sophisticated flat-plate collectors, because their surface thermal losses become appreciable. A possible, and practical, means of achieving higher temperatures is by the use of concentrating-type solar collectors. This necessarily implies that practically all of the diffuse component of solar radiation is lost to the system; attempts must be made to utilize as many of the direct solar beams as possible. Hence, the concentrator is normally equipped with a tracking device, which, in effect, ensures that it follows the sun continuously. The absorber in this case is located close to the geometrical focus of the concentrator, to ensure that it intercepts most of the incident direct radiation.

There are, in general, two types of concentrators: the linear-focusing concentrators and the point-focusing ones. The former are generally equipped with a single-axis tracking system, and the latter with a two-axis system. In the former case, the absorber is a tube on which the solar image shifts as a function of the sun's position, while in the latter, the absorber covers the area around the focal point. Theoretically, linear concentrators are limited by the visible diameter of the sun to a value of about 100, and point concentrators to 10 000. In practice, however, these figures cannot be attained – the linear concentrators being generally limited to a figure between 30 and 40, while point concentrators range from 500 to 2000.

The most familiar linear-focusing collector is the parabolic trough, which not only has a better yield than its competitors but is also cheaper. However, one notable undesirable technical problem is that the total mass of the collector must be displaced in order for it to track the sun. Under certain climatic conditions, this can pose maintenance problems and may require excessive energy input.

Two main classes of point-focusing concentrators can be distinguished, according to the kind of concentration: distributed or centralized. The distribution point-focusing concentrator is a variant of the parabolic dish often operated slightly out of focus, in order to avoid local over-heating on the receiver. The central receiver system (CRS) consists of two elements – a tower which holds the receiver, and heliostats which are distributed on the surrounding ground and oriented in such a way as to reflect the solar beams on the receiver. For the two classes of concentrators, the efficiency of direct solar beam conversion is usually of the order of 60–70%. Point-focusing systems are far more sophisticated and complex than linear-focusing systems and can only be justified when high temperatures (300°C to 1000°C) are to be reached.

The technical viability of linear-focusing concentrators has been established and a number of units are in the process of being put into commercial use after successful field trials. Yet, further development efforts are still necessary in order to improve the operating life and to solve all the interface and control problems that arise when the collectors are integrated into systems. Point-focusing concentrators, particularly of the CRS type, are still at the research and development stage, although various design models have been in operation for some time.

The scale of use is a determining factor. Distributed focus systems, whether linear- or point-focusing, are modular and, therefore, relatively more flexible. However, the size of the collector array is limited because of possible thermal problems. It appears that outputs up to 90 MW thermal are possible. Central receiver system plants cannot be built above a certain size, since the solar image reflected by the heliostats grows with their distance to the boiler. The optimum power range should be between 10 and 60 MW.

The main utilization areas of direct solar energy for heating and cooling purposes are:

4.3.1.1. Domestic and commercial uses

(1) Space heating where solar energy can supply economically 30–50% of the space heating load while operating combined with back-up heating systems based on non-renewable energy resources
(2) Warm water supply
(3) Space cooling and refrigeration, by passive and active systems
(4) Solar cooking
(5) Water purification and distillation.

However, independently of additional back-up systems, solar energy installations must include some kind of heat storage equipment, in order to compensate to some degree for the not inconsiderable variation of solar radiation input.

4.3.1.2. Industry and agriculture

A large part of the energy required by industry is in the form of heat and steam. That requirement could be met by solar energy by means of flat-plate collectors or solar ponds for temperatures below 100°C, and by tracking concentration collectors for higher temperatures. The technologies are similar to those which are used for heating water or space, but the collectors have to be more efficient and designed for higher temperatures (selective coatings, evacuated tube collectors, concentrating collectors). Four main classes of applications can be distinguished:

(1) Water heating or preheating, used in industry for cooling, washing, bleaching or anodizing
(2) Low-pressure steam at temperatures below 200°C, which represents a sizeable proportion of the thermal energy requirements of some industries. Such temperatures are easily attained by concentrators, and major developments are continuing in the area
(3) Hot air for drying and dehydration
(4) High-temperature direct process heat, which represents the bulk of the thermal energy used in some industries in the form of heat (petroleum refining, metal opening, cement glass). However, the desired temperatures correspond to the upper limit of what can be commercially provided by current solar technologies.

4.3.2. *Utilization of direct solar energy for chemical energy production*

Parallel to the thermal collection of energy from solar radiation, a second basic possibility is offered by photon collection, which as shown in Fig.4.6 can take place through photochemical processes or through solar cells.

The main photochemical collection is naturally performed by the photosynthetic process used by plants to convert sunlight into storable, non-renewable fuel resources. Work is still under way to improve understanding of the basic chemistry of the process, and especially to raise the efficiency, which for the general natural processes, averages, as mentioned, only about 0.1%. For example, laboratory experiments on certain algae have resulted in efficiencies in the range of 10%. Some experts have then calculated that such an energy harvest equivalent to 850 km^2 could operate a power plant with a base load of 1000 MW [4.23]. Given the simplicity of the technology, important progress could be expected in ten years or so, in this special biomass utilization alternative.

As far as man-performed photochemical energy conversion is concerned, the technology is not as well developed as photovoltaics, although photochemical conversion has many of the advantages of photovoltaic energy conversion, and in addition, the advantage that chemicals may be stored for later use. However, significant research is under way, especially for using solar radiation to produce hydrogen from water.

4.3.3. *Utilization of direct solar energy for electricity generation*

Electricity can be produced from solar energy in two different ways: by thermodynamics and photovoltaics. For very small amounts of power (to 5 kW) photocells are definitely most appropriate. Beyond that level the thermodynamic and photovoltaic conversion may be competitive. While it is possible that the situation will change, it must be noted that at present solar-generated electricity is often too costly. However, photocells are an ideal power source for remote areas and for equipment which only requires weak power: school televisions (20–30 W), Hertzian relays (1–100 W), air radio navigation systems (6–400 W), railroad signals (to 500 W), telephones in rural areas (0.5–50 W). The production of high levels of electricity (1 MW(e) and more) may be justified only when the electricity produced is integrated into a utility grid. The difficulty of storing energy for night use may, inter alia, impede the isolated use of solar plants. Fortunately, solar electricity works very well as a supplement to the traditional electricity sources: hydro power, fossil-fuel-fired and nuclear plants.

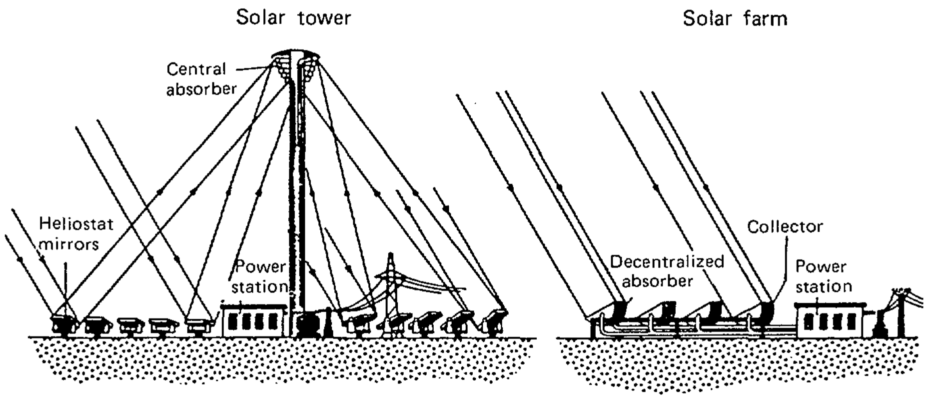


FIG.4.9. Basic concept of solar farm and solar tower electricity generating systems [*3.45*].

4.3.3.1. Electricity generation by thermodynamic conversion

The techniques of electricity production by thermodynamic conversion must be based on high-temperature collection of solar radiation in order to achieve high cycle efficiencies, and the availability of high, direct radiation levels is an essential requirement. Concentrating collectors (one-axis and two-axis tracking) and solar tower systems (central receiver system) are the most suitable for high-temperature collection.

Figure 4.9 displays the two basic alternatives for thermodynamic [3.45] electricity generation: the solar farm and the solar tower radiation collecting system. The solar farm, i.e. the distributed collector system (DCS), works with decentralized collectors, uses thermofluids for transporting the collected heat, reaches a concentration degree of 30–50 and temperatures of 100–300°C.

The solar tower, i.e. central receiver system (CRS), has a central absorber, the concentration of radiation is by optical transport, works between 500–1200°C and reaches a concentration degree of 400–1000.

In power levels up to 2 MW the distributed collector systems (DCS) seem to be the most promising. In power levels from 10 MW to 70 MW the central receiver system (CRS) seems the most suitable.

4.3.3.2. Electricity generation by photovoltaic cells

The basic element of a photovoltaic system is the photovoltaic cell or solar cell, which converts the incident solar radiation into direct electrical current. The solar cell operates on a principle called the photovoltaic (PV) effect, which produces a voltage in a nonhomogeneous semiconductor, such as silicon, by the absorption of light quanta or other electromagnetic radiation. The PV cell

TABLE 4.VII. PHOTOVOLTAIC CELL EFFICIENCY [4.24]

Cell type	Achieved laboratory efficiency (%)
STATE-OF-THE-ART CELLS	
Bulk polycrystalline silicon	16
Single-crystal silicon	18
Silicon ribbon (shaped sheet)	15.5
Thin-film cadmium sulphide	9.2
ADVANCED CELLS	
Thin-film polycrystalline silicon	9.75
Thin-film copper indium selenide/cadmium sulphide	9.4
Cadmium-zinc sulphide/copper sulphide	10.2
Amorphous silicon	5.5
Single-crystal gallium arsenide	23
Polycrystalline thin-film gallium arsenide	6.5

consists of a PN junction (or equivalent interface) which is formed between two electrically different semiconductor materials. When light is absorbed near such a junction, mobile electrons and holes (positive and negative charges) are produced. The movement of these charges causes an electric potential (voltage) to develop across the junction. When an external circuit is connected, electrical energy is produced.

There are numerous materials being investigated for use in PV cells. Accordingly the PV cell types are grouped into three categories depending on their stage of development. The first category includes cell types which are being manufactured and marketed. These include single crystal silicon wafer, and semicrystalline silicon. While silicon ribbon cells are still under development, recent laboratory progress indicates the possibility of starting mass production by the mid-eighties.

The advanced cell research types have been sufficiently demonstrated in laboratory prototypes to indicate promise for commercial products. Thin-film cadmium sulphide and semicrystalline silicon are prime candidates for rapid advancement. It is conceivable that advanced cells may be commercially available by 1995.

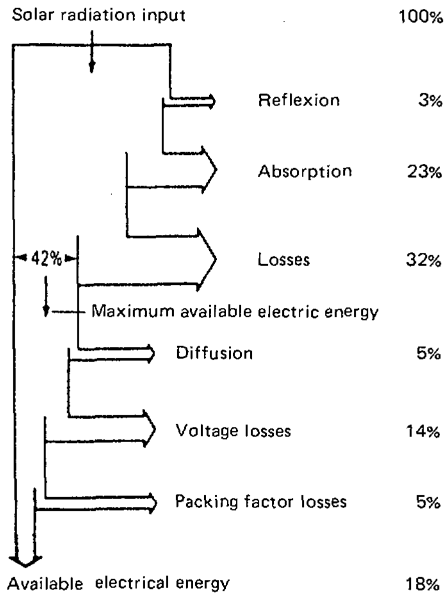


FIG.4.10. Energy balance of a single crystal silicon cell. Percentages refer to surfaces not in contact nor in shadow [4.25].

The last category entails research for new cells. Emerging materials are those whose intrinsic properties indicate potential for low cost, and greater than 10% efficiency in thin-film form. There is no indication whether or not any of these cells will be commercially available by 1995 [4.24]. Without modification or concentration of the incident spectrum, the maximum theoretical efficiency of a single-crystal silicon cell is around 25%. The achieved laboratory efficiencies of various types of cells are shown in Table 4.VII.

Figure 4.10 presents the energy balance of a single crystal silicon cell, illustrating the nature and magnitude of the intervening losses from the 100% radiation input to the electricity output [4.25].

The performance of PV cells varies with operating temperature. Gallium arsenide cells exhibit only small decreases in efficiency with increasing temperature, which is an advantage of this type of cell. By contrast, silicon solar cells are affected more severely by higher temperatures; they have very low efficiencies about 200°C, and are virtually unusable at 300°C. For temperatures less than 200°C the silicon cell efficiency is affected by 0.04 to 0.06 percentage points per °C. Cadmium sulphide cells have a much smaller temperature dependence below room temperature than other types of devices. In general, their change in efficiency with temperature is smaller than in silicon and gallium arsenide devices.

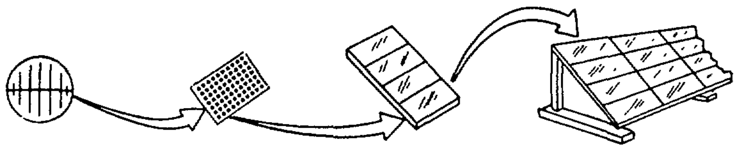


FIG.4.11. Definition of array elements [4.24].

The use of optical concentrators (lenses) can greatly increase the energy density on a PV device. When the light intensity on a PV device is increased at constant temperature the cell output increases about linearly over its design range. Sunlight can be concentrated by a factor of several hundred on silicon cells and by a factor of several thousand on gallium arsenide cells.

The electrical and physical characteristics of PV devices lead to designing PV arrays from basic building blocks. The smallest building block, the PV cell, is the basic device which generates electricity when illuminated. A number of PV cells are used in the manufacturing of a module. The module is the smallest environmentally protected assembly of PV cells. Several modules are usually factory assembled and wired into a panel, which is the basic unit that is field installed. A number of panels are normally installed to build an array. Figure 4.11 illustrates this series of building-blocks.

Individual PV cells are limited in size by manufacturing considerations. In general, they are a few square centimetres in area and produce a fraction of one watt per cell. The output voltage varies with cell type and illumination intensity, but is usually in the neighbourhood of 0.5 V. The basic PV cell is relatively fragile and must be environmentally protected.

The module provides structural integrity, environmental protection, electrical connections, and mechanical mounting provisions. The cells are placed in parallel and series combinations to achieve various electrical and reliability requirements. Most module designs vary from about 0.2 to 3 m^2 The number of parallel strings in a module varies from one to eight or more. Bypass diodes are normally used around each series block to provide an electrical path around failed strings.

Several modules are usually assembled into panels, which in turn are assembled to produce an array. The panels have a rating of 1.5 kW per panel, so a 750 kW array requires 500 panels. Photovoltaic systems in the 2–10 MW size range should be designed as individual array subfields [4.24].

All PV systems must include a power conditioner subsystem, to perform the following duties: accomplish basic DC to AC conversion, provide an interface to the PV array and to provide interfaces to the load and utility.

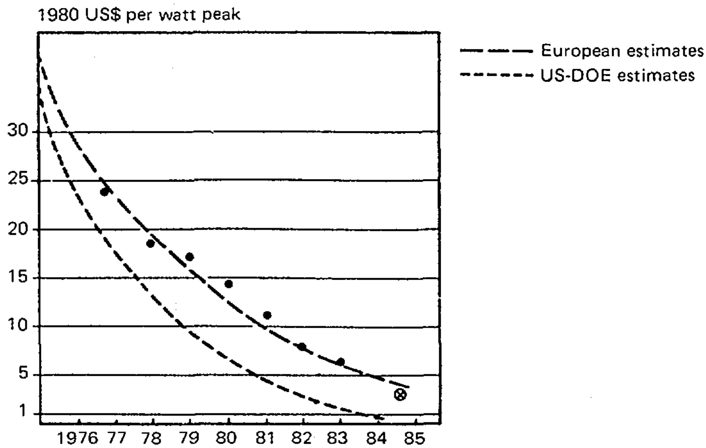


FIG.4.12. Photovoltaic cell costs [4.26].

The technical feasibility of photovoltaic cells has been proven, and silicon photocells have been operating for thousands of hours in space and on earth, sometimes under very rough conditions. Photovoltaic generation has the advantage of producing electricity from both the direct beams and the diffuse component of solar radiation, without any moving parts, at efficiencies ranging from 6–18% (single crystal silicon).

However, the main lasting problem remains the costs. Figure 4.12 illustrates the rapid decrease of costs (1980 US$ per watt peak) of photovoltaic modules since 1975 [4.26]. The upper curve represents the European estimates, confirmed by actual selling prices – black points – while the lower curve corresponds to the more optimistic estimates of the US Department of Energy. In 1983 wholesale prices were around 8, but also US $5–6/W peak. For 1985–87 estimates are around US $3/W peak and possibly 1982 US $2/W peak towards 1990. As an average, estimates converge at US $1.5–3 (1982) per watt peak.

So much for the cost of the cells. The 'balance of system' (BOS) cost, i.e. of all other necessary equipment (control devices, batteries, etc.) including erection costs, amounts to some 10 to 20 US$ per installed watt peak, i.e. double or triple the costs of the cells. Contrary to the cell costs, the BOS has a weaker decrease tendency.

However, in spite of all above hesitant considerations, both technological progress and important cost reductions are likely, and the time will come when terrestrial photovoltaic electricity generation will make an important contribution to electrical energy supply, possibly marking a new era of electrical development.

An even more challenging technical feature, but with very long-term perspective, is satellite power systems. In order to get rid of the constraints that meteorological conditions impose on solar energy availability and also in order to get access to solar radiation that is not attenuated by the atmosphere or the day/night cycle, placing solar plants in geostationary orbit has been proposed. The plants would transmit energy to the earth by means of microwave beams which would be collected by receiver stations on the ground and converted into electrical power. The concept has potential for broad application in the long term, but a large number of technical, environmental, social and economic problems and uncertainties still exist. Additional data are required before a decision can be made to develop the system. One of the more critical issues is the possible biological effect of microwaves.

Chapter 5

INTERMEDIATE ENERGY FORMS

Depending on the structure of the energy system, only a part of the primary energy resources directly reaches the end consumption stage. But even in this case, the majority are previously 'prepared' for more convenient usage, i.e. brought to a physically appropriate conversion form.

A brief review of the primary energy resources, as displayed in Fig. 1.1, may better illustrate the situation:

(1) Coal for end-use supply is always prepared, i.e. delivered in specific marketable sorts of quality and dimensions, including coal briquettes. With the exception of raw brown coal and lignite to be fired in power stations, coal is also prepared for all other conversion stages.
(2) Crude oil, as a primary energy resource, never reaches as such the end-use stage.
(3) Natural gas, very much used as an end-use energy carrier, is always prepared, in the sense that before distribution it is separated from other, mainly liquid, components.
(4) Oil shale, tar sands, nuclear energy (uranium and thorium ores) are always submitted to intermediate conversions, generally after some previous preparation.
(5) Geothermal energy can exceptionally reach unprepared the final consumers, for example as low enthalpy warm water carrier, when not containing noxious solid components.
(6) Of the renewable energy resources, direct solar radiation offers daylight and ambient heat without any preparation, as well as heat and mechanical energy. The latter is similarly supplied by hydro and wind power.
(7) A large proportion of biomass resources is burned without any previous preparation, but an increasing part goes through preparing and converting processes before the end consumption stage.

With the above exceptions, the rest of the primary energy resources, both renewable and non-renewable, are converted into one or more intermediate energy forms, before being supplied in appropriate end-use form to the final consumers.

The main groups of intermediate energy forms, able to supply end-use energy when adequately transported and distributed to the consumers, are the following:

(1) Solid, liquid and gaseous (intermediate) fuels
(2) Heat carriers
(3) Mechanical energy
(4) Electrical energy.

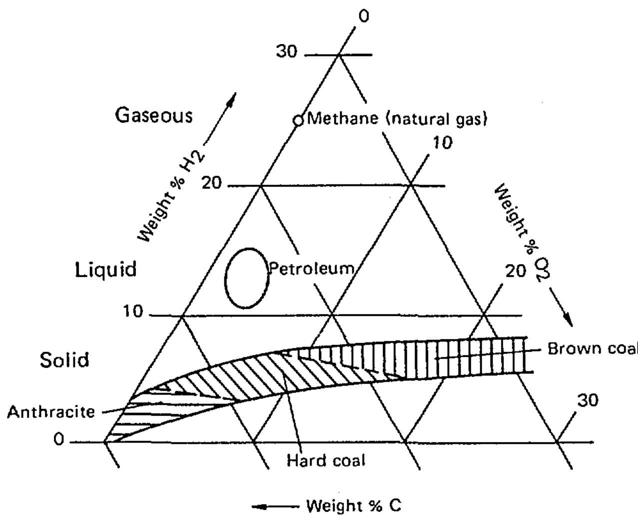


FIG. 5.1. The Bachl fuel triangle diagram [3.69].

The first three groups will be dealt with in this chapter; electrical energy has been reserved to a separate, following chapter.

5.1. Solid, liquid and gaseous fuels[5]

5.1.1. Overview and classification

As far as the generic category of fuels is concerned, all fuels, fossil or biomass, primary or intermediate, are characterized by their position in the so-called Bachl fuel triangle diagram, presented in Fig. 5.1. [3.69].

Depending on their % weight content of carbon, hydrogen and oxygen, the various fuels have specific physical and chemical properties and occupy specific areas in the triangle diagram, as indicated. A move from one aggregate form to another implies changes of the proportion of the three basic components and accordingly another position in the diagram. The latter results, therefore, as the best generic background against which all fuel changes and conversions may be contemplated, including the recently revitalized challenge of gaseous and liquid synfuels.

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[5] In order to simplify the text, the denomination "intermediate" will be further waived, once this character has been clearly established for the fuels dealt with here.

5.1.1.1. Solid fuels

The large majority of primary solid fuels do not enter intermediate conversion processes, the part supplied to end-use stages being only prepared, keeping its primary resource character.

Therefore, the only solid intermediate energy forms are coke, semi-coke and charcoal. The first two are products of coal gasification processes; the latter a biomass product.

5.1.1.2. Liquid fuels

This subsection will exhaustively deal with the predominant petroleum derivatives while the other liquid intermediate fuels, here only briefly mentioned, will be commented on in detail in section 5.1.3.

5.1.1.2.1. Petroleum derivatives

With the rare exception of when it is burned directly, the major part of crude oil is converted (or processed according to other opinions) into petroleum derivatives. The efficiency of modern petroleum refineries is, in general, around 90% with a peak performance of a few more percentage points by advanced energy husbandry.

Figure 5.2 displays graphically the basic products obtainable from the processing of crude oil in modern refineries, both by single thermal distillation as well as cracking processes [5.1]. Typical of refineries structure is a primary crude oil thermal distillation column and a series of downstream processing installations for improving the products' quality. Normally the products structure of the distillation phase depends on the natural composition of the crude oil processed. Changes can therefore be made in the output structure either by changing the crude oil input or by adding conversion installations in which the heavy components are cracked into lighter products such as gasoline and middle distillates.

For the conversion of vacuum distillate, thermal-, catalytic- and hydrocracking are used. The higher the output of light products, the higher are the processing costs. The technically elegant and very flexible hydro-cracking process, which allows an almost complete conversion of the heavy vacuum distillates, is also by far the most expensive [5.2].

The sharply increasing petroleum prices after 1973 both reduced total petroleum demand and also restructured it towards higher shares of light and middle refined products. Figure 5.3 illustrates both these effects in Japan for the period 1975–1981. In these six years, the gasoline component increased from 13.6 to 18.2% and kerosene including jet fuel from 11.1 to 13.6%. The share of heavy products, fuel oils Type B and C , dramatically fell from 43.8 to 34.7%. In the same period the import share of heavier crude oil increased from 6 to 16%.

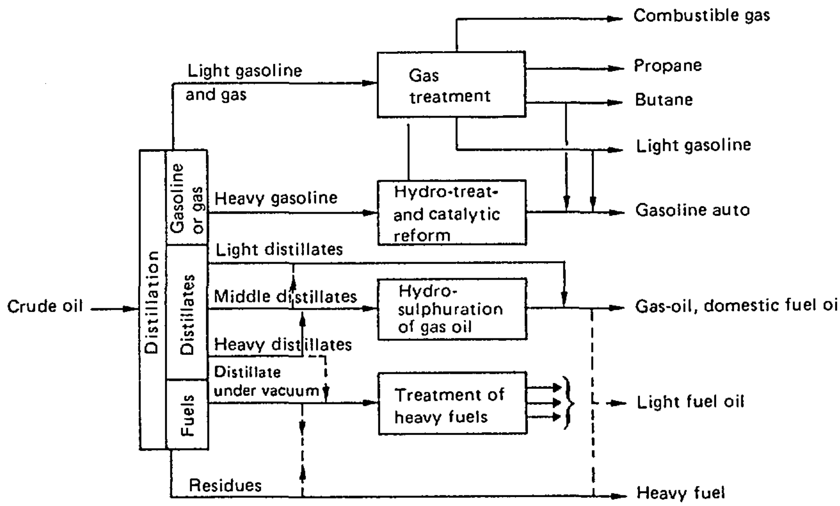


FIG. 5.2. Crude oil refining schema [5.1].

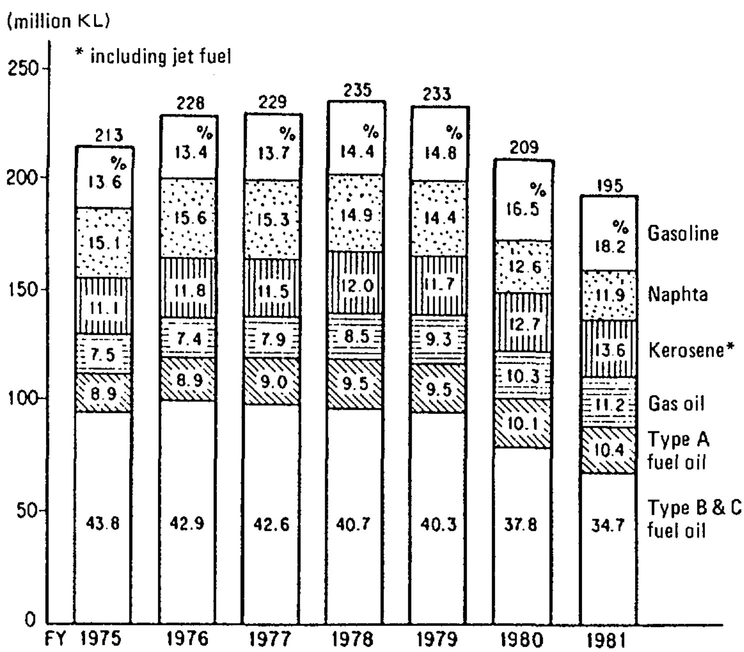


FIG. 5.3. Domestic demand for petroleum derivatives between FY 1975–1981 in Japan [5.2].

TABLE 5.I. DEMAND FOR PETROLEUM PRODUCTS IN THE OECD COUNTRIES IN EUROPE IN 1990 [5.3]

Countries	Light (%)	Medium (%)	Heavy (%)
France	41	36	23
Fed. Rep. Germany	33	53	14
Italy	22	34	44
United Kingdom	45	30	25
Netherlands	21	27	52
Other Europe	25	52	23
Total for OECD countries in Europe	30	42	28
Spain	29	45	26

Source: IEA, Refinery Flexibility in the OECD Area, Paris, 1981.

A similar, even stronger evolution is under way in Spain [5.4]. The share of light products increased from 18% in 1973 to 24% in 1981 and it is estimated that it will reach 29% in 1990. In contrast, the share of heavy products decreased from 57% in 1973 to 46% in 1981 and is expected to fall to 26% in 1990.

The described trend to increasing demand for lighter petroleum products exists also in the OECD European countries, although the individual levels are very different, the average share in 1990 is expected to reach 30% (Table V. [5.3]).

Given the shift in the demand to lighter petroleum products and a certain tendency of the petroleum-producing countries to conserve their reserves of light crude oil, the refining industry has to adapt to this evolution. In addition to the already mentioned long-term extension of existing refineries with effective downstream conversion installations, a series of efficient short-to-medium-range measures can help bridge the immediate difficulties. Reference [5.2] amply presents the related action in Japan, while Ref. [5.3] shows an interesting optimization analysis concerning the return on investment for modern conversion units.

5.1.1.2.2. Other liquid fuels

The other liquid fuels besides petroleum derivatives, encountered as intermediate energy forms are:

(1) Methanol or methyl alcohol, or wood alcohol as it is also called (CH_3, OH), can be thought of as two molecules of hydrogen gas made liquid by one molecule of carbon monoxide. It thus shares many of the virtues of pure hydrogen. It can be made from almost any other fuel – from natural gas, petroleum, coal, oil shale, wood, agricultural and urban wastes – presenting in this respect a remarkable flexibility.

Methanol is among the major basic chemical raw materials in use today and has, although only a fraction of methanol is presently used as fuel, a number of superior fuel qualities, specifically attractive for automotive and power generation uses.

(2) Ethanol or ethyl alcohol (C_2H_5OH), an organic material, has currently three main applications: as a potable alcoholic beverage, as an intermediate chemical and as a feedstock for the production of other chemical materials. Nowadays it plays an increasing role as a gasoline substitute. Ethanol can be produced either from hydrocarbon (petroleum, natural gas) products or from biomass.

Both ethanol and methanol can successfully serve as gasoline blends (in the new automotive fuel class of gasohol) and/or as complete gasoline substitutes.

(3) LPG, i.e. liquefied petroleum gases, are in fact gaseous fuels separated from petroleum processes, which enter the here-described fuel category, only temporarily liquefied for transport, distribution and storage before consumption.

(4) LNG, i.e. liquefied natural gas is in fact a gaseous fuel, temporarily liquefied for long-distance transport and storage, which regains its natural condition in the consumption areas.

Since the most challenging features of LNG are the preparation for and the transport itself, it will be further dealt with in chapter 7: Energy transport, storage and distribution.

5.1.1.3. Gaseous fuels

Depending on the primary energy resource processed and the nature and parameters of the gasification process itself, the intermediate gaseous fuels obtained arise differently and with different qualities.

Figure 5.4 illustrates the two basic coal gasification routes, in normal air or in an oxygen atmosphere, in both alternatives with addition of steam (water vapour) under ambient or a higher pressure [5.4]. In both alternatives the process is autothermally conducted, i.e. without external heat input.

The gas obtained in the air-fed process is a low-heat-content-gas – formerly called low BTU gas – used for industrial and power generation purposes.

In the oxygen-supplied gasification process, a medium-heat-content gas is produced, with a heating value around 12 000 kJ/m^3, which could be used for hydrogen production, ore reduction, methanol and liquid fuels as well as other chemical synthesis. Gasification under steam pressure leads to a gas of town gas quality for public distribution and industrie supply or to synthetic natural gas (SNG) of high heat content for supply instead of natural gas.

Traditional town gas, historically the first gaseous fuel distributed through a public gas network, is a mixture of low-heat-content gas with hydrogen, the latter simply obtained by blowing steam over an incandescent coke bed. The mixture standardized heating value is around 19 000 kJ/m^3. However, this variety of town gas is nowadays only met in old networks and when no other alternative supplies are available. Its main disadvantages are its toxicity (high CO content) and its very low production and distribution pressure.

Biogas is a mixture of gases containing principally methane and carbon dioxide which is obtained by the anaerobic fermentation of organic waste matter, usually animal dung but also at times including human waste and raw vegetable matter. Depending on its methane content its heating value varies between 20 000 and 25 000 kJ/m^3.

Hydrogen, as an intermediate energy carrier, has, in contrast with its long-known industrial uses, still to make its entry in the commercialized energy supply. It has a heating value around 12 600 kJ/m^3 and almost ideal burning conditions, since it completely burns into water vapour.

5.1.2. Gasification and liquefaction of coal

The gaseous and liquid fuels manufactured from coal and biomass are intermediate energy carriers, currently called synfuels, which stands for synthetic fuels.

Since synthetic oil and gas are manufactured forms of energy like electricity, they will require, if developed on a large scale, capital-intensive industries which will face many of the same financial, environmental, and regulatory problems as electric utilities [5.5].

In connection with Ref. [5.5], an interesting point of view is worth mentioning. The article regards shale-oil as a synfuel, i.e. an intermediate form of energy, manufactured from oil shale as a primary energy resource and including it as such in all further considerations. This could be a valid approach. However, should then enriched uranium or natural uranium when fuelling the reactor core not also be regarded as an intermediate form of energy manufactured from the primary energy resource, uranium ore?

5.1.2.1. Synfuels from coal

In order to better understand the present status and future potential development of coal as an important feedstock for gaseous and liquid fuels, it

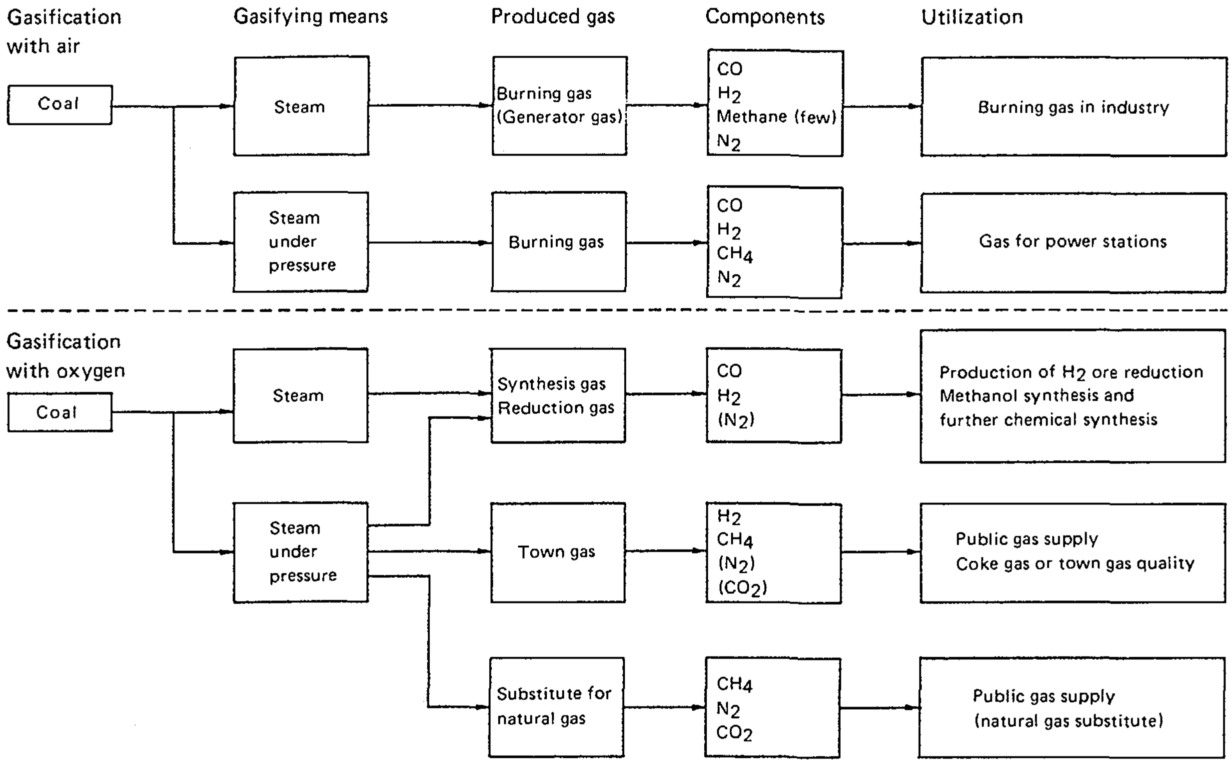


FIG. 5.4. Coal gasification with steam, products obtained, their composition and utilization areas (autothermal process) [5.4].

would be helpful to judge the issue in the much larger context of coal utilization for worldwide energy development and as a most important industrial raw material [5.6].

Figure 5.5 offers in this respect an overview on the various possible inputs of coal as an energy carrier and the conversion methods and coal products involved [3.2].

As far as conversion of coal to gaseous and liquid fuels is concerned, it is useful to consider coal as a hydrocarbon fuel which, compared with oil and natural gas, has a deficiency of hydrogen – see Fig. 5.1. Coal also suffers the disadvantage of being mixed with significant quantities of mineral matter. Processes for upgrading coal into clean liquid gaseous fuels must either introduce additional hydrogen (as in gasification or hydrogenation) or remove the hydrogen-rich species from the coal and leave a char residue (pyrolysis). The three basic coal conversion techniques are summarized in Fig. 5.6 and can conveniently be considered in terms of the way in which they alter the chemical structure of the coal.

The most destructive route is gasification. In all cases, coal is converted into a synthesis gas which, after purification, consists of a mixture of carbon monoxide and hydrogen. These are then made to recombine in the presence of a catalyst to produce the required fuel. Catalysts have been developed for the manufacture of methane (SNG – substitute natural gas), methanol and light oils, underlining the flexibility of this approach.

A less destructive route is the thermal decomposition (pyrolysis) of coal. By heating coal under controlled conditions, a range of gas and liquid fuels can be obtained. Since no additional hydrogen is provided to supplement that in the coal, a char residue remains which can take part in further processing (e.g. gasification or combustion). Several processes are under development with the objective of improving the yield of liquid or gaseous products. These include fluidized bed and entrained systems, and a process which has been pioneered by the National Coal Board in the United Kingdom, using gases under supercritical conditions as solvents for the volatile species in the coal.

Hydrogenation is the least destructive route, as hydrogen is induced to combine directly with the coal molecule. Most of the current processes involve dissolving the coal in a solvent such as anthracene oil at 400 to 500 degrees centigrade. This is then treated with hydrogen at high pressure and often in the presence of a catalyst. The mineral matter is removed by filtration at an appropriate stage and the solvent is separated and recycled, leaving a liquid hydrocarbon product suitable as a refinery feedstock.

Hybrid processes can also be considered. For example, gasification and pyrolysis can be carried out in the presence of hydrogen under high pressure to induce hydrogenation. Also, some gasification and hydrogenation processes resemble pyrolysis by rejecting a char residue.

After this general overview, gasification and liquefaction of coal, although sometimes combined, will be treated separately in more detail.

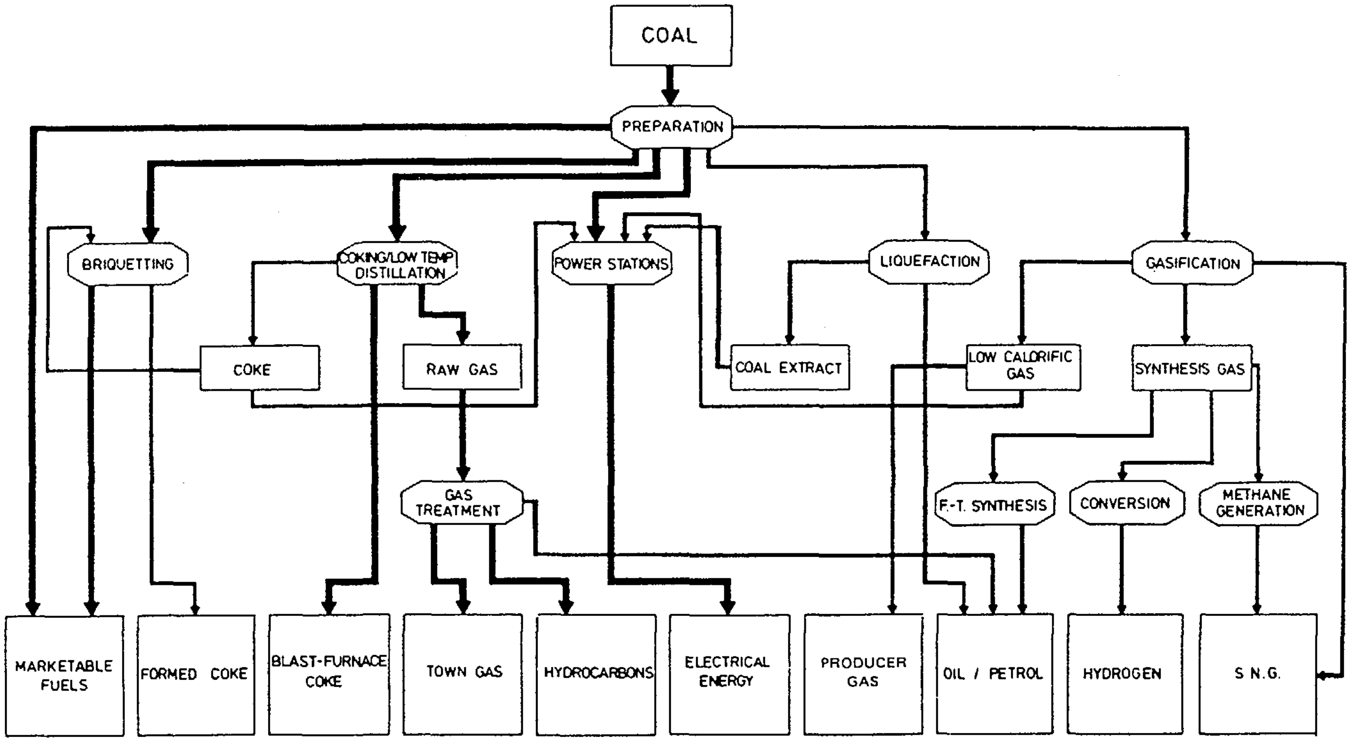


FIG. 5.5. The most important coal conversion methods and coal products [3.2].

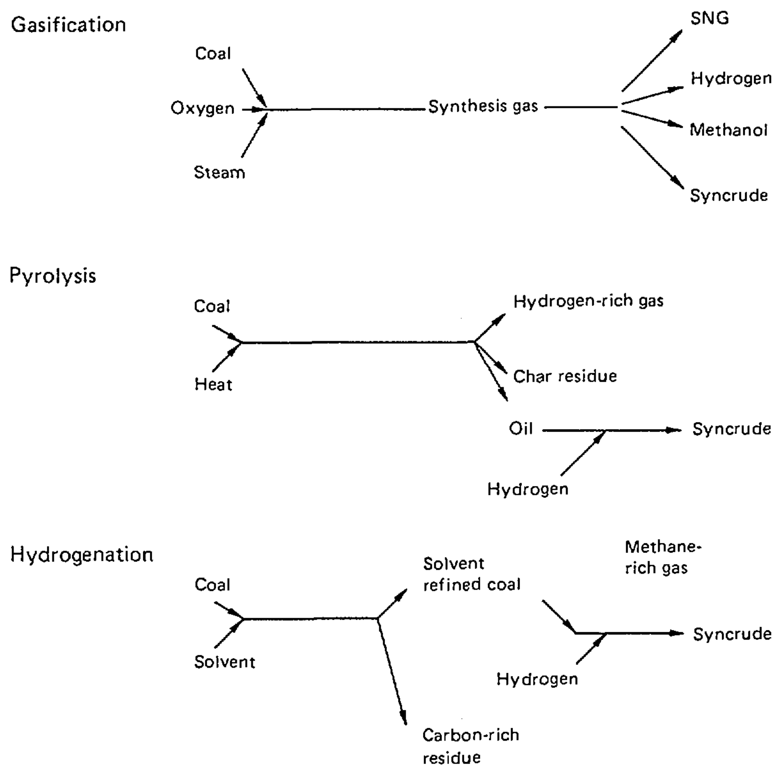


FIG. 5.6. Basic coal conversion processes [5.7].

5.1.2.1.1. Coal gasification

As already mentioned, coal gasification could pursue two basic goals:

(1) Production of low-heat-content gas to be used in chemical synthesis units or for electricity generation. As shown in Fig. 5.4 there are two basic processes available for this purpose:
- introducing air and steam (water vapour) in the gasifier and obtaining a gas with a heating value of some 6300 kJ/m^3, or
- introducing oxygen and steam (water vapour) and obtaining a gas with a heating value of some 14 700 kJ/m^3.

The recent installations are all of the latter type, the commercial plants using the Lurgi process.

(2) Production of a rich, high-heat-content gas with a heating value of some 37 000 kJ/m^3, substitutable for natural gas (SNG – substitute or synthetic natural gas). This means to carry out the synthesis of methane from coal.

The above described processes are realized according to following primary reaction sequence [5.6]:

Step 1: coal + steam $\longrightarrow$ $CO + H_2$

coal + oxygen $\longrightarrow$ CO_2

In this step the reaction of coal with water is highly endothermic (requires additional heat). In most of the present processes this extra heat is supplied by the reaction of part of the carbon with oxygen of the air (by burning part of the coal). A problem immediately results in that additional carbon dioxide is produced. In step 1, a combustible gaseous mixture of carbon monoxide, hydrogen and carbon dioxide is produced; this gas, called producer gas, is generally considered the cheapest form of coal-derived gas. If pure oxygen is used instead of air, synthesis gas or medium-heat-content gas results. Coal-derived low- and medium-heat-content gases could be utilized after cleaning, as mentioned, for industrial supply or electric power generation.

Step 2: $CO + H_2O \longrightarrow CO_2 + H_2$

In step 2 more water vapour is added and the mixture is shifted to yield more hydrogen. Before step 3, the removal of carbon dioxide and sulphur compounds of coal should be achieved.

Step 3: $CO + 3H_2 \longrightarrow CH_4$ (methane) + H_2O (steam)

In step 3 the methanation reaction requires a catalyst. The reaction is highly exothermic (it releases heat) and must be carried out at low temperatures and high pressures to get reasonable yields; these requirements complicate the process significantly.

The gasification route described above is considered the first generation of gasification processes or conventional gasification technology. Its three basic commercial processes – the Lurgi, the Wellmann-Galusha and the Koppers-Totzek gasifiers – are well proven and many such plants operate in Europe and one in South Africa. The commercial plants have no methanation compartment and produce gas with a heating value around 14 500 kJ/m^3. One reactor has a daily output of 600 000 m^3 by 700 t daily coal loading.

The second generation of gasification processes is more advanced, and operates with higher pressure – 40 to 70 bar – and in general in a fluidized bed. A third generation of gasification technology is expected, able substantially to improve the efficiency of coal gasification.

References [5.6, 5.7 and 3.9] include detailed descriptions of the various gasifier types of the first two generations.

Present SNG production from coal requires for each output unit of heating value of the gas an input of 1.7 units in coal. This enormous additional heat input comes normally from coal and represents considerable additional coal consumption.

Together with other options, alternative solutions for supplying this heat from nuclear power stations are under study. This heat could be supplied to hydrogen or to steam before injection over the coal to methane reforming by steam injection – a French process.

The alternative described would thus open up a new and substantial heat consumption market for nuclear energy, the heat being eventually supplied from large co-generation nuclear plants, provided with high-temperature reactors, in the case of the Federal German coal gasification process – see Fig. 8.16. Such a complex could reach an overall thermal efficiency ratio – (methane + electrical energy + coke output) to (coal + uranium) input – of the order of 80%.

A further interesting proposal of coal gasification, supplying a combined gas/steam cycle for power generation, is described in chapter 8. The present world gas production from coal is around 100×10^9 m^3.

Underground (in situ) gasification of coal can look back to first experiments in 1912 in the UK and up to 1941 in the USSR [5.8]. The following plentiful availability of petroleum and natural gas slowed down interest in further development. After 1973 interest and research in this area revived and currently active experiments are under way in Belgium, the Federal Republic of Germany, Poland, the USA and the USSR [5.8, 5.9 and 5.10]. However, although the process is attractive in theory, no technological research has succeeded so far in designing a practical commercial process.

5.1.2.1.2. Coal liquefaction

The first field plant for coal liquefaction was installed in 1915 by the German scientist Bergius. The process bearing his name consisted in the hydrogenation of coal, i.e. incorporating hydrogen under high pressure (200 to 700 bar) and at high temperature (450°C) in the presence of a catalyst. The coal was mixed with tar-oils.

In 1926, Fischer and Tropsch utilized water gas as a hydrogen and carbon monoxide source for obtaining liquid hydrocarbons in the presence of a catalyst.

Figure 5.7 presents the two processes [5.11]:

In addition to the German plants which produced up to four million tonnes a year of liquid fuels during World War II, three other synthetic gasoline plants have been installed in France, two following the Bergius process and one the Fischer-Tropsch system. They were, however, closed in 1950. At present up to 4.5 million tonnes a year of gasoline are produced in South Africa (Fischer-Tropsch process) from coal.

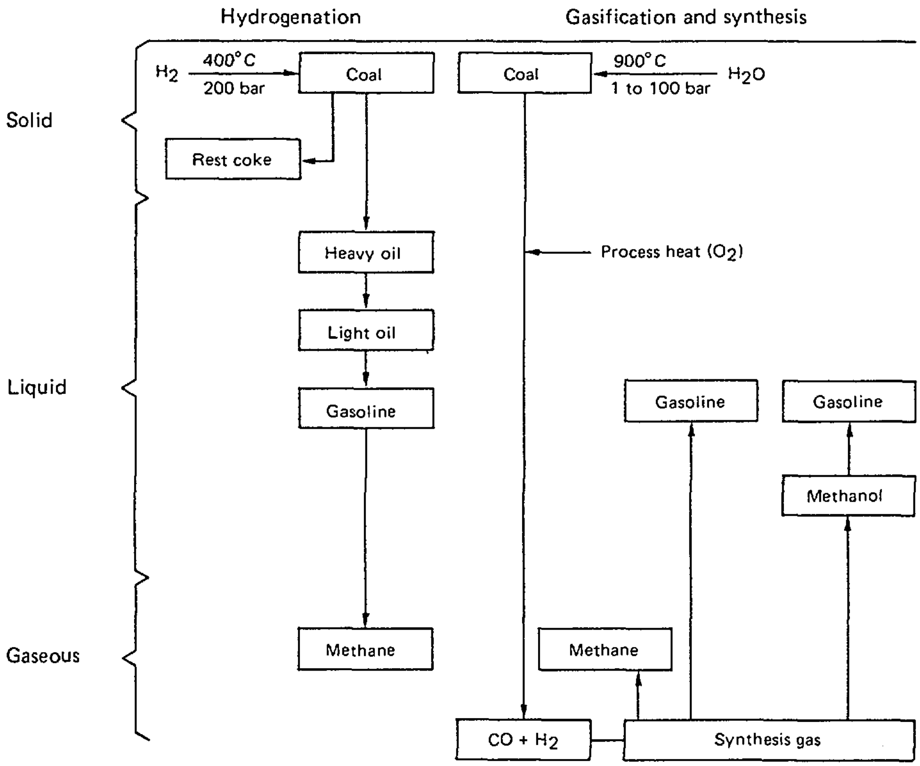


FIG. 5.7. The two routes to obtain liquid and gaseous products from coal: hydrogenation and gasification [5.11].

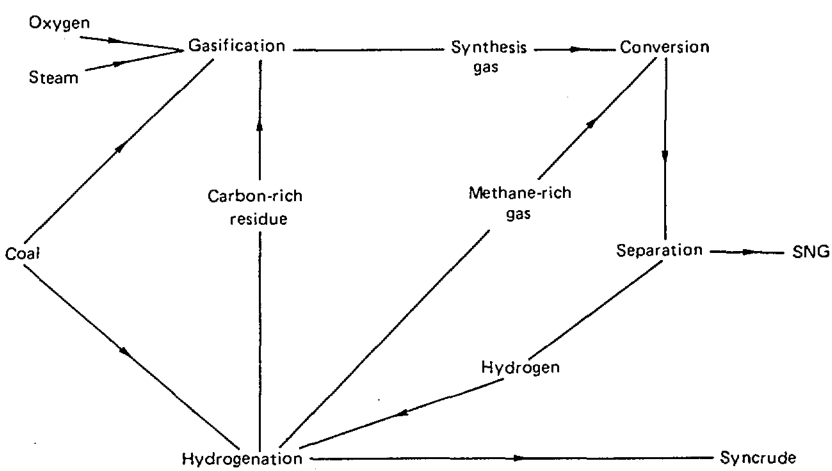


FIG. 5.8. 'Coal refinery' producing syncrude and SNG [5.15].

In the meantime, research has progressed and other coal liquefaction processes are under consideration and in various phases of research and development [5.6, 5.7 and 5.12].

As far as the economic aspects are concerned, it appears that the price of coal has a decisive influence on the competitivity of liquid synfuels. In South Africa, where gasoline is manufactured from very cheap coal, the synproduct is competitive.

In the Federal Republic of Germany, from coal of 220 DM/t, i.e. US $80/t, the equivalent price of the synfuel would be some US $60/barrel, double the present world price [5.13].

Of the liquid synfuels derived from coal, gasoline deserves, of course, the main attention. As shown in Fig. 5.6, also methanol can be obtained from coal. For the time being this line of production does not appear of particular interest. It seems that methanol's well-established chemical production process based predominantly on natural gas and partly on naphtha and residual oil is preferred. However, coal-based methanol production could be expected to start by the end of the 1980 in some developed countries [5.14].

5.1.2.1.3. Coalplex

The term 'coalplex' has been coined to describe a complex of coal-based processes producing a range of products such as electricity, substitute natural gas, liquid fuels and chemicals. Such combinations of processes offer the potential for improvements in efficiency and flexibility, and a reduction in capital cost. This can be achieved by using rejected heat or by-products from one process in another.

It is even possible to go a step further and consider a combination of energy processes with industrial processes, for example with iron manufacture through formed coke, cement and concrete manufacture using mineral matter by-products, or other industrial processes which require process steam or fuel gas [5.15].

While such combinations of energy and industrial processes are discussed in detail in subsection 8.2, it is interesting to examine such a scheme combining for example syncrude and SNG production in a so-called coal refinery schematically illustrated in Fig. 5.8. A gasification stream manufactures a mixture of methane and hydrogen. These are separated by liquefaction, the methane being used as a substitute natural gas and the hydrogen to manufacture a substitute crude oil from coal. The hydrogenation process produces a carbon-rich residue and a methane-rich gas, both of which are used in the gasification stream [5.15].

5.1.3. Gasification and liquefaction of biomass

Biomass can also be converted into intermediate energy carriers, although its main energy utilization is by direct supply to the end-energy users. The

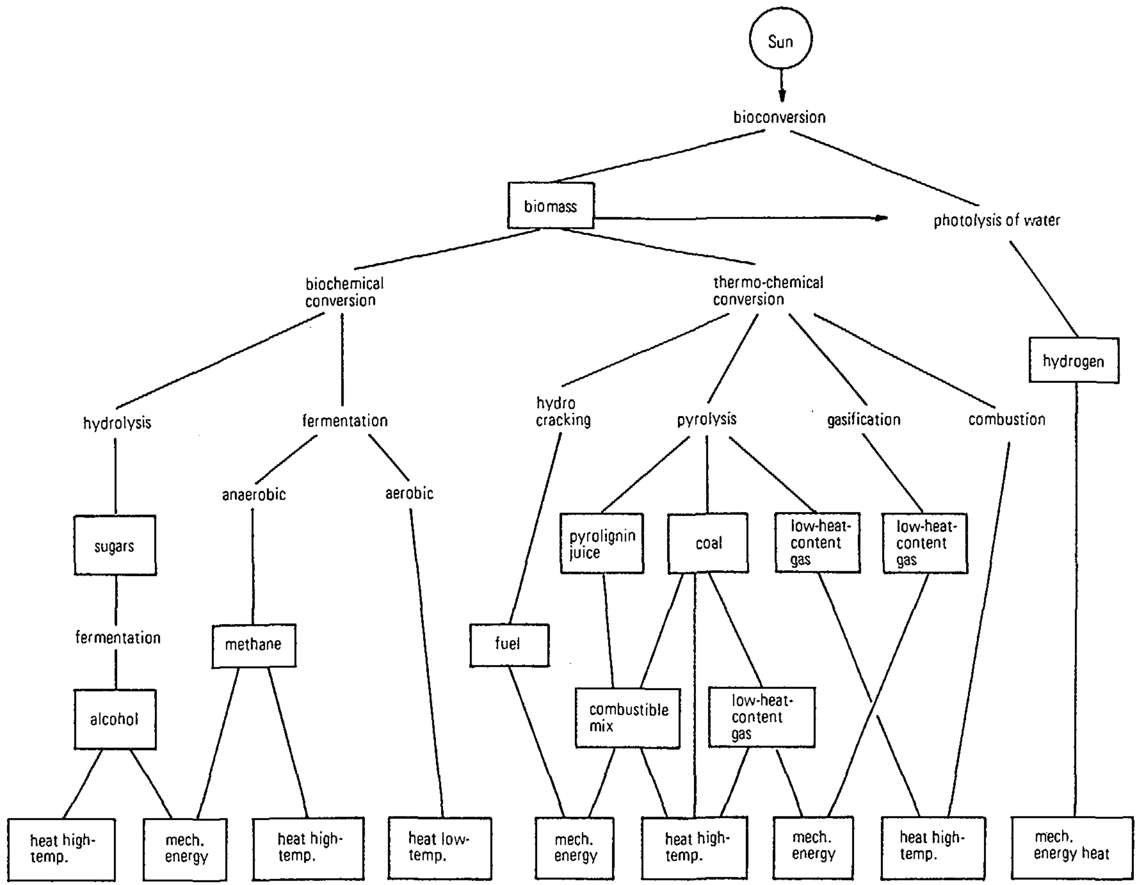


FIG. 5.9. Bioconversion of solar energy to intermediate energy forms [5.16].

intermediate energy forms are gaseous – low-, medium- and high-heat-content gas from wood and vegetal wastes gasification or biogas from animal and vegetal waste anaerobic conversion – or liquid, for example ethanol and methanol, the latter also possibly originating from solid or liquid fossil fuels.

Fig. 5.9 presents an overview on the possible bioconversion of solar energy into intermediate energy forms and their further supply possibilities to the end consumers [5.16].

5.1.3.1. The biomass energy factory

A presentation of the conversion of primary biomass renewable energy resources into intermediate energy carriers is very much facilitated using the classification approach adopted in the recent Ref. [5.17]. This approach categorizes the processes involved according to the concept of a biomass energy factory, consisting of a minimum of two components, the farm component and the conversion component.

The farm component captures solar radiation through photosynthesis and requires, depending on the nature of biomass, additional energy inputs, for example labour, fertilizers, transportation fuels, etc.

The conversion component could employ various processes to convert biomass produced in the farm component into solid, liquid and gaseous fuels plus residues. The conversion phase equally requires energy and material inputs.

5.1.3.1.1. The farm component of the biomass energy factory

Table 5.II presents an overview of the farm component of the biomass energy factory, in which for each biomass category the obtainable intermediate fuels, the annual productivity (GJ/ha·a), the technological status and the involved key issues are displayed [5.17].

The food crops, sugar-cane, mandioca (cassava), corn, etc., are feedstock for fermentation ethanol production – described later on – while vegetable oils could be used as substitutes or additives for diesel fuels [5.18]. However, their high price and the domestic and export demand for edible sorts are against this substitution.

Forestry wood, although largely directly used as firewood, could serve as fuel feedstock for a wide range of intermediate fuel carriers, i.e. wood charcoal, ethanol, methanol, low-heat-content gas. In contrast to sugar-cane, corn and cassava, which compete in the food and feed market, wood may compete in the fibre market.

Agricultural residues and process wastes refer to all residues resulting from harvest or processing of agricultural products, including crop residues, wood residues including branches, leaves and shavings resulting from the cutting and processing of wood, municipal wastes (sewage, solid residues) and livestock

TABLE 5.II. OVERVIEW OF THE FARM COMPONENT OF THE BIOMASS ENERGY FACTOR [5.17]

Farm component	Status	Primary fuels	Overall energy productivity ($GJ/ha \cdot a^{-1}$)	Key issues
Food crops				
sugar-cane	Commercial	Ethanol	75	· high edaphoclimatic requirements · food vs fuel · six months harvest season
mandioca	Development	Ethanol	50	· process energy supply · large-scale problem
palm oil	Commercial/ Development	Vegetable oils	195	· suitability of direct use in diesel engines
Fibre crops				
forestry	Commercial/ Development	Firewood Fuelgas[a] Charcoal Methanol Ethanol[b]	180 175 155 50 35/50	· forest management · period of growth · exploitation of natural forests

Farm component	Status	Primary fuels	Overall energy productivity ($GJ/ha \cdot a^{-1}$)	Key issues
<u>Wastes/residues</u>				
crop residues food processing residues	Commercial/ Development	Biogas Firewood[c]	Variable	· lack of adequate conversion technologies · high dispersion and water content · soil properties affected · nutrient recycle
forest industry residues manures municipal wastes				
<u>Aquatics</u>				
water hycinth sea weeds, kelp	Development	Biogas	1300	· harvesting · low dry matter content · large area requirements

[a] Low-heat-content gas.
[b] Acid hydrolysis/enzymatic process.
[c] Direct combustion of cellulosic residues.

manures. All three residues consist basically of cellulosic materials (cellulose, hemi-cellulose and lignin). However, in many cases, substantial quantities of starch and other carbohydrates, oils, greases, etc., are present as well.

Aquatic plants can also be employed as a source of biomass energy. Use of the free water surface of rivers, lakes, lagoons and oceans can represent an increment in vegetable biomass production, sometimes to a large extent. Aquatic weeds are often more productive than terrestrial plants.

5.1.3.1.2. The conversion component of the biomass energy factory

The second major component of the biomass energy factory is the conversion component. Although it often requires extensive investment costs, these usually account for less than 50% of biomass energy production costs.

The two basic conversion technologies involved are thermochemical and biochemical conversion. The intermediate energy forms and products obtained are: solid, liquid and gaseous fuels, mechanical and electrical energy, heat and petrochemical substitutes.

5.1.3.1.2.1. Thermochemical conversion processes

Thermochemical conversion denotes technologies that use elevated temperatures to convert the biomass materials by (1) direct combustion to produce heat; (2) pyrolysis to produce gas, pyrolytic liquids, chemicals and char; (3) gasification to produce low- or intermediate-heat-content gas, which can be subjected to indirect liquefaction processes to produce ammonia, methanol or Fischer-Tropsch liquids or can be upgraded to synthetic natural gas; and (4) liquefaction to produce heavy fuel oil or, with upgrading, lighter boiling liquid products used as distillates, light fuel oil or gasoline.

(1) Direct combustion of biomass does not belong in the framework of this subsection; however, no opportunity should be lost to emphasize the considerable importance of improving the efficiency of the biomass combustion processes, since these represent one of the major forms of energy consumption in the world.
(2) Pyrolysis is thermal decomposition of carbonaceous materials in the absence of oxygen. Some examples of pyrolysis are the destructive distillation of wood and other agricultural products to produce methanol, charcoal, and low-heat-content gas; batch coking of coal in iron and steel making, and coking in the petroleum industry. Approximately equal quantities of oil, charcoal and gas are produced, but one or more of the three products must be used to supply the energy for the facility.

    The oils produced by pyrolysis of biomass are low in sulphur, ash and nitrogen, and create few problems in combustion. However, they are acidic and heat sensitive and require certain precautions for storage and handling. The charcoal is easier to store, transport and distribute than biomass; it is low in sulphur and nitrogen and may be used in households for cooking and in industry for process heat. The heating value of the charcoal, however, is not greater than that of the biomass.

The gas produced is a dirty, low-heat-content gas which can be burned directly to produce the process energy or cleaned up and used in engines.

(3) Gasification has been defined as the thermal decomposition of organic matter with the help of an auxiliary gas, such as air, oxygen or hydrogen, to yield only gaseous products. Low-heat-content gas has been produced and used for gas engines, power generation or industrial uses for years. The size of the units has been limited to about 50 oven-dried tons per day. The technology is well-developed and a number of manufacturers produce commercial units. The principal focus of research and development in the areas of gasification and indirect liquefaction of biomass has been the production of medium-heat-content gas, high-heat-content gas or substitute natural gas, and the conversion of the gas to a liquid fuel by indirect liquefaction to produce methanol or synthetic fuel (gasoline). A number of medium- and high-heat-content gas gasifiers are under development for use with primarily woody biomass, since that represents the largest supply. The candidate gasifiers are grouped in fixed bed, fluid bed, entrained and molten bath types with variations of stages gasification, catalytic gasification and other classifications.

Gasifier systems used or proposed for biomass are primarily oxygen or steam-fluidized bed units which produce synthesis gas and superheated steam. The synthesis gas is taken to a shift reactor where the carbon dioxide is converted to carbon monoxide and the gases are scrubbed to remove the carbon dioxide, hydrogen sulphide (if any) and water vapour prior to application to a catalyst bed where the methanol is formed.

(4) Liquefaction of biomass is a thermochemical process which at high temperatures and pressures and in the presence of catalysts yields liquids. Process development plants are being operated in several countries to produce oil from biomass by liquefaction.

5.1.3.1.2.2. Biochemical conversion processes

Biological energy conversion entails energy-yielding enzymatic breakdown of biomass by microorganisms under anaerobic conditions. The main routes are (1) biomethanation (anaerobic digestion), which produces a fuel gas composed of methane and carbon dioxide (biogas); (2) ethanol fermentation, which produces a liquid fuel; (3) chemical or enzymatic depolymerization of lignocellulosic material; and (4) other anaerobic microbiological processes.

(1) Biomethanation is a microbiological process which converts biomass in the absence of oxygen to methane and carbon dioxide (biogas), leaving a

stabilized residue which is particularly suited for use as an organic fertilizer or soil conditioner.

Biomethanation is a familiar process because of its wide application in waste-water treatment for stabilization of precipitable solids and recycling of nutrients. In spite of being in use for about a century, it is only now beginning to be understood. The process works best on organic substances with high moisture content. Normally the quantity of methane gas produced is larger than that of carbon dioxide. The process is very slow at ambient temperature in septic tanks and land fills. Recent research and full-scale facilities have led to an improvement in methane generation and content through the use of microorganism accumulation or thermophilic microorganisms or by better adaptation of the process to environmental conditions. Selection of appropriate environmental parameters can also lead to higher production of methane. The gas can be burned directly or it can be upgraded to high heat content or substitute natural gas (SNG) by the removal or the carbon dioxide.

Current research efforts are being concentrated on the conversion of other biomass raw materials such as maize stalks, straws, grasses and aquatic plants, either alone or as a synergetic mixture, or other energy crops grown for conversion into intermediate and high-heat-content gases. The results of this research have indicated the need to optimize the yields of energy products and the necessity to speed up the reaction by appropriate pretreatments to achieve shorter mean residence times.

(2) Ethanol is produced by anaerobic biological conversion of sugars by microorganisms such as yeast, bacteria, or fungi. These sugars are obtained from carbohydrates, starch and lignocellulosic materials. Ethanol so produced is concentrated for use as an energy source.

Short-term fermentation efforts have concentrated on the use of sugar crops, namely sugar-cane, sugar-beet and sweet sorghum, instead of grain. Sweet sorghum appears to be the most viable crop in that it can be grown over large areas of the world, and it is not widely used as a food crop for either humans or animals. The sugar yields and gross alcohol yields from sweet sorghum per hectare are about double that of maize. The energy inputs into the systems need to be carefully reviewed to ensure that the energy balance is positive. Many different approaches have been used to determine the energy balance.

(3) Medium-term and long-term research and development efforts have been directed towards the hydrolysis of agricultural and forest residues and new crops, especially grown for conversion into fuels. These biomass feedstocks can be converted into sugar by either acid or enzymatic hydrolysis.

In the fermentation process, some of the sugars are converted to ethanol. Research and development are directed towards production and separation of fermentable sugars at low cost, leaving the non-fermentable

TABLE 5.III. OVERVIEW OF BIOMASS THERMOCONVERSION PROCESSES [5.17]

Primary fuel	Status	Process	Thermal efficiency [a]
Charcoal, oil, gas	Commercial	Pyrolysis	70–75% [b]
Oil, gas, charcoal	Development	Flash pyrolysis	[c]
Low-heat-content gas (producer gas)	Commercial	Air gasification	70–75% (gas) 16–20% (electricity)
Medium-heat-content gas	Development	Oxygen gasif.	60–65% (SNG) 55–60% (methanol)
Medium-heat-content gas	Development	Steam gasif.	60–65% (SNG) 55–60% (methanol)
Heat Steam/electricity	Commercial	Combustion	20–30% (electricity) 75–80% (steam) 75–80% (co-generation)
Oil	Development	Direct liquefaction	50–60%

[a] All data based on wood with 50% moisture level.
[b] Gas used as energy source for on-site electricity generation and wood drying in the pyrolysis plant.
[c] Product yield very sensitive to actual conditions of flash pyrolysis.

sugars and lignin. These fractions represent approximately two-thirds of the materials fed into the processes. The lignin can be used as a fuel for the process.

5.1.3.1.3. The thermal efficiency of biomass energy factories

In addition to the efficiency figures given in Table 5.III for the thermochemical conversion process, Table 5.IV displays some more detailed figures and also efficiency figures of the main biochemical conversion processes. The figures ranked by decreasing values encompass an interval from 88% to merely 18% [3.62].

5.1.4. Production and utilization aspects of biomass originating gaseous and liquid fuels

5.1.4.1. Gasification of fuelwood and biomass wastes

In isolated rural areas of developing countries, diesel-driven units are currently used for electricity generation, drinking water supply, milling systems and

TABLE 5.IV. RANKING OF BIOMASS CONVERSION PROCESSES BY EFFICIENCY OF PRODUCTION OF INTERMEDIATE ENERGY FORM [3.62]

	$\frac{\text{(Heating value of intermediate energy form} \times 100)}{\text{(Heating value in feedstock)}}$
Densification	88
Gasification, LHC gas, raw	81
Gasification, MHC gas	76
Combustion, steam	70
Gasification, LHC gas clean	69
Combustion, steam + power	68
Liquefaction	63
Gasification, SNG	61
Gasification, methanol	57
Fermentation, corn	57
Digestion, MHC gas, (manure)	48
Digestion, SNG (kelp)	46
Gasification + conversion (gasoline)	45[a]
Fermentation, aquatic crop	37
Fermentation, wood	35
Fermentation, sugar crop	32[a]
Fermentation, agricultural residue	31
Liquefaction, pyrolysis	29
Combustion, power	20
Polymerization, gasoline	19.
Extraction, resin	18

LHC = low heat content

MHC = medium heat content

SNG = substitute natural gas

[a] By-products with fuel value produced in addition to intermediate energy form but not included in efficiency calculation.

irrigation systems. However, gas from biomass could advantageously be substituted for diesel fuel. In addition, small gasifiers could be coupled to a mobile engine and thereby provide motive power, as was done frequently in the past, especially during World War II.

Initiatives in this direction are under way in a few developing countries, in considering installing dual fuel engines, i.e. diesel units capable of operating both on biomass gas or fuel oil alone, or in any combination of the two. However, when operating only on the low-heat-content biomass gas, about 10% of diesel oil has to be added to ensure ignition of the mix.

The first biomass approached is fuelwood, the traditional input primary energy resource, also used in the past. There are, unfortunately, only a few developing countries with enough wood resources to meet this additional consumption, unless special wood energy plantations with rapid-growing tree species are organized for this purpose.

However, developed countries, too, are showing interest in small fuelwood gasifiers, for example Canada [5.19] and South Africa. The latter has targeted 1 000 000 t of wood to be burned in gasifiers by the end of 1985. This implies more than 2000 gasifier systems to be manufactured every year [5.20]. It is expected that about 50% will be used for heating and the balance for electricity generation.

Another approach, very logical and attractive, is the one searching to gasify biomass wastes, of which , particularly in warm developing countries, enormous quantities are otherwise completely lost. Such biomass wastes or residues could be gasified in a second generation of gasifiers specially developed to deal with them. In non-compacted form: coconut and palm shells and husks, bamboo waste, corn cobs and wood residues; in compacted form: coffee, cotton and sunflower shells, rice husks, anas (hemp, flax, etc.) and bagasse (this latter is in a design stage) could be commercially gasified.

Several gasifying or pyrolysis processes have been developed for this purpose, the main idea being to try to obtain a clean enough gas to guarantee the reliable operation of an electricity generating set. However, only a few of the gasifiers tested succeeded in this respect, and they have neither performed over a long enough period of time nor been large enough in number to provide a final, positive demonstration. Nevertheless, in view of the considerable importance of a successful solution and the research and development effort involved, it is likely that in a few more years the substitution of diesel oil by biomass wastes could become one of the most efficient energy policy measures in the majority of developing countries in their struggle for a better foreign currency balance.

As far as economics is concerned, a specific consumption of 1 kg of biomass waste per kW · h plus 0.25 g of diesel fuel[6] could be regarded as a reliable

[6] Specially adapted gas motors do not need any additional fossil fuel, because of spark ignition.

average figure, while the investment cost of the dual engine – diesel or gas motor – could be up to 60% more, since the average pressure in the cylinders is sensibly lower due to the less rich fuel. However, preliminary calculations show that with the present price relations, the higher investment costs are paid back by the value of the fuel oil replaced in some five years.

Recently it has been reported that pyrolysis processes for combined production of mechanical energy and charcoal from wood or biomass wastes have reached the development stage. Such biomass-based processes could, therefore, contribute in addition to electrification of remote rural areas in developing countries to the supply of an adequate fuel for cooking and small industrial needs.

5.1.4.2. Methanol from wood and biomass wastes

Methanol could be produced in addition from hydrocarbons and coal by pyrolysis, i.e. destructive distillation of wood or other agricultural products and by gasification and indirect liquefaction of woody biomass.

In the latter alternative, a number of gasifiers are under development for producing medium- and high-heat-content gas or substitute natural gas.

The technology for conversion to methanol of synthesis gas (carbon monoxide and hydrogen) obtained from biomass gasification is well-known and used widely on a commercial basis. The technology to convert methanol – so far not used as such in a gasoline-methanol mix, similar to an ethanol-gasoline mix – to gasoline is also available [3.21] and the first commercial unit is being planned for implementation in New Zealand [3.62]. It has also been proved that wood can produce the synthesis gas in an appropriate ratio of carbon monoxide and hydrogen for methanol production, but only on a small scale. Complete processing from wood to methanol using the preferred technology – in one system – has not yet been carried out and although it might become feasible, it still needs substantial technological progress [5.14].

The economics of biomass systems indicates that methanol from wood would be more expensive than methanol from coal owing to the smaller size of biomass units. Nonetheless, there are opportunities to decrease the costs. Proposed modifications include the catalysts and the elimination of hydrogen sulphide and carbon dioxide clean-up units. In addition, the clustering of gasification units near biomass sources and transmitting gas by pipeline to a central methanol unit can greatly reduce costs.

In any case, the methanol options remain important for developing countries, not only as an additive to gasoline or as a full automotive fuel, but also as a potential substitute for kerosene, which would have to be imported otherwise.

5.1.4.3. Ethanol from biomass

Ethanol from biomass is the major renewable non-conventional energy resource which offers immediate prospects for partial substitution of lighter

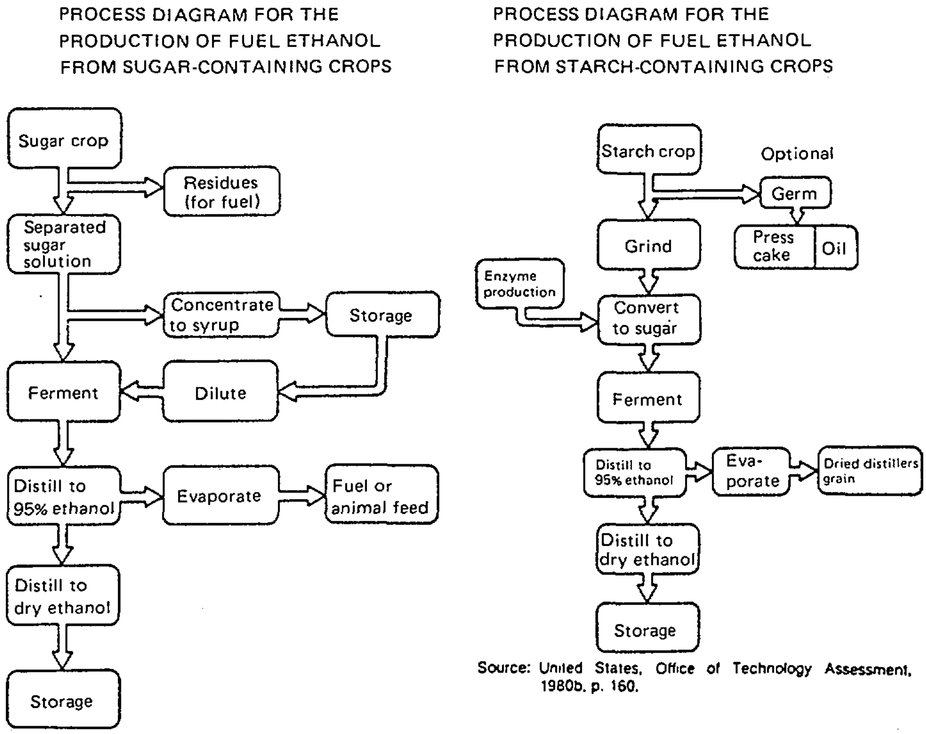


FIG. 5.10. The two processes for producing ethanol from sugar and starch feedstocks [5.22].

petroleum products in the transportation sector. The basic technology for producing ethanol from a number of biomass raw materials is well known and easily transferable to developing countries. The medium-scale industrial units involved can be advantageously located in rural areas, creating additional rural employment at relatively low cost.

Ethanol is produced almost exclusively by fermentation and all such processes consist of four basic steps: (1) the feedstock is processed and/or treated to produce a sugar solution; (2) yeasts or bacteria convert the sugar to ethanol and carbon dioxide; (3) distillation is used to remove the ethanol from the fermentation solution, yielding an ethanol/water solution which is at best 95.6% ethanol at normal pressures; and (4) any remaining water is removed to produce 'dry' or anhydrous ethanol. This latter step is usually accomplished by a second distillation in the presence of another chemical.

The main distinctions between fermentation processes utilizing different feedstocks arise primarily from differences in the pretreatment steps to which the feedstock is subjected.

Sugar-bearing crops are plants such as sugar-cane, sweet sorghum, sugar-beet, sugar-mangels and Jerusalem artichokes, which contain carbohydrates in sugar form. They yield sugar directly upon processing, but the sugar must be concentrated or treated in some other fashion for storage to prevent it from being broken down by bacteria.

Starch-containing feedstocks are primarily grain crops, such as corn, wheat and oats but also include various root plants such as potatoes, cassava, etc. The carbohydrates are in starch form. These feedstocks need to be broken down (hydrolyzed) with enzymes (biological catalysts) or acids to reduce or convert the starch to sugar.

The two processes for producing ethanol from sugar and starch feedstocks are shown schematically in Fig. 5.10. Both use commercially available technology [5.22].

Similarly, cellulosic (woody or cellulose-containing) feedstocks such as crop residues, grasses, wood and municipal waste paper require extensive hydrolysis (either acidic or enzymatic) to reduce their more inert, long-chain, cellulose molecules to sugar sub-units.

The proposal to make ethanol from cellulose is very appealing as it would allow exploitation of substantial cellulosic biomass resources, including wood wastes, spruce-budworm and fire-damaged wood, for feedstock. This resource is in general much larger than that represented by the starch and sugar crops and food processing wastes combined, and its exploitation would avoid using food crops for energy production. Unfortunately, there are problems in breaking down cellulose to sugars which can be fermented to ethanol.

Compared to other fuels, ethanol has a heating value of 26.8 MJ/kg (21.15 MJ/L) as against gasoline, 44 MJ/kg (32.3 MJ/L), diesel oil, 29 MJ/kg, or fuel oil, No.6 for example, 40 MJ/kg (36.9 MJ/L). Methanol lies substantially lower with 20 MJ/kg (15.9 MJ/L).

Table 5.V displays the raw materials and ethanol yield of different input biomass [5.23]. The figures of Table 5.V are based on average yields in Brazil, except for corn, where the figures are based on the average in the USA. The figures in brackets for cassava relate to potential of improved production technology while for sweet sorghum, they refer to one crop, two crops per year being possible in some locations.

A rough check with the figures of Table 5.V shows that for an annual total of 17 500 km driven, with an average specific consumption of 8.5 L ethanol/100 km, the yearly quantity of 1500 L ethanol would require 0.5 ha of cultivated sugar-cane, i.e. a hectare for every two automobiles.

Ethanol can be used as automobile fuel either as 'gasohol' in which case anhydrous (99.8%) ethanol is mixed with gasoline up to a 20% ratio, or as hydrous or straight alcohol, in which case 94% pure ethanol is used straight.

Ethanol when used in gasohol increases the octane number of the gasoline blend. Existing internal combustion (Otto cycle) automobile engines do not

TABLE 5.V. ETHANOL YIELDS OF MAIN BIOMASS RAW MATERIALS [5.22]

Raw material	Raw material yields	Ethanol yield	
	($t/ha \cdot a^{-1}$)	(L/t)	($L/ha \cdot a^{-1}$)
Sugar-cane	50.0	70	3500
Molasses	–	280	–
Cassava	12.0 (20.0)	180	2160 (3600)
Sweet sorghum	35.0	86	3010
Sweet potato	15.0	125	1875
Babassu	2.5	80	200
Corn	6.0	370	2220
Wood	20.0	160	3200

require any changes to run on gasohol of up to 20% ethanol blend and obtain practically the same mileage performances. Thus, the opportunity value of ethanol as gasohol is equivalent to the economic cost of gasoline.

Cars adapted to run on straight ethanol cost 5% more and have a 20% higher specific consumption compared with regular gasoline. Taking into account all intervening factors, the opportunity value of straight ethanol appears to make it unsuitable as fuel in the immediate future.

Despite its obvious merits, biomass ethanol cannot offer a radical solution to the worldwide demand for light petroleum products nor is its large-scale use indicated under any conditions and in any developing country. For example, if the entire current world production of sugar-cane, molasses, corn and sweet sorghum, for which proven fermentation technology is available, were converted into ethanol, this would substitute for only a small fraction of the present world petroleum consumption.

As far as the suitability of biomass ethanol production for a given country is concerned, the decision will depend on a series of specific and more general economic aspects:

First of all, the energy balance of ethanol production has to be positive, i.e. the total energy consumed for its production less the by-product energy credit should be less than the energy content of ethanol (its heating value). In this respect, the structure of the agricultural system is very important [5.14].

For example, the US agricultural system is considerably more energy-intensive than that of developing countries, due to higher rates of fertilization and the higher degree of mechanization. Since this balance in the USA is very finely differentiated, a series of studies have been carried out for different specific conditions. One of the most comprehensive, which also critically reviews several earlier studies, concludes that the net energy balance for gasohol production in the USA depends on what options are assumed. While the total energy balance is uncomfortably close to or less than zero, the petroleum-only balance is positive for most practical situations. Therefore, in contrast to an inconclusive total energy balance, for a petroleum-only consideration it could be stated that to move a car a unit distance by burning gasohol requires about 5% less petroleum than by burning gasoline [5.24]. The analysis refers to a blend of 10% grain-based ethanol and 90% gasoline.

Under these circumstances, biomass ethanol production has to be approached on an integrated system basis in which, in addition to the economic considerations, all other involved social, financial and strategic issues should duly be included. Considerations related to the availability of sufficient agricultural land might either favour (for example Brazil) or constrain the final decision. It is significant in this respect that the World Bank's readiness to support ethanol production programmes in developing countries is based on a careful evaluation of all factors influencing their viability [5.23].

A particularly successful ethanol national programme is under implementation in Brazil. In 1979, Brazil achieved a nationwide average of 19% ethanol mixed with gasoline for use in unconverted engines and began in 1980 to produce automobiles that are specially designed to use ethanol as the optimal fuel [5.25, 5.26]. In 1984 ethanol production is expected to be over 8.5 million m^3. A fleet of over 600 000 vehicles (including cars and trucks) is running on neat alcohol and all gasoline sold is blended with up to 20% ethanol. Current feedstock is mostly sugar-cane, processed in about 200 distilleries with an additional 100 under implementation. Mandioca (cassava), sorghum, babassu and wood are also being processed, mostly in small- to medium-scale experimental or demonstration units [5.16].

The World Bank study [5.23] analyses the economics of alcohol production in "standardized plants operating under parameters that simulate the conditions expected to prevail in different countries". While not substituting for a specific country analysis, it offers, nevertheless, broad parameters which can be used to identify countries and situations where further in-depth reviews appear justified.

5.1.4.4. Biogas

5.1.4.4.1. General considerations

The production process of biogas is basically an artificial adaptation of that which takes place in swamps to produce marsh gas. It is not new, in the sense that for many decades plants have been built to process raw sewage in urban areas before discharging it into natural drainage systems. In this case, the primary function of the digestion treatment was to eliminate pathogens rather than to produce fuel gas, then known as sewer gas, although some gas was produced and was sometimes used as fuel for pumps and other equipment connected with the plant.

Fermentation plants have been built for gas production in a number of scattered locations around the world over a period of many years, sometimes for experimental purposes, sometimes on large farms or estates where conventional fuels were either very expensive or difficult to obtain, and many small plants were constructed in Germany during World War II. The most extensive development of biogas plants to date has been in India, China and Korea, but in most cases, the development has not been of heavy impact on the overall energy balance of the countries concerned.

The question of mass utilization of biogas came into prominence following the petroleum price increases in 1973, which caused nearly all the developing countries which were deficient in indigenous fuel resources to re-examine their fuel needs, and particularly those of the rural sector, which were in many cases being subsidized by the government, either in the form of sales of kerosene at prices below the true economic cost or in the provision of subsidized rural electrification schemes.

The advantages of biogas development are many, especially in Asian countries where dried cattle dung has traditionally been used as an everyday domestic fuel. The plants themselves are of relatively simple construction and can be made to a large extent from indigenous materials; the process can be made to work even down to the single-family unit.

The benefits of biogas plants are multiple and are not confined solely to the production of a clean and desirable fuel. In fact, their installation could be justified under some circumstances even if no fuel at all were produced. The practice of burning cattle dung robs the soil of an important fertilizer and soil conditioner and leads to its steady impoverishment, with reduced fertility and greater susceptibility to erosion. Spreading raw dung on the fields leaves the rural household with little alternative fuel. In contrast, the use of biogas digester provides a desirable fuel, while returning a large part of the feedstock in the form of slurry or liquids which can be used as a highly effective soil conditioner and fertilizer. The fermentation process destroys most of the pathogenic organisms present in the raw feedstock and so interrupts the parasite breeding cycle. One of the most noticeable features of a properly operated biogas digester is the almost complete absence of flies around the discharged material.

Despite its undoubted advantages, the biogas digester suffers from some disadvantages which have so far prevented its large-scale adoption in developing countries. Of these the most serious seems to be the capital cost of the digester itself, which is apparently beyond the means of the average rural inhabitant –

however, note the great exception of China. Others are the poor operating record of many prototype designs, which have often been built on a 'one-off' experimental basis by individuals with no specialist knowledge of the biological processes involved and lacking the technical knowledge to design a practical working system. The end result has sometimes been an unexplained suspension of the fermentation process, sometimes a mechanical breakdown of the digester; both cases result in an immediate loss of interest by the very people who are supposed to benefit from the device.

The potential advantages of the biogas digester to the inhabitants of rural areas in developing countries are undoubted. The technical disadvantages can be overcome by increased attention both to the biochemistry of the fermentation process and to better design of the digesters themselves. As regards the financial aspect, many governments may wish to consider digesters as qualifying for a capital grant or subsidy payable in local currency, as an alternative to the open-ended commitment in foreign currency which results from subsidizing imported petroleum fuels and fertilizers.

5.1.4.4.2. The fermentation process and biogas plant operation

The fermentation process, or rather processes, by which methane is formed. from organic wastes are complex and not yet completely understood. It is probable that the organisms involved change in both type and population density with changes in the composition of the feedstock and the temperature at which fermentation is carried out. A number of methane-producing bacteria have been isolated and identified, and most of these feed on relatively simple organic compounds which have been formed by the breakdown of the complex substances comprising the feedstock. It seems, therefore, that the fermentation must proceed in two stages, the first involving a breakdown of the feedstock by one set of bacteria with the evolution of carbon dioxide and hydrogen, and the second stage in which methane is produced by a number of different anaerobic bacteria, some of which combine the carbon dioxide and hydrogen to produce methane, while others produce methane from the mixture of organic acids, alcohols, and esters which are produced in the first stage of fermentation. All the methane-producing bacteria are extremely sensitive to free oxygen, and most of them are sensitive to alkaline conditions. Methane gas will only be produced in reasonable quantity if the fermenting sludge is acid and without free oxygen.

The successful production of methane is the result of a delicate balance among the microflora in the slurry; the fact that it has been possible to operate biogas digesters in an empirical fashion without any real knowledge of the processes involved indicates that this balance is, in fact, not too difficult to maintain.

It has been found empirically that the process is temperature-sensitive, methane production decreasing with decreasing temperature and becoming very limited at temperatures below 14°C. The upper limit at which fermentation has been successfully carried out so far is about 55°C, and at this temperature gas yield seems to be greater than at lower temperatures.

As already explained, biogas is composed predominantly of methane and carbon dioxide, of which the methane is the useful component. As would be expected from the empirical way in which work on biogas has been conducted in the past, analyses from different areas show considerable variation in the proportion of the two gases; there are also a number of minor gaseous components, some of which (such as hydrogen sulphide) are undesirable. The composition of biogas varies between: 55–65% methane (CH_4), 34–45% carbon dioxide (CO_2) and minimal nitrogen (0.3%), hydrogen (0–1.0%) and hydrogen sulphide (H_2S) (0.1%) content.

The heating value of the gas is almost entirely due to its methane content, although the hydrogen and hydrogen sulphide contribute something to the heating value to the extent that they are present. The heating value of methane is approximately 36 000 kJ/m^3 so that the heating value of biogas will usually lie in the range of 20 000 to 25 000 kJ/m^3.

Basically, the operation of a biogas digester consists of loading it with a slurry made of animal manure mixed with water and allowing fermentation to take place in a random and uncontrolled manner. In some cases, chopped vegetable matter, such as straw, leaves, kitchen waste, and weeds are added to the slurry. Human wastes can also be loaded into the digester, and an improved design which incorporated a latrine would be highly desirable.

Biogas having a heating value some two-thirds that of natural gas could be used in any natural gas-burning appliances which have been adjusted for the lower heating value and the speed of combustion of the flame.

Most conventional gas-burning devices can be so adjusted, so the range of uses is limited only by the availability of equipment. Cooking, heating, lighting and refrigeration are obvious applications.

All spark-ignition internal combustion engines can readily be adapted to run on biogas by provision of a suitable carburettor, so that it is possible to run most types of stationary farm machinery and prime movers for cottage industries by means of biogas generators.

The limitation of the use of biogas as a source of energy is primarily one of availability of sufficient gas. On the assumption that one cow produces about 11 to 12 kg of wet dung per day, the output of two and a half cows would be required to provide biogas with the energy equivalent of one litre of gasoline.

Table 5.VI presents an histogram of the number of cattle per head of rural population in a series of developing countries, divided into two characteristic groups, depending on the possibility of meeting the rural energy requirements for subsistence [5.27].

TABLE 5.VI. HISTOGRAM OF THE NUMBER OF CATTLE* PER HEAD OF RURAL POPULATION IN THE DEVELOPING COUNTRIES [5.27]

							Colombia
							Chile
							Brazil
							Mexico
							Cuba
Sri Lanka	Khmer Rep.				Ecuador		Tanzania
Pakistan	Upper Volta	India			Bolivia		Sudan
Afghanistan	Mozambique	Burma	Nepal		Mali		Zimbabwe
Tunisia	Morocco	Bangladesh	Guatemala		Kenya		Madagascar
Nigeria	Cameroon	Iraq	Uganda	Peru	Angola		Ethiopia
> 0.2	> 0.3	> 0.4	> 0.5	> 0.6	> 0.7	> 0.8	> 0.9
Only partial rural energy requirements for subsistence could be provided			More than subsistence level rural requirements could be provided				

* *If buffaloes and oxen are included, then some countries move to the other side, for example India.*

TABLE 5.VII. COMPARISON OF INDIAN AND CHINESE BIOGAS PROGRAMMES [5.27]

Details	India	China
Programme commenced	1961	1970
Number of plants – 1973	8000	5000
– 1979	80 000	7.2 million
Common plant capacity (m^3/day)	1.7	1.7
Daily input	Dung from 4–5 cattle	20 kg waste from 4 pigs + 4 kg from 5 persons + 6 kg straw
Gas yield	Cattle 100%	Pigs 61%, human 18%, straw 21%
Rural families with input	Richest: 20%	100%
Plant designs in vogue	Only KVIC design	20 designs
Plant designs approved	Only KVIC design	Any
Cost of plant	RS 3000	30 yuan
Cost of plant/monthly income of poor household	20	0.2

5.1.4.4.3. Biogas evolution and outlook

As mentioned before, the practical results of biogas development are rather disappointing, considering that it is a process with such a long technological history. However, the problem seems to be not simply of technical character. In this respect, a comparison between achievements in India and China, two developing countries where biogas has been utilized on a large scale, may shed some light on some of its controversial aspects and approaches.

A purely statistical comparison of Indian and Chinese biogas programmes – see Table 5.VII [5.27] – shows essential discrepancies. The number of biogas plants grew in China from 5000 in 1973 to 7.2 million in 1979, whereas in India, where the programme started earlier, the corresponding figures were 8000 and 80 000. In addition, many other figures, e.g. costs, number of available designs, inputs, etc., appear in favour of the Chinese approach.

It is impossible for an outsider – even having had the chance of a random look at some plants in a remote Chinese village – to explain objectively the reasons for such different results.

However, facing such an attractive possibility to improve rural energy in developing countries, one hardly could do better than to support recommendation I of the "Report of the Technical Panel on Biomass Energy for the United Nations Conference on New and Renewable Sources of Energy – Nairobi 1981", to establish demonstration plants in other countries in different regions of the world in order to facilitate both the evaluation of the technology and the wide adoption of the technology for the bio-methanation of manures, agricultural residues and other organic materials [3.62]. There is ample scope for further research, both into the biochemistry of the fermentation process itself and into the design of cheaper and more efficient digestors. Biogas deserves indeed much more attention than it has yet received [5.28, 29].

5.1.4.5. Hydrogen

Very much is spoken and published about the hydrogen economy or the hydrogen society, as one of the main issues of energy in the next century. The following, however, will be limited to a brief presentation on the current situation. Hydrogen (H_2) is also an intermediate energy carrier, which, burnt into water vapour (steam), releases a heating value of 12.6 MJ/m^3. Hydrogen can be stored as gas under high pressure (150–200 bar) and liquefied at temperatures lower than 252.5°C. It can also be stored as magnesium hydride and released again as gas at temperatures around 300°C.

It is now produced commercially from petroleum and natural gas and by coal gasification. Figure 5.11 presents the energy input for hydrogen production through different technological processes. Against the current production from

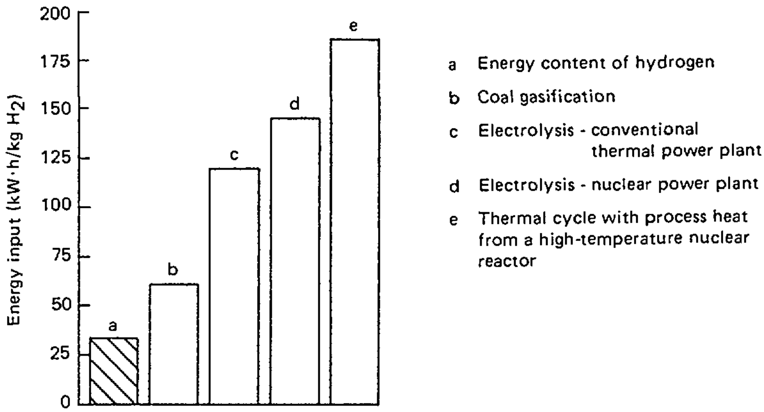


FIG. 5.11. Energy input for hydrogen production by various technologies [*5.30*].

coal gasification with an efficiency of 55%, i.e. an energy input of some 60 kW · h/m^3, electrolysis by electricity from a fossil-fired thermal power station needs some 120 kW · h/m^3, from a nuclear power station some 145 kW · h/m^3. A thermal cycle with heat from a HTGR power plant would require around 185 kW · h/m^3 [5.30]. On the large scale that hydrogen utilization for energy purposes would involve, only production of hydrogen from water could be considered.

In addition to electrolysis, thermochemical methods are in different stages of research. However, from the over one billion cycles, based on five reactions, studied in a first approach by computer combinations, only a few deserve further examination [5.31].

The alternative, to use solar-derived electricity for hydrogen production, would apparently involve enormous surfaces for the collecting and concentrating devices in relation to the output obtained. Even further off is the prospect of getting hydrogen as one of the products of plant photosynthesis by a special intervention in this process.

If the production problems could be solved, hydrogen could be advantageously used for heat supply and probably for transportation purposes. The hydrogen motor reaches an efficiency close to that of the natural gas motor, the remaining problem being the high weight of hydrogen storage devices on the vehicles.

In spite of so many currently still unsolved aspects of the future hydrogen economy, 86 experts consulted in a Delphi survey came to a positive conclusion, evaluating the share of hydrogen in the world energy consumption at 2.5% in 1990 and at a 5% in the year 2000. How much further and how fast the evolution will continue is difficult to predict. However, even if one does not share the optimistic vision of the hydrogen era as coming so soon, the fact remains that in the next century the development of nuclear energy to overcome the shortage of hydrocarbons requires a gaseous vector as a partner for electricity. This partner could well be hydrogen produced by water decomposition as the ultimate gaseous intermediate carrier of energy.

5.1.5. *Future of synfuels*

Future demand for synfuels, liquid and gaseous, will very much depend on the patterns electricity demand will follow, since for certain areas these energy carriers can easily substitute for each other.

As regards the general trend of development, the evolution in the USA is typical. The share of primary energy converted to electricity has risen continuously in the overall energy balance during the last 30 years, reaching 33% in 1980, and if this trend, established during decades of abundant and cheap petroleum and natural gas, were to continue, by 2000 conversion to electricity could reach 45–48% [5.5].

In general a long-term interplay between electricity and synfuels could be expected, possibly directed in the very long run to a complementary co-operation between electricity and hydrogen, especially if and when hopes materialize to produce them commercially from water (fusion-electricity).

5.2. Mechanical energy

Mechanical energy could appear as a final or as an intermediate energy form, depending on its input. Its intervention as final energy form has been discussed in detail in chapter 2, where needs and demand for this energy form are amply analysed.

As an intermediate energy form, mechanical energy appears when it serves as a link in a conversion chain which continues with another intermediate energy form or energy carrier.

In the most frequent cases it serves as an intermediate energy form for electricity production in all power plants with rotating electrical generators, i.e. hydro-, steam-, diesel- and gas-motor and gas-turbine power plants.

It also appears as an intermediate energy form when driving pumps, compressors, blowers, etc. which put fluids under pressure and enable them to carry out further mechanical work (water jets, compressed air, etc.).

A common characteristic of all interventions of mechanical energy as an intermediate energy form is their stationary, site-bound nature. It is only as a final energy form that mechanical energy also displays an extraordinary mobility.

All other specific aspects regarding the low efficiencies of mechanical-energy-producing thermodynamic processes, the high dependence on liquid and gaseous high-grade fuels, etc., are discussed in the chapters related to the main issues in which mechanical energy structurally intervenes.

5.3. Heat

As explained in chapter 1, when speaking of heat in this framework, also cold (or 'coolth'), i.e. heat of lower temperature, is included. However, for some specific aspects the terms heat and cold could be used separately.

Heat could appear, similar to mechanical energy, as a final energy form or as an intermediate one. Its character would be determined by its role and position in the energy system. According to these criteria, it would appear, exceptionally, even as a primary energy form, such as geothermal heat.

However, heat under the above heading is referred to in the following as an intermediate energy form, and as such used either for an end-use energy supply, or for producing another intermediate form of energy, for example, mechanical energy and electricity.

Practically all non-renewable primary energy resources and the majority of the solar energy forms – see Fig. 1.1 – might be converted into heat carriers (steam, hot water, hot air, etc.) as intermediate energy forms. The efficiencies vary, depending on the primary energy form and the size of the installation, between 65 and 92%; the low figures relate to solid fuels and the highest to gas-buning installations. Along lines which are not included in Fig. 1.1, any other groups of intermediate energy forms can supply steam and hot water from boilers. In such cases, the steam, hot water, etc., would appear as tertiary energy forms.

Heat as an intermediate form of energy presents special features if supplied by a public or industrial network – either produced in single or combined processes – or originating as waste heat from industrial processes or as 'pumped' ambient heat by adequate heat pumps.

5.3.1. Exclusive generation of heat

There is little to be added in relation to the exclusive production of heat, either in high-temperature furnaces or boilers, except insisting again on efficient and reliable generating units. However, district heating may be singled out, both for centralized production and distribution by public networks as well as providing a suitable basis for eventual district heating by co-generated heat. Insofar as it is exclusively used for electricity generation, heat production is intimately integrated in the electric power plant concept and operation and is accordingly commented on in chapter 6.

5.3.2. Heat co-generated with electricity

The co-generation or combined production of heat and electricity for supplying industrial processes and district heating systems is a thermodynamic conversion process of high efficiency, which deserves special attention both for its massive energy-saving effects and substitution potential, as well as for improved comfort and environmental advantages attached.

The basic idea of this process, to combine the advantages of the separate heat or electricity generating processes and to reduce or avoid their disadvantages, is described in detail in subsection 8.2.1.

5.3.3. Waste heat

Theoretically, waste heat is that portion of initially produced or harnessed (if solar) heat which is not finally consumed as useful energy. However, this definition is too general, since it includes as waste, losses which are inherent to energy processes, and which, as discussed in chapter 1, cannot be totally avoided.

In this situation, another approach might be more helpful, i.e. to consider a quantity of heat really wasted if evacuated from an energy process with still a potential to be used; no utilization takes place till it is finally absorbed in the ambience. From this point of view, a major part of the heat evacuated from energy conversion processes is not what is commonly called waste heat, but with its potential for further utilization it represents a real energy resource, and particularly, an intermediate form of energy.

Since the parameters, quantities and availability of such intermediate forms of heat cannot be freely selected because they are dictated by the technological process they originate from, it has been proposed to call them secondary energy (heat) resources. Furthermore, since by far the most interesting of these secondary resources, both as regards temperature and quantity, appear in industry, the acronym ISER, standing for industrial secondary energy resources, has been introduced.

Because of their importance for industrial energy husbandry, a separate subsection, 8.2.2, deals with their characteristics and utilization ('recovery') options.

Among the heat released, some heat carriers are of very low temperature, mainly cooling water from industrial installations and, in very large quantities, from electrical power plants. These enormous quantities of heat are probably the most representative type of waste heat, because during the steam expansion in the turbine their temperature is reduced to the technically and economically extreme lowest level, and the heat is discharged at only some 10°C temperature difference from that of the cooling water. Because of its low temperature this waste heat is also called 'cold heat'. Practical utilization is known so far for agricultural soil heating (agrotherm), greenhouse (hortitherm), fish ponds (limnotherm) [5.32] and space heating.

In the latter case the cooling water is transported to the utilization area where its temperature is raised with heat pumps to the necessary heating level.

In this process the waste heat corresponding to the temperature gradient to the ambience is fully used, i.e., no exergy losses are incurred any more at the back-end of the power production process. In addition, this heat recovery also has environmental benefits, less heat being discharged in the final cooling natural circuit.

In the general framework of energy conservation, an increasing interest is devoted to ISER utilization and subsequently to the lower temperature zone of poor energy 'cold' heat carriers. With the improvement of conventional heat pumps, already commented upon, it is obvious that whenever possible it is preferable to use such a low-exergy heat carrier as a heat source rather than the lower ambient temperature heat.

However, in addition to improving operation and reliability of commercial heat pumps, research work is under way for developing new, more advanced devices, for example, a heat transformer. This would operate on a reversed cycle of an absorption heat pump process. Such a device could upgrade a heat carrier of 65°C to 110°C, with an ambient temperature of 15°C. In contrast to usual heat pumps, the heat transformer would not require an external high energy input [5.33].

Moreover, efforts are being made to use low-grade heat not only as a passive heat source for a heat pump system, but to use it actively as an external energy source for new advanced absorption machines working with new combinations of working fluids [5.34].

5.3.4. Ambient heat

The ambient heat diffusely stored in the lower part of the atmosphere and the upper part of the Earth's crust cannot be further used, since no practically usable temperature gradient exists.

Ambient heat constitutes an intermediate energy form since it represents the balance between the incoming solar radiation, geothermal heat reaching the earth surface and the heat as the final stage of all energy conversion processes including intermediate losses taking place in the world on one side, and the outgoing earth heat flow to the universe, on the other side. However, ambient heat exists at different temperature levels, and varies geographically and during the year; even at the same location differences exist between air, water and soil temperatures.

Although of low temperature level, ambient heat represents an enormous reservoir of exergy. If some exergy is added by heat pumps and its temperature raised to higher levels, ambient heat can be usefully used, as exemplified in chapter 2.

5.4. Animate energy

Animate energy is the energy that human beings and animals could put to work. Since it is based on and renewed by nutrition it is an intermediate energy

TABLE 5-VIII. TOTAL LIVESTOCK POPULATION AND PROBABLE DRAUGHT ANIMAL POPULATION (MILLIONS) [5.36]

Species	Total livestock population			Population of draught animals in developing countries
	Total world	Developed countries	Developed countries	
Cattle and yaks[a]	1212.0	425.0	787.0	246.0
Buffaloes	130.6	0.9	129.7	60.0
Horses	61.8	22.4	39.4	27.0
Mules	11.6	0.7	10.9	10.0
Donkeys	42.8	2.0	40.8	40.0
Camels	16.8	0.2	16.6	16.0
Ilamas	1.4	-	1.4	1.0
Elephants[b]	-	-	-	-
Total	1477.0	451.2	1025.8	400.0

[a] Yaks of China have been included under cattle.
[b] There may be about 20,000 elephants engaged in logging work.

TABLE 5.IX. ESTIMATED NORMAL DRAUGHT POWER OF VARIOUS ANIMALS [5.36]

Draught Animal	Weight (kg)	Average speed of work (m/h)	Power developed (kW)
Light horse	400-700	3600	0.75
Bullock	500-900	2160-3240	0.56
Buffalo	400-900	2880-3240	0.56
Cow	400-600	2520	0.34
Mule	350-500	3240-3600	0.52
Donkey	200-300	2520	0.26

form. It can either supply directly end-use energy or intervene earlier in the consumption-oriented energy chain.

Human energy, in the sense of potential to perform mechanical work, is the form of interest to the energy system. In addition, there are the permanent heat losses to the ambience and, somehow outside the current energy system, the spiritual energy as a potential of man to influence, organize and manage the outside world and improve his own performance and cultural level [5.35].

Work animals, i.e. the bearers of animal energy, provide motive power for ploughs, carts and agricultural implements and, in addition, bequeath man food and leather at the end of their working life.

Although draft animal power (DAP) is one of the oldest used of energy forms, little attention has been given to upgrading and modernizing it, in spite of its great potential for rural areas, except in China, which has an excellent record of development of this energy resource.

Table 5.VIII presents the total world livestock population, its distribution in developed and developing countries, and the probable number of draught animals in developing countries [5.36].

The 400 million draught animals in developing countries i.e. 39% of their total livestock population or 27% of the total world livestock, provide energy for the cultivation of nearly 50% of the world's total cropped area, feeding almost two billion people. In addition, they haul over 25 million vehicles, mostly in Asia.

Normally a draught animal generates 0.3 to 0.6 kW on a sustained basis. Table 5.IX displays the normal draught power output by different species of animals, as estimated by FAO.

Evidently, a great difference exists in the level of energy input in developing countries – in India, for example, two-thirds of the energy input into the farms comes from animals, 20% from man's muscle and only 10% from conventional energy forms – and the highly energized agriculture of developed countries. However, while mechanization should be encouraged in developing countries, this should be done only where conditions are conducive to such a switch over and in full agreement with all other development requirements specific to the particular countries.

Reference [5.36] is recommended as an excellent document for further, more detailed information on draught animal power systems.

Chapter 6

ELECTRICAL ENERGY

Electrical energy or electricity, as it is often called for short, is an intermediate form of energy according to its current place in the global energy system. Considering its quality and potential functions, it emerges as a particularly outstanding one. Indeed, it is able to mobilize any of the primary energy resources and provides multiple services for the final energy consumers. This versatility and its efficient centralized production, bulk transport and easy distribution give electricity a key position in any energy system and explain its paramount role in the modern economy.

On the production side, electricity can be generated by any one of the primary and secondary energy resources, with no exception – i.e. fossil fuels, hydro, geothermal, nuclear and all new and renewable energies, including energy waste recovery – and is, therefore, not dangerously dependent on a specific source; on the utilization side, electricity can meet with merely a single circuit all the needs of final consumers for light, communication, heat and cold, mechanical energy, electrolysis, etc. In addition, at this stage electricity utilization exerts no harmful environmental impact.

These are the reasons why the share of electricity in the world energy balance increased from 12.5% in 1950 to 25.3% in 1980, and might reach over 35% in the year 2000 – see Table 13.V.

Electricity techniques and economy are more familiar than the overall energy problems. Therefore, in the following only some specific, less well known aspects will be commented on in more detail.

6.1. The electrical system

In the introductory comments on the energy system in chapter 1, due mention was made of the pioneering role played by the electrical system in the development of the concept and operational techniques of the energy system approach. The emphasis was less on the input, since practically the same primary energy resources were concerned, than on the subsequent conversion, transport and end-use stages.

Two elements which are essential for the electrical system but not of significance for the transfer were consciously omitted: the physical metallic continuity of the electrical system between the generators' output terminals and the final electrical connections of the consumers, and the synchronous production and consumption of electrical energy.

Although a subsystem, the electrical system operates within the overall energy system. However, the two above-mentioned elements, so decisive for electricity supply, have no impact on the latter, other than their specific technical

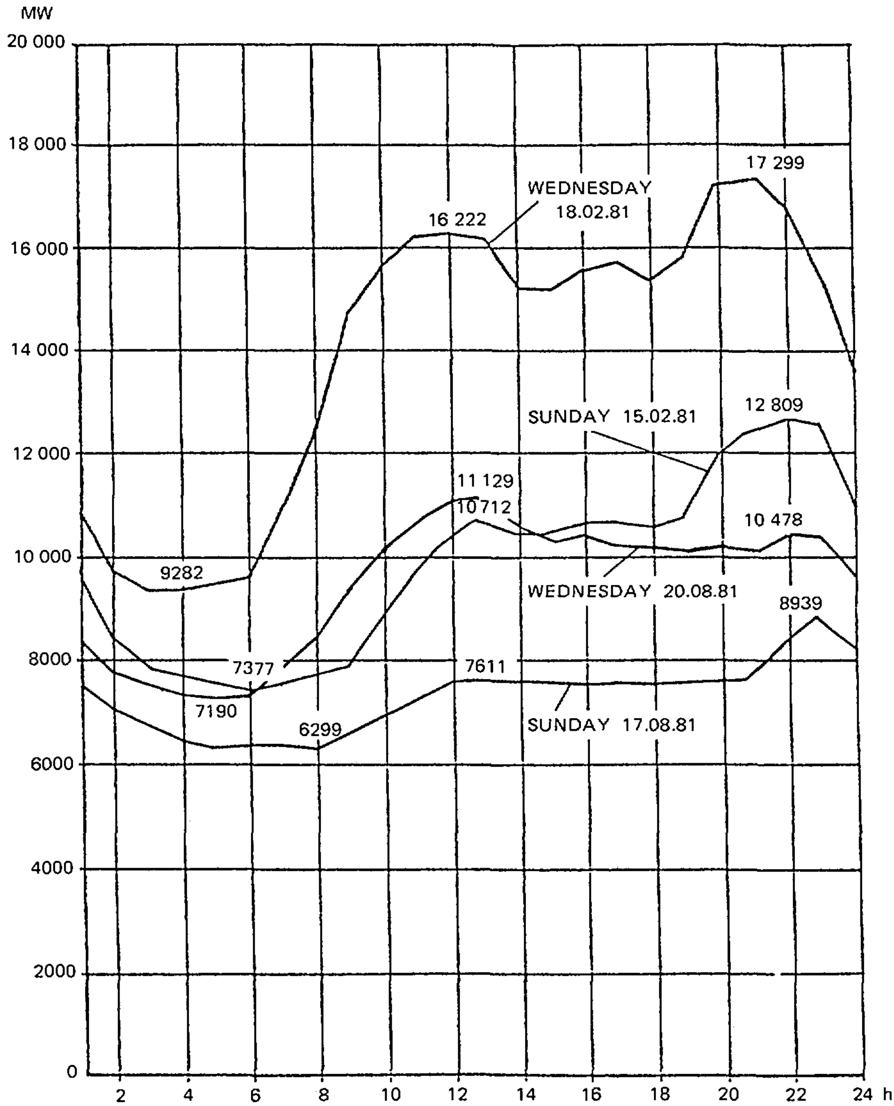


FIG.6.1. Daily electrical load curves (consumption plus losses) in Peninsular Spain in 1981 [*6.1*].
[*6.1*].

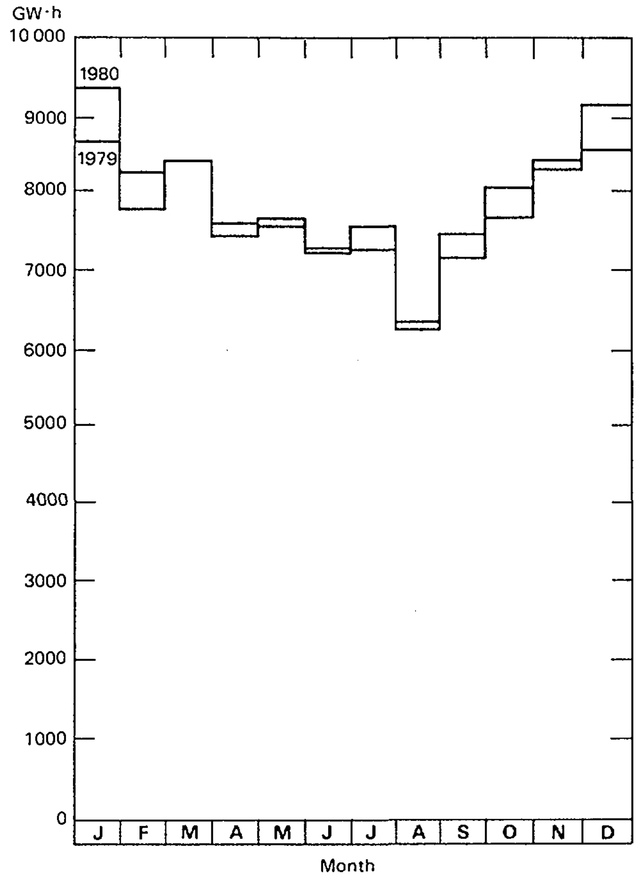


FIG.6.2. Monthly electricity consumption in Peninsular Spain [6.1].

and economic effects. In other words, the integration of the electrical system in the consolidated energy system is limited to the same general reciprocal and loose relationship in time as all other energy forms, which are less time-dependent.

As a consequence of its structure and operational conditions, an electrical system, however large or small, constitutes an operational entity with its own technical and economic rules. According to its integrated operation, its design and management have to observe the same conditions of integral optimization. While these conditions are self-consistent in a national electricity corporation, in an electrical system similarly operated but integrated by different utilities, optimal planning is more difficult. However, such interconnected systems at regional, national and international level exist and operate to the mutual advantage of their constituent subsystems.

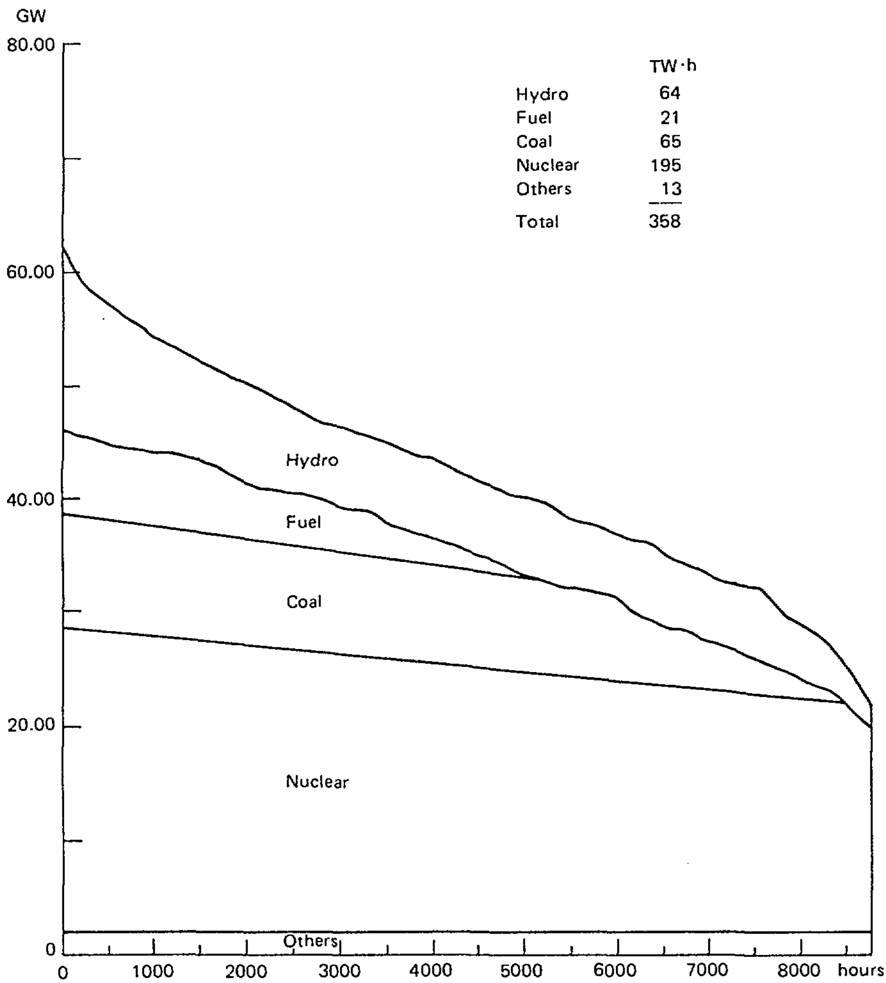


FIG. 6.3. Load duration curve in France – estimated for 1985–1986 [6.2].

6.1.1. Specific character of electricity demand

The demand for electricity in an electrical system is the consolidated sum of the individual consumption of all connected consumers in the given moment plus the accompanying losses in the transmission and distribution subsystems.. As such, the demand varies during the 24 hours of the day, from one day of the week to the next and over the year for seasonal reasons.

Although electricity is not a final energy form, in chapter 2 a detailed analysis was made of the typical demand for electricity as an end-use energy form, both by category of consumers and as integrated system demand. In this chapter, the interest focuses on the latter, especially as regards generation design and operation. Accordingly, electric load characteristics are briefly reviewed as the basic starting point of every optimization.

Figure 6.1 presents as another example the daily electrical load curve of Peninsular Spain for a series of characteristic days between 15 February and 20 August 1981. The day of maximum load was Wednesday, 18 February 1981, with a peak load of 17 299 MW against a peak load of only 12 809 MW on the previous Sunday. In summer, the peak load on Wednesday – currently the day of maximal load in the week – 20 August 1981 was only 11 129 MW and occurred not in the evening but at mid-day; on the previous Sunday only 8 939 MW were reached, late at night.

Figure 6.2 displays the monthly electricity consumption in Spain in 1979 and 1980. The month of August – a typical vacation month in Spain – showed a consumption of hardly two-thirds that in January.

Figure 6.3 shows a typical annual electric load duration curve. It is the estimated curve for 1985–86 in France, also including one of the supply options [6.2].

6.2. Electricity generation

Electricity supply in an electrical system has to be optimized from the combined aspects of generation, transmission and distribution of the required electrical energy. The corresponding planning and optimization methodology is discussed in detail in chapter 14.

The present chapter is intended to describe briefly the main types of electrical power plants and their characteristics with the purpose of organizing all the information needed for determining the most suitable combination to meet a certain electrical demand.

6.2.1. Hydro power plants

6.2.1.1. Energetic aspects and layout

Power and annual electricity production of a hydro power plant depend, as shown in section 3.2.1, on the water flow and the height the water descends.

The optimal height depends on the geographical and geotechnical conditions of the site, but also on the optimal harnessing scheme of the whole river. Once selected, the height is constant, except for the differences of the water level in a possible storage lake, if the power plant is of the storage reservoir type.

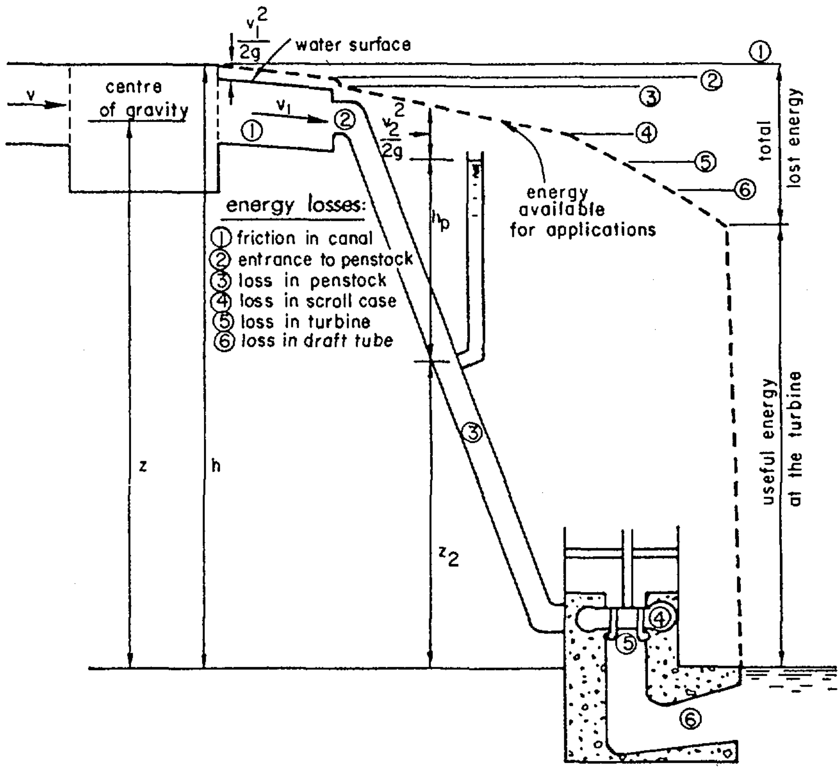


FIG. 6.4. Energy conversion in a typical hydro-electric plant [6.3].

The energy obtainable from a water flow of V m^3 descending a height of h (m) is calculated as:

$$E = 1000\ Vh\eta\ (\text{kgf}\cdot\text{m}) = 1000\ Vh\eta \times 9.8\ (\text{J})$$

$$= \frac{9.8\ Vh\eta}{3600} = \frac{Vh\eta}{367}\ (\text{kW}\cdot\text{h})$$

where η represents overall efficiency, consolidating the friction losses in the pipeline system and the water turbine's and electric generator's efficiencies.

The corresponding power is

$$P = 1000\ Dh\eta\ (\text{kgf}\cdot\text{m/s}) = 1000\ Dh\eta \times 9.8\ (\text{J/s}) = 9.8\ Dh\eta\ (\text{kW})$$

where D is the water flow in m^3/s.

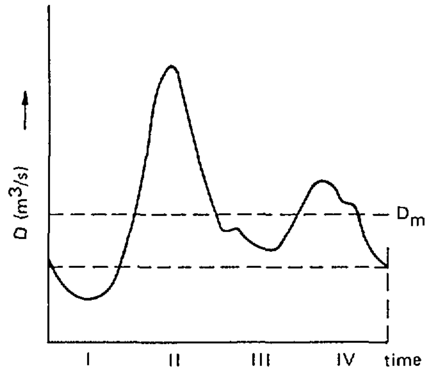


FIG.6.5. Annual variation of the natural water flow of a river in a high-altitude region.

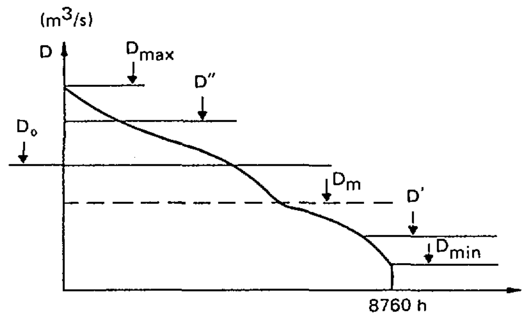
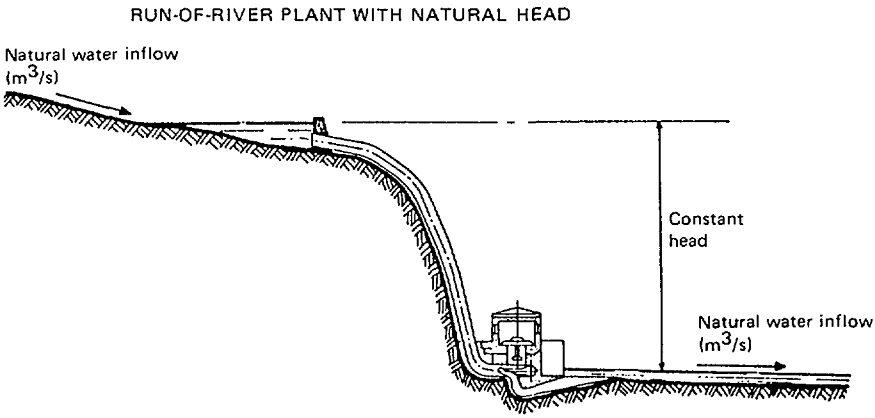


FIG.6.6. Annual duration curve of water flow at the site of a hydro power plant.

Figure 6.4 illustrates the basic features of a typical hydro-electric plant and specifically the energy losses reducing the gross to the useful head.

The natural water flow varies a great deal over the year. Figure 6.5 shows for example the annual variation of the natural water flow in a high-altitude region. D_m is the average water flow calculated over the year.

For electrical calculations, the annual duration curve of water flow – Fig.6.6 – is used for determining the optimal outlay of the hydro power plant. D_o is the optimal resulting water flow, here for example slightly higher than the average water flow D_m.



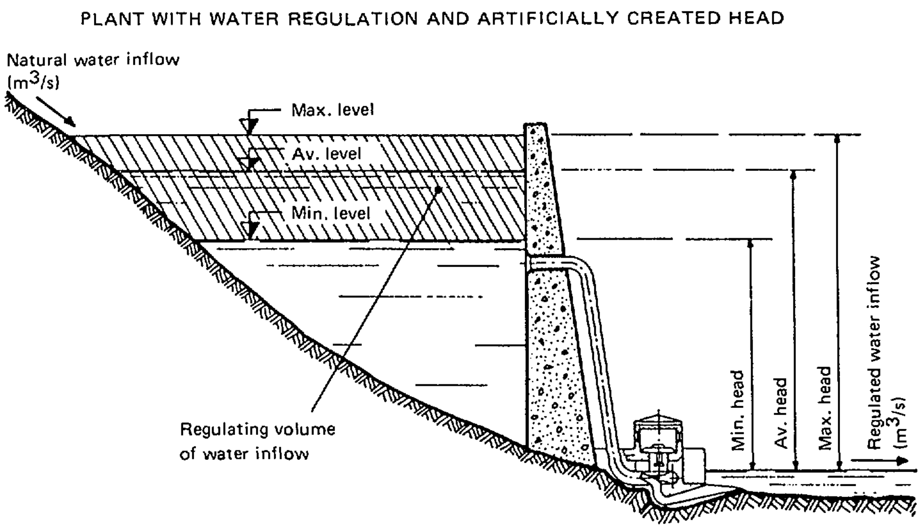


FIG.6.7. Two basic types of hydro-electric power plants [6.3].

Basically, hydro power plants are of two types: of the run-of-river type or of the storage reservoir type. Figure 6.7 shows two extreme designs of each type [6.3].

For electricity generation, hydro power plants without storage reservoirs can use solely the water actually running down at any moment. The electrical power variation will depend on the selected design water flow, and so will depend on the annual electricity production. However, the higher the design water flow, the less hours in the year the design power capacity might be available. In return, the annual energy – the productiveness – increases with higher selected design water flow. Taking into account these variations, an optimal design water flow D_0 might be determined as a function of the total electrical load of the system and the operational role reserved for the plant in the daily and annual load diagram.

For this type of hydro power station, special attention has to be paid to the selection of the design water flow if it operates alone and supplies an electrically isolated system, as is often the case of mini- and micro-hydro power plants. In such cases, the availability of a minimal electrical power (kW) supply for longer periods in the year might gain priority over the legitimate desire to harness more yearly energy (kW·h).

Hydro power plants with storage reservoirs, i.e. with water regulation and an artificially created head, can generate electricity independently of the actual water flow of the river, provided that site conditions allow the construction of sufficiently large storage reservoirs. The latter, depending on their volume and water flow conditions, might serve for daily, weekly, monthly, seasonal, annual and multi-annual storage.

The selection of the design water flow for such power plants very much depends on the storage capacity of the reservoir and the role of the plant in the electrical system. In any case, these power plants will intervene for peak load covering in the system and in emergency situations as a quick reserve. Their main value consists in the power (kW) contribution and less in their energy delivery (kW·h), although this is still very important. With the condition that their design capacity covers the apportioned energy demand, optimal layout alternatives can be computed as a function of the form of the peak portion of the daily load curve of the system, in the short and medium term and, at a guess, for the long term. The majority of the optimization programmes for electrical system development include such an analysis.

An important exception could arise in the case of multi-purpose projects, for example when a water storage reservoir is constructed to serve both irrigation and power generation purposes. Although in general an optimum operational programme could be worked out to the advantage of both functions, in some cases, when for example longer-than-weekly storage is involved, difficulties might emerge, the needs of the two purposes not being close enough in time to be served by the same water out-take from the storage reservoir. In such cases irrigation must be given priority. However, since natural storage reservoirs are not numerous, a trend has developed, when other utilization purposes are not the determining factor, to use the few existing ones best for peak coverage, by installing a higher electrical capacity that would normally correspond to the natural water flow of the river. Owing to this super-sizing, the yearly utilization duration of the plants' installed capacity could result in values as low as 1800 – 200 h/a, and still represent a very economical solution.

Because of the limited number of available sites for natural water storage and the continuously increasing demand for peak-load covering, a third type

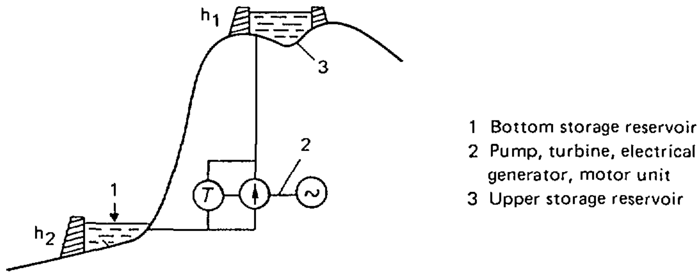


FIG.6.8. Hydro power plant with pumped storage.

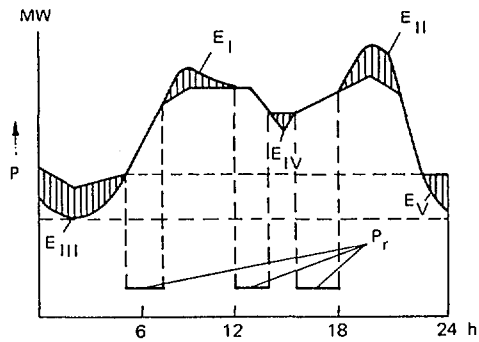


FIG.6.9. Daily operation diagram of a hydro power plant with pumped storage.

of hydro power plant has been developed: hydro power plants with pumped storage – see Fig.6.8. Usually such plants are erected when insufficient natural peak hydro power plants could be installed and/or in cases where cheap base-load energy can be provided, originating for example from large run-of-river hydro power and/or nuclear power plants.

Figure 6.9 illustrates the operation of such a hydro power plant with pumped storage, designed for daily peak coverage.

During the night and early afternoon, with the artificial additional energy consumption E_{III}, E_{IV} and E_V, water is pumped into the upper lake; during the peak periods in the morning and evening, the pumped water redescends and generates the peak energies E_I and E_{II}.

The ratio of the regained output energy to the energy consumed in pumping is the recovery or efficiency factor of the complex and currently averages between 68 and 75%. These relatively high values have been made possible by substantial progress in pump construction in recent decades. The pump and water turbine may be combined in so-called reversible pumping units.

In the past, when fossil fuels used to be abundant and cheap, it was technically and economically attractive to maintain thermal power stations during the night working at better loads by supplying storage pumping electricity, since the additional costs were practically only the marginal fuel costs. At present fuel prices, careful calculations have to be made for such solutions, unless, as mentioned, the energy is no-cost run-of-river energy or marginal energy from nuclear power plants.

6.2.1.2. Construction and equipment features

Hydro-electric power plants contain four structures: the forebay, penstocks, hydraulic turbines and draft tubes [6.3].

The forebay serves as a water-storage system during times of reduced plant loads and as a water-supply system during periods of load increases. If the hydro-electric plant is located at the base of a dam, the water reservoir acts as the forebay. For plants situated at the end of a canal this can be enlarged to provide a forebay. In installations where a pipeline supplies the water, a surge tank constitutes the forebay.

The connection between the forebay and the turbine inlet or scroll case is called a penstock. The flow in the penstocks is controlled by forebay-penstock gates, turbine penstock or a combination of the two.

The draft tube connects the turbine outlet with the tailrace (water exhaust channel) or the tail water (free water to which the plant water is exhausted). The draft tube functions to slow down the water at the turbine exit with a minimum of energy loss, allowing the removal of more energy from the water by the turbines. During normal operation the water pressure in the draft tube is below atmospheric pressure.

Hydraulic turbines perform a continuous conversion of the potential and kinetic energy of a fluid into useful power. They are classified as either impulse or reaction turbines, depending on the type of hydraulic action involved.

In an impulse turbine, the available energy head is converted into kinetic energy by a contracting nozzle, the action taking place by the impact of the water jets at nearly atmospheric pressure on a set of spoon-shaped blades. The only modern turbine of the impulse type is the Pelton turbine (also called Pelton wheel) – see Fig. 6.10.

An impulse turbine cannot develop all the total available head. The nozzle has to be set above tail water level – see Fig. 6.9. Usually a high flood level is selected for tail water. The vertical distance between nozzle and average tail water is lost permanently.

In a reaction turbine, part of the total available energy head is converted into kinetic energy, the remainder being maintained as a pressure head which then decreases through the turbine passage. The pressure head is required because the water flows through the penstock, turbine and draft tube forming a closed conduit

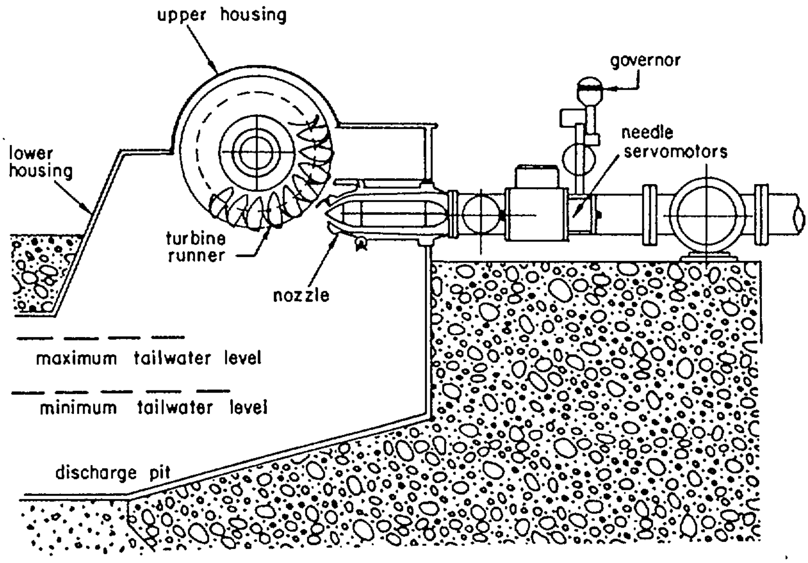


FIG.6.10. Typical Pelton impulse-type turbine [6.3].

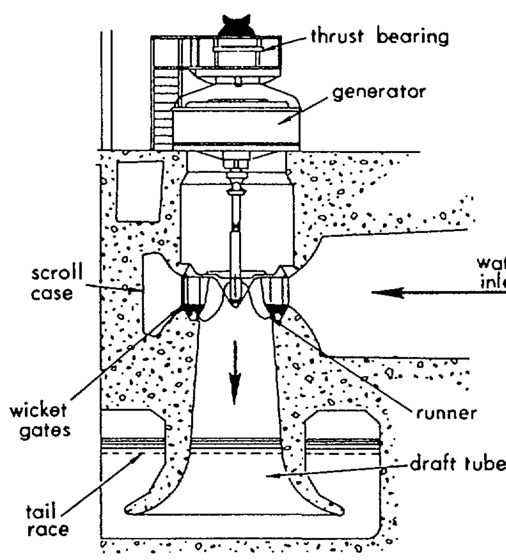


FIG.6.11. Cross-section of a Francis reaction-type turbine.

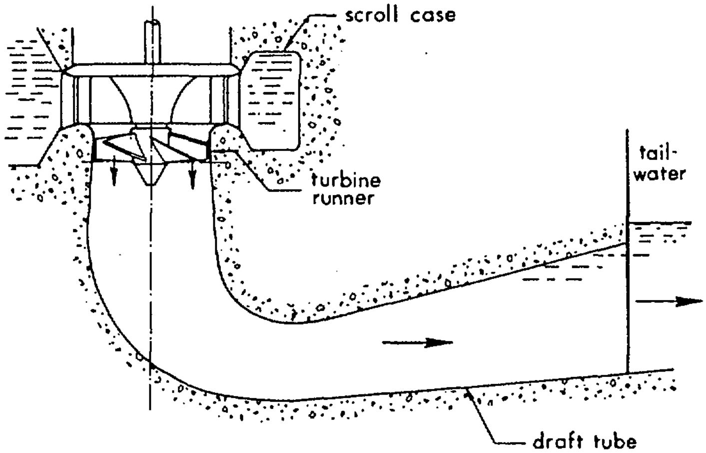


FIG.6.12. Fixed black propeller turbine installation [6.3]

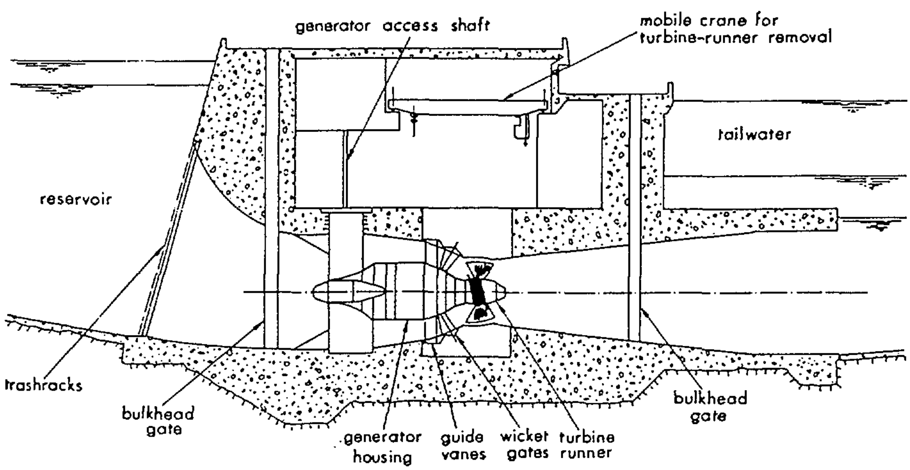


FIG.6.13. Bulb-type axial-flow turbine [6.3].

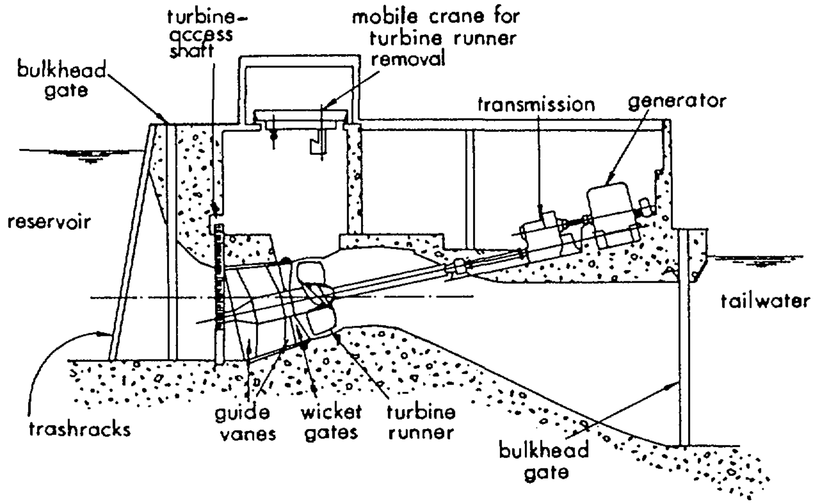


FIG.6.14. Tubular turbine [6.3].

system. The water entering the turbine exerts an impulse on the turbine runner in the direction of the flow and the discharged water exerts a reaction on the runner in the direction opposite to the flow. Reaction turbines operate with radial, axial or mixed flow through the runner. The Francis turbine and the propeller turbine are two types of reaction turbines in wide use – see Figs 6.11 and 6.12.

Francis turbines usually are designed in either an axial or a mixed flow configuration.

The choice between a Pelton, Francis and Kaplan turbine depends almost entirely on the available energy head.

For use in low-head installations, other designs such as bulb-type and tubular turbines can be used with advantage. The bulb-type turbine and the associated generator placed in a bulb-shaped housing are positioned in the centre of the water passageway – see Fig. 6.13.

The tube or tubular turbine design (Fig.6.14) uses an axial-flow turbine mounted in the centre of the water passageway. The turbine is connected by a shaft to a conventional horizontal-type generator located outside the water passageway.

Probably the most versatile type, especially for larger plants, is the bulb turbine, which is also the most economical to use at heads below 20 m. Smaller, faster and easier to build than other types, bulb turbines are frequently 25–50% cheaper in capital cost than Kaplan turbines [6.4].

The already mentioned trend to transform old hydro-electric power plants built around the beginning of this century into modern plants is leading to substantial gains in power and annual energy output as well as to increased reliability of operation and manpower reduction due to advanced automation. The gain in power is usually due to lower head losses and better turbine efficiencies, and could reach 10–20%. For example, against a Francis turbine which when new had in 1910 at full load an efficiency of 78%, a modern Kaplan turbine would reach 91–92.5% at full load and maximally even 93–95%. In addition, the flatter efficiency curve of the Kaplan turbine, would result in a much higher yearly energy output [6.5].

As far as the mini and micro hydro-power plants are concerned, special attention should be paid to their local and simple design; they should not be conceived as down-scaled conventional hydro plants, such projects resulting both in too complicated and exorbitantly expensive installations [6.6].

6.2.2. Thermal power plants

To better understand the great diversity of thermal power plants, one must remember that classical thermal power generation is governed by the second law of thermodynamics, the level of efficiency depending on the temperature difference the power cycle might use in relation to the ambience and on the ability of the equipment to convert it into mechanical and/or electric energy.

Although remarkable progress has been achieved, the efficiencies of thermal power plants still remain frustratingly low. The best high-pressure/high-temperature steam power plants may reach 38–40%, gas-turbines between 20 and 30%, the latter with recuperation of heat from the exhaust gases. Diesel power plants perform at 30–37% efficiencies. Nuclear power plants equipped with light-water reactors operate at 30–31% since the fuel elements permit no higher live steam parameters. CANDU plants lie in the same range. Only nuclear power plants with AGR reactors, where the steam pressure and temperature can be raised at the high level used in modern steam power plants, may reach 38–39%. With helium turbines, 40–42% appears possible.

In combined gas/steam plants, with the turbine flue gas being used as combustion air for boilers of steam power stations, efficiencies of 44% or even more are possible.

6.2.2.1. Electrical steam power plants

While co-generation plants are dealt with in chapter 8, a few detailed comments follow regarding steam-condensing plants.

Figure 6.15 presents the heat cycle of a large steam-condensing turbine with intermediate steam superheating and advanced boiler feedwater reheating, both important features for reaching a higher thermal efficiency.

Figure 6.16 represents schematically the energy and mass flows in a steam-condensing power plant.

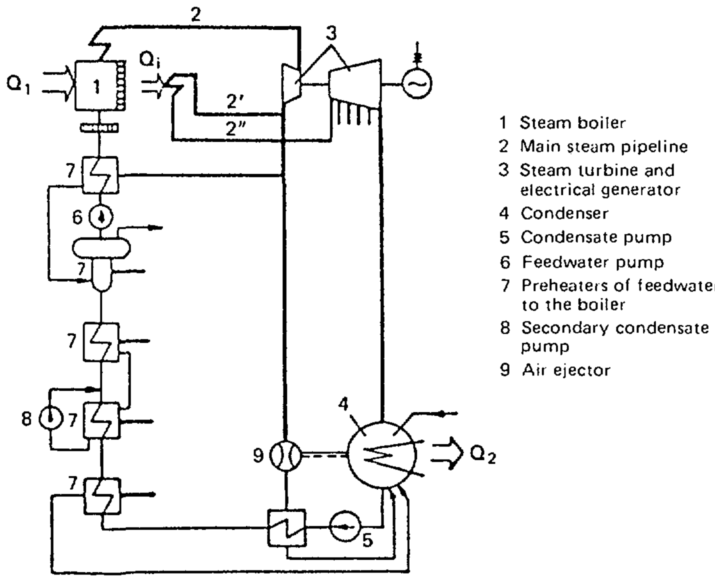
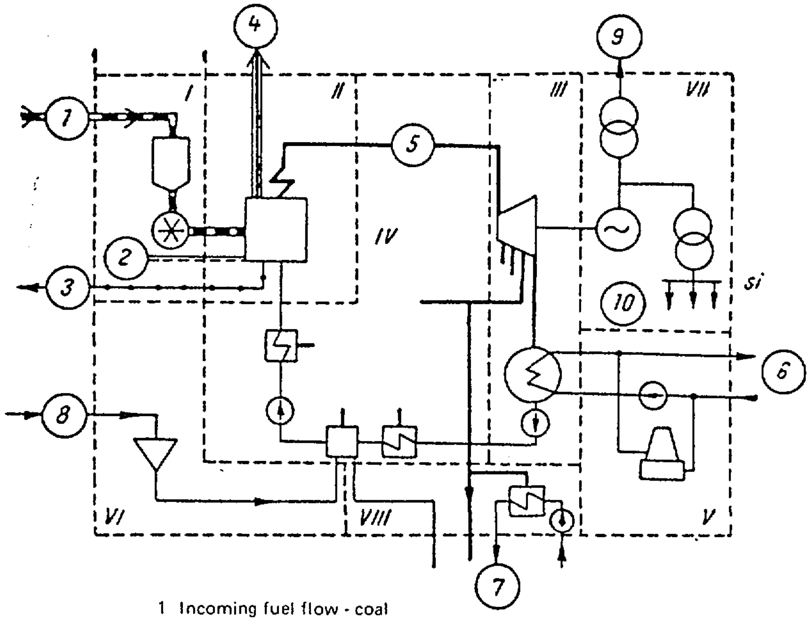


FIG.6.15. Heat cycle of an electrical steam condensing power plant.

As far as specific fuel consumption is concerned, Fig.8.6 presents the heat rate of steam-condensing power plants – curve 1 – as a function of the live steam parameters (pressure and temperature).

Curve 1 presents for higher live steam parameters a certain saturation trend, towards a marginal efficiency figure of some 42–43%.

The obvious explanation for the low efficiencies of thermal power is that when electricity – via mechanical energy – is obtained from heat, only the exergy component of the heat content can be transformed into mechanical work and subsequently into electricity, whereas the remaining heat content – the anergy – has to be evacuated (according to the second law of thermodynamics) to a colder source which, in general, is the ambient environment. Exergy is, therefore, defined as the maximum mechanical work obtainable from an energy carrier at a certain temperature in an irreversible transformation down to the ambient temperature. The higher the exergy component, the lower the share of the anergy content, i.e., the lower the loss by heat which at ambient temperature has no further utilization value. This is the explanation for the interest in pursuing power heat cycles with the highest possible and technologically acceptable live steam parameters and for the handicap of present nuclear power stations with water-cooled reactors, which are limited to saturated steam of relatively low pressure. However, in spite of all efforts, and even with the best and most sophisticated layouts of modern steam power stations, the aforementioned practical efficiencies of around



1 Incoming fuel flow - coal
2 Combustion air
3 Released ash
4 Flue gases
5 High-pressure superheated steam flow to the turbine
6 Cooling water
7 Make-up water heating
8 Chemical pretreated water to compensate the cycle losses
9 Outgoing electricity flow

I–VIII define the typical operational compartments of the power plant

FIG.6.16. The energy and mass flow in an electrical steam power plant [6.7].

40%, with the prospect of adding in the future a few more percentage points, leave these largest thermal power producers at a rather unsatisfactory performance level. The main reason for this is the relatively high heat content evacuated in the cooling water or cooling towers for each useful generated kW.

As far as the optimal commercially available steam-condensing power plant is concerned, the base parameter would be 240 bar, 538°C/572°C/566°C. The net heat rate for a 725 MW block would be 9750 kJ/kW·h, including all auxiliary consumption, by cooling tower operation, i.e. a net efficiency of 37% [6.8].

An improved or advanced design could further reduce the net heat rate by 10%, i.e. 8970 kJ/kW·h, raising the live steam parameters to 310 bar and 593°C with two intermediary steam superheating stages at similar high temperatures. The net efficiency would increase over 40%, the optimal outlay capacity is 750 MW.

Both the base and advanced plants are technically and economically competitive with other power-generating options, even when including the most stringent measures regarding SO_z, dust and NO_x emission and measures to reduce heat, chemical and waste environmental effects [6.8].

The specific investment costs (\$/kW installed) are presented in detail in chapter 11, dealing with conventional thermal and nuclear power costs. For example, Figs 11.1 and 11.2 show the specific investment costs of coal- and oil-fired power plants in their evolution between 1960 and 1983 and compared to those of nuclear power stations. Figure 11.3 gives figures for different power plant size in constant US \$/kW(e) while Fig.11.6 displays the kW·h costs, also depending on the plants' size.

Under the same heading, some less current steam power plants could be included, for example: municipal waste burning power plants [6.9], industrial power plants supplying in addition to electricity, or even exclusively, compressed air or driving directly industrial machines, all of them possibly also designed for co-generation.

6.2.2.2. Gas turbine power plants

The gas turbine is a useful and reliable prime mover that can be run on a variety of liquid and gaseous fuels. It is extremely compact, having a higher output per cubic metre of occupied space than any other prime mover; this is conducive to low building and foundation costs. It is smooth-running and can be started and loaded with great rapidity. Both the capital costs and maintenance costs are unusually low; but the efficiency is only moderate unless relatively high capital expenditure is incurred. The auxiliaries are few, and the plant is simple to operate and can easily be arranged for remote control. The requirements of cooling water are either nil or negligible, and this makes the gas turbine a suitable prime mover for arid countries; it also enables the power plant to be located close to the load centre without being dependent upon riverside or estuary sites.

Gas turbine generators are now produced in large sizes well in excess of 100 MW, but several good small machines can also be obtained within the range of sizes usual for diesel plants.

The gas turbine generators can take various forms. First, there are 'open-cycle' and 'closed-cycle' plants. The latter type has the advantage of keeping the turbine free from contaminating deposits, but it has high capital cost and is restricted to a very small range of applications. It is the open-cycle plant that more often attains importance in power generation. These open-cycle plants can be built to a varying degree of complexity, according to the relative weight attached to capital cost on the one hand, and efficiency on the other. Sophisticated plants may be provided with recuperators, inter-coolers or reheating. Differences in first cost may be bartered for differences in efficiency, and the type of plant best suited to a particular task will depend mainly upon the fuel price and the expected plant factor.

Gas turbines transform the latent heat of fuel into useful mechanical power. If a generator is added, this mechanical power can be converted to electricity. Despite their complex appearance and multitude of internal components, all gas

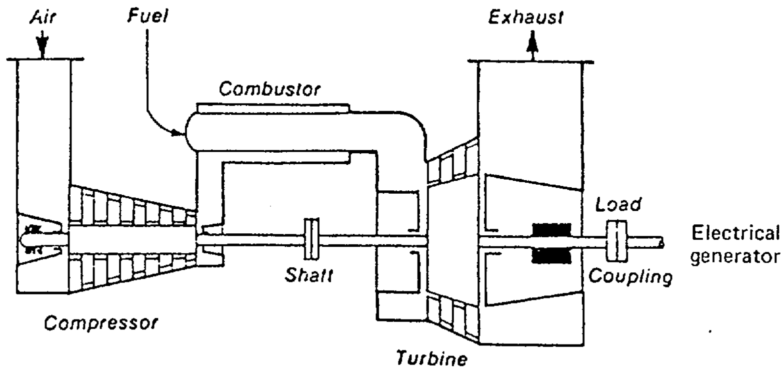


FIG.6.17. Simple open-cycle gas turbine [6.10].

turbines rely on three pieces of equipment to effect the conversion: a compressor, a combustor and a turbine. The overall operation of the simplest gas turbine, an open-cycle unit, is shown in Fig.6.17 [6.10]. As the compressor rotates, it sucks in ambient air, pressurizes it, and forces it into the combustor in a steady flow. No heat is added to this stage; however, the temperature of the air rises upon compression.

In the combustor (combustion chamber), the pressurized air combines with injected fuel (oil or gas). As the burning fuel releases thermal energy, the temperature rises substantially.

The high energy combustion gases then expand in the nozzle section of the turbine (just as steam does in a steam turbine), and their temperature and pressure drop as they do work on the turbine buckets. Roughly two-thirds of this work never leaves the machine; it is needed to keep the compressor spinning. The remaining one-third represents the turbine's useful output, which drives an external mechanical load through a shaft coupling. This may seem like a large proportion of work to sustain the cycle, but it is typical for any heat engine that converts the energy in hot gases directly to mechanical work.

After doing work in the turbine, combustion gases leave the machine through the stack at atmospheric pressure and high temperature.

Thermodynamically, as commented upon, a heat engine can attain high efficiencies only if the temperature of heat intake is high and if the temperature of heat rejection is low. The simple-cycle gas turbine satisfies the first requirement since inlet temperatures normally range from 650°C to 900°C. However, it does not satisfy the second condition and the chief source of losses in this type of plant is in the exhaust gases. The use of recuperators can reduce the losses and raise the efficiency, but the expense of doing this cannot always be justified. In general, the efficiency of a gas turbine plant can vary over a very wide range according to the size of plant, the turbine inlet temperature, and the degree of sophistication of the cycle; as with other power plants, it is

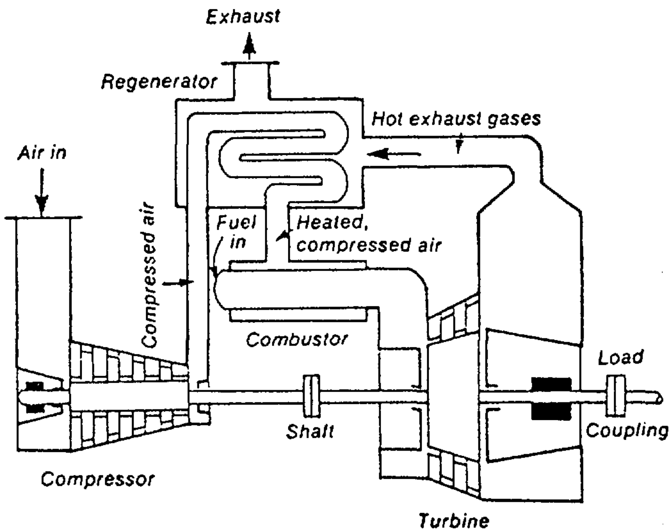


FIG.6.18. Open-cycle gas turbine with recuperator (regenerator) [6.10].

possible to trade capital outlay for fuel savings. Overall efficiencies (based on net heating value and kW·h put out) usually lie between 15 and 23% for simple open-cycle plants and between 21 and 27% for recuperative open-cycle plants. Still higher efficiencies – up to 32–33% – are obtainable from elaborate two-shaft or three-shaft plants having inter-coolers, recuperators and reheat. Closed-cycle plants can also attain efficiencies up to 33%. Efficiency is sensitive to ambient temperature, on the pressure losses in the air and gas ducting, and upon the loading of the plant. Although altitude affects output, it has little effect upon efficiency.

As mentioned, an obvious way to improve the thermal efficiency of an open-cycle gas turbine is to recover some of the energy-rich exhaust and to add it to the cycle at the highest possible temperature. This is done by adding a regenerator (Fig.6.18).

A regenerator (or recuperator) is nothing more than an extended-surface, counter-flow, one-pass heat exchanger, which transfers exhaust heat to the compressed air before it enters the combustor. Its purpose is to reduce the amount of fuel needed to heat the air to combustion temperature. Since it frees more fuel for combustion, a regenerator can cut fuel consumption by up to 25%.

In addition to the large utility unit, there are two basic types of industrial gas turbines: heavy-duty and aircraft derivative. Aircraft derivative types are light-weight units modelled after familiar jet engines, while heavy-duty machines combine the rugged mechanical construction of utility-size gas turbines with the light weight and compactness of aeroderivative gas turbines.

With the single-shaft type, a single gas turbine and its air compressor are mounted on the same shaft, and the electrical generator is driven either directly or through gearing from that shaft. A two-shaft gas turbine has two separate turbine units: one is directly coupled to the air compressor, and the other – the power turbine – is mounted on a separate shaft which runs at a different speed and drives the electrical generator. The single-shaft type is mechanically simpler, can be run up to speed very quickly, has fewer bearings and has better governing response to changes of load; but the two-shaft type gives better part-load efficiency.

Open-cycle gas turbines can be run on the same wide range of fuels as diesels; that is to say on natural gas, methane, certain industrial or waste-product gases (such as blast-furnace, refinery or sewage gases), light distillate oils and even on Bunker C oils. The chief problems with residual oils arise from their ash content, and since the ash must pass with the gases of combustion through the turbine, the quantity of ash must be low and, chemically, it must not contain harmful ingredients that will rapidly damage the turbine blades.

The gas turbine is even more sensitive than the diesel engine to site conditions. The output of a gas turbine is usually specified for operations at sea level and for an ambient air temperature of 15°C. The reduction of air density with rising temperature and altitude causes a falling-off in the weight of air entering the combustion chamber, and therefore, in the quantity of fuel that can be burnt without exceeding the permissible turbine inlet temperature, so that the power output must fall. For every 300 m of altitude above sea level, a gas turbine must be derated by about 3% and for every 10°C of ambient temperature above 15°C it must be derated by about 10% or more. Conversely, in cold weather it is possible to obtain a high output from a gas turbine, provided that it is coupled to a sufficiently large generator. This feature is sometimes regarded as an advantage in places where the winter demand for electricity exceeds the summer demand.

For peak-load duties, it is well to adopt the simplest of all possible cycles so that the fixed cost may be kept to an absolute minimum. Simple open-cycle gas turbines, devoid of all sophisticated complications, will be the most suitable for peak-load operation, even though their efficiency may be rather low.

The recently commissioned, world's largest one-shaft 120 MW gas turbine, installed for peaking operation, also constitutes a quick reserve. It is able to start and reach its full capacity in 13 minutes, even in six minutes when urgent intervention is required [6.11].

6.2.2.3. Combined-cycle gas/steam power plants

Combined-cycle installations vary widely in size, from 15 MW or so to well into the hundreds of MW range. Operation on natural gas, distillate and heavy oil fuels have all been demonstrated in plants located in widely diverse environments.

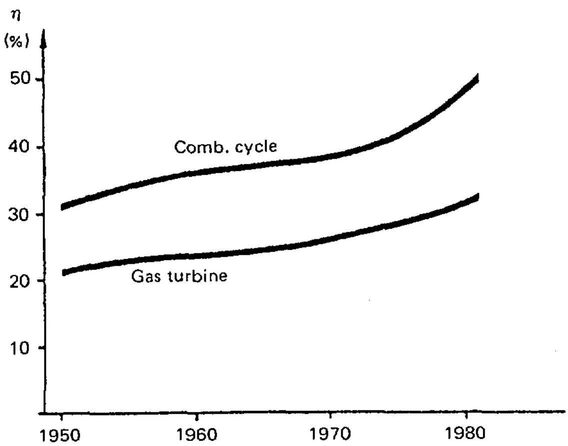


FIG.6.19. Evolution of efficiency of combined-cycle systems and gas turbine plants [6.12].

The characteristics of these systems which contribute to their outstanding economics are high thermal efficiency and low installed cost. The requirement for fuel conservation is well served with fuel cost savings approximating 10–20% compared to operation of the currently next most efficient power generation system, modern steam plants burning gas or fuel oil.

Factors conducive to low installation costs are the gas turbines themselves, which traditionally have been the power generation equipment, with the lowest installed cost, and other pre-engineered and highly factory-packaged equipment which substantially minimizes site construction costs. Capital investment shows about a 25% saving compared to a conventional steam plant, with erection cycles being roughly $2\frac{1}{2}$ years in most cases.

Schedules can be arranged also so that the gas turbine portion of the combined cycle is installed first, in less than one year, with power being generated while the steam system is being installed. The gas cycle produces revenue for the utility and results in minimum interest during construction, which is further reduced by the two-phase installation.

The thermal efficiency of combined-cycle systems is superior to that of other power systems because the thermodynamic cycle has the highest source/sink temperature ratio of any power-and-steam-generating equipment currently available. The source temperature is the gas turbine firing temperature, which for current generation gas turbines is in the range of 1100°C. The sink temperatures are approximately 40°C to 150°C. These are the heat rejection temperatures for the steam and gas cycles, respectively. With today's large, high-specific-work gas turbines, combined cycle efficiency may reach 42–46%.

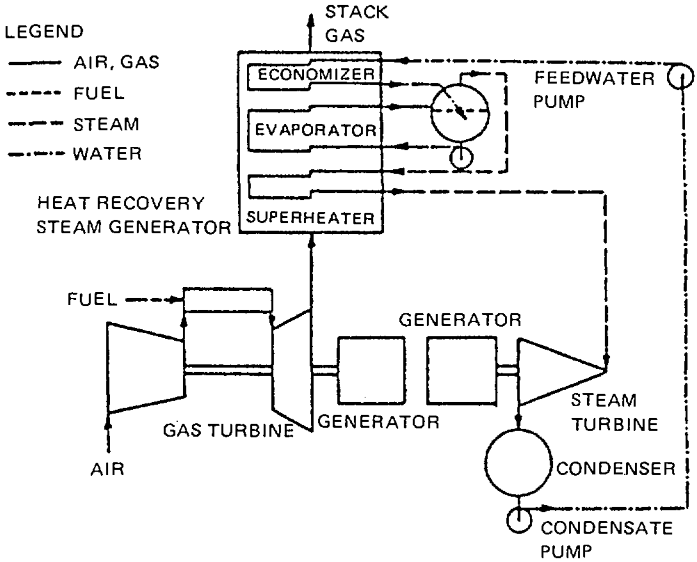


FIG.6.20. Cycle diagram for unfired HRSG combined cycle [*6.13*].

Figure 6.19 presents the evolution of the efficiency of combined-cycle systems since 1950 compared with the efficiency of straightforward gas turbine plants [6.12].

The systems vary principally in the type of equipment used to transfer the exhaust heat to the steam cycle and the amount of fuel that is burned in the steam cycle. Three major categories relate to the amount of fuel used in the steam generator. These range from 0–80% of the total fuel fired. The most common combined cycles are those with unfired heat recovery steam generators (HRSGs). Systems with moderately fired HRSGs have been employed with 10 to 30% of total fuel fired in the steam generator. Fully fired combined cycles use conventional steam generators with radiant furnaces. In these systems, fuel fired in the steam generator ranges from 30–80% of the total used. All of these cycles have been used for utility and industrial power and steam generation [6.13].

The current trend is towards the increasing application of the unfired HRSG steam cycle. In combined cycles of this type, approximately two-thirds of the total plant power is generated by the gas turbine and one-third with the steam turbine. In world areas where drinking and cooling water is in short supply, this cycle has a distinct advantage. Heat rejected to the steam turbine condenser is only about 40% of that for a conventional steam installation on a total plant MW basis. The reduced water requirement offers the user greater flexibility in local siting and plant arrangement.

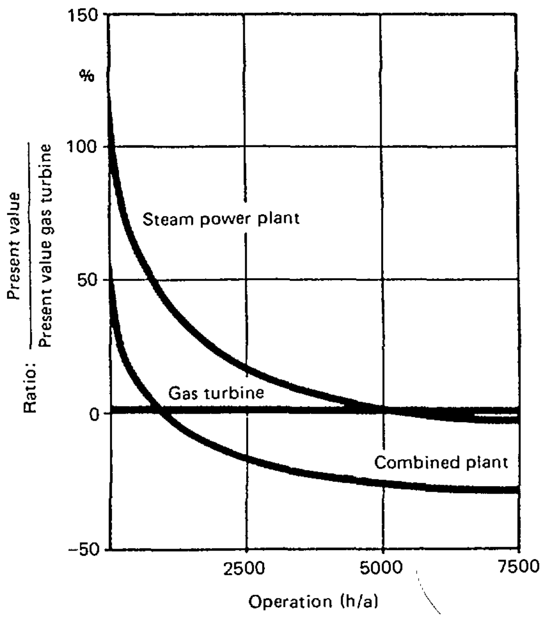


FIG.6.21. Present-value comparison between combined-cycle, gas turbine and steam power plant alternatives [6.12].

Figure 6.20 presents a cycle diagram for a simple steam cycle with unfired HRSG. The cycle employs a non-reheat steam cycle with no extraction feedwater preheaters and operates at modest steam conditions, 30–60 bar pressure and 425–510°C temperature.

The rapid startup capability of a combined-cycle plant is another of its many key advantages. Those systems using unfired steam cycles and which can produce up to two-third of the total plant power with the gas turbines can be at full rated power in well under 20 minutes. The availability of the remainder of the plant depends on the condition of the steam turbine when starting. For a steam turbine in a hot stand-by condition, the total plant is available within 45 minutes. After a prolonged state when the steam equipment is cold, the total startup is accomplished in 2½ hours.

An economic comparison is shown in Fig.6.21 for three alternatives: combined-cyle, gas turbine and steam power plants, supposing that all three use the same liquid fuel. The comparison is based on the present values of the difference (revenue – costs) referred in % to the gas turbine figure.

The combined-cycle alternative appears as the most favourable solution – except for less than 1000 h/a utilization, which is not a practical case – over all other utilization durations. This result, valid where all alternatives use liquid fuels [6.12], may change if the steam power plant is fired with cheaper coal, and in the short term coal could be in this situation. However, in the long run, the price of coal would probably asymptotically approach petroleum prices, and the conditions of Fig.6.21 remain valid.

A further advanced alternative is the coal gasification combined cycle (CGCC), which combines several well-known technologies: coal gasification to produce a low- or medium-heat-content gas, gas turbine technology and steam cycle with heat recovery boiler experience. Figure 6.22 shows the thermal diagram of the CGCC, with a more detailed representation of the gasifier. Figure 6.23 displays the calculated kW·h costs – at 1985 level – for the CGCC solution compared to two other alternatives: combined cycle operated with distillate oil, and coal steam power plant.

The combined CGCC plant would consist of four gas turbines producing 393 MW(e). The exhaust gases from these four turbines will produce enough steam to drive a steam turbine producing an additional 285 MW(e), of which approximately 43 MW(e) is required for in-plant use. Net power output is about 636 MW(e). Each combustion turbine will be serviced by several gasifier modules. By using multiple gasifiers, each reactor can be made small enough to allow for shop fabrication, thus reducing overall costs. Additional units for the gasification section can be modularized as standard sizes and shop fabricated, adding to the cost savings.

The largest combined-cycle gas/steam power plant yet built is the 2000 MW plant ordered by the Tokyo Electric Power Company. It comprises two 1000 MW plants each built up from seven units [6.15]. Each of these units will have a gas turbine and a steam turbine and generator on a single shaft with an unfired heat recovery steam generator supplying the steam turbine.

The plant will burn LNG at a gross thermal efficiency, based on the lower heating value, of 47%. Output from each of the combined-cycle plants is about 143 MW at the stipulated rating point of 32°C ambient. Due to the low sulphur content of the fuel, extensive heat recovery is possible in the boiler using a two-pressure system. Thus heat is taken from the gas turbine exhausts at 538°C and the gas is discharged from the boiler at 107°C. This high efficiency is maintained over much of the operating range and the use of gas turbine and steam turbine on a single shaft, each with its own dedicated steam generator, means that no separate steam turbine load controls are required and there is no need for a gas bypass.

Tokyo has very strict limits on nitrogen oxide emissions – very much tighter than those in the USA, even though these are regarded as strict by international standards. Thus, in general, the US NO_x requirement is less than 75 ppm; in parts of the USA such as California the limit is 40 ppm. In Tokyo the requirement is for a quarter of this. To achieve it requires costly solutions.

The technique selected for the TEPCO plant is to inject steam into the gas turbine combustor. Doing this reduces the thermal efficiency slightly and also

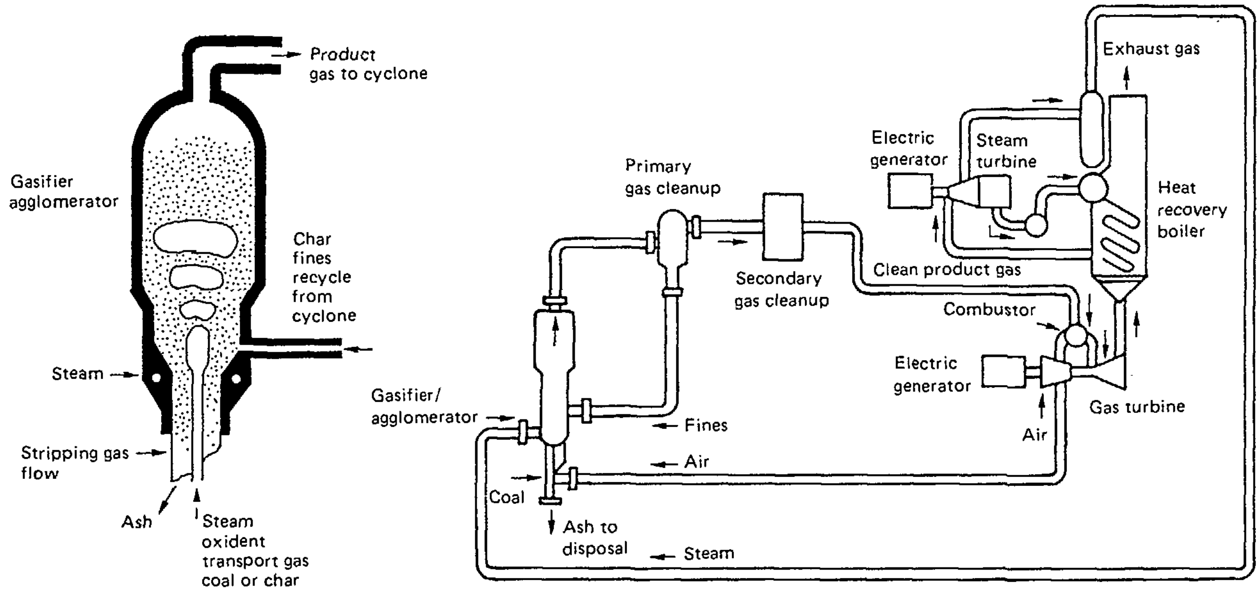


FIG.6.22. Diagram of coal gasification combined-cycle plant and a more detailed representation of the gasifier [6.14].

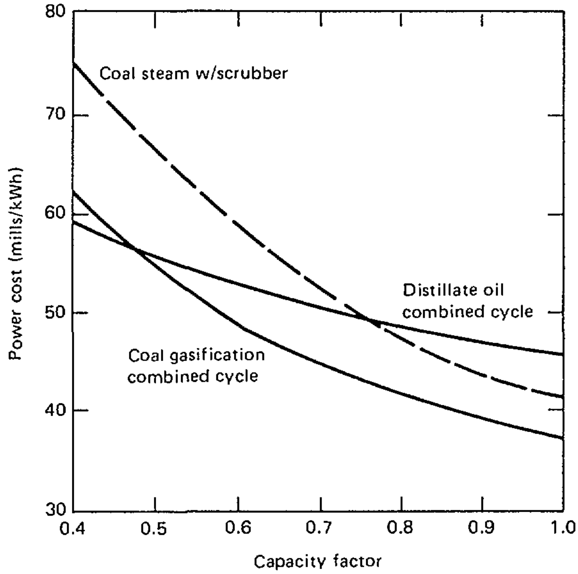


FIG.6.23. Alternative power costs for 1985 operation (CGCC, coal steam and combined cycle with distillate oil) [*6.14*].

requires additional make-up feedwater, but it critically reduces the NO_x emissions.

The NO_x reduction system constitutes a significant percentage of the total cost of the plant and though it is the key to acceptability in Tokyo, the high cost relative to the results achieved could only be justified for locations where NO_x emissions are of the utmost concern.

A quite interesting line of development for combined cycles appears in the co-production of electricity and methanol [6.16]. Except for its cost, methanol would be an almost ideal turbine fuel for generating electricity. It contains no sulphur or nitrogen compounds or ash that can cause air pollution. It burns at a relatively low temperature, which inhibits formation of nitrogen oxides, and it can be easily transported and stored. Co-production of electricity and methanol could very much benefit from a very attractive new technology – the coal gasification-combined-cycle power plant. To integrate methanol production into a GCC plant involves placing the methanol synthesis reactor between the gasification system and the gas turbines. Removing some of the combustible gases from this stream to produce methanol would lower the net power output of the plant by about one-quarter, but the value of the methanol produced would more than compensate for the loss because methanol can replace the expensive oil used in peaking- and intermediate-load generators.

In fact, progress in coal and nuclear gasification, together with the advanced technology of combined gas/steam power plants, open wide possibilities for

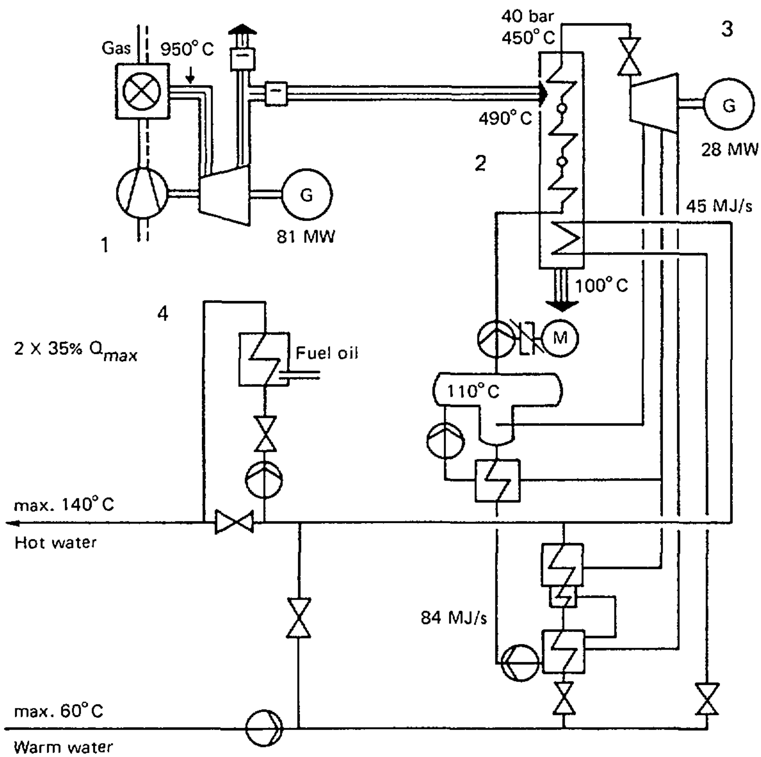


FIG.6.24. Combined-cycle gas/steam co-generation power plant [6.17].

future electric power generation, which might be even enhanced by co-generated heat utilization for long-distance district heating schemes. For further reading a few more articles are indicated in the bibliography.

Another interesting application of combined gas/steam cycle would be as co-generation power plant which would reach the highest ratio of generated electricity per unit of heat delivered. Figure 6.24 displays the thermal diagram of such a co-generation plant and the heat delivery to the urban hot-water network – see also chapter 8 [6.17].

6.2.2.4. Diesel power plants

The diesel engine is an extremely versatile and useful prime mover. It is obtainable from a large number of manufacturers in many countries, and the market is, therefore, competitive.

The diesel engine is generally suited to the combustion of light distillate oils, but can also be run on certain gases. Diesel engines of about 1 500 kW rating and over can sometimes be adapted to burn medium-heavy residual oils (which are generally much cheaper than light distillate oils) provided the speed is not excessive. Whereas the use of these heavier, cheaper fuels has until recently been confined to engines of low speed – say 250 rev/min or less – the modern trend is for higher-speed engines to accept such fuels, and this is greatly extending the scope of the diesel electric generator. Thus, over the whole range of diesel plants, a wide variety of fuels can be used.

The diesel engine can be quickly started up and brought into service; it is efficient, reliable, cheap in first costs and has low stand-by losses. If well-maintained, it can run for long periods between overhauls and will have low wear rates. Maintenance can be simplified by the provision of easily replaceable assemblies of parts, thus enabling reconditioning to be undertaken away from the manufacturing plant. Manufacturing periods are short and a diesel power station may, therefore, be rapidly extended by adding suitably sized units to meet growing electricity demands.

Diesel sets for power generation are obtainable over a wide range of running speeds. As a broad classification, it is convenient to regard speed as being divided into the following categories (approximate limits, regardless of whether 50 or 60 cycles): low speed: from 80 rev/min to 300 rev/min; medium speed: from 300 rev/min to 600 rev/min; high speed: from 720 rev/min to 1800 rev/min.

High-speed sets are of more compact design and, therefore, have a lower weight per kW than low-speed units. This broadly means that the high-speed diesel/electric set costs less per kW not only in FOB price, but also in transport, foundations, and building costs. On the other hand, low-speed sets tend to have slightly higher efficiency, to consume less lubricating oil, to have lower wear rate, to incur lower expenditure in repairs and maintenance, to be more dependable and to be able to run for longer periods between overhauls [6.18]. For example, a 450 rev/min engine can probably run for at least twice as many hours between major overhauls as a 750 rev/min engine.

The choice of rotational speed will be a matter of compromise between these pros and cons according to prevailing circumstances. For the generation of alternating current without the use of gearing, the speed must of course be suitable for producing electricity at the required frequency – i.e. for direct coupled sets, it must be an integral fraction of 3000 rev/min for 50 cycles and 3600 rev/min for 60 cycles; but this still leaves a very wide choice of available speeds.

Diesel engines can be either naturally aspirated or supercharged. A supercharged engine is supplied with an air compressor which enables a heavier charge of air, and therefore, of fuel to enter the cylinder. The addition of an air cooler further increases the weight of the cylinder charge. By fitting a supercharger and air cooler, the power output from an engine can be raised by about 50% and the efficiency can be improved by about 3.5–4%. In fact, almost all diesels of 1000 kW or more are supercharged, and the modern tendency is to adopt supercharging to an increasing extent in smaller and smaller engines.

Except for very small high-speed sets, it is necessary to provide diesel engines for power generation with water cooling. To avoid the sealing up of the water passages in the engine, the primary cooling water circulates around a closed circuit.

The diesel engine is the most efficient of the smaller fuel-consuming prime movers. Efficiency varies with the load for any given engine, but less so than with gas turbines or steam turbines; in any case, this variation is slightly over the range of half to full load, particularly with supercharged engines. This makes the diesel very suitable for variable-load duties (though at very light loads, the efficiency deteriorates rapidly, in common with other prime movers). Unless a diesel is very much underloaded, it will usually be found that the average efficiency of a diesel-driven generating plant will lie between 31.5% and 37.5% (on a basis of net heating value and kW·h generated). The higher figure could be lower with a small, high-speed, naturally aspirated plant. Optimum efficiencies at economic load would be rather higher than these average figures – say 33–39%. Two-stroke medium-speed engines might consume perhaps 4–5% more fuel than four-stroke engines of the same speed and power. Where the load factor is very low, the average annual efficiencies may be considerably lower than the figures quoted above. For micro-sets in the 15 to 30 kW range, the mean efficiency may be as low as 24–25%.

Where there is a demand for supply of hot water or steam for heating or process purposes, it is possible to recover a large amount of the heat that would otherwise be wasted in the exhaust gases and in the engine-cooling water. A well-designed waste-heat recovery plant can sometimes ensure that up to 75% or more of the heating value of the fuel is recovered either as electrical energy or as usable heat.

The rated continuous output of a diesel engine is usually quoted by manufacturers on the assumption that the plant is to be operated at lower altitudes (less than 200 m above sea level) and in an ambient temperature not exceeding 30°C and a cool-water temperature of 25°C. For more arduous conditions, it is necessary to derate engines, for example for every 300 m higher altitude by 3% (naturally aspirated engines) or 2% (turbo-charged engines) and for every 10°C above 30°C by 2 or 3% respectively.

Apart from oils of various grades, certain gases can be used for driving diesel engines. Natural and industrial gases, methane and low-heat-content gas can all be used in this way. Diesels are obtainable which are suitable for dual firing – oil and/or gas. Oil must always be used for starting up such engines and can also be used as a stand-by fuel.

6.2.2.5. Other thermal electricity generation patterns

There are three more thermal electricity generation technologies: MHD, fuel cells and Stirling engines. All of them are in advanced stages of research and development but none has reached effective commercial availability.

6.2.2.5.1. Magnetohydrodynamics (MHD)

MHD – standing for magnetohydrodynamics – is a conversion process where heat energy can be converted directly into electricity. Fossil fuels may be burnt at very high temperatures (2800 K to 3000 K) with preheated air and/or oxygen enrichment. An easily ionizable substance (alkali salts) called a seed, is added to produce an electrically conducting gas (plasma). This gas is expanded at high speed through a channel with an applied transverse magnetic field. An electric potential is induced on two opposite walls of the generator and electric power can be extracted.

By installing an MHD generator as a topping plant in a conventional power station, efficiencies of 45–50% may be achieved using established technology and 55–60% with second generation development. The useful power range extends from 20–2000 MW(e), the lower range being suitable for co-generation applications.

Extensive research and development programmes have been established in many countries. These programmes cover direct gas-, oil-, and coal-fired MHD plants, as well as combined gasification/MHD/steam plants. A 250 MW(th) gas-fired power plant, the U-25 in Moscow, has been operational since 1972, and the USSR is constructing a 500 MW(e), i.e. 1100 MW(th) power station, the U-500 at Ryazan near Moscow, which is planned to be operational in 1985–1986. Several other 5 to 10 MW(th) facilities are being used in the USSR to develop gas- and coal-fired MHD [6.19].

Coal-fired MHD is being most intensively studied in the USA, with several 10 to 20 MW(th) coal-firing and simulation coal-firing experiments in progress. A 50 MW(th) system using oil or coal is currently operational. Japan has been operating a 10 MW(th) facility since June 1981. China has available several test facilities and is actively studying oil- and coal-fired MHD. India has a national programme to integrate coal gasification with an MHD/steam binary cycle. Poland has acquired extensive experience with a 4 MW(th) cyclone MHD coal combustor. Australia is operating a 4 MW(th) MHD facility. Along a different line, the Netherlands is studying fossil-fuel-fired, closed-cycle processes and has successfully operated a 5 MW(th) blow-down facility at Eindhoven [6.20].

MHD/steam electric power generation can offer higher efficiency and improved utilization of coal resources, as well as a reduction in the cost of electricity, as predicted by a number of recent substantial studies. It might become of great impact, especially if used on a large scale.

6.2.2.5.2. Fuel cells

Fuel cells are, similar to MHD, devices for direct conversion of fuel energy into electricity, and therefore, not subject to the limitations of intermediate conversion via mechanical energy.

Although the principle has been known since the last century, the fuel cell process has developed very slowly. The first practical applications have been in the US space programme, in the form of H_2/O_2 cells, fuelled with hydrogen.

With this type of cell, the well-known electrolysis of water is reversed. Hydrogen gas is oxidized at the anode in a 30% solution of potassium hydroxide, while oxygen is reduced at the cathode. The chemical equations of the process are:

$$\begin{array}{lll} \text{Cathode:} & \tfrac{1}{2}O_2 + HOH + 2e^- & \rightarrow \quad 2OH^- \\ \text{Anode:} & \underline{H_2 + 2OH^- \qquad\qquad} & \underline{\rightarrow \quad 2H_2O + 2e^-} \\ \text{Cell:} & H_2 + \tfrac{1}{2}O_2 & \rightarrow \quad H_2O + 286\ \text{kJ} \end{array}$$

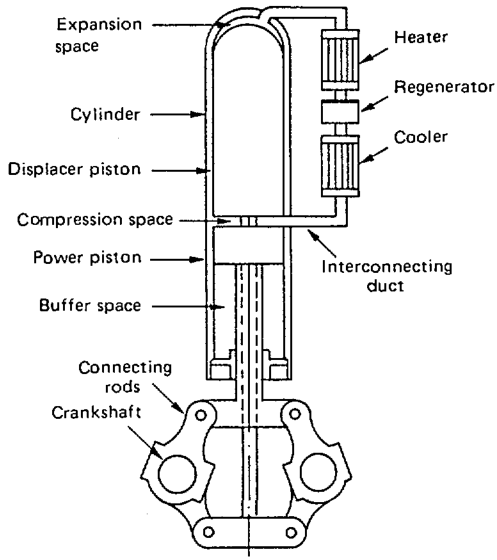
The fuel cell supplies electric current to a load connected between electrodes when these electrodes are fed with hydrogen and oxygen. The end-products of this reaction are water and heat, which dilute and heat up the electrolyte.

The advantage of fuel cells is that it is possible to store fuel such as hydrogen for an unlimited period of time without losses. As against accumulators, the rated power and hence the cost of the fuel cell generator depends only on the output power required.

The efficiency of this fuel cell is relatively high, 50% at the rated power and increasing to 60% at reduced load. Other advantages of fuel cells are that they are completely free from noise and vibrations, have no noxious emissions, and have low maintenance requirements, etc. [6.21]. Because of all these advantages, research and development of fuel cells are actively under way, both for a variety of materials for electrodes as well as for fuel inputs. In addition to the uses for decentralized electricity generation, fuel cells might develop as important devices for peak-load supply from suitably stored fuel. A 4.8 MW fuel cell power plant being started up in New York City may be the forerunner of 10 MW systems that will begin to see utility service within the decade.

6.2.2.5.3. Stirling engines

Stirling engines are a potentially advantageous alternative to diesel, combustion turbine, and steam turbine electricity generators due to their potentially higher thermal efficiency, greater fuel flexibility, good part-load characteristics, low emissions, and low noise and vibrations. Figure 6.25 shows the scheme of a Stirling cycle engine. Gas (e.g. hydrogen, helium) entrapped by a piston is alternately compressed and expanded to turn a crankshaft. Because the pressure during the hot expansion step is significantly greater than during the cool compression step, there is a net work output from the engine.



SOURCE: Application of Solar Technology to Today's Energy Needs, Volumes I and II (Washington, D.C.: U.S. Congress, Office of Technology Assessment, 1978).

FIG.6.25. Scheme of a Stirling engine [8.1].

Small generator sets are now being produced, powered by Stirling engines able to run on various fuels. From standard, packed, portable units of a few kW [6.22] the trend is to a few hundred kW and possibly units up to 1 to 1.5 MW by 1990 [8.1].

6.2.3. Wind power stations

Wind energy features have been described in subsection 3.2.3. In addition to the numerous mechanical energy applications – windmills, wind-pumps, etc., wind energy is now resolutely entering the area of electricity generation. After a series of smaller designs, slowly increasing in capacity from 40–50 kW to a few hundred kW, the MW range has now been reached, either by wind farms [6.23] or large single units. In the higher range for example the Growian 3 MW wind power plant was commissioned in December 1983 in the Federal Republic of Germany [6.24], a 7.3 MW prototype wind turbine-generator was ordered for Hawaii [6.25] and in the USSR a project for a 40 MW wind power plant, consisting of eight wind rotors placed on a 200 m high tower, is in execution [6.26].

TABLE 6.I. AVERAGE CONSTRUCTION TIME OF NUCLEAR POWER PLANTS (TIME IN MONTHS FROM START OF CONSTRUCTION TO GRID CONNECTION)[a] [6.28]

Status \ Group	All plants in PRIS	All LWRs in PRIS	All LWRs in France	All LWRs in Federal Republic of Germany	All LWRs in Sweden	All LWRs in Japan	All LWRs in USA
Plants in operation	67.6 (238)	66.5 (184)	65.1 (22)	62.7 (12)	65.2 (9)	50.8 (23)	72.4 (74)
Plants under construction	100.3 (179)	98.5 (140)	62.1 (25)	104.2 (7)	77.3 (3)	57.6 (9)	126 (55)

[a] Figures in parentheses indicate number of units.

6.2.4. Nuclear power plants

The technical aspects of nuclear power plants have already been discussed in chapter 4 as far as the nuclear part of the plant was concerned. Regarding the classical part, more comments would be hardly significant in this framework since the aspects are very similar to those of large steam-condensing power plants with the exception of the low live steam parameters of the nuclear power plants. These lead to much lower thermal efficiencies, which after a minimal 19% at Calder Hall (1956) increased between 1962 and 1967 with the improved Magnox reactor to 22–28%. The parallel developing LWR and CANDU have net efficiencies depending also on the turbo-generator size, between 32 and 34%. The only reactor type in operation which allows thermal efficiencies in the order of magnitude of the large fossil-fuel steam power stations is the AGR, which in Hunterstone and Hinkley Point B reached over 37% [6.27]. Evidently, low efficiencies result in much larger material flows to handle for a similar electrical output, larger and heavier thermomechanical equipment and substantially larger discharges of waste heat into the environment.

However, a few brief comments relating to construction of nuclear power stations, operational experience, dismantling and specific nuclear safety aspects might round off the subject. They are all based on IAEA materials since the Agency regularly collects relevant data on nuclear power plants and publishes each year, among others, the following three documents:

(a) Nuclear Power Reactors in the World
(b) Operating Experience with Nuclear Power Stations in Member States
(c) Performance Analysis Report.

6.2.4.1. Construction of nuclear power plants

For the reasons discussed in detail in chapter 11, regarding the economic aspects of electricity generation, nuclear power plants included, short construction times are highly desirable. However, experience in recent decades has been rather disappointing in this respect.

Table 6.I shows a selection from the IAEA documentation of average data about construction time of nuclear power plants, in a fairly rough grouping of plants now in operation and under construction [6.28]. Construction time has in this table been defined as the time between start of construction, i.e., first placing of concrete, and connection of the plant to the grid. Already from this simple presentation it is clear that average construction times have been increasing drastically, from an average of about 68 months for currently operating plants to 100 months for those now under construction. The construction times for the plants in operation in Table 6.I are those actually achieved; those for plants under construction are the schedules reported to the IAEA. The latter are, naturally, more uncertain but they are unlikely to be shortened in actual project execution. The

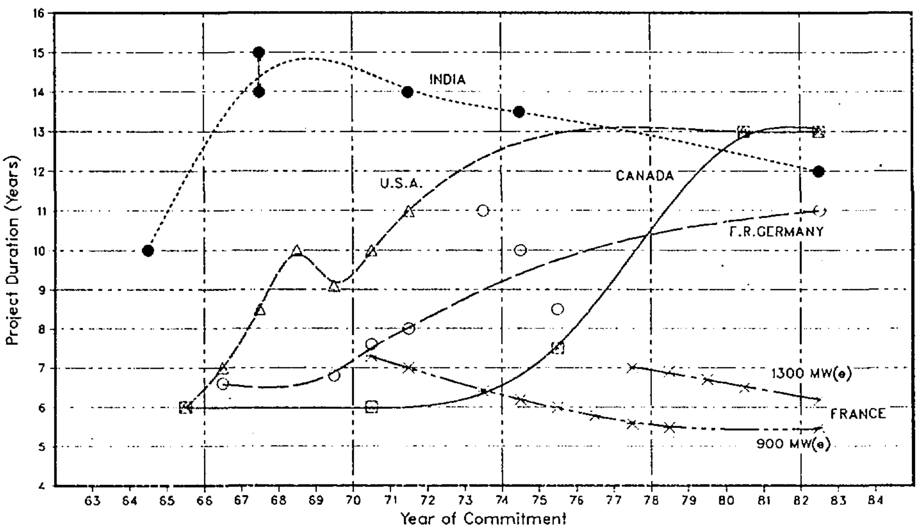


FIG.6.26. Trends of average project time for nuclear power plants in various countries [6.28].

increase in construction time is, however, not valid for all countries. It remains about constant in Japan and France at some five years, while a drastic increase to about ten years has occurred in the USA, and to nine years in the Federal Republic of Germany. A doubling of the construction time has the already mentioned aggravating economic effects besides creating major uncertainty as regards any electricity supply planning which such long project times entail.

In contrast to Table 6.I, Fig.6.26 refers not only to the actual construction time on site, but displays historical data and trends on nuclear power plant project duration between 1965 and mid-1982, based on IAEA studies [6.28]. The difference between the data relates to the time period when preparatory activities took place, i.e., engineering work and site preparation.

How frustratingly engineering input can escalate is singled out in Fig.6.27, which refers to a nuclear power station in the Federal Republic of Germany [13.22]. The figures show how the initially planned engineering input of 1 100 000 man-months, actually escalated to 3 850 000 man-months, contributing to the delay of the plant's commissioning from planned end-1978 to end-1981, i.e. three years [6.29].

As a matter of fact, very few plants were ever built on the schedule contracted or planned for. Delays of one year, two years or even more due to unforeseen occurrences seem to be the rule.

Similarly, very few plants were built at the cost (including contingency) originally foreseen. Cost increases due to construction delays, additional safety requirements, and design changes and modifications have occurred in the majority of cases. But experience also shows that nuclear power plants in operation are

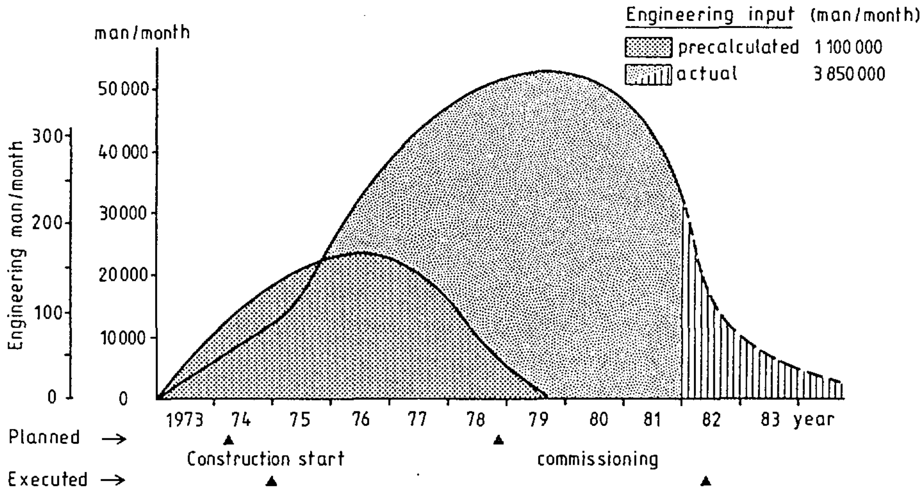


FIG.6.27. Nuclear power plant Grafenrheinfeld (FRG): escalation of engineering man-month input [6.29].

producing electricity not only at competitive costs but with substantial margins of benefit when compared with current fossil-fuel generation costs – see chapter 11.

Some major problems during construction which have occurred with a significant frequency and hence require special attention are:

(1) Inadequate site evaluation studies
(2) Interface co-ordination problems
(3) Increased regulatory requirements
(4) Delays in regulatory procedures
(5) Opposition by anti-nuclear groups or organizations
(6) Technical difficulties caused by unproven equipment, components or design features
(7) Lack of adequate quality assurance and quality control.

6.2.4.2. Nuclear safety

The record of safety and environmental protection in achieving the goals of safety in the operation of nuclear power plants is outstanding. Even with the Three Mile Island reactor accident on 28 March 1979, the worst accident in the history of commercial nuclear power generation, there have been no radiation-induced fatalities or serious injuries that can be specifically identified as caused by a commercial nuclear power plant.

The record in avoiding accidents resulting in economic loss has been far less impressive. Nuclear power plants are complex and high-capital-cost installations. A large generating plant that is not functioning is a heavy financial burden to any utility. It should be recognized by reactor designers, constructors, operators, owners and regulators that accidents resulting in severe economic loss are far more likely to occur than a reactor accident of significance to the health and safety of the general public or to the utility employees. This is because the engineered safety features are designed to prevent radioactivity from reaching the environment and people in the course of an accident. The serious accidents to date in commercial nuclear power plants have been primarily accidents with economic consequences only, because engineered safety features performed their function and protected the public. In the case of the Three Mile Island accident the costs amounted to several hundreds of millions of dollars, while the radiation health consequences were very small. Based on experience, the economic incentives alone for safety and reliability are indeed great.

Nuclear power involves the production of large quantities of radioactive materials. Protection against radiation emitted from such materials has been and still is the subject of extensive studies over a span of more than five decades.

The designers, manufacturers, owners and regulators of nuclear power plants and other facilities have recognized from the beginning the requirement for safety and have imposed stringent controls on the radioactive material associated with nuclear power plants and related fuel cycle facility operation. The achievement of safety and reliability requires a level of design innovation, quality assurance and human expertise not previously required in the electric power industry.

The principal goals of nuclear safety may be expressed as follows:

(a) Public safety. There should be no release of radioactive material, through accidental or other means, that will present a significant risk to the public. In normal operation the radiation exposure to individuals should be as low as reasonably achievable and within dose limits.
(b) Personnel safety. Radiation exposure to personnel in nuclear plants shall not exceed dose limits and shall be kept as low as reasonably achievable.

The above considerations, tersely stated in this present context, address a capital component of nuclear power development, since both public acceptance and economic viability of nuclear power as a major source of energy are entirely dependent on the achievement of a high level of safety and environmental protection. The bibliography for this chapter offers a deeper insight into the complex and challenging issues of nuclear power safety.

6.2.4.3. Reliability of nuclear power plants

Together with safety, reliability is the principal parameter of nuclear power plants. The IAEA pays it permanent attention and analyses it constantly. Such an analysis is similarly carried out for classical thermal generating plants by a joint UNIPEDE/World Energy Conference (WEC) Committee. For nuclear power plants this joint committee relies on the IAEA to provide availability and unavailability data.

The IAEA has published an annual report on operating data from nuclear plants in its Member States since 1971, covering also back data from the early 1960s. These reports have developed over the years and in the early 1970s the format was brought into close conformity with that used by UNIPEDE and WEC to report performance of fossil-fired generating plants. Since 1974 an annual analytical summary report has been prepared.

The data for the IAEA reports are supplied by national authorities or designated national correspondents in response to annual questionnaires. For the European Economic Community the EEC supplies the information centrally. The coverage is not complete but about 80% of all nuclear power plants have consistently contributed information.

Since 1973, information on nuclear power plant outages has been included in a systematic fashion. In 1981 all information for 1971–1980 was placed in a computer file for easier reference. Information for the years before 1971 is also being entered using the present definitions. The computerized Power Reactor Information System (PRIS) of the IAEA now covers more than 15×10^6 reactor operating hours or 1760 reactor years, which is about two-thirds of the total experience in the world so far (2600 reactor-years). The increase in the next five years will amount to an additional 2000 reactor-years. The available information consists of performance indices and energy production data for the period 1963 to 1980. The outage file of the system contains information about some 9000 full and partial plant outages affecting 3.3×10^6 hours of plant operation between 1971 and 1980.

PRIS contains two files, one on the current status of power reactor projects including some basic design data, and one operating experience file with data on production, outages and operation highlights in separate subfiles.

With the development of the database the objectives for its use have also changed. In the beginning the IAEA primarily wanted to provide a possibility for the individual power plant operator to compare the performance of his own plant with others of the same type. In the early 1970s enough data had been collected to provide the basis for assessment for the fundamental performance parameters used in economic project studies. At present it is felt that the database merits being used in setting availability objectives for power plant operations.

The IAEA and UNIPEDE/WEC reports use strictly defined performance factors, firstly the load and operating factors:

The load factor (LF) is the ratio between the energy that a power plant has produced during the period considered and the energy that it could have

TABLE 6.II. IAEA DATA ON UNVAILABILITY OF NUCLEAR POWER PLANTS [6.28]

	PHWR 100–599 MW(e)			PHWR >600 MW(e)			GCR 100–599 MW(e)			PWR 100–599 MW(e)			PWR >600 MW(e)			BWR 100–599 MW(e)			BWR >600 MW(e)		
Year	Capacity (MW(e))	No. of units	UF (%)	Capacity (MW(e))	No. of units	UF (%)	Capacity (MW(e))	No. of units	UF (%)	Capacity (MW(e))	No. of units	UF (%)	Capacity (MW(e))	No. of units	UF (%)	Capacity (MW(e))	No. of units	UF (%)	Capacity (MW(e))	No. of units	UF (%)
1977	2863	8	23.0	0	0	0	6653	26	22.1	9 936	24	22.7	29 604	35	33.9	6653	17	43.3	18 415	23	45.8
1978	2840	8	21.9	2220	3	21.5	6623	26	28.0	11 018	26	19.5	34 085	40	34.8	6966	17	37.5	19 288	24	33.9
1979	2856	8	20.3	2960	4	20.6	6523	26	27.7	11 612	28	29.6	40 006	46	47.5[a]	6599	15	30.6	23 289	29	36.9
1980	2856	8	21.8	2960	4	13.2	6418	26	36.5	12 042	29	31.6	43 445	49	38.7[b]	6599	15	32.4	26 104	32	41.2
Average			21.7			18.2			28.5			26.1			39.2			36.0			39.4

[a] 7.5% due to regulatory limitations after the TMI-2 accident.

[b] 3.1% due to regulatory limitations after the TMI-2 accident.

produced at maximum capacity under continuous operation during that period.

The operating factor (OF) is the ratio between the number of hours the unit was on line and the total number of hours in the reference period.

In applying the load factor as above, the definition of maximum capacity is, of course, of particular importance. It is defined as follows:

The maximum capacity of a nuclear station is the maximum power that could be maintained or is authorized to be maintained throughout a period of continuous operation, in practice 15 hours or longer.

All data and calculations refer to net capacity at the station outlet terminals.

In addition, unavailability factors (UF) are used, based on an energy definition of unavailability as follows:

Unavailability means that the available capacity is lower than maximum capacity.

Unavailability is classified as planned if it is foreseen long in advance, generally at the time when the annual overhaul programme is established, and if the beginning of the unavailability period can largely be controlled and deferred by management. All other unavailability is classified as unplanned.

The unavailability factor over a specified period is the ratio of the energy E_u that could have been produced during this period by a capacity equal to the unavailable capacity C and the energy E_m that could have been produced during the same period by the maximum capacity.

The unavailability factor over a specified period can be divided into : PUF = unavailability factor owing to planned outages such as refuelling and maintenance work, and UUF = unavailability factor owing to all other reasons.

The information about unavailability of nuclear power plants is a key feature of the IAEA's power reactor information system, which so far is unique and should be used more extensively by plant operators.

Capacity-weighted average factors are used whenever averages are given. Four major reactor types are considered in the combined statistics: PHWR, GCR, PWR and BWR. Data are, of course, also available for other plants, such as FBRs and HTGRs. The following also apply: (1) a distinction is made between small and large commercial power reactors, i.e. with outputs below and above 600 MW(e) net, and (2) only plants with an output of 100 MW(e) net and above are included.

The load factor was adequate as a performance factor for nuclear power plants as long as they were scheduled exclusively for base-load operation. In 1981 six countries already produced more than 25% of their electricity from nuclear plants (three more than 35%) and it is clear that the load factor will become unsatisfactory as the sole measure of performance as the plants begin to be operated in

TABLE 6.III. WEC DATA ON UNAVAILABILITY OF FOSSIL-FIRED PLANTS [6.28]

	Size range 400–599 MW(e)									Size range >600 MW(e)								
	Europe			USSR			USA			Other countries			USSR			USA		
Year	Capacity (MW(e))	No. of units	UF (%)	Capacity (MW(e))	No. of units	UF (%)	Capacity (MW(e))	No. of units	UF (%)	Capacity (MW(e))	No. of units	UF (%)	Capacity (MW(e))	No. of units	UF (%)	Capacity (MW(e))	No. of units	UF (%)
1977	45 856	91	33.4	1500	3	31.6	52 200	101	31.0	975	2	28.9	4800	6	23.9	52 470	72	35.4
1978	48 088	94	29.9	2000	4	29.1	66 900	128	29.9	1950	4	18.2	6400	8	20.1	57 400	79	33.5
1979	51 247	99	26.4	2500	5	29.8	70 400	135	30.1	3400	7	15.6	6400	8	21.9	61 660	85	32.2
1980	53 784	104	24.5	3000	6	24.8	83 900	160	31.1	4925	10	25.3	6400	8	19.9	69 500	95	29.6
Average			28.3			28.3			30.5			21.5			21.3			32.5

TABLE 6.IV. UNPLANNED FULL REACTOR OUTAGES 1971 TO 1980: ALL NUCLEAR POWER PLANTS [6.36]

Reason for outage		Energy lost		Time lost	
		(GW·h)	(%)	(Hours)	(%)
Nuclear system	Reactor and accessories	10 824	2.0	25 763	2.4
	Fuel	8 070	1.5	18 948	1.7
	Reactor control system and instrumentation	27 021	5.0	57 164	5.2
	Nuclear auxiliary and emergency system	15 044	2.7	33 396	3.1
	Main heat removal system	77 330	14.2	151 237	13.9
	Steam generators	59 039	11.0	144 201	13 2
	Feedwater, condenser and circulating water systems	28 613	5.3	48 773	4.5
	Turbine generator system	86 215	15.9	156 145	14.3
	Electrical power and supply system	22 011	4.0	38 420	3.5
	Miscellaneous	13 186	2.4	31 837	2.9
	Operating error	8 974	1.6	16 318	1.5
Refuelling and maintenance	Refuelling	2 844	0.5	3 943	0.4
	Refuelling; maintenance and repair	18 056	3.3	31 067	2.8
	Maintenance and repair	61 108	11.3	152 447	14.0
	Testing of plant systems/ components	4 733	0.9	10 633	1.0
	Training and licensing	49	0	91	0
	Regulatory limitations	42 077	7.7	56 495	5.2
	Other	58 293	10.7	113 783	10.4
	TOTAL	543 487		1 090 661	

cycled manner to follow demand. In the past the IAEA has calculated an availability factor as 1 − (all unavailabilities). It will be necessary in the future to use an availability factor to supplement the load factor but it will then also be necessary that consistent reporting be achieved by all utilities of availability based on energy, and this has not been the case in the past.

Through the operating information of WEC and IAEA it is possible to display comparable data for fossil-fired and nuclear plants. Present sets of such data are

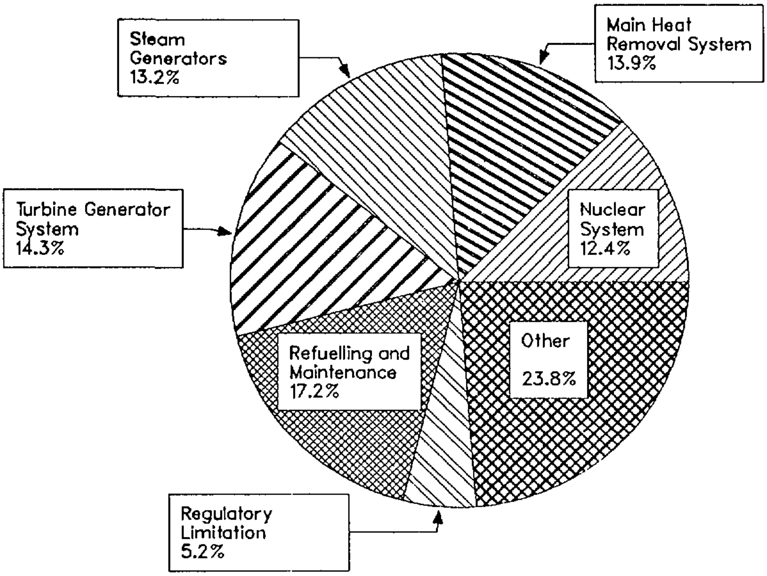


FIG.6.28. All nuclear reactors 1971–1980 – unplanned full outage statistics [6.28].

shown in Table 6.II for nuclear power plants [6.28] and in Table 6.III for fossil-fired power plants [6.28, 6.36].

From these tables it appears that there are differences between fossil-fired plants in different countries, as well as between different types of nuclear power plants, among which the large LWRs have higher unavailabilities, which is partly attributable by regulatory limitations imposed after the TMI-2 accident. These internal differences inside the main groups are more significant than the overall differences between the unavailability of nuclear and fossil-fired plants.

With the high capital cost of nuclear power plants the attainable load factor in what has essentially so far been base-load operation is, of course, of fundamental economic importance. During the 1960s a theoretical load factor of 80% was often used in economic evaluations for off-load refuelled reactors; for on-load refuelled plants the assumed load factor was sometimes as high as 90%. Reality has been different. It was actually one of the first analytical uses of the IAEA's collection of operating information to correct the assumed load factor in the IAEA's work on LWR plants. This is not to say that an average load factor for all plants of 62.4%, which was achieved in 1980, should be considered as reasonable. On the contrary, it is obviously necessary to improve plant performance, and not only in order to improve economics. In comparison with a theoretical load factor of 80%, which is still what manufacturers quote as attainable for off-load refuelled plants, the 62.4% in 1980 for the plants included in PRIS meant a loss of generation of 160 TW(e)·h, corresponding to a generating capacity of 23 120 MW(e) at 80% load factor. This loss could be regarded as a reserve which could be available in the future without building new plants, if it is possible to improve the performance.

In the IAEA's power reactor information system there is information about 9004 nuclear power plant outages between 1971 and 1980. While planned outages account for two-thirds of the total outage time, the unplanned plant outages still add up to 1 090 000 hours down-time or 550 TW(e)·h in lost generation for all the nuclear power plants in PRIS over the ten-year period 1971 to 1980.

Table 6.IV presents a breakdown of the causes for all unplanned outages in PRIS and Fig. 6.28 illustrates the main structure. Both presentations show the predominant role of equipment failure in the main heat removal system, steam generators and the turbo-generator systems, together accounting for more than 41% of the unplanned outage time, with diverse maintenance and repair adding another 14%. The equipment failures which are most specific for a nuclear plant, i.e. the reactor with accessories, fuel, the reactor control and instrumentation system and the nuclear auxiliary and emergency systems on the other hand account for only 12.4% of the total unplanned outage time, with regulatory limitations accounting for an additional 5.2%. These statistics thus bear out what has often been quoted in the past, viz. that the major reasons for unavailability are in the non-nuclear parts of the plant systems and most often without relation to the safety of the plants. By paying more attention to these non-nuclear systems in design, construction and operation it should be possible to achieve better load factors in the future.

Reference [6.28] further provides detailed information on the distribution of nuclear power plant outages durations and their effect on the plants' main equipment.

In general it can be concluded that nuclear power plants have not had significantly lower availability than fossil-fired plants in the same size ranges. It still would be desirable and would seem possible to improve nuclear power plant availability. The major problems affecting reliability (but generally not safety) which have caused the long outages have their reasons in major design errors or major material failures of the types which occur in all industries under rapid development and which can be difficult to foresee and avoid. The non-nuclear or conventional parts of nuclear power plants are, as mentioned, major contributors to unavailability. A careful and conservative approach to standardization of major components and to size and performance extrapolation in design should help to avoid such problems (and this seems to have been achieved by some nuclear steam supply system manufacturers). It seems, however, that it is in the category of short outages that major improvement could be achieved by the plant operators, mainly through improved feedback of operating experience information from all similar plants and through improved management.

TABLE 6.V. OPERATING EXPERIENCE OF NUCLEAR POWER PLANTS IN 1979

Reactor groups	Number of reactors	Net capacity MW(e)	Average load factor	Average operating factor
All	193	104 527	61.4	68.3
All excluding prototypes	174	103 764	61.4	68.3
All excluding prototypes and excluding those starting commercial operation in the second half of 1979	164	92 290	59.6	66.8
All excluding those starting commercial operation in the second half of 1979	183	96 053	59.6	66.8
Prototypes	19	763	63.1	68.4
Those starting commercial operation in the second half of 1979	10	8 474	81.8	85.8

Source: Operating Experience with Nuclear Power Stations in Member States: Performance Analysis Report 1979, IAEA, Vienna (1981)

Table 6.V provides an overview on the operations experience, i.e. on the average load and operating factors of different reactor groups in 1979, while Fig.6.29 displays the average annual figures from 1970–1979.

As far as historical experience is concerned, between 1970 and 1979 average load factors and average operating factors varied as follows:

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Load factor	59	65	59	64	62	61	62	64	67	61
Operating factor	77	76	72	73	74	71	72	72	75	68

For many years there has been discussion about whether nuclear power plant availability improves with the age of the plant. In some countries an increasing load factor over the first three to five years has actually been assumed in economic project assessments. Reality would indicate that some caution should be used in such assumptions.

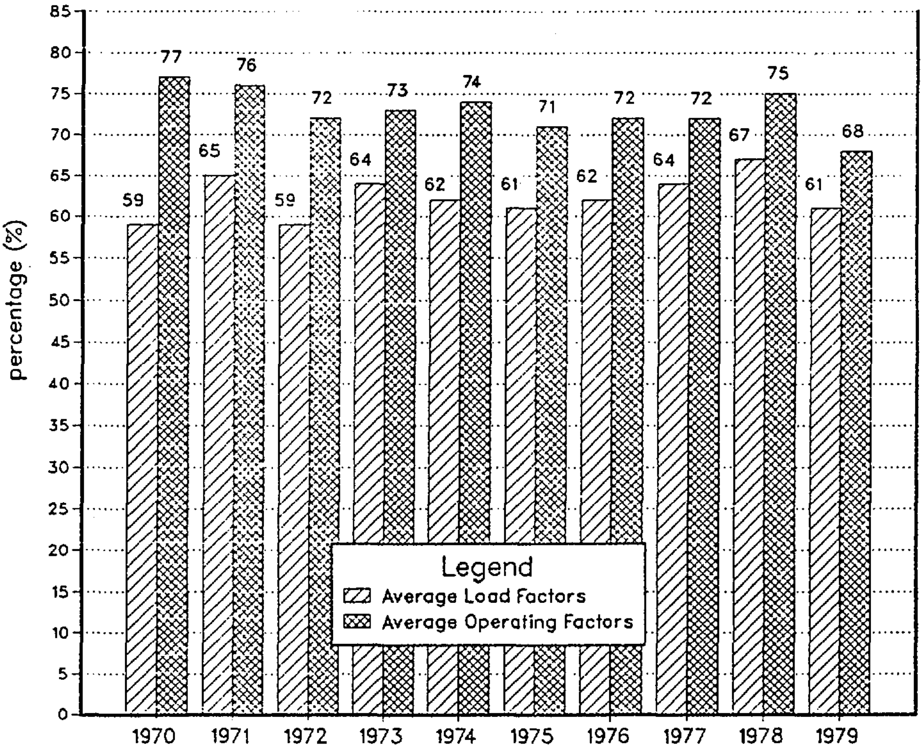


FIG.6.29. Performance factors of nuclear power plants 1970–1979.

Many important lessons have been learned from experience in operating and maintaining nuclear power plants. Most of these may seem obvious; nevertheless, emphasizing them might be useful:

(1) Safety considerations in operation and maintenance must override other concerns
(2) Availability of highly qualified operations and maintenance management and staff is essential
(3) Qualification, training and retraining requirements must be clearly defined and complied with
(4) The power plants must be designed and constructed for good operability and maintainability, in addition to safety
(5) Operation and maintenance procedures must be clearly stated and rigorously complied with
(6) Lines of authority, distribution of responsibilities, functions, duties and tasks must be clearly defined and understood by all.

Experience with the first nuclear power plants in a country and in particular with the first projects in developing countries has shown that there are problems and difficulties which have to be solved. Experience, however, has also shown that these problems and difficulties can be overcome satisfactorily.

6.2.4.4. Dismantling of nuclear power plants

Another essential difference between nuclear and conventional power plants appears at the end of their technical and/or economic life, when radioactive issues regarding the former raise new problems. Although a series of experimental and demonstration reactors have been mothballed, entombed or dismantled, it is felt that alternatives for the decommissioning of larger nuclear power plants have not yet received the amount of attention that such an inevitable end-situation really deserves, and which for an increasing number of older nuclear power plants is beginning to get frighteningly close.

A number of detailed analyses of decommissioning alternatives have, of course, been undertaken, concluding basically that decommissioning is feasible, practicable and not excessively expensive. However, more organized information on the subject is desirable, both as to technical and economic aspects. In relation to the latter aspect, it appears necessary in the kW·h cost calculations that in addition to the cost of disposal of radioactive wastes provision should be made for the costs of dismantling, even if it represents an expenditure far in the future.

6.2.5. Solar power plants

This heading refers to electric power plants using direct solar radiation as an energy resource, i.e. based on thermodynamic and photovoltaic conversion.

6.2.5.1. Solar power plants with a thermodynamic conversion system

Except for the steam-producing installation, thermodynamic solar power plants have the same classical equipment as the normal thermal power plants. However, the solar radiation collecting system makes an enormous difference, because of the large surfaces it needs for the solar collectors or the concentrating mirror system. For example, it has been estimated that under present conditions, to achieve the equivalent power of a 1300 MW nuclear unit, a solar power plant would need some 68 km^2, i.e. the surface of a town with 150 000 inhabitants. Even then, it would produce electricity only when the sun was shining, i.e. during some 2000–3000 h/a, which is a small fraction of the capability of the equivalent (as installed capacity is concerned) nuclear or other classical thermal power plant.

As described in subsection 4.3, thermodynamic solar power plants could be designed as solar farm (DCS) or solar tower (CRS) type.

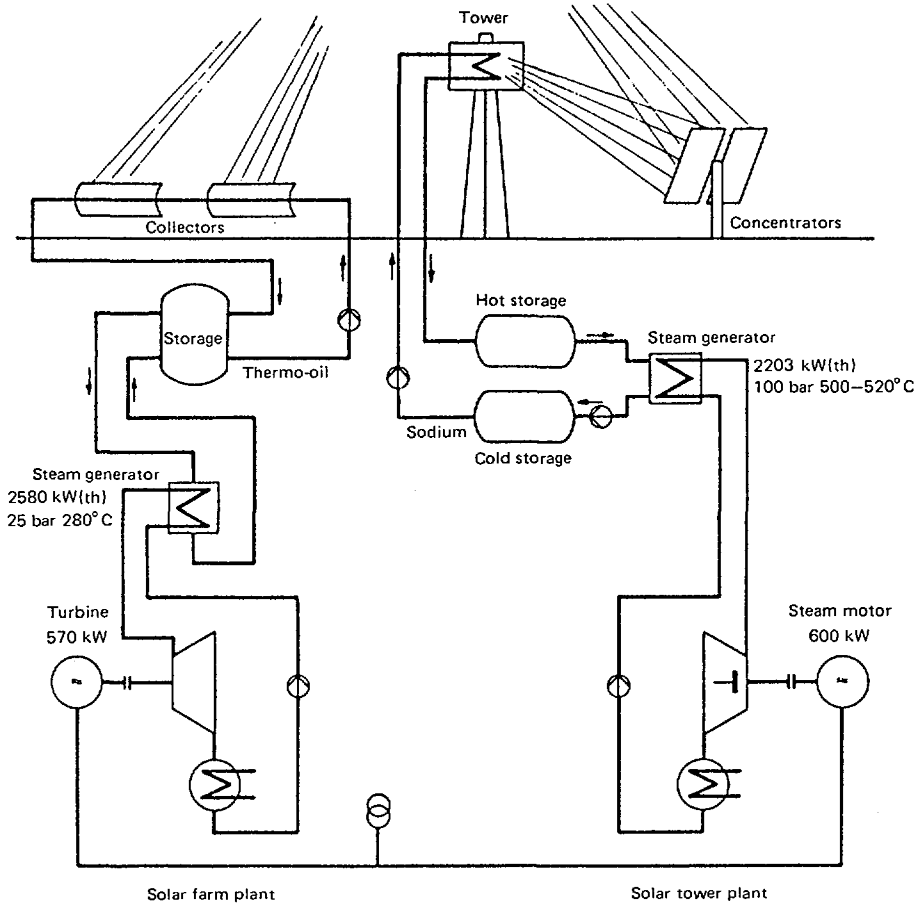


FIG.6.30. Solar power plant Almeria [6.31].

A difference between the two types of plant exists, in addition to concept and spatial arrangement, in the obtainable performances: while DCS plants could reach only some 400°C thermal carrier temperatures and efficiencies of 10–12%, CRS solar power stations could work up to 800°C and with 15–20% efficiency [6.30]. The relatively low efficiency of both types is due to the relatively high losses in their solar components (25–50%).

After a series of small experimental and demonstration installations, the first larger solar power plant based on thermodynamic conversion, the EURELIOS of 1 MW, went into commercial operation at the beginning of 1981 near Adrano, feeding electricity into the grid of a public utility. It is a CRS plant.

In order to be able to compare operation and cost performances of the two basic types of thermodynamic solar power plants, the IEA started in 1979 the SSPS (small solar power systems) project. Two plants for a 500 kW output to the public network, a DCS and a CRS, have been installed close to each other on the 'Plataforma solar' near Almeria in the south of Spain. Figure 6.30 presents in parallel the concept and significant data of the two units, in operation since 1982.

Remarkable are the high steam parameters of 100 bar and 500–520°C of the tower alternative, the sodium heat carrier and the very efficient 600 kW steam motor. The net efficiency of the tower power plant, 25.6%, represents an excellent performance [6.31].

The largest solar power plant presently in operation is 'Solar-One' in Barstow, 150 km from Los Angeles, of the solar tower type. The concentrating mirrors are displayed on a 290 000 m^2 surfaces; the absorber-tower is 86 m high. A further comparison between the two types of thermodynamic conversion solar power plants, on a higher scale, however, will be possible when a 12 MW plant of solar-farm type which is being erected close to Solar-One is commissioned. Apparently it would cost only half per kW installed, and could herewith be competitive with gas turbines in California [6.32].

Other projects are contemplated, a 5 MW CRS in Switzerland, a 5 MW DCS and possibly a 320 MW CRS in the USSR, a 100 MW tower plant in California, by the same utility which operates Solar-One in Barstow, etc.

In addition to the described "classical" models, interesting alternatives are examined: a 20 MW plant – GAST – in Europe is designed to use 3000 concentrators of 40 m^2, each occupying an area of 50 ha. Two receivers on a 200 m high tower will heat compressed air up to 800°C which will drive two gas turbines of 7 MW each. The evacuated air of 500°C will heat steam boilers driving a 6 MW turbine placed in the bottom of the tower. When no sun shines, the compressed air could be heated in the turbine combustion chambers with gas or fuel oil, and the installation could operate at full capacity, without needing any energy storage.

An alternative is being examined in the USA, to construct the solar part only and supply the steam produced to the turbines of a classical thermal power plant. With this re-powering solution investment costs would be saved on the solar side and fuel in the thermal power plant [6.33]. In Switzerland, combinations of solar power plants with pumped storage hydro power plants are being studied, the solar power serving to pump the water in the upper storage lakes.

Last but not least, co-generation solar power plants, with their high combined efficiency for concomitant supply of heat and electrical energy could be considered, an advantage which the photovoltaic electricity generation described below could not offer.

6.2.5.2. Photovoltaic solar power plants

With its modular capability, photovoltaic solar electricity generation can be both centralized and decentralized, without the otherwise usual penalty relating to economy of scale.

Photovoltaic electricity generation can be concentrated in or at large power plants, decentralized at the users' houses or sited inbetween at different points in the distribution and subtransmission utility's network. In residential areas it could be owned and operated by a further utility or by the customer. It is possible that this unique site flexibility of photovoltaic solar energy will become one of its decisive advantages for development when the present phase of maturing technology and rational cost decrease is achieved.

Solar power plants with photovoltaic electricity generation are less developed in relation to total installed capacity than those using thermodynamic conversion. In addition to a series of small research and experimental projects, a 300 kW pilot plant on the island of Pellworm in the North Sea is the largest photovoltaic project in the European Community [6.34]. Currently, the largest photovoltaic solar power station in the world, with an installed capacity of 1 MW, is in Hesperia, 50 km south of Barstow, USA [6.32].

A detailed overview on the problems of photovoltaic solar cells siting and operation in a utility network is offered in an EPRI study, Ref. [4.24].

6.3. Operation of the electrical system

The electricity system has to be planned, constructed and operated according to its integrated and consolidated character. Operation must be carried out under extreme pressure due to dynamic expansion of the system.

Planning of the electrical system is dealt with in chapter 17 and electricity demand has already been scrutinized. However, general aspects of supply still require comment, i.e. preparing and ensuring availability of the necessary capacities in generation, transport and distribution, and actually delivering the required electrical power and energy.

Current operational problems are well illustrated by the example of the daily load curve of the Peninsular Spain electrical system presented in Fig.6.31.

The example displays the following information:

(a) The comparison between the forecast and the actual load curve. In fact the real morning peak was higher, the evening peak lower than forecast.
(b) The load curve was covered: in the base-load area by hydro power of the run-of-river type (some 1000 MW) and by thermal power stations (7500 MW).
(c) The thermal power stations (including nuclear) supplied between midnight and 08:00 up to 3000 MW for water pumping in the storage reservoirs (included in the maximum 7500 MW mentioned under item (b)).
(d) Hydro power operated between 08:30 and 24:00 with a maximum scheduled input of 4000 MW and up to 6500 MW after 18:30 when replacing failing thermal power.
(e) Throughout the 24 hours, the regulating capacity was active, supplying up to 1500 MW at the morning peak and intervening temporarily up to 3000 MW

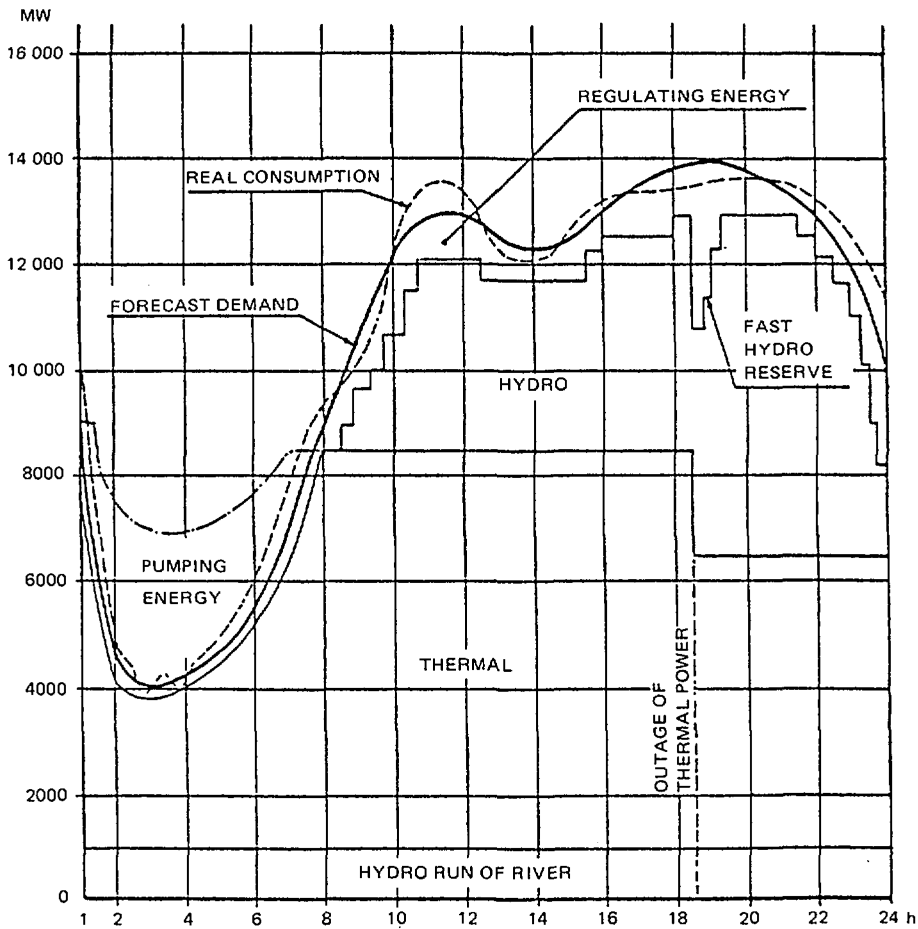


FIG.6.31. Daily load curve of the Peninsular Spanish electrical system [6.35].

at 18:30 when thermal power failed. Owing to its rapid intervention and subsequently to the step-up generation of normal hydro power, the supply requested by the network was not affected by the partial thermal power outage.

In addition to the regulating capacity used, more capacity was in spinning reserve and ready for quick intervention. Unfortunately, the daily load curve does not provide information on this aspect.

While Fig.6.31 presents the operational situation on an unspecified particular day, Fig.6.3 brings an example covering a year: the projected annual electrical load duration curve of France in 1985–86 (358 TW·h annual production and some 61 000 MW peak load) which demonstrates the considerable share of nuclear energy, the role of hydro power and the low participation of industrial, auto-producing power plants.

The outage of thermal power capacity shown in Fig.6.31 illustrates the importance of reliability and availability aspects in the operation of an electrical system.

No technical equipment is infallible and all equipment needs to be taken out for servicing, repair and maintenance procedures after certain periods of operation. On the other hand, the variable electrical load character during the year does not call for continuous operation of all equipment and certainly not at its nominal capacity.

From the interplay of these facts, optimized combinations of installed capacity structures might be planned with a view to ensure the security and availability of the electrical supply.

One of the basic questions to answer is how much electrical capacity has to be installed in order to ensure the coverage of a given electrical demand. An obvious answer is apparently: less if the reliability of the equipment is higher and therefore the availability of the generating plants during the year higher. Here begins a practically interminable trade-off between spare capacity and the damage to the utility and even more so to the national economy resulting from the non-supply of energy, effects of black-outs and brown-outs (supply at lower voltage), etc.

While not discussing here the resultant economic effects, it is interesting to present in addition to the information for nuclear power plants figures on the availability of classical thermal power plants.

Tables 6.VI presents the annual unavailability data, according to the joint UNIPEDE/WEC Committee on availability of thermal generating plants, for four groups of conventional thermal unit capacities for the period 1977–1981, i.e. 100–199 MW, 200–399 MW, 400–599 MW and 600 MW and over, separately for Europe, the USSR, the USA, and other countries. For each year, the number of units and their total installed capacity are indicated. The unavailability factor due to planned maintenance is presented as G1, G2 represents unplanned maintenance and G is the total figure.

As far as consolidated data for all countries are concerned, a previous publication [6.37] gave the following figures for the period 1973–1977:

Group of units	Unavailability factor in % (work days)		
	G1	G2	Total (G)
100–199 MW	9.8	8.5	18.3
200–399 MW	10.7	9.7	20.4
400–599 MW	11.0	17.9	28.9
600 MW and over	11.5	19.2	30.7

While the figures for planned maintenance do not show significant differences, the figures for unplanned outages show substantially higher values.

TABLE 6.VIa. ANNUAL UNAVAILABILITY FACTORS IN % [6.36]. CONVENTIONAL UNITS (100–199 MW)

	Europe		USSR		USA		Other countries	
	A	T	A	T	A	T	A	T
1977	43 104	344	12 600	84	51 430	316	6 686	41
1978	43 504	347	12 600	84	51 601	327	6 876	42
1979	44 526	355	12 600	84	54 713	334	6 876	42
1980	44 526	355	12 600	84	52 093	352	6 876	42
1981	43 381	348			57 287	393		

Year	Europe G1	Europe G2	Europe G	USSR G1	USSR G2	USSR G	USA G1	USA G2	USA G	Other countries G1	Other countries G2	Other countries G
1977	12.5	9.7	22.2	8.2	3.7	11.9	11.4	9.1	20.5	9.2	17.4	26.6
1978	10.7	9.9	20.6	8.0	3.9	11.9	10.3	8.2	18.5	10.8	13.2	24.0
1979	10.7	8.3	19.0	7.6	2.9	10.5	12.0	8.1	20.1	11.2	13.9	25.1
1980	10.8	8.4	19.2	8.0	2.8	10.8	10.4	8.5	18.9	11.0	18.7	29.7
1981	10.6	8.0	18.6				10.4	8.0	18.4			
Average	11.0	8.9	19.9	8.0	3.3	11.3	10.9	8.4	19.3	10.6	15.7	26.3

Number of units on 1 January = T.
Maximum capacity of units on 1 January = A (in MW).
Unavailability factors: G1 = due to annual planned maintenance, G2 = unplanned, G = total.

TABLE 6.VIb. ANNUAL UNAVAILABILITY FACTORS IN % [6.36]. CONVENTIONAL UNITS (200–399 MW)

Europe			USSR			USA			Other countries		
	A	T		A	T		A	T		A	T
1977	62 566	237	1977	64 500	255	1977	56 767	182	1977	7 226	26
1978	69 517	265	1978	66 300	263	1978	60 359	213	1978	7 526	27
1979	73 623	281	1979	68 200	271	1979	64 780	227	1979	8 176	29
1980	75 524	288	1980	70 000	279	1980	69 529	241	1980	7 940	28
1981	77 740	295	1981			1981	72 249	252			

Year	Europe G1	Europe G2	Europe G	USSR G1	USSR G2	USSR G	USA G1	USA G2	USA G	Other countries G1	Other countries G2	Other countries G
1977	10.4	13.5	23.9	9.2	3.5	12.7	12.8	13.1	25.9	5.9	16.9	22.8
1978	11.2	12.4	23.6	8.3	3.7	12.6	12.2	11.5	23.7	7.1	18.4	25.5
1979	11.8	11.0	22.8	7.9	4.3	12.2	12.7	13.1	25.8	5.7	17.1	22.8
1980	11.6	11.4	23.0	7.7	4.5	12.2	12.1	11.1	23.2	7.9	25.2	33.1
1981	11.5	11.6	23.1				12.9	10.3	23.2			
Average	11.3	11.9	23.2	8.4	4.0	12.4	12.5	11.8	24.3	6.7	19.4	26.1

Number of units on 1 January = T.
Maximum capacity of units on 1 January = A (in MW).
Unavailability factors: G1 = due to annual planned maintenance, G2 = unplanned, G = total.

TABLE 6.VIc. ANNUAL UNAVAILABILITY FACTORS IN % [6.36]. CONVENTIONAL UNITS (400–599 MW)

	Europe			USSR			USA			Other countries		
		A	T		A	T		A	T		A	T
	1977	45 856	91	1977	1 500	3	1977	49 061	92	1977	975	2
	1978	48 088	94	1978	2 000	4	1978	57 264	115	1978	1 950	4
	1979	51 247	99	1979	2 500	5	1979	64 080	127	1979	3 400	7
	1980	53 784	104	1980	3 000	6	1980	73 495	144	1980	4 925	10
	1981	55 738	107	1981			1981	83 142	165	1981		
Year	G1	G2	G	G1	G2	G	G1	G2	G	G1	G2	G
1977	13.3	20.1	33.4	12.8	18.8	31.6	15.9	12.1	28.0	15.6	13.3	28.9
1978	11.1	18.8	29.9	9.8	19.3	29.1	14.7	14.5	29.2	11.2	7.0	18.2
1979	11.5	14.9	26.4	14.0	15.8	29.8	14.4	14.3	28.7	8.9	6.7	15.6
1980	10.4	14.1	24.5	9.4	15.4	24.8	15.7	15.3	31.0	9.0	16.3	25.3
1981	9.6	14.2	23.8				14.6	12.0	26.6			
Average	11.1	16.3	27.4	11.3	17.0	28.3	15.0	13.7	28.7	9.9	11.6	21.5

Number of units on 1 January = T.
Maximum capacity of units on 1 January = A (in MW).
Unavailability factors: G1 = due to annual planned maintenance, G2 = unplanned, G = total.

TABLE 6.VId. ANNUAL UNAVAILABILITY FACTORS IN % [6.36]. CONVENTIONAL UNITS 600 MW AND OVER

	Europe			USSR			USA			Other countries		
		A	T		A	T		A	T		A	T
	1977			1977	4 800	6	1977	48 396	63	1977		
	1978			1978	6 400	8	1978	57 008	73	1978		
	1979			1979	6 400	8	1979	63 073	79	1979		
	1980			1980	6 400	8	1980	70 101	89	1980		
	1981			1981			1981	81 042	104	1981		
Year	G1	G2	G	G1	G2	G	G1	G2	G	G1	G2	G
1977				12.8	11.1	23.9	16.2	17.9	34.1			
1978				10.2	9.9	20.1	13.3	20.2	33.5			
1979				11.4	10.5	21.9	13.0	18.7	31.7			
1980				11.3	8.6	19.9	14.9	14.2	29.1			
1981							14.2	13.1	27.3			
Average				11.3	10.0	21.3	14.3	16.4	30.7			

Number of units on 1 January = T.

Maximum capacity of units on 1 January = A (in MW).

Unavailability factors: G1 = due to annual planned maintenance, G2 = unplanned, G = total.

TABLE 6.VII. UNAVAILABILITY FACTORS ACCORDING TO FUELS [6.36]. CONVENTIONAL THERMAL UNITS

	Europe	
	100–199 MW	200–399 MW
Years 1977/81	G	G
Coal	18.9	17.7
Oil and gas	20.6	28.9

	USA								
	100–199 MW			200–399 MW			400 MW and over		
Years 1977/81	G1	G2	G	G1	G2	G	G1	G2	G
Coal	10.5	9.6	20.1	12.6	13.0	25.6	14.1	17.4	31.5
Oil	11.9	8.1	20.0	12.2	11.2	23.4	15.3	11.4	26.7
Gas	10.9	5.1	16.0	13.2	8.0	21.2	16.2	10.1	26.3

Unavailability factors: G1 = planned, G2 = unplanned, G = total.

Finally, Table 6.VII presents the unavailability factors for conventional thermal units according to fuels [6.36].

With the above figures for generation and additional ones for the very much lower outages in the transmission and the distribution areas, complex calculations can be made to determine reliability indicators, cost of outages, consequences for risks and planning margins, real advantages of economy of scale, advantages of interconnections, etc.

It is, however, easy to appreciate that although very advanced in relation to other economic systems and especially to the overall energy system, the electrical system, mainly because of its structure as a physical system with production synchronized to consumption patterns, is still capable of progress, both in relation to technical aspects and comfortable management.

Nevertheless, the volume of centralized information, computer capacity, automatic protection and optimization facilities at the disposal of a central dispatching centre, represent a fascinating, hardly matched potential for operational supervision and emergency intervention. In spite of all this, colossal black-outs –

in New York twice, and over all France – have occurred when human failure amplified instead of limiting the impact of failing equipment and automation devices.

There are many more detailed aspects, important ones, related to the operation of electrical systems which could well have been included to better round off the subject. The interested reader may, however, turn to the recent IAEA "Guidebook on Expansion Planning for Electric Generating Systems" [6.3], to the IAEA "Guidebook on Interaction of Grid Characteristics with Design and Performance of Nuclear Power Plants" [6.38] and to the further recommended bibliography, if more than just introductory background information for planning is desired. In this connection the following topics in relation to the operation of the electrical system would deserve further reading: the management of peak-load [6.39], optimal operation and regulation including international interconnections [8.40, 41, 42] and again, the multilateral facets of generating plant availability [13.22], the latter becoming the central issue for extending the plants' life [6.43] and reducing or postponing new plant investment. Reference [6.44] presents with the life cycle cost (LCC) analysis of thermal generating plants a particularly interesting approach to reliability engineering. LCC includes, namely, in addition to the other costs a power replacement cost due to compulsory recourse to more expensive power when the plant is unavailable.

Chapter 7

ENERGY TRANSPORT, DISTRIBUTION AND STORAGE

The geographical location of primary energy resources and main final energy consumption rarely coincides. Usually, transport is necessary between the site of the primary energy resource and the centre or place of consumption. Depending on the prevailing conditions, the primary energy resource itself or an intermediate energy carrier then has to be transported.

Primary energy production, preparation, and intermediate conversion are usually carried out in bulk installations, while final energy consumption, with a few exceptions, takes place in much smaller geographically disseminated units. A distribution of the end-use energy carriers is therefore necessary.

While distribution of energy always implies covering a geographical area of a certain maximum size, the notion of transport applies to unidirectional distances, varying from short national ones to long international or even intercontinental ones and usually involving movements of bulk quantities.

Furthermore, since energy production, with the exception of electrical energy, generally does not coincide in time with energy demand, some storage in the linking energy chain becomes necessary. It can be placed either in one or both ends of the chain and/or in the chain itself in an adequate form and geographical location.

7.1. Basic modes of transport, distribution and storage of energy

The most suitable economic mode of transport, distribution and storage of a given form of energy depends on the volume involved, the geographical distances of transport and distribution, the time parameters of the energy production and consumption and, possibly, its storage requirements.

7.1.1. Basic modes of energy transport

The basic systems of energy transport are:

(1) Railroad and road systems, large belt systems.

(2) Waterborne systems, from barges on inland waterways, to sea-going vessels of various sizes, up to the large special ships, petroleum tankers and LNG ships.

(3) Pipeline systems on land or under water and as a special form, slurry pipelines.

(4) Electrical conductor systems, high-voltage overhead lines and underground or underwater electric cables.

In addition to the aforementioned energy transport modes of wide application, there are some more special ones, as for example airborne or submarine tankers, microwaves, laser beams, heat pipes, etc., of rather limited present use.

7.1.2. Basic modes of energy distribution

In contrast to transport or transmission, as used for electrical energy, distribution of energy implies the supply with energy of a geographical area, urban or rural or even regional. It therefore suggests the presence of a network, be it physical or organizational. In the first case, the end-use energy is supplied by a network linked to the consumer, in the second the latter must pick it up from a distribution point, for example a gasoline or kerosene station or have it specially delivered to the home (fuel oil).

Accordingly, the basic energy distribution modes are:

(1) Railway, barge or truck systems.
(2) Pipeline network distribution systems, for example natural gas, distant-heating networks, etc.
(3) Electrical distribution networks, both overhead lines and underground cables.

7.1.3. Basic modes of energy storage

The storage modes are usually described in close connection with the energy form or carrier which is stored. A broad classification could be the following:

(1) Natural, large-volume deposit storage, for example water storage reservoirs, coal deposits, large crude oil petroleum derivatives deposits, etc.
(2) Pumped water storage
(3) Pressurized or liquefied gas storage
(4) Compressed air storage
(5) Thermal storage, as for example steam or hot-water storage
(6) Battery storage
(7) Electro-chemical storage, for example nuclear energy – hydrogen production
(8) Mechanical storage – fly wheel
(9) Storage in superconducting magnets.

7.2. **Transport, distribution and storage of solid energy carriers**

7.2.1. Conventional solid energy carriers

The solid energy carriers involved are coal of various qualities, i.e. anthracite, bituminous and sub-bituminous coal, brown coal, lignite, peat and fuelwood as primary energy forms and coke, coal briquettes and charcoal as intermediate energy forms. Oil shale, tar sands and uranium ore and oxides belong to the same category, until releasing their energy content.

From the above energy carriers, only the ones with higher energy content (in heating value), i.e. superior hard coal varieties, coke, coal briquettes and uranium oxides, are technically and/or economically transportable over long distances by train, barge or bulk carrier. The rest of them are confined to local

Source: Salzgitter AG

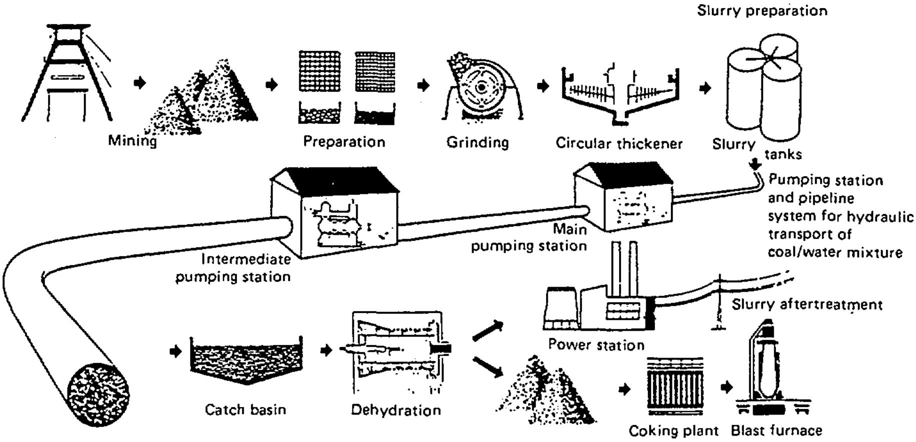


FIG. 7.1. Slurry pipeline coal transport from the mine to the user [*7.1*].

utilization, or in the case of oil shale and tar sands to local conversion to liquid-energy carriers. Their transport over short distances could be either by special railway cars and trains (unit trains) or, up to certain distances, by large belt systems, bringing them directly to conversion plants or electric power stations of the mine-mouth type.

A unit train is a single-purpose shuttle train operating over a non-dedicated general purpose railroad system. It is made up of some 100 rail cars hauling up to 16 000 t of cargo (coal). Each car can carry from 70 to 125 t. The system is designed to permit rapid discharge without uncoupling cars. Used all over the world, nowadays also for long distances, unit trains together with normal trains transport nearly two-thirds of the coal in the USA.

Hard coal varieties for thermal power stations might also be transported by inland river and canal barges or by pipelines, when mixed with water, i.e. slurry pipelines.

Although the patent for slurry transport of bulk materials was issued in 1891, the Ohio coal pipeline, 170 km long and leading to a Cleveland power plant, was the first major operation, in 1975 [7.1]. However, this line ran only briefly, abandoned when railroad rates were reduced to meet its threat. Since then over 80 solid pipelines have come into operation and many others are planned across the world. So far, the longest slurry pipeline for hydraulic coal transport in operation is the 435 km Black Mesa system, supplying 660 t/h slurried coal from a mine in Arizona to the Mojave power station on the Colorado River.

Figure 7.1 presents schematically a slurry coal transport from the mine to the user [7.1]. Coal is specially sized for slurrying to minimize dewatering

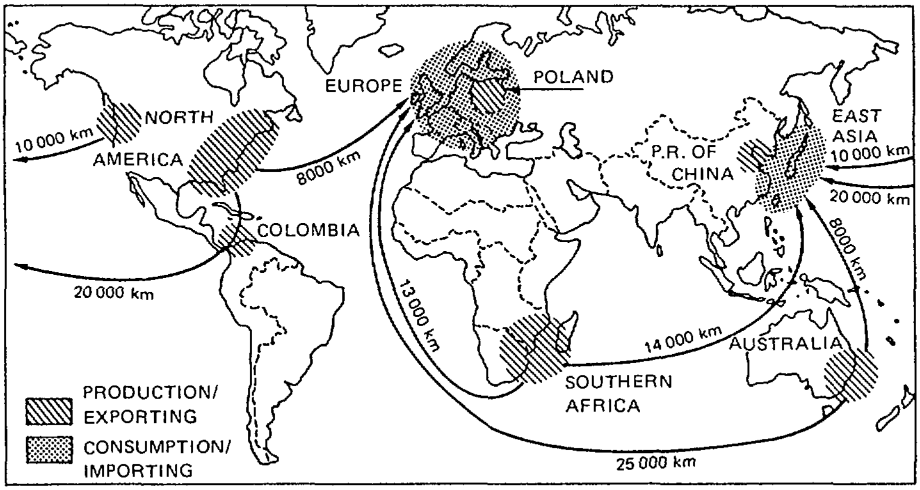


FIG. 7.2. Major steam-coal production/exporting and consumption/importing regions [7.2].

difficulties at the discharge terminal. The proportion of coal to water is some 50% by weight. The large volume of water necessary along with the treatment and purification of water at the destination are the main drawbacks of a slurry system. Nevertheless, such coal transport is becoming increasingly popular, and a large number of systems are planned or in construction across the world, for example the ETSI slurry coal pipeline in the USA, 2200 km long and with 30×10^6 t/a coal transport capacity.

The distribution of solid-energy carriers is by railway and lorries, and is confined in general to heating, small industrial and household purposes.

The international and intercontinental movement of coal and coke is still rather limited, and it will take time and tremendous efforts to develop an infrastructure permitting in the future major worldwide coal transport with a view to partly substitute petroleum by coal. On the other hand, the transport of uranium for nuclear power stations creates few problems, except for safety aspects, owing to the relatively small quantities to be transported. This is because of the high energy content.

Figure 7.2 illustrates the long distances between the main steam-coal-producing countries and the worldwide consumption areas [7.2].

The storage of solid energy carriers is relatively simple; it can be in the production area as well as in the conversion and utilization areas; it requires only sufficiently large depositing surfaces and volume. In general, the shorter the transport distances, the smaller the quantities it is necessary to store to ensure the continuity of operation of the supplied plants. However, the storage of large and/or expensive quantities of energy carriers has, besides the technical aspect also an important economic one; for example, the security stock of

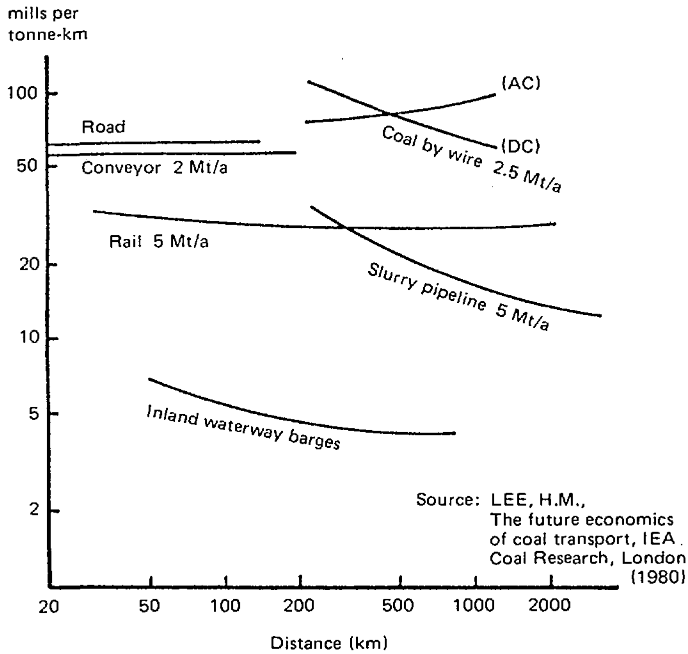


FIG. 7.3. Conceptual relative cost of modes of inland transport for coal [7.1].

coal or liquid fuel of a large thermal power station or the first core uranium load of a nuclear power station represents a major investment, which naturally increases the kW·h costs of the plant.

There is not too much to be said with regard to fuelwood transport, storage and distribution, since the major part of consumption takes place in a non-commercial circuit, and as far as commercial firewood is concerned, neither bulk transport nor very long transport distances create problems. In spite of its important share in the world energy balance, fuelwood economy hardly exceeds local or provincial dimensions.

7.2.2. Transport and storage of nuclear fuel and waste

Under this heading no further description is given of the transport of uranium ore, yellow cake, uranium oxides, pellets and fuel elements, since this belongs to the conventional, common transportation modes, although careful handling is needed.

The part involving critical, technical, safety and economic aspects is not the energy carrier, as in all the above-mentioned cases, but arises after its conversion (partial) in the energy production process.

The nuclear fuel has to be transported after it has been used in the nuclear reactor. This is true whether or not reprocessing takes place; even if a nation decides that it does not need the potential energy contained in the spent fuel, the fuel elements cannot be allowed to accumulate for ever at power stations. They must be moved to some location where they can be either reprocessed or stored in perpetuity [7.3].

International co-operation has been, and indeed has to be, a characteristic of the international transport of spent fuel; some of the major transport companies in this field are multinationals.

The modes mainly used so far are road, rail and water. Whilst it is not impossible to transport spent fuel a considerable distance by aircraft, so far there has been no significant movement via this mode. Thus the three normal major methods, for freight of significant size, have been used by this relatively new transport industry.

Road and rail transport have been used for movements within and between countries, as has river traffic; sea transport has been used for the passage of fuel between countries and between continents. Indeed the most significant flow of spent fuel, across the sea, is from Japan to the United Kingdom and France; it travels half-way around the world on a journey which takes about six weeks.

Sea and rail have tended to be the preferred method for moving the heavier fuel flasks. Transport by sea may, of course, be mandatory if intercontinental movements are required. However, transport by road will also be necessary, even with the heavier flasks, if there is no railway at an inland reactor site.

The cornerstone of the laws, throughout the world, governing the transport of spent fuel is the regulations published by the IAEA. These were first published in 1961, underwent revisions and are regularly updated in the light of the best available technical advice and experience.

The regulations cover both normal and accident conditions, the guiding principle being that the packaging should provide adequate shielding and containment. The aim is to ensure that when the radioactive material is in the appropriate packaging, and the carrier follows simple rules for stowage and segregation from persons, it can be transported at least as safely as other potentially dangerous goods that are continually being moved around the world.

The packaging for the transport of spent fuel invariably involves a massive flask; at present such a flask weighs up to about 110 t. The fuel will normally be producing a considerable amount of energy which has to be dissipated by the packaging, if excessive temperatures are to be avoided. Thus some means of heat transfer is required to transmit the heat generated to the flask body from whence it can be transferred to the external atmosphere, usually by finning the outside of the flask. The coolant can be either a liquid or a gas; the corresponding flasks are usually referred to as wet and dry flasks respectively. The coolant in wet flasks is usually water. The fuel assemblies are located within the flask by means of a basket or a bottle.

The vehicles used to transport spent fuel flasks by road and rail are heavy units, but they are not extraordinarily different from those for moving other heavy loads. The transport industry had considerable experience prior to the advent of fuel flasks in moving loads of the same order of weight.

On removal from the reactor core the spent fuel is stored at the power station prior to being transported to either the reprocessing plant or an intermediate store; these are termed away-from-reactor stores (AFR). Notwithstanding a considerable amount of discussion on the intermediate store concept, very few AFRs have been built as yet except at reprocessing plants. Hence, at present, almost all spent fuel is stored either at power stations or at reprocessing plants.

The natural inclination of the utility is to move the fuel from the power stations as soon as possible, its prime function being to produce energy, not to store spent fuel. However, the ability to transport the fuel is limited by two factors: it has to remain at the power station for a cooling period in order to make the transport reasonably economic; also, the storage capacity at reprocessing plants is limited, with few other AFR stores available. Utilities have to store spent fuel at their power stations for a minimum of about six months for LWR fuel.

The stores for spent-fuel elements, at either the power station or the reprocessing plant, can be grouped into two broad categories – wet stores and dry stores. The wet stores are essentially ponds filled with water in which the fuel is submerged, thus providing shielding and cooling for the fuel in a transparent medium. The dry stores are essentially some method of containing the fuel in a gas which provides cooling for the fuel, the shielding being provided by various other means. Dry stores are a relatively new concept; there is one significant dry store complex in operation at present, others are being considered.

7.3. Transport, distribution and storage of liquid energy carriers

Liquid energy carriers can be transported either by pipelines, railwaysand lorries on land or by large sea tankers overseas. Up to certain distances, submarine pipelines are also used, as well as smaller tanker vessels for shoreline or innerwaterway supply. In recent decades, owing to the rapid increase of petroleum consumption, increasing quantities of crude oil have had to be transported overseas. The main crude oil overseas streams, originating from the Middle East, South America and Africa, are directed mainly to Europe, the United States of America, Japan and Australia. A significant amount of transport on land within the USA and from the USSR to Central Europe must also be considered. The main crude oil streams total some 1.4×10^9 t/a for overseas transport. An almost equivalent quantity has been consumed in the producer countries or shipped over smaller distances.

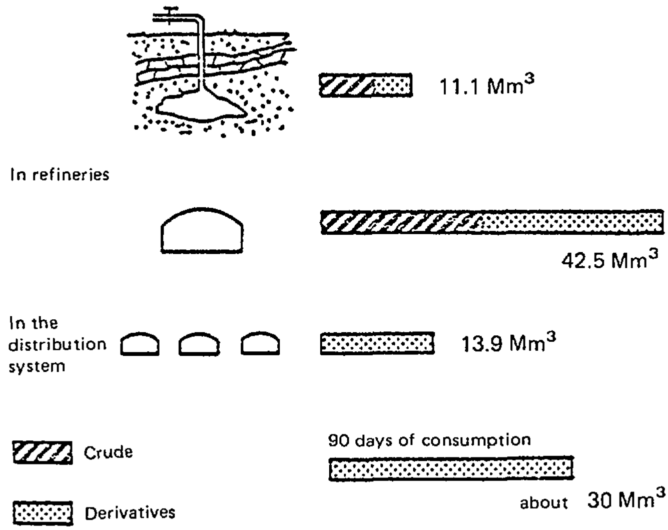


FIG.7.4. French petroleum storage capacities in 1977 [7.7].

In order to be able to ship such enormous quantities of crude oil, the world transport capacity of the petroleum tankers increased rapidly. Starting from some 25 X 10^6 tdw in 1945, it more than doubled between 1970 and 1975, and reached a peak capacity of 380 X 10^6 tdw in 1978 [7.4]. However, at the beginning of 1983 the total available capacity decreased to 304 X 10^6 tdw, a part of which remained idle all that year. Experts estimate that in the next years a capacity of 180 to 200 X 10^6 tdw would be sufficient for the expected crude oil transportation demand.

According to the boom demand, the unit size of the tankers increased, reducing specific transport costs, but also engendering new environmental risks. At the beginning of 1981, 30 tankers had a unit capacity of 400 000 and more tdw, some 350 ranged between 250 000 and 399 000 tdw, another 275 units had 200 000 to 249 000 tdw, etc. The total number of tankers amounted to 3197, with a total capacity of 316 000 000 tdw, slightly more than a tenth of the world annual petroleum consumption.

To illustrate the order of magnitude of crude oil pipeline capacities and performances, here are two extreme examples: the Alaska pipeline commissioned in 1977 has a maximum transport capacity of 13 500 m^3/h (e.g. over 100 X 10^6 m^3/a), a diameter of 1200 mm and is 1285 km long. It has to operate between −60 to −70°C in winter and +38°C in summer. The crude oil enters the pipeline at 62°C and never drops under 30°C. The oil travels some six days, pumped by 12 pumping stations with 10 MW gas turbine units. Half of the pipeline is underground. The transport costs are around US $2/barrel [7.5].

The second example refers to the Petroline, the new east-west pipeline in Saudi Arabia, commissioned at the beginning of 1983. Its nominal capacity is 425×10^6 t/a, some 80% of the maximum Saudi Arabian yearly production [7.6]. This strategical pipeline could reduce the transport distance to Europe and America by 3000 km compared to the classical route via the Persian Gulf.

The distribution of petroleum derivatives takes place from a basic pipeline system via rail, but mostly via an automotive tanker fleet.

The storage of petroleum – crude oil and derivatives – is well understood, and well organized along the entire energy chain of supply, worldwide. Figure 7.4 presents the French storage capacity for crude oil and petroleum derivatives in 1977: subterranean and refineries 53.6×10^6 m^3 and in the distribution system: 13.9×10^6 m^3, totalling 67.5×10^6 m^3 against 30×10^6 m^3 for 3 months' consumption of derivatives [7.7].

An enormous quantity is also stored in the tankers during their long journeys. Because of the large quantities involved and the high prices, the economic aspects of storage, i.e. the stocking of petroleum, have strong economic repercussions.

Besides the strategic stocks that the European developed countries built up for the security of their supply, the USA strategic reserves of crude oil also constitute an immense security deposit for the same purpose. Such storage however, goes beyond the technical-economic framework of the book and is determined by political and strategic considerations.

Natural water storage for hydro power production is dealt with in subsection 6.2.1; pumped water storage is discussed in subsection 7.6.4.1.

7.4. Transport, distribution and storage of gaseous energy carriers

Gaseous energy carriers are basically transported and distributed by pipelines and a local gas network or in liquefied form in LNG tankers and transportable bottles. This applies both to natural gas and artificial town and coke gas, and also to LPG (liquefied petroleum gas).

On land, huge quantities of natural gas are transported by pipelines over distances of several thousand km, both in the USA as well as in Europe and the USSR. Figure 7.5 illustrates the geographical extent of the West European natural gas network. Figure 7.6 shows the natural gas consumption of the different countries and the sources of supply, e.g. West European production and natural gas imports.

Figure 7.5 indicates, in addition to the gas networks, the sea transport routes of LNG and the location of the production fields.

Figure 7.7 adds a new dimension to Fig.7.5, displaying the very large project of the USSR natural gas supply from the permafrost northern Urengoy region. Of the many trunk gas pipelines planned and under construction, the branch for the West European supply was commissioned in 1983 and gas delivery started early in 1984. The pipeline Urengoy → Ushgorod (western USSR frontier) is

—— Natural gas pipelines — — — Sea transport of LNG o Natural gas fields

FIG. 7.5. European natural gas network, including LNG routes [7.8].

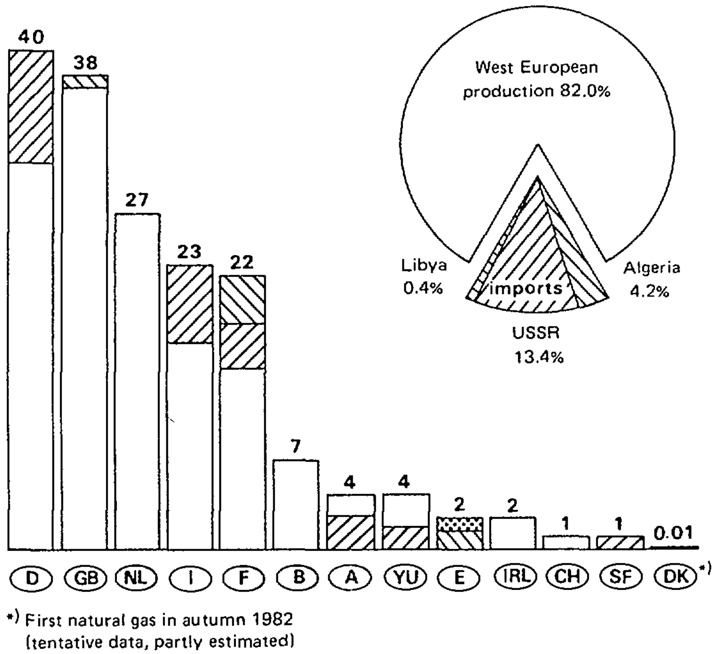


FIG. 7.6. Consumption and natural gas supplies to western Europe in 1982 [3.34].

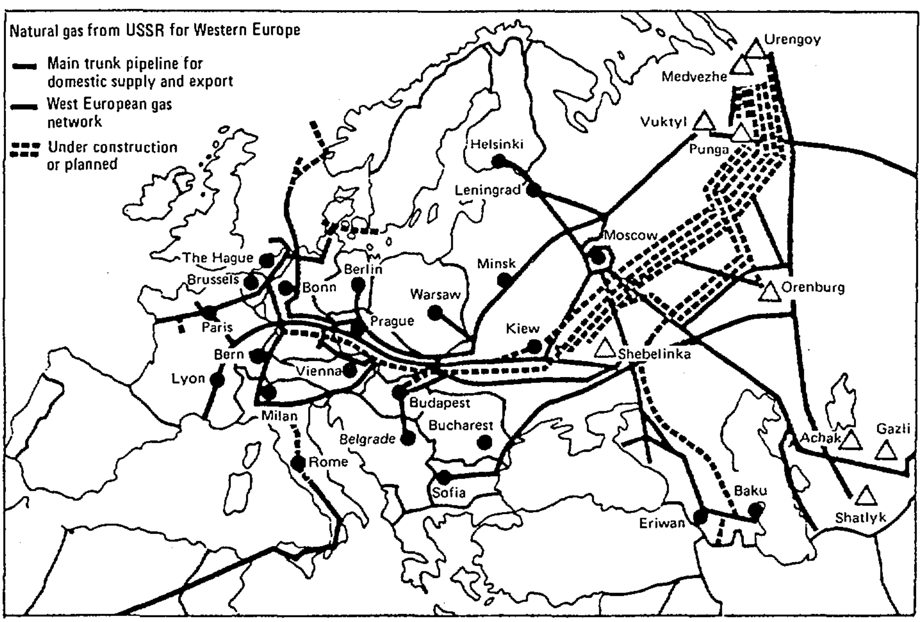


FIG. 7.7. The natural gas trunk pipelines project for gas supply from the permafrost region of Urengoy, including the first branch for supplying western Europe [7.9].

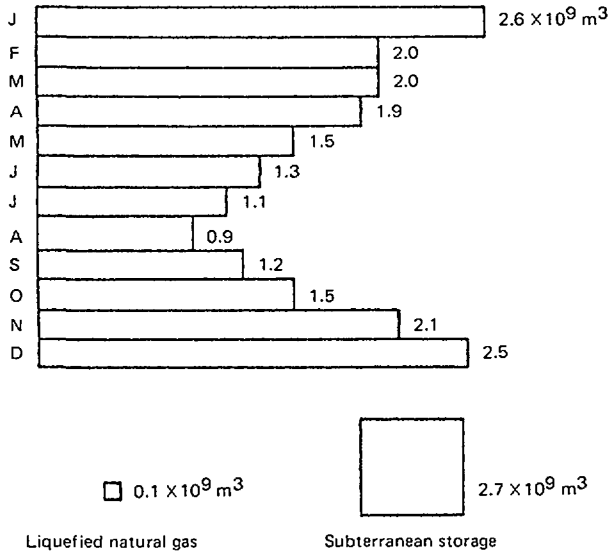


FIG.7.8. Monthly supply of natural gas by Gaz de France in 1977 and useful storage capacities [7.7].

4451 km long, has a 1420 mm diameter and works at 75 bar. The 17 compressor stations have new 25 MW units, in addition to the 10 and 16 MW sizes, which are the standardized units in the USSR [7.9].

An even longer natural gas pipeline 'Angts' (Alaska, 800 km) is under construction in the USA, and scheduled for operation in 1987 [7.8].

The fast-increasing natural gas quantities to be transported have led to new gas pipeline technologies, characterized by large diameters, high working pressures – 55 to 90 bar – and gas cooling in transport. In 1980 the USSR had about 130 000 km trunk gas pipelines in operation with more than 80% using pipes 500 mm diameter and over, and Canada about 48 000 km, 30% with pipe diameter over 500 mm [7.10].

The storage of natural gas – except for the gas currently stored in the capacity of the pipelines and networks – can be in large subterranean deposits and reservoirs, also in liquefied form. Figure 7.8 shows on the one side the monthly variation of natural gas distribution in France in 1977 and on the other side, to the same scale, the useful storage capacity, underground and in reservoirs, in liquid form [7.6].

A special method of transporting natural gas long distances and also of storing it, is to have it liquefied and transported as LNG in a much denser form. The liquefaction of the gas reduces it to 1/600 of its original volume.

The complex technology for the long-distance transport of LNG was first developed and utilized for LNG export from Algeria to Europe and Brunei to

TABLE 7.I. PRESENT WORLD LNG OVERSEAS CHAINS IN 10^9 m^3 [7–8]

Export country	Import country	LNG volume	Distance (km)
Abu Dhabi	Japan	95.35	12 000
Algeria	United Kingdom	28.25	600
Algeria	France	70.63	bis
Algeria	Spain	42.38	2 900
Algeria	USA	74.16	6 800
Brunei	Japan	275.45	3 600
Indonesia	Japan	420.24	4 500
Libya	Italy	52.97	1 300
Libya	Spain	28.25	1 300
USA (Alaska)	Japan	42.38	6 100

World trade $31.64 \cdot 10^9$ m^3.

Japan, the latter starting in 1972. Interest in LNG transportation has increased significantly since 1973 and LNG worldwide reached in 1980 some 31.6×10^9 m^3.

Table 7.I shows the current exporting/importing countries, trade volume and transport distances. The chain of LNG transportation from the gas well to the place of consumption includes: a pipeline system with compressor stations for conveying the gas from the well to the liquefaction plant on the coast; a liquefaction process through cooling the gas below −150°C; LNG transport by special refrigerator-tankers; regasification and pipeline transport from the coast to the consumer. Some links in this chain, especially in the liquefaction of the natural gas, are very energy-consuming. It has been estimated that approximately 16–20% of the original energy content of the natural gas is 'lost' in the entire process. However, this statement is true only if no use is made of the cold stored in LNG. Some of this energy can be recuperated at the regasification stage by using it for refrigeration purposes.

Another approach to this problem is the combined power generation and vaporization of LNG with a closed-cycle gas turbine. This type of LNG vaporization plant also helps to solve the environmental and ecological problems associated with classical vaporization installations such as those involving the burning of fuel to generate the vaporization heat, or the use of sea water, where seaweeds are destroyed by the necessary sea water treatment.

The largest LNG cryogenic thermal power generation plant ever constructed was completed by the Kita-Kyushu LNG Company Ltd., a joint venture of the Japan Steel Corporation and the Kyushu Electric Power Company Inc. in Japan

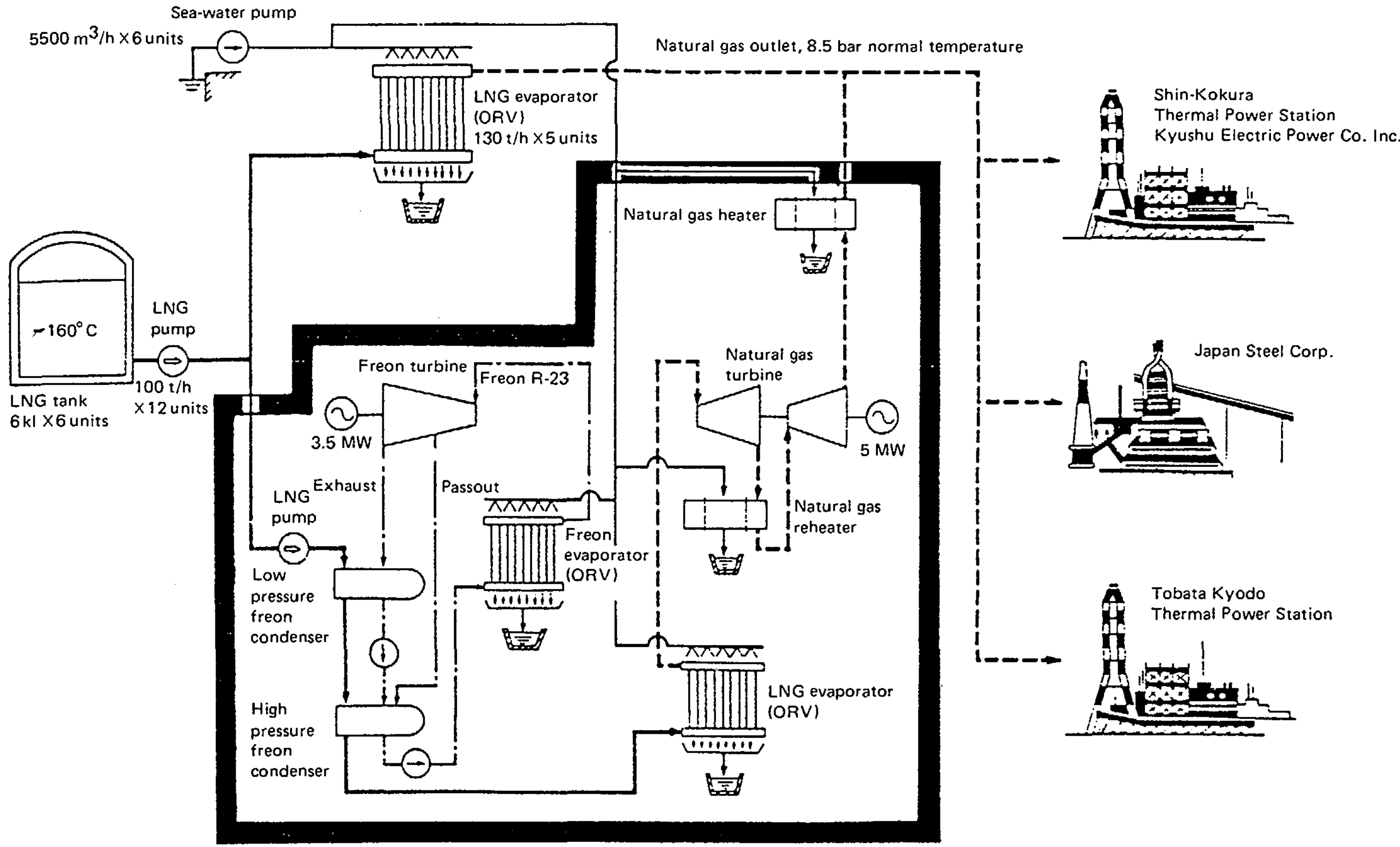


FIG. 7.9. The LNG cryogenic power generation scheme in Kita-Kyushu [7.11].

at its Tobata factory in the northern part of Kyushu Island for commercial operation in October 1982.

As shown in Fig. 7.9, the plant is composed of two kinds of power generation cycle: a Rankine cycle with intermediatepressure passout, and a reheat direct expansion cycle. The working fluid for the Rankine cycle is freon R-23 (CHF_3) and that for the direct expansion cycle is natural gas.

Electrical output depends on the temperature of the sea water. At 15°C, the total output is 8.5 MW(e), i.e. 3.5 MW(e) from the Rankine cycle and 5.0 MW(e) from the direct expansion in the natural gas turbine. For 25°C sea water the output increases to 9.4 MW(e) [7.11].

In addition to LNG long-distance supply, the regional distribution of LPG is developing, both in urban and rural areas. Stored in metallic receptacles, it is distributed by trucks or picked up using self-service arrangements. The main use is for cooking and warm water supply. A month's supply is stored in one to three transportable bottles, depending on the amount of consumption.

7.5. Transport, distribution and storage of heat and cold

Heat, as an intermediate energy form, can be transported, stored and distributed both as a liquid and as a gaseous energy carrier in the form of steam. The transport distances for steam are, however, limited to some 5–8 km, depending on parameters and quantities, while hot water with temperatures up to 150–180°C might be easily transported up to 12–15 km and even over longer distances one-way.

Not commercially in operation but very promising for future heat supply from HTR nuclear reactors is long-distance indirect heat transfer by cycles where heat is absorbed by an endothermal reaction of a methane/steam mix, and reformed into a synthesis gas $CO+H_2$ which can be convenient transported. At destination, the synthesis gas is fed to a methanation installation where in an exothermal (heat-delivering) reaction methane is formed and high-temperature steam produced – see Fig.8.16 [8.14].

Steam networks are mainly for industrial consumption as process steam, while district heating networks use mainly hot water as the heat carrier, although some older steam district heating networks still exist.

Similar, but less used, is the transport and distribution of chilled water in summer through a local "cold" network, chilled water being in fact a much less warm water.

While the technology of conventional heat transport and distribution is well established and in current use, heat storage, i.e. in addition to the normal storage capacity existing in the heat networks, is still under discussion and investigation, although some installations have been working for many decades.

The heat storage is interesting both for the commercial heat-producing and distributing entities as well as for the final consumers themselves. Accordingly, centralized and decentralized heat storage has to be dealt with. When heat alone is produced and supplied, decentralized or centralized heat storage could, as in the case of electricity, reduce the installed capacity, in sofar as peak demand can be partly met by stored heat. The technical problem is – for centralized storage – how large the heat storage reservoir can be made and the economic one, costs of investment and operation. Up to certain sizes, heat accumulators of both the pressure drop and constant pressure types have been in use for a long time.

The issue becomes much more interesting and complicated when heat storage could benefit both heat and electricity supply, i.e. in the case of co-generation of electricity and heat, and public distribution of heat through a district heating network. Since heating and electricity demand peaks do not normally coincide – technological process heat excepted – clever design and operational arrangements can lead to important design capacities reduction for both co-producers.

To this end, the heat supply for space heating and domestic warm water needs can be briefly reduced or even interrupted, since the normal, inertial heat storage of buildings and thermal network compensates.

In this case, too, the problem is how large could the storage facility be and where it should be located. A substantial number of studies has been dedicated to these aspects [7.12, 13], and a few projects for heat reservoirs prepared. Nevertheless, the question is still open. Reference [7.14] contains interesting data and information on a planned pilot heat storage facility. A prototype of long-term heat storage has been studied in detail: it would be built as two earth reservoirs of 10 000 m^3 each, for a water temperature of maximum 95°C. The water is heated via heat exchangers by 120°C water from a district heating network and discharged, when needed, in a second network of 60°C. The hot storage should gradually start in summer and reach 95°C. In October, November, December and January the heat is stored, and it is discharged in February, the coldest month. A second attempt is more advanced: in West Berlin a 165 m^3 heat storage facility has been recently built in connection with the district heating system [7.15].

Definitely in the preliminary study stage are large underground heat storage facilities, which unlike the natural gas ones have hot water reservoirs to meet additional needs. To sum up, long-term heat-storing reservoirs appear still far from commercial maturity, while short-term – with a duration of hours – centralized accumulators could, as in the past, have a positive role to play.

A natural heat storage tank is the earth's crust, which in temperate climates has at 2 m depth an almost constant average temperature over the year of 10°C. This heat can be extracted and used with the help of heat pumps, as described in chapter 2.

Decentralized heat storage, for example for house or building space heating and domestic water supply, is becoming increasingly popular as a basic complementary element for electric and solar heat supply [7.15]. In the

Federal Republic of Germany electric storage heating is very well developed. Over 1.87×10^6 dwellings, i.e. one in thirteen, has such electric heating. The storage heating is charged during the night, when electricity demand is lower, and more favourable rates are offered. When the space temperature is falling, a ventilator blows air through the ceramic heating core, which could be heated up to 650°C, and warm air is distributed in the dwelling. However, as has happened to other self-liquidating ideals, the run on this type of heating in some regions increased the night load almost to the level of daily demand, and subsequently cheap night electricity is no more available.

Solar heat utilization gave heat storage research a new impulse. In addition to the already applied technology, new forms are actively being investigated [7.17, 18].

In contrast to the previously described heat storage technologies, based on storage of the sensible heat of a heat carrier, two other approaches are possible, i.e. using the latent heat (also called phase change or heat of fusion) and by reversible chemical reactions [7.19]. An example of the latter approach has here been described, when suggested for the long-distance transport of heat, via synthesis gas ($CO + H_2$). By storing this gas in a conventional mode, heat storage of possibly large volume can be indirectly accomplished. The use of the latent heat for heat storage implies using the melting and freezing of a substance to store more heat per unit weight and volume. Finally, the very long-term hydrogen economy might represent the largest option for heat storage if eventual development occurs as has been suggested.

As far as cold storage is concerned, little progress may be mentioned in spite of having air conditioning as a large fraction of the electric daily peak load, both in summer in temperate climates and all year long in tropical zones. Cold storage could come into consideration only in the consumer area, and would have to be combined with advanced demand management. Initiatives in this area are, however, still in incipient phases, although much could have been learned by analogy with domestic ice and chilled water consumption alongside domestic water supply and management.

7.6. Transmission and distribution of electrical energy

The special advantages of electrical energy have been praised in the previous chapter and its rapidly increasing share in the world energy balance duly underlined. Although quantitatively so important, it lacks a worldwide dimension both in relation to quantity and distances since its transport is limited to electric lines or cables. However, although limited as regards direct transport, electricity could be easily moved from one electric system to a neighbouring one and, as such, cover by successive steps vast areas. There is not yet intercontinental, major electricity transport crossing oceans, although limited submarine transport exists and is capable of substantial improvement.

The overland transmission limits have reached several hundred MW and thousands of km, both by extra high voltages with AC and DC systems.

In general, the transport of electricity involves electrical 'losses', which would be far better considered as auxiliary consumption and budgeted for as such.

While transport, distribution and storage of the other primary and intermediate forms of energy appear a more easily physically manageable task, electrical energy supply involves in addition highly difficult technical problems both due to its non-storable nature, as well as to its reactive power component, which is highly dependent on supply availability and reliability.

Conceptually, the separation between transmission and distribution of electricity is obvious. Transmission refers to the bulk transport of electrical energy from the generating power plants to nodal points of the electrical system, situated in centres of consumption, and to some large individual consumers. Distribution and networking electricity describe the complex of activities aimed at supplying the consumers with the required electric power and energy including possibly a reactive power complement. To this purpose electricity is tapped in bulk from the high-voltage transmission grid at conveniently located transformer substations, is further distributed to the area by medium-voltage mains and subsequently supplied over a series of small transformers to the low-voltage network for final distribution.

In practice, however, this separation has a dynamic character, since the electrical system in its continuously expanding evolution includes mains of higher voltage to the distribution category and superposes at the upper level transmission lines of very or extra high voltage when growing electrical loads and longer transport distances make it necessary.

7.6.1. Electricity transmission

Depending on the stage of evolution of the electrical system, its geographical configuration, number and location of generating sources, nature and size of consumption, i.e. urban concentrations and country-wide scattered villages (rural electrification), its actual, medium- and long-term anticipated electrical structure, etc., very different electrical energy flows of active and reactive components have to be managed. They will certainly vary in time, sometimes in direction, but always ensure available electrical energy within the nominal voltage ranges and qualities.

Accordingly, an electrical system may start with a first radial high-voltage transmission line and gradually evolve to complicated configurations including international interconnection lines with neighbour countries or integration in a superregional system, as for example the huge West European or East European electrical systems, susceptible themselves to a future interconnection.

For all the intermediate situations, transmission lines have to be planned, constructed and operated at increasing voltage levels and for growing load transfers.

TABLE 7.II. TYPICAL CHARACTERISTICS OF ELECTRIC TRANSMISSION LINES [7–20]

Nominal line voltage (kV)	110	220	380	500	750
Conductors per phase	1	1	2	3	4–5
Thermal limit (MW)	80	280	1000	2000	4000
Transfer capacity for:					
200 km (MW)	45	200	850	1850	3800
400 km (MW)		80	450	1350	3500
600 km (MW)			250	900	3000
Relative line costs per route-km:					
Single-circuit (%)	47	68	100	135	175
Double-circuit (%)	74	88	129	250	335

7.6.1.1. Electric transmission lines

Load transfer capability along alternating current (AC) transmission lines is closely related to line voltage, line length and a series of parameters, summarized in Ref.[7.19] as follows:

– the maximum permissible power loss in the line, which should not exceed 15% for very long lines.
– the maximum permissible voltage drop in the line, ranging from about 10% at 275 kV and less to 5% at 400 kV and more.
– the electrical stability of the line, which limits the maximum phase angle between sending end and receiving end voltage vectors to about 30°.
– the maximum conductor temperature or 'thermal limit' which governs the power transfer capacity for short lines – generally lines 150 km long and less. The maximum permissible temperature for steel-reinforced aluminium conductors (ACSR) is usually about 75°C but the temperature rise that can be tolerated depends greatly on the ambient climatic conditions.

Some typical load transfer capacities of single-circuit AC lines operating at unity power factor within the limits given above are shown in Table 7.II. The higher the transmission voltage the greater is the load transfer capacity of a single circuit and the smaller the number of circuits needed to accommodate a given power flow with acceptable security. On the other hand, the higher the voltage the greater is the cost of the line.

Table 7.II also gives comparative costs per route-km for single-circuit and double-circuit lines, the cost of a 380 kV single-circuit line being taken as the

base figure. Absolute costs depend on a number of project-specific factors and cannot be quoted in a generalized way.

The figures of Table 7.II are no more than broad indications of the range of voltages needed for given load transfer requirements and of relative costs; the detailed design of the line and the operating conditions will probably lead to considerable variations in the permissible line loading. The detailed line routing, the line and tower design, prices of materials, financing and procurement considerations will determine the cost.

Line voltage selection calls for a compromise between electrically desirable characteristics and economic merit. A frequent experience is that line voltages are selected which prove to be too low in the long term. To avoid such errors, a present-value analysis is necessary to establish what line voltage level is best for the total life cycle of the line. Lines can be built for their ultimate voltage level and operated at a lower voltage in the early stages of load development to reduce losses and permit stable operation at the low power flows which are often then experienced. But the terminal equipment and protection system will have to be changed with the voltage level. Redeployment of the replaced equipment may not always be feasible in a developing network and the merits of uprating therefore require careful study before this solution is adopted.

Any electricity transmission scheme needs terminal substations which contain step-up/step-down transformers, switchgear, protection and communications equipment. Substation costs can vary widely; for a transmission distance of 200 km, they may approximately amount in % of total scheme cost to: 7% for a 150 kV line, 23% for a 220 kV line and 42% for a 380 kV line [10.13].

Tapping of transmission lines for supplying intermediate load centres along their route is expensive and cannot generally be justified, economically and technically, for power offtakes of less than about 10% of the rated line power flow. Intermediate substations can be advantageous for increasing the line stability and can then benefit local load centres also. Running high-voltage lines in developing countries through areas unsupplied with electricity is socially undesirable but nevertheless sometimes unavoidable.

Line design also involves detailed study of the potential routing and of the civil engineering and structural parameters for the towers with special reference to the ambient conditions under which the line is to operate. Wooden (H-frame) towers are generally not suitable for voltages of more than 150 kV; guyed aluminium towers are sometimes used at up to 230 kV, but higher voltages call for lattice-type steel construction. The design factors will in turn influence the economics of the arrangement and consequently the principal electrical parameters to be selected. Although transmission line design appears to be a very complex matter, it has by now become widely standardized and many of the investigations needed for achieving a satisfactory solution have become routine exercises.

TABLE 7.III. TYPICAL LOAD TRANSFER CAPABILITIES OF HVDC TRANSMISSION LINES [7–20]

Line voltage (+)	Line length	Load transfer capacity
400 kV	1000 km	1350 MW
450 kV	1000 km	1600 MW
530 kV	1400 km	1900 MW
750 kV	2400 km	6000 MW
1200 kV	3000 km	10 000 MW

Electrically, the lines will form an integral part of the network as soon as they are interconnected. Their characteristics and the influence they exert on the network must be studied in some depth in the design stage to ensure satisfactory operation of the entire power system. Such studies include consideration of load flows and voltage profiles, fault ratings, electrical stability and system load-frequency response. Transmission lines, like power plants, must have a minimum loading to operate effectively. Long and lightly loaded lines will cause high transmission losses, if indeed they can be operated at all with reasonable stability.

Commissioning of the Moscow-Kashira link in 1950 and the Gotland-Continental Sweden link in 1954 clearly revealed the advantages of DC and HVDC (high-voltage direct current) for bulk energy transmission over long distances, for submarine links and asynchronous links [7.21]. The further evolution confirmed the acceptance of HVDC as an established means of electric power transmission. In 1982 some 24 HVDC transmission projects with a total capacity of about 13 000 MW were in service in 14 countries and at least 12 additional projects representing around 21 000 MW of capacity were under construction or had been committed [7.21].

DC transmission has the following advantages: (a) lower losses and a stable load transfer over very long distances, (b) bulk power transfer capacity, (c) it makes possible asynchronous links between totally separated AC systems, (d) it permits submarine links.

Its disadvantage is the higher cost resulting from the need to install AC/DC and DC/AC converter stations at the terminations of the lines. Although DC transmission involves only two live conductors per circuit (instead of 3 with AC), the corresponding saving is countered by the cost of the converter stations, which is dependent only on the power transfer and not on the length of the line. The economic minimum distance for DC transmission by overhead line is now around 500 km but it is only some 30 km for high-voltage underground cables where the losses in AC circuits become very high. DC transmission is occasionally found with shorter distances, but in such cases the need to form an asynchronous link has usually been determinant.

HVDC transmission voltages of up to ±1200 kV are technically feasible but their practical limit is usually at around ±500 kV at the present time. Typical load transfer capabilities are shown in Table 7.III [7.19]. Such loads are far in excess of those which can be transmitted by AC at the same voltage.

The supply security of HVDC transmission lines can be much improved by using a third (neutral) conductor in a circuit. If any one of the live conductors should fail, half the rated load can still be transmitted over the remaining line and the neutral conductor. The need to have a second circuit for reasons of transmission reliability is therefore less important in the HVDC case.

HVDC transmission technology is by now well established especially thanks to the successful development of high-power thyristors, the equipment converting alternating current to direct current and vice versa. The operation of the relatively complex converter stations can be fully automated and causes no serious problems. DC transmission is less versatile than AC transmission because the circuits cannot be readily integrated into a network of growing density. Therefore, DC circuits will remain restricted to bulk power transfers from point to point and/or link two adjoining AC systems, without any intermediary line, the two converter stations being simply connected back-to-back.

Regarding development prospects, it is estimated that total HVDC transmission capacity around the world will triple within the next five or six years [7.22].

Although the major part of HVDC transmission systems operates in developed countries, as early as 1977 such a system was commissioned in a developing African country, between the Cabora Bassa hydro power system on the Zambezi River, with an installed capacity of 2000 MW – which could be doubled by construction of a sister power plant at the same dam – and the Republic of South Africa where the bulk of generated electricity is exported. With its amount of power, length of the HVDC line (1440 km) and its voltage of ±553 kV, this HVDC system was at the time the world's largest [7.23].

As an alternative to overhead transmission lines, high voltage cables are very expensive and limited to short distances. However, high voltage DC cable transmissions (HVDCT) over longer marine distances might play an important role in the future, especially for large load transports.

Typical for such submarine transmissions are links between the mainland and nearby islands. There are several such favourable situations also in developing countries, for example between the islands of Sumatra and Java with a rapidly increasing electricity demand. Although for the next few years maritime coal transport to the new thermal power plants on Java is planned, a HVDC transmission from new mine-mouth power plants on Sumatra to Java might be a later alternative, the sea distance between the two islands being no more than 30 km.

As far as more exotic electric energy transmission modes are concerned, brief mention may be made of microwave transmission, a possible future technology to transmit satellite solar-energy-generated electricity to the earth and of the possibility sometime in the future to transport electrical energy almost without losses using the superconductivity of conductors cooled close to –273°C.

7.6.1.2. Electric interconnections

One of the more recent applications of electrical energy transmission lines, one which has made impressive progress, is their use to interconnect one or several national electricity systems, or even large regional systems consisting of a series of national networks. Accordingly, this subsection will not deal with local interconnections leading to national electric systems, which were discussed in chapter 6.

The development of interconnections between large electric systems is a worldwide phenomenon. It started at about the same time in North America, Western and Eastern Europe and now concerns all continents. Moreover, many projects are at present under study.

The economic advantage in electric energy interchange between neighbouring systems results in the first place from the reduction in maximum installed power, due to differences in the respective load curves and the improved security of supply.

In addition, reliable and economic operation will be obtained by:

– taking advantage of demand diversity which exists in the system loads and outages of the component power systems which will allow each national system to operate on less reserve than would normally be required
– co-ordinating different types of generation
– exploiting the complementarity of different hydrological conditions
– sharing of power system uncertainties
– optimizing capital investment
– having the possibility of adding more economic, larger units to a national system, maintaining a convenient reliability level at a smaller cost.

Although there are also other examples of interesting electrical interconnections in the world, three European examples were chosen for their particularities to be further commented on:

The West European interconnected electric system is self-explanatorily characterized in Fig.7.10, which presents the electric energy flow on 20 January 1982 at 3:00 and 11:00. Figure 7.10 illustrates the actual electric load in each country (P) and the export (E) or import (I) balance at the two times checked. If followed in detail, the changes in the flows, both directional and in terms of volume, convincingly demonstrate the flexibility of this huge but heterogeneous electric system [7.24].

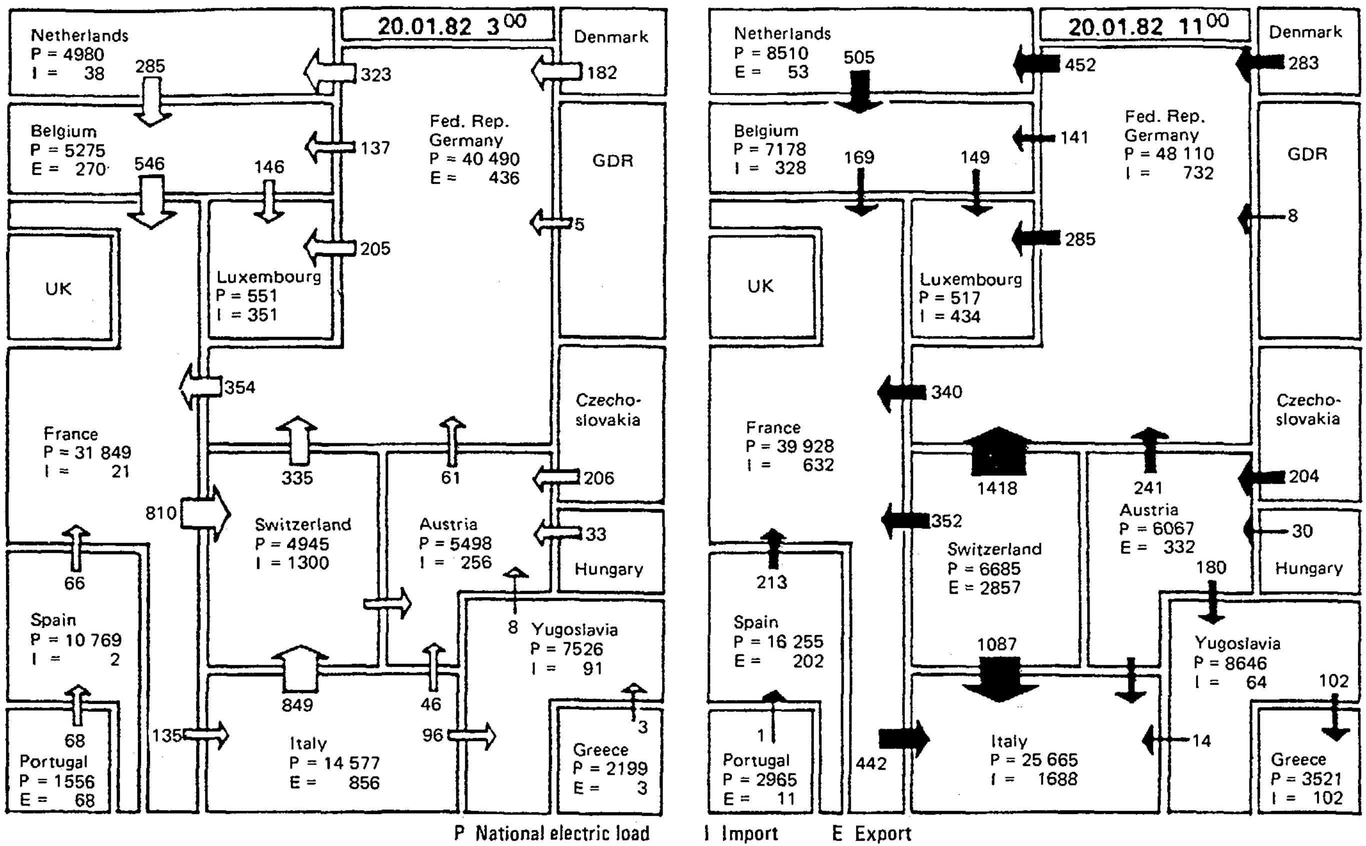


FIG.7.10. The electric energy flow in the West European interconnected system on 20 January 1982 at 3:00 and 11:00 [7.24].

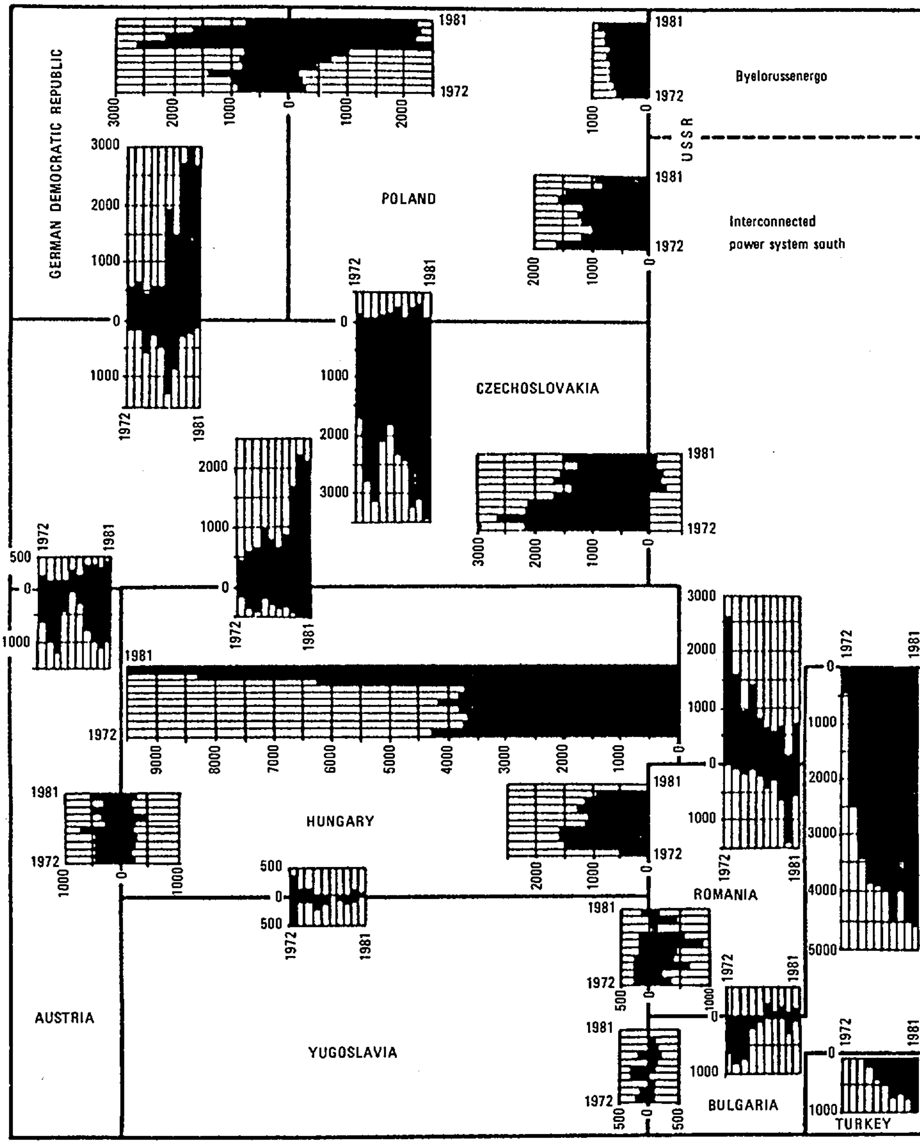


FIG.7.11. Mutual electric energy exchanges within the East European interconnected electrical system between 1972–1981, in GW·h [7.25].

The East European interconnected electrical system of the CMEA (Council for Mutual Economic Assistance) reached in 1982 – after being connected in 1978 to the Unified Power System of the USSR by a 750 kV transmission line –, a total installed capacity of some 140 GW, an electricity production of 650 TW·h and a peak load of 100 GW [7.26]. Figure 7.11 displays the mutual electric energy exchanges within the system between 1972 and 1981. Reference [7.24] brings in addition a detailed report on the operation of the s system and the economic results.

The interconnection between the two large West and East European electrical systems has been studied for years. Currently it appears that by 1990 the installed electric capacity will be approximately equal in both systems, i.e. each will have about 500 GW [7.25]. From the studied AC and HVDC links, probably the latter will be given preference, since by gradual construction of back-to-back links at various points, it would be possible to initiate electric power transfer between the two systems without reinforcing the adjoining grids. A preliminary estimated figure for the volume of electric energy exchanges in 1990 could be around 6000 GW·h.

Two more interesting interconnection studies may be mentioned: the interconnection of the electric power transmission systems of the Balkan countries carried out under the aegis of the ECE [7.27] and the study on the interconnection of the electrical systems of the Central American countries, elaborated in an UN-UNDP technical assistance project. Interestingly enough, it was the latter's requirements which led to improving the WASP II electricity planning model to its present WASP III version, described in chapter 17.

7.6.2. Electricity distribution

Electricity distribution in an electrical system develops as urban electricity supply, rural electricity supply (rural electrification) and possibly as mixed supply in sub-urban, developed rural areas.

An urban electricity supply as it grows will acquire each of the following levels: networking, distribution, subtransmission, transmission.

Accordingly, at each higher level the supply from the electrical generation plant will be more distant – geographically and electrically – and the 'distribution' will take over at higher voltages.

In the interest of a smooth and sensible evolution from one level to another, with rational integration of the lower ones, long-term decisions on the most suitable configuration of the system at each of these levels have to be made so that routine short-term planning can proceed within the framework of such configuration. The arrangement of the system at each level can be treated independently. There may be more than one configuration adopted at any one level. The following configurations have been used in urban systems:

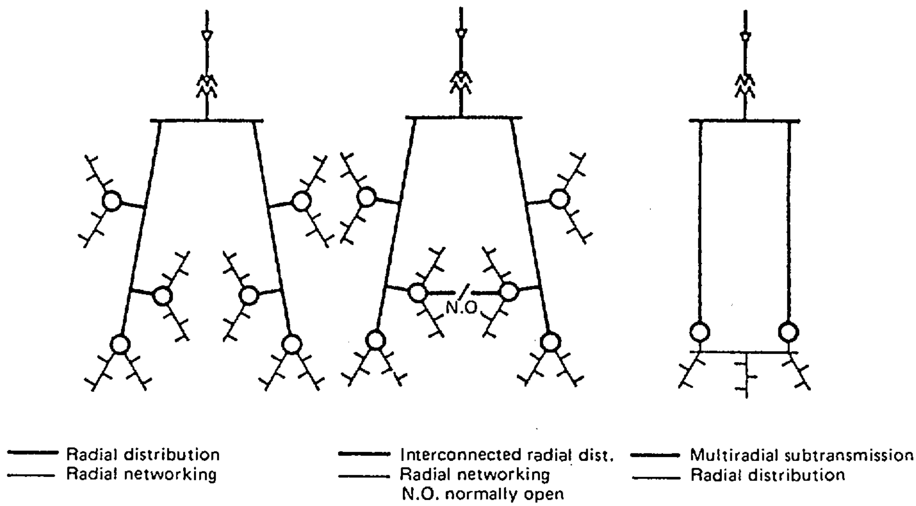


FIG. 7.12. Radial distribution and networking schemes [7.28].

Radial systems, illustrated in Fig.7.12, consist of one or more feeders radiating from a supply bus-bar to a given point. They are the simplest form of system, being easy to plan, protect and operate.

Single radial systems (a) are used for networking and some distribution. When suitably protected, they will give satisfactory service, but each circuit fault will result in an interruption of supply. The duration of the interruption can be reduced in the case of self-clearing transient faults by equipping the sending-end switchgear with automatic reclosing equipment.

Interconnected radial systems (b) are used for networking, distribution and subtransmission. They are a natural development of a number of single radial systems to improve overall reliability. Normally, open interconnections are provided between adjacent single radial systems so that some supply can be restored under permanent fault conditions by isolation of the faulty section and closure of the interconnecting switches.

Multiradial systems (c) are used for transmission, subtransmission and special cases of distribution. They provide a higher degree of reliability than single radial systems. Two or more circuits may be connected between two points, often with the receiving end of each circuit terminating in a transformer, the higher-voltage switchgear being eliminated. The percentage of spare capacity required for reliability decreases as the number of circuits increases.

A disadvantage of radial systems is that all supply to the area is from one source, i.e. the sending-end substation. This need not be of great concern if system design is properly carried out, the greatest risk being a major disturbance which completely eliminates the sending-end substation.

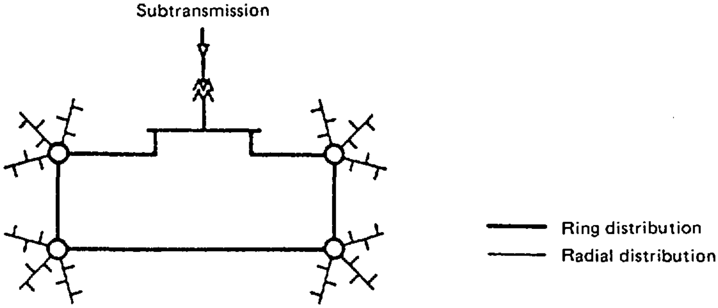


FIG. 7.13. Ring distribution and radial networking [7.28].

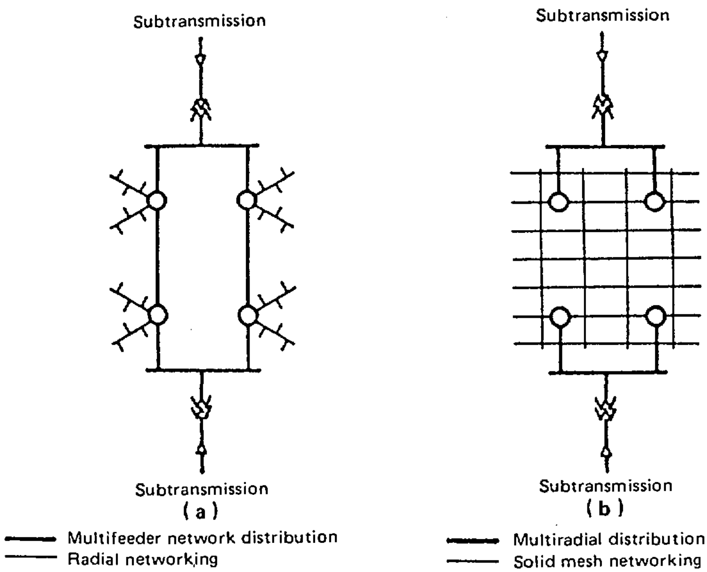


FIG. 7.14. Network systems: (a) multifeeder network, (b) multiradial distribution [7.28].

Ring systems, illustrated in Fig.7.13, consist of a ring of switched circuits connected to a supply bus-bar. They provide a high degree of reliability to all points, providing the rating of each element is satisfactory for the total emergency load to be carried around the ring. They are complicated by the need for switchgear and protection at the intermediate points.

Ring systems are used for distribution, subtransmission and transmission.

Network systems, illustrated in Fig.7.14, consist of a number of switched or non-switched circuits with intermediate loads connected to one or more supply bus-bars.

Multifeeder networks (Fig.7.14(a)) are used for networking and distribution. They have switchgear and protection equipment at the supply bus-bars.

Solid mesh systems (b) are used for networking. They have fuses at the supply bus-bar and often rely upon burning the fault off the system when circuit failure occurs.

Substations join one voltage level of the system to another voltage level of the system and switching stations join together circuits of one voltage level.

In deciding on the system configuration, the single-line diagram of substations on switching stations must be considered.

Substations can be classified in a number of ways, for instance:

– whether one or multiple transformers are used
– whether one or multiple bus-bars are used
– whether or not automatic switchgear is provided.

There are many variations and combinations of these classifications, the arrangement at the high-voltage level of the substation often differing from the arrangement at the low-voltage level.

The smallest, most numerous and least reliable substations are between the distribution and networking levels. It is here that single-transformer substations are usually found with single bus-bars and non-automatic switchgear in the interests of economy.

Substations and switching station size and complexity increase at the higher voltage levels as the area of influence is greater and reliability must be higher. Here multiple transformer substations are found with multiple bus-bars and automatic switchgear.

In considering alternative plans for the development of urban electricity supply – including all other equipment necessary for safety, protection, etc. – the alternatives must be critically compared to ensure that each will give the same service and quality of supply. Only then should an economic comparison of alternatives be made on the basis commented on in chapter 7 (present-value method).

As far as rural distribution is concerned, the problems have to be approached in the light of optimizing rural electrification, which is technically much simpler but economically much more difficult to finance.

7.6.3. Losses in electricity transmission and distribution

As in any other process of transportation, energy is consumed during the transmission and distribution of electricity. This consumption appears as the transformation or deduction of a fraction of the transmitted power and electrical energy. Such transmission-related consumption is termed the 'network loss', or the 'technical loss'. There are also significant 'commercial losses', mainly attributable to incorrect meter readings and to errors in, and delays between, the recording and the accounting of the metered amounts. In frequent cases, pilferage may have a significant contribution.

TABLE 7.IV. ELECTRIC NETWORK LOSSES IN VARIOUS ECE-COUNTRIES IN 1978 [7–29]

	(%)		(%)
Bulgaria	10.49	Ireland	11.12
Czechoslovakia	7.11	Poland	10.29
German Democratic Republic	6.85	Spain	10.40
Federal Republic of Germany	3.50	Switzerland	8.90
France	7.20	Turkey	11.38
Hungary	8.56	Yugoslavia	11.30

Although partly avoidable, losses[7] are to be compensated for by additional installed capacity and electricity generating. The magnitude of network losses is not in itself a suitable criterion for the optimization of network design. There are many other factors involved and best options for network development have to be patiently evolved and time-consumingly computed.

This is also the full explanation why network losses figures are so different in various countries. Table 7.IV presents the network losses figures for a series of ECE countries, extracted from a consolidated ECE report [7.28]. The lowest loss figure appears in the Federal Republic of Germany, with 3.5% in 1978, down from 7.0% in 1970 and from even 14% in the 1950s.

The loss percentage figures of electrical networks of developing countries are considerably higher, up to 20–25% and even higher, the 'commercial' component playing an unusually important part.

One of the very effective measures for electricity losses reduction is the compensation of reactive power through installation of capacitors in low-voltage and medium-voltage networks. The inductive current needed by motors, transformers, etc., is supplied by capacitors in the consuming area, and no longer travels all the way from the power station, which would cause additional losses. The scope for the use of synchronous phase modifiers largely depends on the basic structure of the transmission network, i.e. on the location of generation and consumption points and the resultant transmission distances. Probably a combination of decentralized and centralized compensation would lead to the best results.

[7] The writer would prefer the use of the term "auxiliary consumption" of the electrical energy transport by analogy with the consumption of power generation instead of transmission "losses".

7.6.4. *Electrical energy storage – indirect modes*

Since electrical energy as such cannot be stored, indirect methods have to be applied in order to meet peak demand with electricity which has been generated much earlier in more favourable conditions. That is only possible by temporary conversion of electrical energy into another, storable energy form, which permits reconversion into electricity when need for it occurs. To this purpose, the following conversion and storage routes are available [7.30]:

(1) pumped water storage
(2) compressed air storage
(3) heat storage
(4) battery storage
(5) electrochemical storage
(6) storage in superconducting magnets.

There are two major reasons which are giving the old requirement for electricity storage new impetus:

- increasing solar energy generation of electricity, with its intermittent character, and
- changed economy of electrical-load-curve-covering conditions.

Whereas the first reason is self-explanatory – except for eventual satellite-based power generation – the second needs some explanation.

The classic coverage of the daily electricity load curves used to be as follows: 40 to 50% – the base load – was supplied by hydro-electric run-of-the-river plants and large coal and nuclear units of the highest efficiency operating on the fuel of lowest cost; the next 30 to 40%, the broad daily mid-peak was met by 'cycling' or intermediate generating equipment, usually the system's less modern and less efficient fossil-fuel (coal, oil or gas) units, hydro-electric power units if available and gas-turbine units where needed. Although this part of electricity costs more, such plants are the best suited for operating only part-time during the day, i.e. for 1500–4000 h/a. Brief peak demand was met by specialized units, hydro power plants, gas- or oil-fired turbines and diesel generators, operating from a few hundred hours per year to 1500 hours.

This traditional three-level combination supply has become increasingly less attractive as sharply rising fuel costs penalize the less efficient units. Moreover, coal-fired units now require costly pollution control equipment that represents a technical and economic disincentive to cycling operation. Together with the imperative of oil substitution, pressure and interest is for efficient base-load plants as the source of power now generated by cycling and peaking. That is only possible by flattening the load curve by demand management on the one hand and energy storage on the other, i.e. accumulating the output of base-load plants during periods of low demand (nights and week-ends) for periods of high demand.

7.6.4.1. Pumped water storage

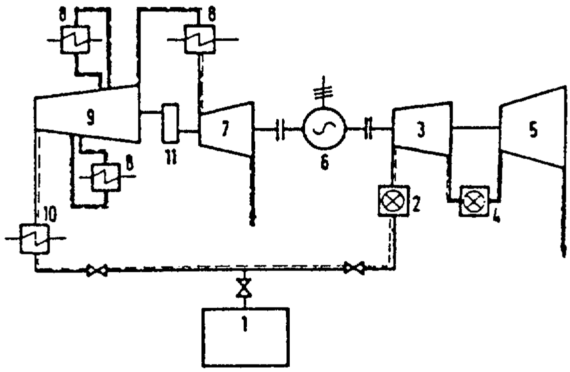
In addition to natural water storage as practised for over a century, pumped hydro-electric storage is the only well-established commercial method of energy storage for electricity. Its main features were described in chapter 6 and its basic concept and operation shown in Figs 6.8 and 6.9. However, the method is of limited applicability both because of the shortage of suitable bodies of water and topographic sites and because of objections from people who perceive such plants as being a major threat to the natural environment.

One of the several new energy storage concepts being examined is underground pumped hydro-electric storage, which would be less limited by topographic and environmental constraints than conventional pumped hydro-electric systems. In the proposed system a lower reservoir is constructed underground in hard rock, without any connection to a natural body of water. The upper reservoir can also be artificially created and can be much smaller than the one that would be needed for a surface pumped hydro-electric system of the same energy storage capacity. The reason is that the distance between the lower reservoir and the upper one can be over 1000 m compared with less than 300 m for a typical surface pumped-storage system. Energy storage capacity is directly proportional to the height of the head of water.

The prospects for underground pumped hydro-electric storage seem good, because practical cavern-excavation and tunneling methods exist for the construction of the lower reservoir and because high-lift pump-turbine technology is essentially in hand although further improvements are desirable. The chief geological constraint is the need to identify and to predict the characteristics of suitable rock formations [7.30].

7.6.4.2. Compressed air storage

Another conceptually simple way to store energy in a form convenient for power generation is to pump compressed air into an underground reservoir. Compared with pumped hydro-electric storage this method has several advantages: a wider choice of geological formations (the storage cavern could be in either hard rock or salt), compactness (the density of the energy stored could be higher) and a smaller minimum size for an economically attractive installation. There is, however, one complication: since the air gets hotter when it is compressed, it must be cooled before it is stored in order to prevent fracturing of the rock or creeping of the salt. The stored air must then be reheated by burning a certain amount of fuel as the air is expanded into the turbine that drives the electric generator.



1 Air storage
2 High-pressure combustion chamber
3 High-pressure turbine
4 Low-pressure combustion chamber
5 Low-pressure turbine
6 Generator/Motor
7 Low-pressure compressor
8 Intercooler
9 High-pressure compressor
10 Aftercooler
11 Gear box

FIG. 7.15. Air-storage gas turbine, Huntorf [7.31].

Separating air compression from electricity generation, which concomitantly takes place in normal gas-turbine units, enables on the one hand a higher production of electricity at peak demand and on the other, compressing the air with less costly night electrical energy.

The world's first commercial compressed air underground storage installation was commissioned in Huntorf in the Federal Republic of Germany, at the end of 1978.

During peak demand, the turbine-generator set – uncoupled from the air compressor (7 and 9) – can produce up to 290 MW. The air is taken from the storage reservoir (1) and reheated with natural gas. During off-peak hours, the generator, uncoupled from the gas turbine (3–5) and coupled with the air compressor, operates as a synchronous motor of 60 MW and charges the air storage reservoir up to 65 bar – see Fig.7.15.

The cavern storage volume, 230 000 m^3 air at 65 bar, can provide for two hours of maximal load operation, till the pressure drops to 45 bar. Normally the unit operates up to two hours a day, generating at the three peak hours – morning, mid-day and evening – and needs then eight hours to recharge the air cavern excavation. For each kW·h of output an electric energy input of 0.83 kW·h is needed for air compression and a fuel input of 6000 kJ for air reheating.

The unit operation is fully automated and remotely controlled. From normal start to full load, the unit needs 11 minutes, for urgencies only six minutes, Five years of satisfactory operation have confirmed the maturity and advantages of this new storage technology [7.31]. The next step in the development of this technology must be to reduce the quantity of high-quality fuel needed for reheating the air in the expansion phase. One way to get better efficiency will be to recover exhaust heat from the power-generating turbine and use it to preheat the expanding air. That is the direction on which the first compressed air energy storage (CAES) system in the USA recently embarked [7.32]. The new plant, scheduled to start operation in 1986, has a generator output of 220 MW, an operating time of 11 hours as generator, and an air charging time also of 11 hours with a power input of 162 MW.

In addition to the difference in the charging/generating ratio which is 4:1 at Huntorf and 1:1 for Soyland plant, the latter reheats the compressed air by turbine exhaust heat, i.e. with recovered heat instead of primary energy. Also, the air storage system is different: Huntorf operates on sliding pressure with a pressure reduction of about 20 bar during the two hours of discharge, while the Soyland system is designed to operate at almost constant pressure of 54 bar when discharging and 0.7 bar more when charging.

The heat rate of the Soyland unit should reach a 30% lower figure than the one in Huntorf, i.e. 4100 kJ/kW·h against 5860 kJ/kW·h due to the much better heat husbandry.

7.6.4.3. Heat storage

Storage of heat has been dealt with in subsection 7.5, both per se as well as in connection with its favourable effects on electricity generation. However, one rather historical comment might be added regarding the utilization of Ruths steam accumulators. Some fifty years ago, at the Berlin-Charlottenburg steam power station a battery of Ruths steel storage vessels was installed. It was designed to store a pressurized mixture of power plant steam and hot water which during peak hours released steam to drive special steam turbines. Although effective for the then particular existing conditions – total power generation and size of the storage batteries –, this technique should be outdated in relation to the new dimensions of present-day power economy. Apparently, this has also been the conclusion of an examination carried out in the USA, which concluded that such storage schemes are likely to be costlier and less efficient than pumped hydro-electric or compressed air energy storage [7.30].

7.6.4.4. Battery storage

The energy storage system most widely useful to electric utilities could be one based on secondary batteries (batteries that can be recharged). In the early years of this century lead-acid batteries were used in cities to supply electric streetcars with direct-current electricity during rush-hours.

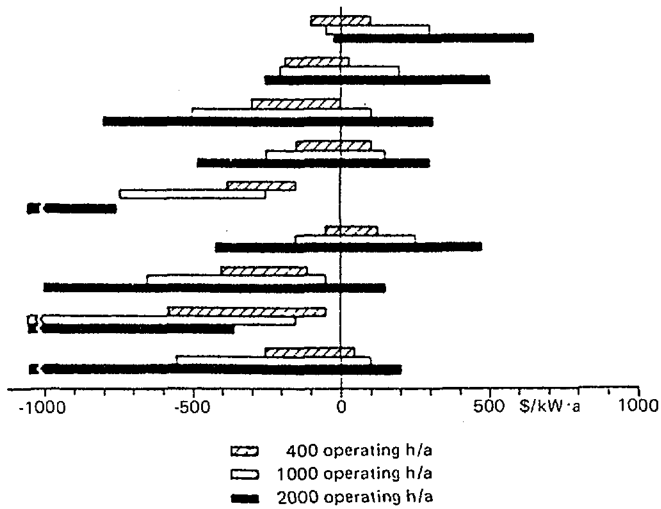


FIG.7.16. Economic aspects of energy storage modes in electric power systems, after solving some still unsolved technical problems [7.33].

In actual power systems, battery storage plants could be located at various places within an electric-power grid. In hours of low demand electricity would be converted from high-voltage AC into lower-voltage DC and stored in the batteries. During peak hours the process would be reversed to carry part of the utility's load.

Battery storage systems could be attractive to utilities on several counts. Their input and output would be entirely electric and could respond rapidly and efficiently to changes in load. The capacity of a storage plant could be established and increased in modular increments, and the batteries could be produced and installed rapidly when they were needed.

In recognition of this situation, high priority has been assigned in some industrialized countries to electric battery research and development.

The development programmes are focused on several new types of battery that promise both lower initial cost and longer service life than the traditional lead-acid battery. For example, in the sodium-sulphur battery a radical departure from conventional designs, in which the electrodes are solids and the electrolyte is a liquid, has taken place, i.e., the electrodes are liquid and the electrolyte is a special solid ceramic [7.30].

Anyhow, prospects of development are good in this area, which could also benefit decentralized electricity supply in rural areas, where eventual input of new and renewable energy resources needs particular support to bridge their inherent periods of non-availability.

7.6.4.5. Electrochemical storage

Hydrogen generated from water by electricity could be stored as a compressed gas or as a metal hydride and reconverted into electricity in a fuel cell. A hydrogen energy storage system would have considerable flexibility with respect to the location and operation of the energy storage plant but as already discussed in subsection 5.1.4.5 the hydrogen economy is not for this century.

7.6.4.6. Storage in superconducting magnets

Superconducting magnets could store electricity directly and with high efficiency, but the method appears to be inherently costly; to be economic the superconducting installations would need to have an extremely large storage capacity, at least 10^6 kW·h, and even on that scale their ultimate economic viability is questionable [7.30].

7.6.4.7. Summary

The display of the estimated specific cost (US$/kW·a) of the various modes of indirect storage of electricity in dependence of their annual utilization, in Fig.7.16, presents an excellent overview on the subject [7.33]. In fact, only the right side of the figure deserves attention, and this confirms the positive comments expressed. However, the accompanying remark that some progress remains to be made suggests both reflection and caution should be exercised.

Chapter 8

IMPROVED ENERGY HUSBANDRY – ENERGY CONSERVATION

In chapter 2, "Energy demand and demand management", subsection 2.3 dealt with all action for improving energy husbandry and energy conservation in the final consumption stage of the energy system.

In line with the basic approach there explained, this chapter deals in detail with the subject as related to all other stages of the energy system. The comments will continue to focus mainly on technical aspects, but still taking economic aspects into account.

The subject of integrated optimization of the energy system will follow in chapter 13, based on the preparatory content of chapter 2 and the present chapter as well as on the economic aspects dealt with in Part II.

There are three basic ways of improving the efficiency of the conversion and transport processes between the primary energy and the end-use energy stages of the energy system:

(a) Improving the efficiency of single processes
(b) Combining energy processes with a view to reaching a higher common efficiency
(c) Promoting the recovery of industrial secondary energy resources (ISER)
(d) Combining the three above activities.

8.1. Improving the efficiency of single energy processes

It would be practically impossible within the framework of this textbook to examine every conversion and transport process of the various energy chains linking primary and end-use energy stages of the energy system, and assess, based on the evolution of present and probable future technology, the span of possible and reasonable improvements in efficiency. Although such an endeavour is not possible at the broad overview level, it is however not impossible that for the concrete conditions of a case study, a detailed, quantitatively correct assessment, however time-consuming, might be successfully carried out.

Under the assumption that every time they are needed such detailed assessments are effectively undertaken, comments on the subject will be confined to the presentation of Table 8.I, which summarizes the conclusions of a comprehensive study elaborated by the United Nations Economic Commission for Europe in 1976 [8.17]. Since referring basically to efficiency ranges, the figures should still be pertinent.

A glance at Table 8.I shows no great prospects for improving the efficiencies of the range of single processes presented, the majority having already reached

TABLE 8.I. TYPICAL ENERGY PROCESSING AND CONVERSION EFFICIENCIES IN THE ECE AREA [8.17]

Process	Currently obtained (%)	Practically possible by early 1990s (%)	Maximum possible by early 1990s (%)
Coal preparation	90	90	92
Coal conversion into coke and coke oven gas; patent fuel; brown coal briquettes; brown coal coke	90	90	92
Coal conversion into synthetic liquid and gases	60–70	60–70	65–75
Refining of oil	88–94	90	94
Refining of oil shale	85	97	99
Processing of natural gas	96–97	97	97
Conversion of primary energy into electricity:			
– at conventional fossil plants	30–35	38	50–60
– at nuclear plants (nuclear reactor excluded)	32	36	45–50
Conversion of primary forms of energy into electricity and heat	70–80	70–80	70–80
Enrichment of uranium ore	60	70–80	70–80

their upper limits. However, the figures fit well in the middle part of the energy chains involved, whilst the major potential for improving efficiency remains in their initial part – the extraction stage of primary energy resources – and in the final stage, as shown in chapters 2 and 3.

8.2. Combined energy processes

8.2.1. Co-generation of heat and electricity

Co-generation is the combined production of two forms of intermediate energy, mechanical and/or electrical plus heat of sufficiently high temperature to be supplied for further usage. Although it is one technological process, it can take place in 'topping' or 'bottoming' cycles, depending on which energy is produced first.

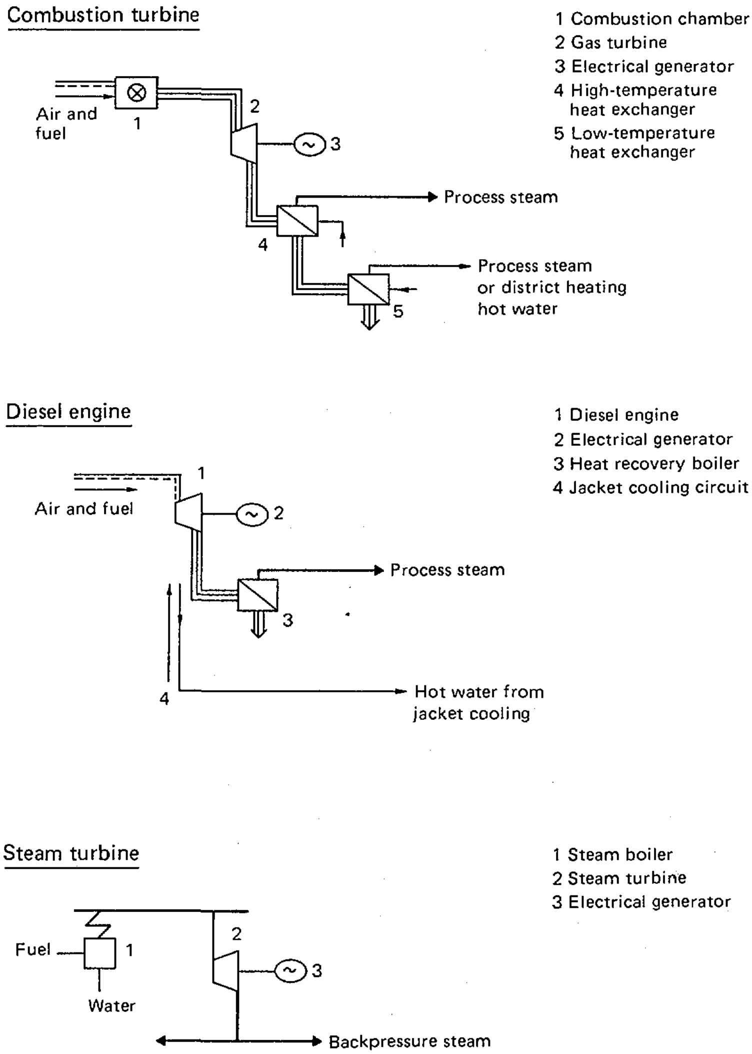


FIG.8.1. Illustration of topping-cycle co-generation systems [8.1].

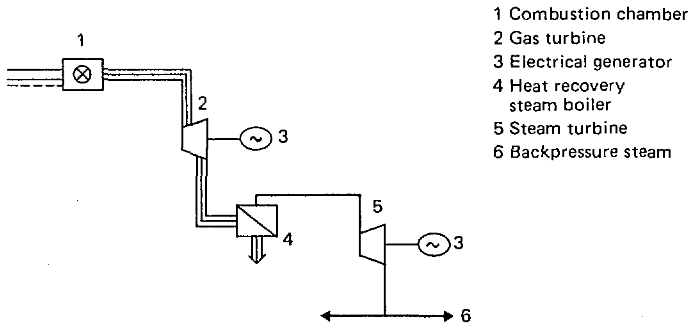


FIG. 8.2. Illustration of a combined gas/steam co-generation cycle [*8.1*].

Figure 8.1 illustrates topping-cycle co-generation systems, i.e.:

(a) A combustion turbine power-generating cycle, with optional heat outputs for high- and low-temperature processes. In a more advanced form the turbine cycle might be closed and externally fired
(b) A diesel engine power-generating cycle with high- and low-temperature exhaust gas heat and jacket-cooling utilization
(c) A Rankine steam turbine cycle, with backpressure heat utilization.

A combined gas/steam cycle with cascade power generation and high- and low-temperature exhaust gas heat recovery is shown in Fig. 8.2.

Figure 8.3 schematically displays a bottoming co-generation cycle.

There are some further promising future co-generation technologies that are not now available commercially, such as organic Rankine bottoming co-generation cycles, fuel cells and Stirling engine co-generation cycles [8.1].

While all the above-described systems may concomitantly supply mechanical and/or electrical energy, a basic distinction, however, exists between real co-generation cycles and electrical power generation with waste heat recovery systems. For instance, in all cycles (a) and (b) where combustion gas turbines and diesel engines are involved, the heat which can be used is from the point of view of power generation a 'waste heat' since it could not be used to increase the electrical output of the cycle.

The same applies to the bottoming cycle, Fig. 8.3, since only as much power may be produced as the source supplies waste heat.

The only simple real co-generation cycle is the Rankine steam turbine cycle, where from the live steam supplied by the boiler, more or less specific electric power could be produced depending on the pressure level of the required process steam; or in more complex steam turbine cycles, discussed later, depending also on the output of the additional condensing parts of the turbines. It is only in this

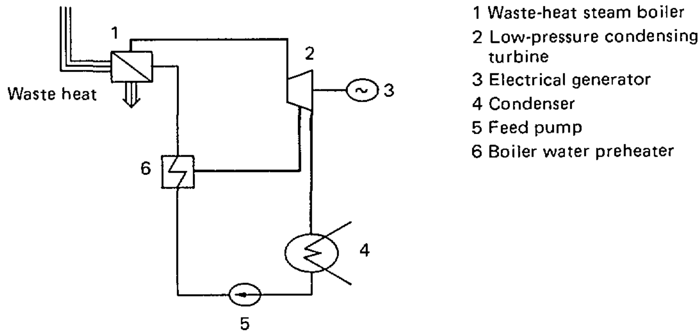


FIG. 8.3. A bottoming co-generation cycle [*8.1*].

way that both heat and power can be co-produced in the desired quantities and proportions. The combined cycle, Fig. 8.2, offers similar possibilities, to a certain extent.

With this basic difference acknowledged, all cycles will be organizationally dealt with in this chapter on co-generation. However, because of their structure and importance, the Rankine steam co-generation systems will be examined in more detail.

8.2.1.1. Steam cycle co-generation of electricity and heat

8.2.1.1.1. Thermodynamic basis of Rankine steam cycle co-generation

Figure 8.4 presents schematically the two basic technical solutions for supplying heat from a Rankine steam co-generation cycle, at a required pressure p_2. In principle it could apply to an industrial process steam demand or to an urban district heating supply; only the p_2 values and extracted heat quantities would differ, both in their absolute figures and variation over time [8.2].

In alternative (a), the live steam with a high pressure p_1 is expanded in a backpressure turbine down to the required pressure p_2, generating electricity. Since the electric power generated strictly depends on the required steam quantity, any deficit or excess of power compared to the electricity demand must be supplied or absorbed by the utility electrical network.

In alternative (b), an extraction-condensing turbine delivers the process steam at the pressure p_2, and if a higher power demand appears, it is covered with electricity generated by steam additionally expanded to the condenser.

Figure 8.5 presents the specific electric power generated by a unit of heat required at different pressure levels when expanding from different entry pressures in the turbine. The higher the entry live-steam pressure in the turbine and the lower the backpressure level, the higher the specific electrical power output per unit of heat supplied.

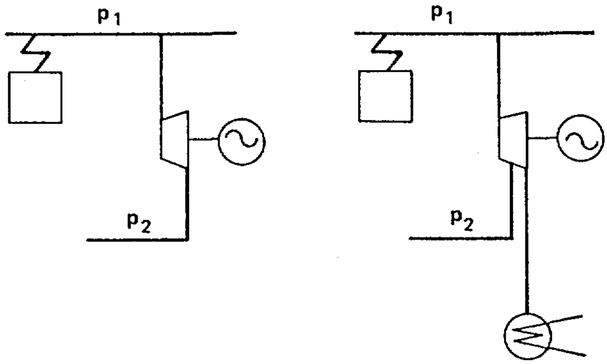


FIG.8.4. Alternative steam co-generation schemes for supplying heat at required pressure p_2 [8.2].

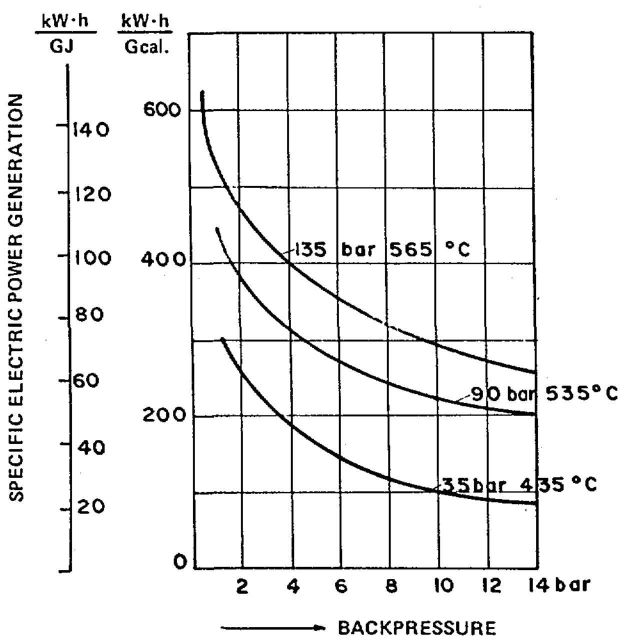


FIG.8.5. Specific electric power generated by steam expanding between different entry- and backpressures [8.2].

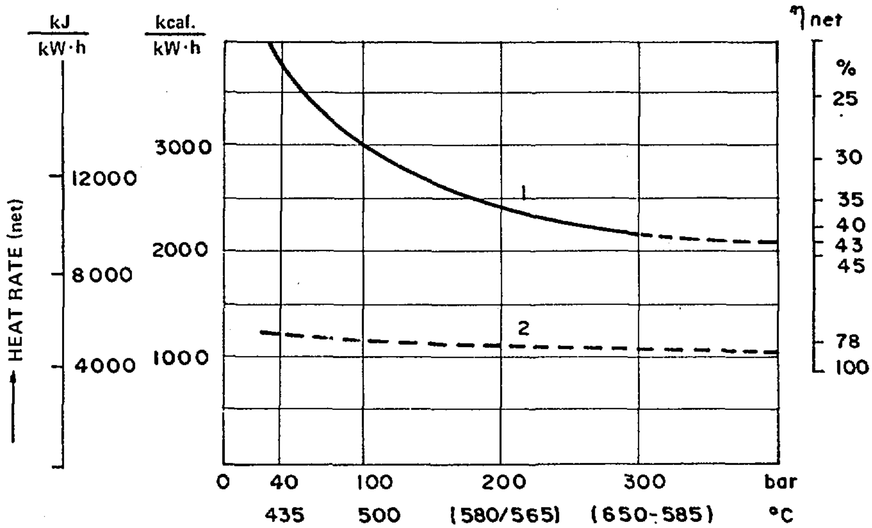


FIG.8.6. Net heat rate of condensing and co-generation plants [8.2].

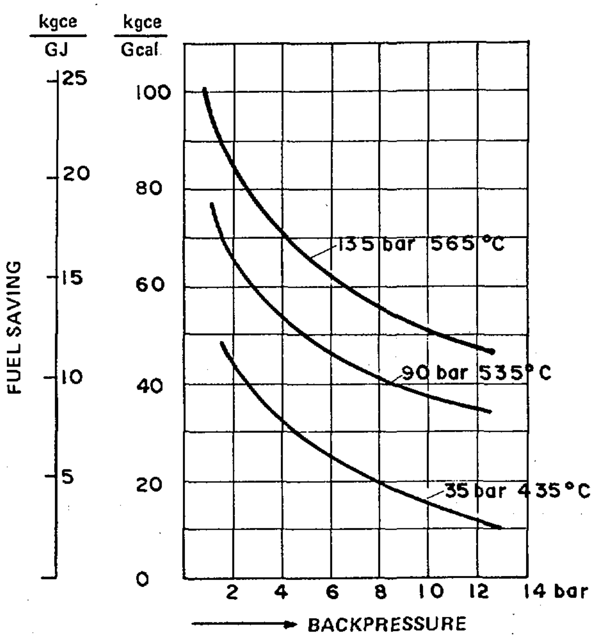


FIG.8.7. Fuel savings in co-generation operation [8.2].

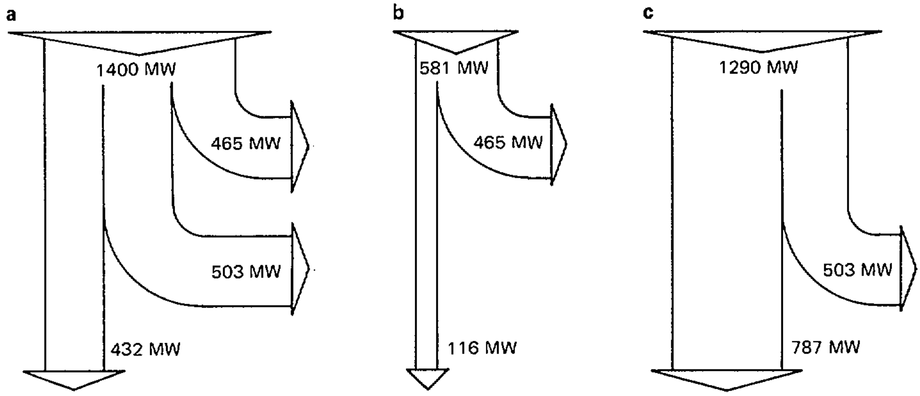


FIG.8.8. Separate and co-generated production of heat and electricity [8.3].

Figure 8.6 displays the specific net heat rate – kJ/kW·h – of condensing thermal power stations (1) and in co-generation operation (2), in dependence on the live steam parameters. The interval between curves (1) and (2) indicates the fuel saved per co-generated kW·h. The net efficiency of the process can be read on the right ordinate scale.

Figure 8.7, derived from the two previous figures, indicates directly the fuel saved per unit of heat supplied, depending on the required supply level and the live steam conditions of the combined power plant.

The last three figures display the interest for using co-generation wherever heat and electricity are needed by industrial consumers instead of separately produced electricity and heat, provided that minimal heat demand density and favourable geographical conditions exist. The fuel savings increase with higher live-steam conditions in the supplying thermal power plant and lower pressure of the heat demand. The fuel saving varies accordingly between 10 and 25 kgce for each GJ of process steam (approximately each 400 kg of steam) supplied.

8.2.1.1.2. Fuel saving by co-generation

Figure 8.8 illustrates convincingly the fuel saved (ΔB) when instead of generating $P_e = 503$ MW in a condensing steam power station and supplying $Q_h = 465$ MW of heat /h from a separate boiler house, the same quantities of electricity and heat are supplied from a co-generation steam power plant, i.e.:

$$\Delta B = 1290 + 581 - 1400 = 1871 - 1400 = 471 \text{ MW}$$

The fuel consumption of the separate alternative is 1.33 times higher, i.e. co-generation saves 25% of the fuel otherwise needed to supply by separate production the required electrical energy and heat [8.3].

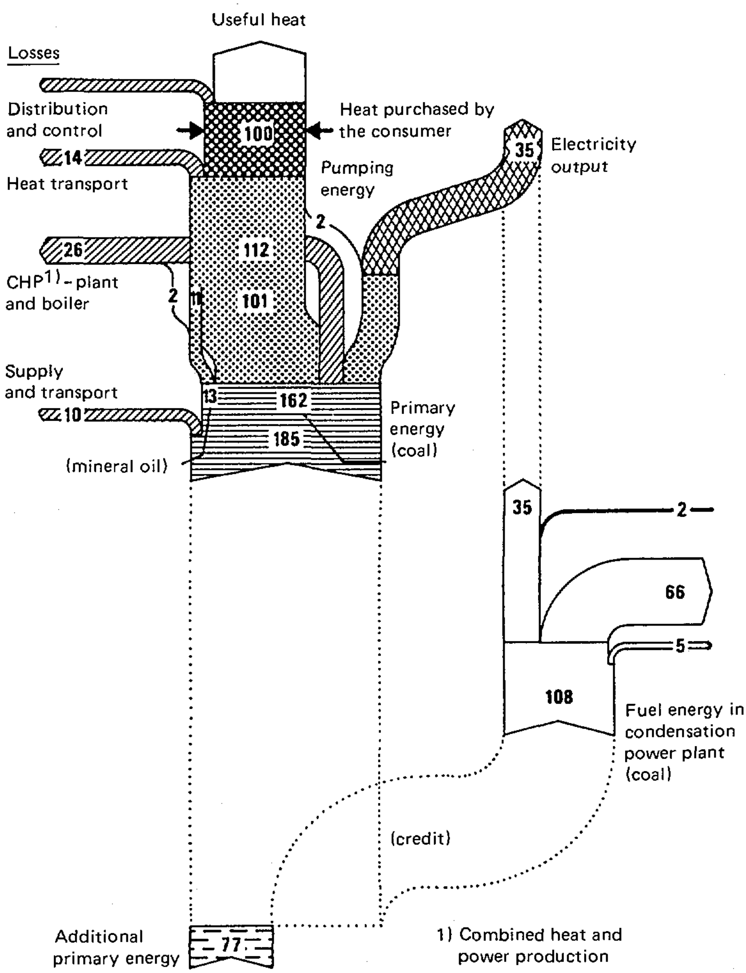


FIG. 8.9. Energy flows of a 23 MW backpressure co-generation plant compared to a condensation plant of same capacity [*8.4*].

Figure 8.9 compares in more detail the heat flows in a 23 MW condensing turbine and a backpressure steam co-generation plant of the same generating electrical capacity and delivering the steam plus peak-heat from an additional heating boiler to the city of Flensburg in the Federal Republic of Germany [8.4]. With 100 parts of useful heat supply and a simultaneous electricity output of 35 parts, the primary energy requirement of the co-generation plant amounts to 185 parts. The condensation power plant requires 108 parts to generate the same amount of electricity. Crediting 108 parts to electricity, only 77 parts of primary energy remain the charge for the heat supply.

In an analytical form, the fuel saving by co-generation can be expressed as:

$$\Delta B = E_c\,(b_s - b_c) + Q\left(\frac{1}{\eta_{HP}} - \frac{1}{\eta_c \cdot \eta_{tn}}\right) - E_{cd}\,(b'_c - b_s)\quad \text{J/year}$$

Where:

ΔB = Fuel savings realized yearly, in J/year

E_c = electric energy produced yearly by backpressure or extracted steam, in kW·h/year

E_{cd} = electric energy produced yearly in the condensing parts of the combined heat and power units, in kW·h/year

b_s = average yearly heat rate of the condensing power plants of the system, in J/kW·h

b_c = average yearly heat rate for the production of electric energy in backpressure or extracted steam, in J/kW·h

b'_c = average yearly heat rate for the production of electric energy in the condensing parts of the combined heat and power units, in J/kW·h

Q = quantity of heat delivered yearly to consumers, in J/year

η_c = average yearly efficiency of heat production in combined heat and power plants

η_{tn} = average yearly efficiency of heat transport and distribution by the heating net

η_{HP} = average yearly efficiency of heat production in boiler houses (heat plants).

The first term of the equation always has a positive influence, the value of its effect depending on the one hand upon the quantity of electricity produced by backpressure or extracted steam and on the other hand upon the difference between the heat rate in the large condensing plants of the power system and the heat rate in combined production. However, this difference shows a tendency to diminish as new condensing power plants are erected with larger units and higher steam characteristics. Nevertheless, as shown in Fig. 8.6, the value of this difference still remains important.

The second term of the equation also has a positive influence, its effect depending essentially upon the output level of the installations producing heat separately as against the output level of the boilers in co-generation plants, as well as upon the quantity of heat losses in the heating net.

However, the possibility in the future of using individual boilers or heating plants with almost equal efficiency – particularly in the case of gaseous or liquid fuel – to that of the boilers of co-generation plants will substantially reduce the contribution of the second term of the equation.

The third term of the equation always has a negative effect, since the heat rate for the power produced in the condensing parts of co-generation plants is sensibly higher than that in large condensing power plants. This term may have a strongly diminishing effect upon the fuel savings ΔB and consequently upon the economy of combined production, if E_{cd} results in a large figure.

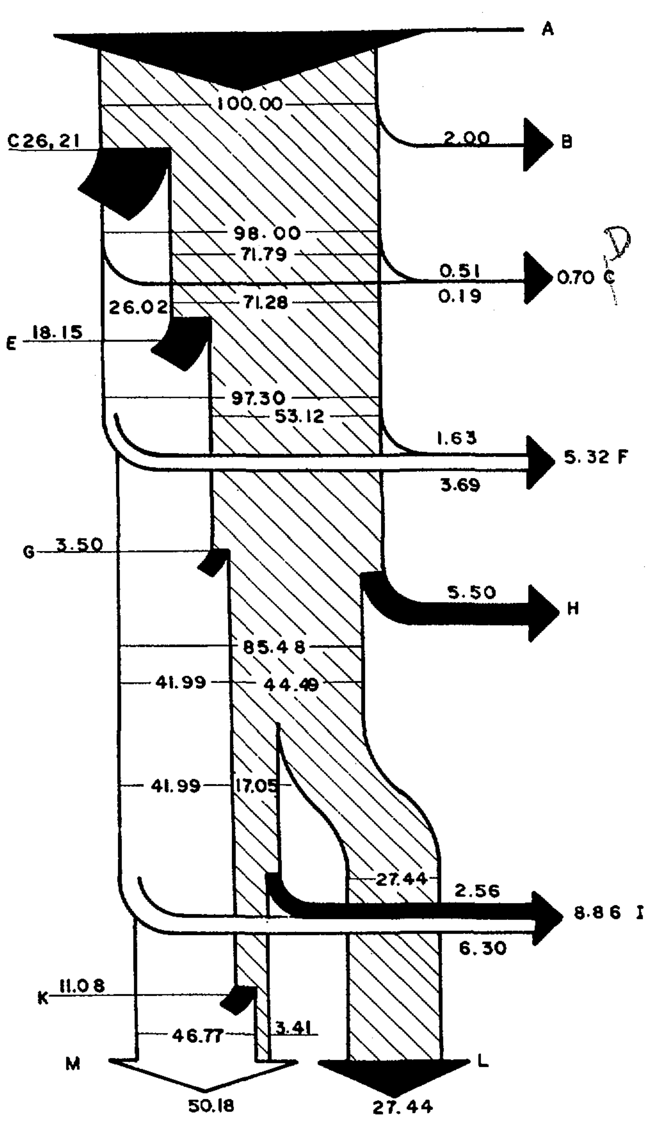


FIG. 8.10. Combined energy/exergy flow chart of a co-generation steam power plant with backpressure turbines [8.2].

A:	*Exergy input*	*G:*	*Irreversibilities of steam flow*
B:	*Losses by incomplete combustion*	*H:*	*Mechanical and electrical losses*
C:	*Combustion irreversibilities*	*I:*	*Losses in warm water distribution*
D:	*Radiation losses*	*K:*	*Irreversible heat transfer from water to space heating*
E:	*Irreversibilities of heat transfer in the boiler*	*L:*	*Electrical energy output*
F:	*Stack losses*	*M:*	*Heat output.*

A fourth term may appear, i.e., ΔEb_s if, in the case of separate production, the electricity produced in large system plants must be increased to compensate for the losses of electrical energy ΔE due to transport to the consumption centre; this penalizes the solution of separate production with an additional fuel consumption ΔEb_s. Yet, within the following general considerations, no consideration will be given to this term, the influence of which varies depending on the given concrete conditions.

In the case of a backpressure co-generation plant, the third, the fuel-saving diminishing term, is waived.

Figure 8.10 presents a combined energy/exergy flow chart, which displays the energy flow – starting as 100% fuel exergy – between the primary energy input to the final electrical power and heat output. The figures plotted at the characteristic levels facilitate the self-explanatory follow-through of the diagram. Remarkable is the overall energy efficiency of 77.62% as against an exergy efficiency of 30.85%.

8.2.1.2. Basic forms of co-generation

The basic forms of co-generation are mainly determined by the nature of the heat-consumers supplied and the characteristics of the heat demand. Accordingly, the following basic forms may be encountered:

(a) Industrial co-generation
(b) Commercial co-generation
(c) District heating and cooling
(d) Rural co-generation
(e) Mixed forms of co-generation.

In addition, depending on the nature of the energy source, newer forms such as nuclear, geothermal and solar co-generation could now be considered. Organic bottoming cycles, fuel cells and Stirling co-generation technologies represent, as mentioned, promising but still only future application forms.

8.2.1.2.1. Co-generation of electricity and heat for industrial supply

Industrial co-generation systems usually have a concentrated demand, both for heat and electric power, need mainly steam as heat carrier, in general require heat supply at several temperature levels – a good deal of it at relatively high temperatures – and with a few exceptions of seasonal campaigns, have year-round operation, often with rather high load factors. Depending on the nature, size or concept of the supplied industries, the capacity of industrial combined heat/power plants ranges from a few hundred kW up to hundreds of MW and steam delivery from a few t/h to 1000 or even more t/h of steam of different parameters.

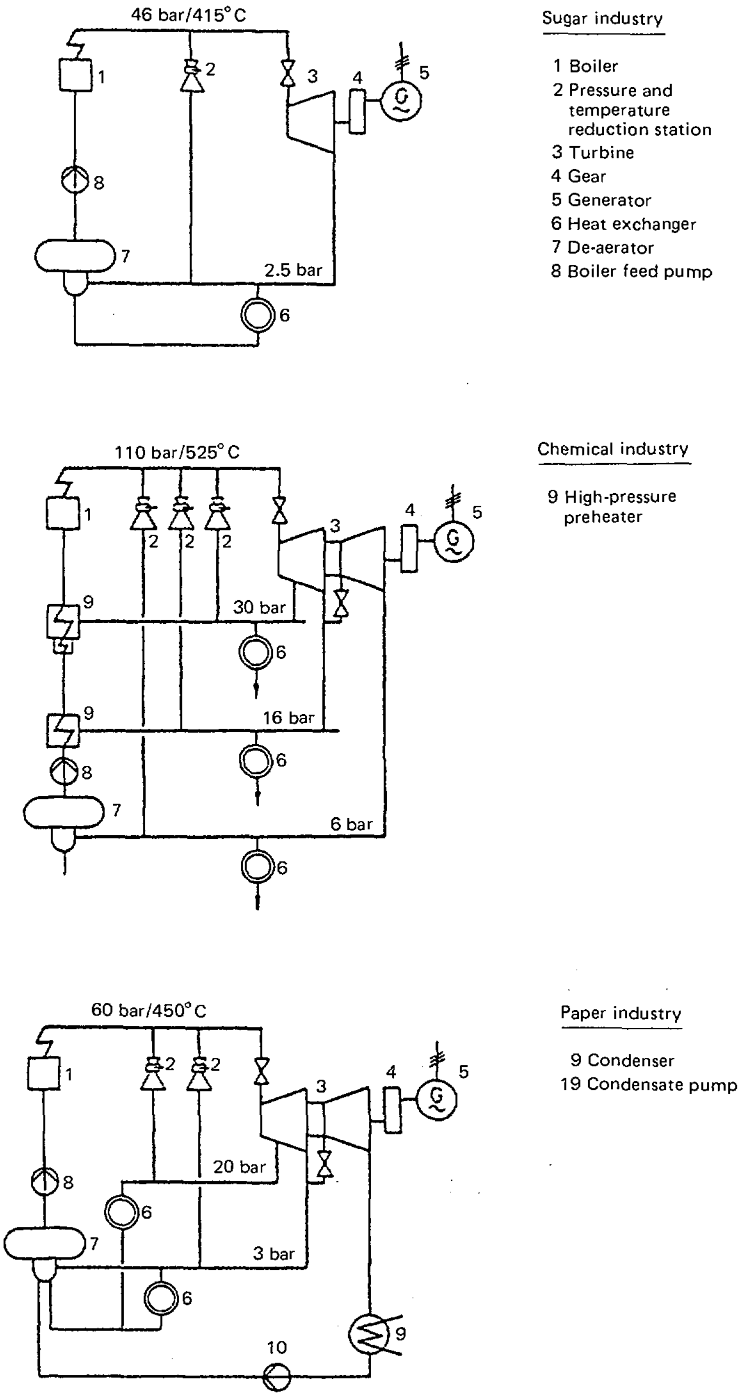


FIG.8.11. Typical heat cycle diagrams for industrial co-generation [8.5].

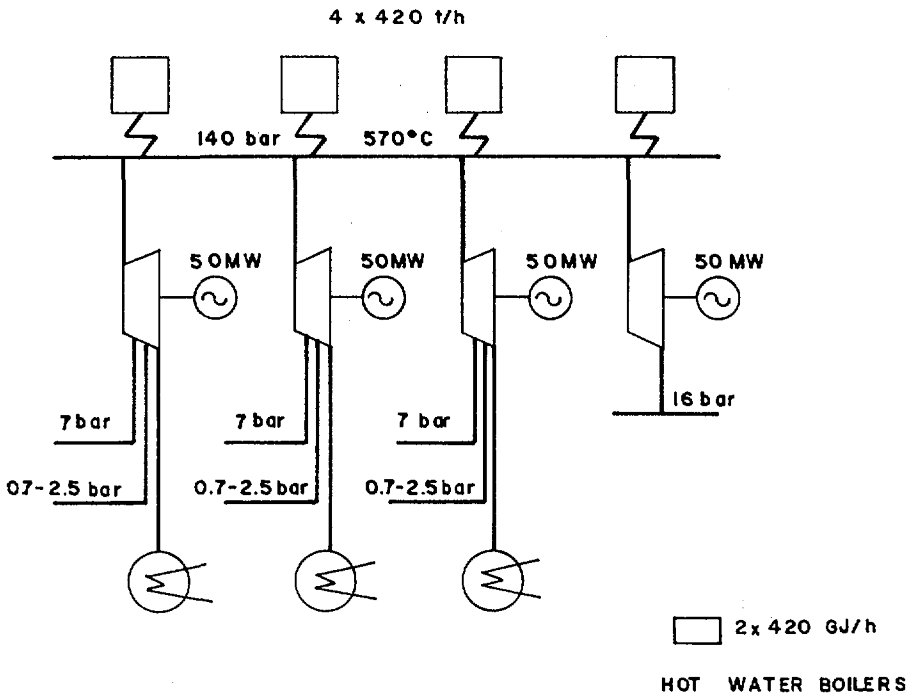


FIG.8.12. Heat cycle diagram of a refinery co-generation plant [8.2].

In the larger plants, provision is often made to install some condensing power capacity, mainly in the form of extraction-condensing turbine units, in order to be able to meet a greater electric power demand even at lower heat supply.

Figure 8.11 displays some typical heat cycle diagrams of smaller to medium-size co-generation power plants for heat supply to the sugar, chemical and paper industries. Two of the plants are equipped with backpressure turbines, the third with condensing turbines provided with a regulated steam extraction. The level of live-steam pressure and level of steam demand appear typical for the selected industry branches.

Figure 8.12 presents the heat cycle diagram of the co-generation power plant of a large petroleum refinery [8.2]. For more information on the subject see Refs [8.6, 7] and the recommended bibliography.

A special form of industrial co-generation, enjoying all its benefits, is the combined production of electricity and desalted water. In this special cycle the co-generated heat is supplied to a battery of heat exchangers, where the salted water evaporates and delivers, through successive cascade flashing, the required desalted water, of fresh water quality. Reference [8.8] reports on recent development in this area in Libya.

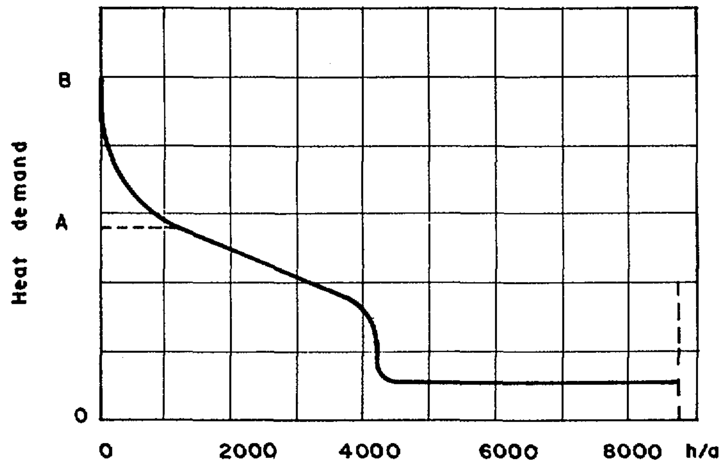


FIG.8.13. Annual duration curve of heat demand for space heating and urban warm water supply [8.2].

8.2.1.2.2. Commercial co-generation

Commercial co-generation involves the electricity and heat supply of large commercial or appartment buildings from their own co-generation plants, using both diesel and gas engines or small steam turbines as the main equipment. Depending on needs and in combination with reversible heat pumps or compressor systems, cooling may be advantageously integrated and accordingly total energy systems designed.

New regulations in many countries now promote industrial and commercial co-generation by requiring the utilities to purchase excess power and to meet the auto-producers' shortfalls by selling to them at equitable rates, and to interconnect and operate in parallel with them. Under these conditions both security and economy of operation are ensured.

8.2.1.2.3. District heating

In contrast to industrial co-generation, which enjoys concentrated heat consumption and heat demand throughout the year, district heating co-generation systems have a rather large area to supply and only seasonal space-heating demand — see Fig. 8.13. During the rest of the year, the demand for domestic warm water supply represents only about 15–20% of the maximum annual heat demand. Since most district heating systems are operating with hot water as the heat carrier, the level at which the heating steam can expand in the turbine is much

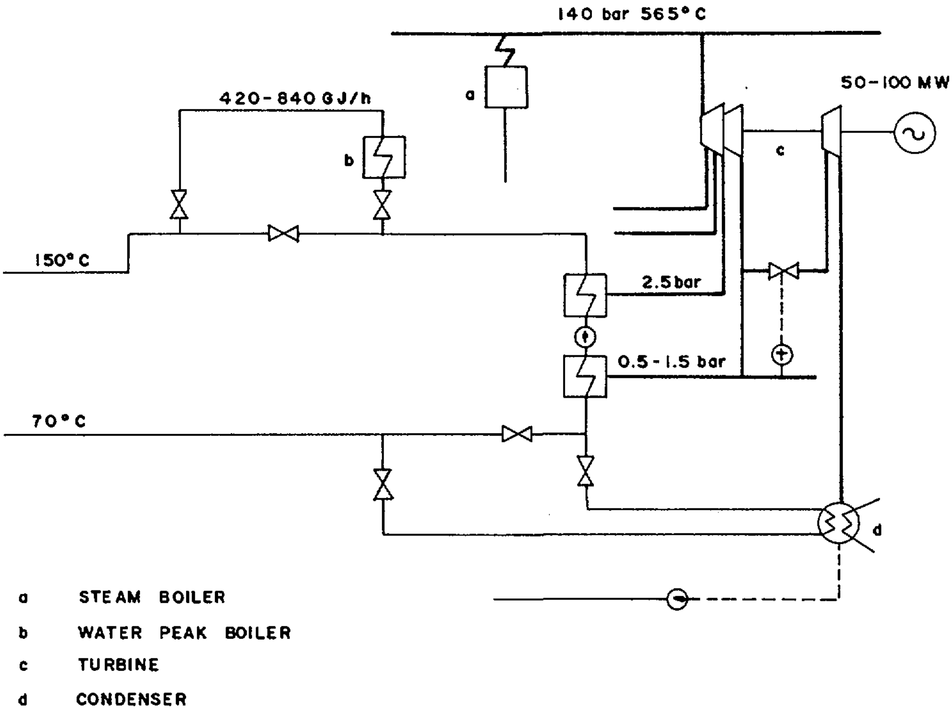


FIG.8.14. Basic structure of a co-generation district-heating system [*8.2*].

lower, so the specific electric power output is substantially higher (kW·h/GJ) than in industrial systems, where process steam is required at much higher pressures.

Figure 8.14 displays the basic structure of an urban co-generation system. The heat carrier in the network is water, which is heated in two preheaters in the power plant and, if necessary, has its temperature – which is regulated depending on the outside air temperature – further elevated in a peak hot-water boiler.

Although district heating developed early and was practically confined to industrialized countries with colder and temperate climates, in the last decade interest also grew for this energy-efficient technology in some developing countries with cold winters, for example in Turkey and in the Republic of Korea. For the latter a detailed report on an economic feasibility study for urban co-generation in Seoul was recently presented [8.9].

In countries with cold winters but hot summers, alternating heating and cooling co-generation systems are being studied, offering both a better yearly load factor and extended comfort. Reference [8.10] describes, for example, the total energy district heating and cooling in Reggio Emilia, including design and operation details.

8.2.1.2.4. Rural co-generation

Although industrial, commercial and urban co-generation are widely accepted, little attention has been paid to co-generation applied in rural areas, particularly in agriculture. By meeting heat demand for drying crops or wood, heating livestock shelters and supplying warm water for domestic purposes, small co-generation rural power plants could substantially contribute to rural energetization, as further commented on in chapter 8, section 3.

The main equipment would be reciprocating internal combustion engines, diesel or gas engines, working at average efficiencies of 33% for power generation. The balance (67%) of the fuel input is evacuated as heat in the exhaust gases and cooling water, of which easily half could be used. There are, however, in some countries large applications of rural co-generation, using hot water for heat supply to greenhouses. Since the supplied surfaces can reach up to 100 and more hectares, substantial electric capacities (steam power plants) are involved [8.2].

8.2.1.2.5. Mixed forms of co-generation

Often some of the described co-generation forms appear in various combinations, the most common being a large district-heating system integrating heat supply to industrial consumers located within the urban area, or large industrial co-generating plants delivering process steam to their own consumers and supplying with hot water as energy carrier an internal and external network for space heating and domestic warm water consumption.

Depending on the predominant basic form, mixed co-generation systems have different characteristics, with design and operational conditions adapted accordingly.

8.2.1.3. Newer and future forms of co-generation

As previously mentioned, newer forms of co-generation systems are those making use of nuclear, geothermal and solar energy.

8.2.1.3.1. Nuclear co-generation

The impact of the use of nuclear energy in a national energy balance would be substantially amplified, if in addition to power generation, nuclear energy were also applied for heat supply. This could be realized either by direct reactor heat delivery and/or by nuclear co-generation of electricity and heat.

The first alternative, which is district heating but not with co-generated heat, was realized as early as 1958 with the Halden boiling water reactor in Norway. This reactor, with a thermal capacity of 25 MW(th), still in operation after 25 years, mainly serves fuel-elements research. However, it also supplies heat –

when operating over periods of a few weeks – via a tertiary circuit to a paper factory located nearby in the centre of a small town [8.11].

The conventional form of nuclear co-generation is a topping cycle with steam turbine equipment – backpressure and/or extraction-condensing units –, as previously described, with the difference that the steam is generated by nuclear reactor heat. Because of the lower live-steam parameters, the specific power produced per unit of heat delivered is very much lower.

The first nuclear co-generation district heating system was implemented in 1963, supplying urban heat from the nuclear co-generation plant Ågesta, located in Farsta, a satellite town of Stockholm. The HPWR reactor had a capacity of 50 MW(th), the turbine 10 MW(e). After 11 years of successful technical operation, the plant was shut down in 1974 because of poor economic performance. However, owing to oil price increases its reactivation might be considered.

The 1000 MW(th) fast breeder reactor plant BN-350 in Shevtshenko on the Caspian Sea, has since 1973 operated a co-generation plant of 150 MW(e) which supplies with heat a desalination plant with a desalted water production of 5000 t/h.

In Canada five CANDU reactors of the most modern type supply with 1500 MW(th) steam of 193°C, two heavy-water factories located about 3 km from the nuclear co-generation plants. Their total installed capacity is 740 MW(e). The first unit was commissioned in 1977 [8.11].

In Switzerland a special form of co-generation operates in the PWR nuclear plant Gösgen of 970 MW(e). Process steam, since 1979 some 36 t/h, but extendable up to 81 t/h, is supplied to a paper factory located 3 km away. The process steam is co-generated by nuclear heat, but separately in evaporators fed by live steam, which is derived before entering the turbine. The process steam, therefore, does not produce any electrical power, i.e. no fuel saving effects could take arise from backpressure generation. The heat supply has been particularly reliable: in its last operating cycle the nuclear power plant reached a time availability of more than 97%.

In the Federal Republic of Germany, the heavy-water-cooled PWR of 200 MW(th) and 50 MW(e) electrical capacity which is installed within the nuclear research centre at Karlsruhe, supplies it with 20 MW(th) heat.

Important district heating systems supplied from nuclear co-generation plants are operating and further planned in the USSR. A typical example is the Bilibino co-generation plant located in the far north of the Chukotka region, with its extreme weather conditions. The plant has been in operation since 1974. It consists of four identical extraction-condensing turbines of 12 MW(e) each, delivering up to 78 MW(th) to the heating network of the village of Bilibino [8.12]. Further nuclear co-generation district heating systems are operating in Gorki, Volgograd and Voronesh.

In the USA an interesting industrial nuclear co-generation project is scheduled for commissioning in 1984. The Midland-1 nuclear plant of 530 MW(e) in Michigan will supply 800 MW(th) process steam to a close-by chemical plant [8.11].

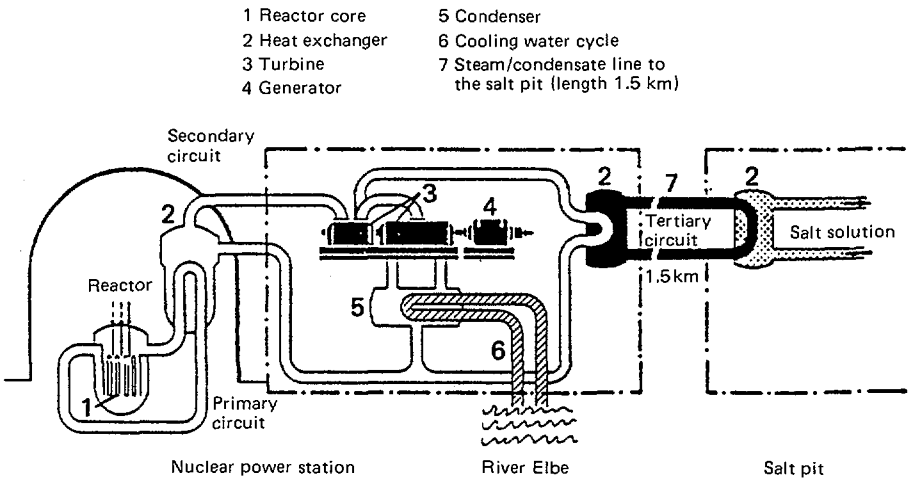


FIG. 8.15. Heat supply from the Stade nuclear power plant for salt processing [*8.11*].

An example of organizing a heat supply from an existing nuclear power plant, i.e. creating a nuclear co-generation system, is the planned heat supply of 60 t/h process steam of 8 bar and 270°C from the Stade plant to a neighbouring salt-pit in the Federal Republic of Germany.

The salt-pit was designed to be supplied with heat from the existing, close-by oil-fired Schilling power plant. During the '70s, oil prices increased rapidly and made the generation of power and heat from oil more and more expensive, whereas coal and nuclear energy showed greater economic advantages. A search for possible alternatives to the system was launched and finally it was decided to provide the heat for the salt-pit mainly from the nuclear power station in Stade. One factor in the decision was the good operational experience gained with this plant.

Figure 8.15 shows the structure of the heat supply system. Steam is taken from the turbine in the conventional sector of the power station where no radioactive material is used. It flows through a new heat exchange station where the heat is passed over to a third steam circulation system. This conveys heat to the salt-pit where it performs its destined tasks. It also provides heat for heating the Schilling power station, some other NWK buildings and a fuel dump nearby. The heat exchange stations segregate the respective steam loops completely from each other in order to ensure that all radioactivity remains in the nuclear power station. The individual sectors are also controlled and secured by various control and shut-off installations.

The power station provides the heat supply project described above with a heat output of about 40 MW(th). The capacity of the power station available for power generation is therefore reduced by about 10 MW(e). When the nuclear

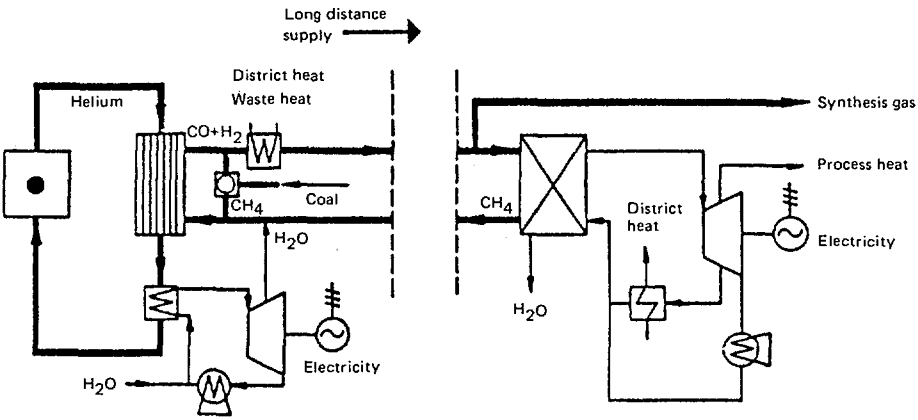


FIG.8.16. Half-open nuclear co-generation and long-distance heat transport cycle [*8.14*].

power station in Stade stops operation during the annual fuel rod change, steam is supplied by the Schilling stand-by oil-fired power plant.

Since it will have a high utilization, the heat supply system will save about 30 000 t of fuel oil which would be needed with a standard heating system.

A future envisaged nuclear co-generation alternative is using the evacuated heat of a helium turbine fed from a high-temperature reactor [8.13] similar to a closed air turbine cycle externally fired.

A more complex utilization of the high-temperature reactor for co-generation is in a combined bottoming-topping cycle with coal gasification and indirect heat transfer over long distances.

Figure 8.16 displays the principle of such a half-open nuclear co-generation and long-distance heat transport cycle. With high-temperature reactor heat (over 800°C) brought from the HTR reactor (1) by helium as cooling gas into the methane fissioning furnace (2), the methane/steam mix is reformed to a synthesis gas $CO + H_2$ in an endothermal (heat-absorbing) reaction. The helium gas is further cooled down in the boiler (10) where steam of about 550°C is produced, which enters the turbine (9) for electric power generation. Heat can be extracted both at high temperature level as live steam or at lower temperatures from the turbine extractions. The synthesis gas is cooled down in the heat exchanger (3) for heat supply in the reactor vicinity and further transported in normal gas-pipelines over long distances to the final consumer destination. Here the synthesis gas is partly supplied to final gas consumers for chemical processes (5), partly fed to the methanation installation (4) where in an exothermal (heat-delivering) reaction methane is formed and high-temperature steam produced. While the steam enters the turbine (6) for a co-generation cycle supplying process steam and hot water (7) for district heating, the methane (CH_4) returns to the reactor area, where mixed with steam (OH_2) enters again the furnace (2). A coal gasifier (8), also supplied with high-temperature reactor heat, replaces the synthesis gas extracted from the circuit by the gas clients (5).

The important advantages of the described cycle are that it offers nuclear co-generation new dimensions both in relation to higher temperature levels and to very much longer transport distances; it considerably extends therewith the area of impact of using nuclear energy also for rational heat supply per se and as a most welcome substitute. From all these viewpoints accelerated promotion of research and development in the main involved issues and process is highly desirable.

8.2.1.3.2. Geothermal co-generation

Geothermal co-generation, although offering basically the same advantage of fuel saving and partial substitution, appears more limited, both because of the relatively low parameters of the turbine entry steam as well as by the heat supply radius, which in addition is affected by the source's geographical location. Nevertheless, there still will be areas where especially in its industrial and rural form, geothermal co-generation will find potential uses.

8.2.1.3.3. Solar co-generation

So far not yet applied, solar co-generation could develop in relation with solar thermal power plants in the described conventional steam cycle scheme or even as an alternative to the Stirling engine.

8.2.1.3.4. Fuel cell co-generation

The fuel cell electricity-generating chemical reaction described in chapter 6 produces in addition waste heat, which can be recovered either all as hot water, or partly as steam and partly as hot water, depending on the pressure [8.1].

8.2.1.3.5. Stirling engine co-generation

Because Stirling engines are still in the development stage – see chapter 5 – not much can be said about their practical co-generation abilities. However, with their external combustion system, enabling them to operate on a wide variety of fuels and with their greater thermal efficiencies, which give them one of the lowest percentages of waste heat – i.e. a higher specific electricity production per heat unit evacuated – once developed, Stirling engine co-generation may emerge with fair chances in specific areas of application.

8.2.1.4. Final remarks

Of the two major forms of co-generation of electricity and heat, district heating is more dependent on economic factors and the need to find technical solutions, as well as on climatic conditions and geographically concentrated heat demand. Industrial co-generation, on the other hand, has, owing to its higher load factor and shorter heat transport, a much wider potential field of application and is less dependent on scale. That is the reason why industrial combined production of heat and power is more common in the world. It also offers good possibilities for developing countries where even incipient heat-consuming industries such as iron and steel plants, oil refineries and petrochemical plants, sugar, textiles, food industries, etc., could quickly benefit from its technical, economic and environmental advantages.

However, in any form, the system concept is of major importance, as only full integration of co-generation functions leads to the high efficiency and reliability desired. The combined heat/power plant has to cope simultaneously with all operational conditions of the electric network – local, regional or national – and it belongs to and must supply concomitantly the required heat with optimal availability and temperature level.

At this point, the environmental advantages of co-generation of heat and electricity have to be strongly emphasized. By reducing the total quantity of primary fuel burned, less air-polluting flue gases are released into the atmosphere and their effect can be substantially cut down by advanced cleaning devices, easier to apply in large modern co-generation plants than in many isolated boilers and ovens, for example, in an urban community. At the same time, since most of the evacuated heat of the electricity generating process is usefully supplied, the discharges to rivers or cooling towers are very much reduced or even completely avoided.

Finally, the comfort of having space heating (cooling) and warm water available in the same simple and reliable manner as the water and electricity supply is an additional, not unimportant amenity, among other socio-economic advantages.

In conclusion, the economic features of industrial co-generating systems are, in general, more favourable, although district heating systems in many cities with colder climates perform extremely well. However, since for most developing countries industrial co-generation might successfully be envisaged, it is worth recalling here that a kW·h of electricity generated by even a small, insignificant backpressure turbine in co-generation requires only 50% of the fuel it would consume in the most advanced condensing thermal power plants in the world. Compared to a 100 bar power station, it needs only one-third of the heat and has even less fuel consumption in medium-steam-pressure installations.

Last but not least, there are two important issues to be briefly addressed, and both are specific to a real form of co-generation, i.e. the steam/Rankine co-generation cycle. The reason is, as explained, that this cycle can operate only if an exergy sacrifice is made on the power-generating side, which serves to increase the temperature level of the heat supply to the required level. All other described co-generation forms in no way alter the electricity production, since the heat component is by its structure in any case evacuated heat, always at a higher temperature than that of the condensing level of the steam cycle.

Accordingly, a very popular question arises as to which is preferable for space heating: steam cycle co-generation or heat pumps? Theoretically they are absolutely equivalent. The exergy loss of the steam cycle to permit the heat supply at the required temperature is equal to the exergy that has to be used to pump the ambient heat to the same required level. The actual cycles have small differences. However, the comprehensive study of the WEC Joint ad hoc Committee on CHP (Combined heat and power plants)/and Heat Pumps, concludes that while the two systems are equivalent, CHPs are indicated for the supply of large amounts of heat to high thermal load density whereas heat pumps are more suitable for low heat density in areas further away from the co-generation plant [8.15]. Under certain conditions, heat pumps may be worth integrating in the traditional Rankine steam cycle, at its lowest temperature levels, i.e. on the return flow side of the heating network.

The second controversial question is: what form of the co-generated energies, electricity and heat, should receive the credit of the fuel and costs saved by the combined process. In this respect there are two schools of thought: the USSR as well as some other countries ascribe all benefits to electricity [8.16]; a few others ascribe it to the heat supply, considering the heat as a waste heat (which is correct for all other forms of co-generation). Optimally it should be at least split according to the exergy utilization, or even more objectively according to the double structure of the generating (fixed and variable) costs [8.2].

8.2.2. Recovery of industrial secondary energy resources (ISER)

The already mentioned predominant position of industry as an energy consumer is due, on the one hand, to its own rapid development, on the other, to the fact that the efficiency of energy utilization in industry is still in general rather low, varying between 30–50%.

Table 8.II presents some characteristic figures on average net efficiencies of energy – primary and intermediate energy carriers – utilization in a series of industrial processes [8.17].

Energy efficiencies and specific energy consumption vary according to the structure of the industry in particular countries, the technologies used in the different branches of industry, the number of processing operations, the level of technology and condition of the energy-consuming plant, the forms of primary energy and raw materials used and the steps taken to improve energy efficiency. Table 8.III displays 1975 figures for specific selected IEA countries. The largest industrial consumers of primary energy are the metallurgical, chemical and

TABLE 8.II. AVERAGE NET EFFICIENCIES OF THE UTILIZATION OF ENERGY IN SOME SELECTED COUNTRIES [8.17]

	(%)
Steam boilers	76–90
Space heating in industrial buildings	45–55
Metallurgical blast furnaces	45–55
Furnaces for forge operations	19–22
Siemens-Martin furnaces	38–40
Pusher-type metallurgical furnaces	33–40
Foundry cupolas	30–32
Electric arc furnaces for steel	35–37
Electric induction furnaces for smelting	33–35
Magnesite sintering furnaces	36–38
Tunnel furnaces for ceramic and refractory materials	45–48
Drying plants for wood-derived materials (wet process)	48–50
Glass manufacturing furnaces	8–12
Plants manufacturing ammonia from methane	33–35
Cellulose boiling plants	70–75

building materials industries, heat accounting for up to 85% of the end-use energy demand. A large part of the heat is supplied at high temperatures and is released after usage into the environment at still relatively high temperatures. That leads to important energy losses and subsequently low efficiency of the utilization of the input energy.

The evacuated heat often appears in large quantities and at attractively high temperatures. It would be preferable, therefore, to consider it not as an imposed energy loss but as a secondary energy resource; secondary not because of minor importance, but because it is intimately connected, as regards availability, to variations in the industrial process which releases it. This time-dependence and the fact that many of these resources are locally bound and often not transportable over longer distances influenced negatively their utilization in the past; they were simply considered waste heat and as such were mostly ignored or accepted with calm resignation.

As time and conditions changed, an improved approach gradually developed and a move was made to generalize the utilization of industrial secondary energy resources (ISER) in place of past, only disparate actions for recovering industrial waste energy.

TABLE 8.III. SPECIFIC ENERGY CONSUMPTION IN THE MAJOR ENERGY CONSUMING BRANCHES OF INDUSTRY IN SELECTED IEA COUNTRIES (1975) [8.18]

	GJ per tonne output
Iron and steel industry	
Germany, Federal Republic of	13.65
Sweden	16.65
Netherlands	19.70
Italy	20.00
United Kingdom	20.00
Aluminium manufacture	
Netherlands	54.00
Austria	56.35
Japan	58.00
Germany, Federal Republic of	62.00–63.50
Sweden	69.00
United Kingdom	88.20
Petroleum industry	
Japan	1.90
Sweden	2.05
Denmark	2.20
United Kingdom	3.05
Germany, Federal Republic of	3.35
United States of America	3.75
Cement manufacture	
Germany, Federal Republic of	3.80
Canada	3.95 (dry process) 6.20 (wet process)
Italy	4.00
Japan	5.00
Spain	5.45
Netherlands	5.50
United Kingdom	5.80
Sweden	5.85
United States of America	6.75
Denmark	6.85
Pulp and paper industry	
Italy	14.25
Austria	14.40
Denmark	14.80
Germany, Federal Republic of	18.35
Sweden	20.45
Japan	21.45
United States of America	24.25
United Kingdom	26.25
Norway	27.60
Canada	28.20

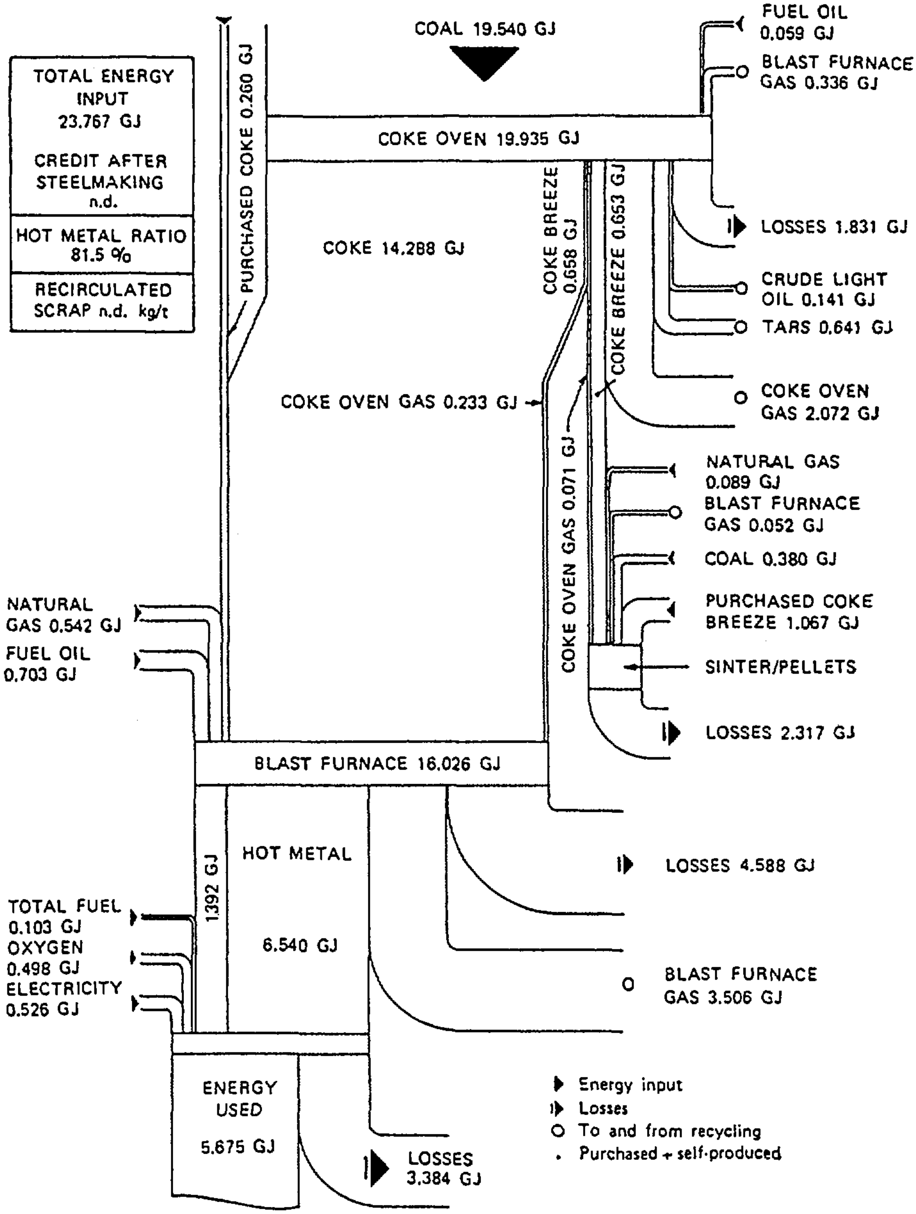


FIG. 8.17. Energy flow diagram for 1 t crude steel (Belgium, 1979) [8.19].

8.2.2.1. Classification of ISER

A summary classification of ISER displays them in three main categories:

(a) Combustible ISER
Combustible gases from pyrotechnological processes in the metallurgical industry, the chemical industry, petroleum refineries (blast furnace gas, cokeworks gas, converter gas, gas from ferro-alloy furnaces, carbon oxides discharged from chemical plants, combustible gases discharged in acetylene and ammonia manufacture, etc.)
Solid or liquid combustible products from technological processes (such as lyes and tars)
Combustible industrial waste (wood, flax and hemp dust, middlings and slurries from coal preparation, wastes and residues from refineries, chemical plants, etc.).

(b) Thermal ISER
Chemical heat from combustible gases discharged by chimneys after incomplete combustion
Sensible heat from combustion gases discharged by chimneys from all kinds of industrial installations (furnaces and boilers)
Sensible heat discharged into the atmosphere with particles of unburnt fuel borne by combustion gases
Chemical heat from combustion gases lost from furnaces and boilers, through openings, cracks, vents, etc.
Sensible heat from liquid or granulated slag cooled in the open air
Sensible heat from finished or intermediate material industrial products which cool in the open air (heat contained in liquid steel, incandescent coke, ingots and billets, etc.)
Heat lost from exothermic chemical processes
Heat lost from furnaces and boilers (and from thermal installations in general) by radiation (radiant heat) through walls and openings and through accumulation, when there is inadequate thermal insulation
Heat contained in process waste and industrial rejects
Heat contained in condensed steam
Steam escaping from thermal-energy installations into the atmosphere
Steam produced in refrigerating plants by vaporization
Heat discharged from industrial plants in cooling water (or air)

(c) Other ISER
Loss of mass (by leakage, run-off, evaporation, condensation)
Mechanical losses (through friction) – transformed into heat
Losses of kinetic energy or pressure – in heat equivalent
Hydraulic energy losses (pressure losses through "wire drawing", friction).

As an example, Fig. 8.17 displays the energy flow for a tonne of crude steel in a Belgian plant identifying well all loss and recycling energy flows.

8.2.2.2. Recovery of ISER

In the present state of industrial technology, the principal systems and installations for recovering and utilizing industrial secondary energy resources are as follows:

Combustible waste gases from production processes in the iron and steel and chemical industries and petroleum refineries should be utilized in the process furnaces and boilers of the industrial plants producing them, in gas turbines and in electricity and heat co-generating plants.

Special attention should be paid to the recovery of the heat lost to the atmosphere by burning combustible gases (of high calorific value) in flame stacks at petroleum refineries and in chemical plants. This heat could easily be recovered in hot-water boilers for technological processes and for district heating systems.

Much of the heat contained in exhaust gases discharged into the atmosphere may be recovered for use in air heaters, recuperators and regenerators, heat exchangers and economizers, as well as in gas turbines if the ISER are at a sufficiently high temperature.

The priority usage of the heat recovered from exhaust gases should be pre-heating the air for combustion and the primary fuel, to increase the energy efficiency of the main technological process.

Economizers can be used for pre-heating the water supplied to steam boilers.

Heat recuperators, of which manufacturers produce many different types, can be used for pre-heating the air for combustion.

Drying processes generally function at fairly low temperatures, ranging between ambient temperature and 150°C, rarely higher. However, with a view to ensuring the quality of the dried product, high-grade fuels at efficiencies of 30–33%, or steam also obtained from hydrocarbons by a two-state transformation process, are used in the drying units. The most suitable medium for drying operations is undoubtedly hot air, and the cheapest source available for heating air is undoubtedly heat recovered from exhaust gases. All plants which include a drying process, e.g. for brick and building materials, as well as industrial wood-working and sugar manufacturing plants and factories producing paper, glass, china and porcelain, discharge into the air vast quantities of heat in the form of exhaust gases from their furnaces. Great quantities of primary fuels can be saved by using the heat from exhaust gases for the drying processes.

In many industrial processes requiring heat at fairly low constant temperatures, in foundries, for instance, for drying moulding sand, moulds and cores, in agriculture for drying seeds and green forage, for the drying of lacquers and many other chemical products, for drying beet pulp in sugar factories, and for drying panels and veneers in furniture manufacturing, where hot-air drying using the heat recovered from the exhaust gases of the industries' own furnaces and boilers has been adopted, reductions in the cost of the drying operation ranging from 70–75% are being achieved.

In the textile industry, the major demand for heat, in the form of low-temperature steam and hot water, is in the finishing sections, where drying the product accounts for 50% of the heat requirement for the whole production process. Much of the heat recovered from exhaust gases can be used in these installations to produce the hot air needed for drying and afterwards in economizers where the water needed for dyeing and finishing processes is heated. Savings in primary fuel of 20–25% can be obtained.

With regard to the heat discharged in cooling water it could be used for space heating and warm-water supply.

The heat contained in hot industrial products can be recovered in chambers where the products and air move in opposite directions. Similar chambers can be used in lime calcination and cement manufacturing plants and in the tunnel furnaces used for ceramic products. The products cool from 700–800°C to 80–100°C, releasing their heat to the back-draughted gaseous fluid.

Liquid metallurgical slag is discharged from furnaces at a temperature between 1200 and 1600°C, with a heat content of 300–500 kcal/kg (1257–2093 kJ/kg). The physical heat of the slag may represent 20–30% of the primary energy consumption for the preparation of non-ferrous metal concentrates. Systems for recovering heat from metallurgical slag are based on granulation of the liquid discharge in a cold medium used as heat carrier (water, air).

Granulation is necessary because most of the heat recovered comes from the slag as it solidifies and the material must be granulated in order to have the greatest possible surface for heat exchange. Hot water at 90–95°C can be obtained for heating installations, or steam at 1.1–1.2 bar. The same operation carried out in air-draught granulators can produce air heated to 900–1000°C. The heated air is conveyed to a recuperating boiler producing steam. Calculations show that the steam can be obtained at 40–60 bar and 400–450°C. With these parameters the steam can be used in turbines to produce electric power.

By dry quenching of metallurgical coke a large proportion of the sensible heat of the coke (100–1200°C) (on leaving the oven) may be recovered to produce steam for technological processes or for supplementary production of electrical power.

The technological processes for the manufacture of cellulose result in the production of combustible black liquors which can be burned in regenerating boilers to recover the chemical components contained in the liquor and at the same time produce steam at 40 bar/430°C for electrical turbo-generators. The energy content of the liquors corresponds to about 30% of the heat energy needed in cellulose manufacture (sodium sulphate process). For greater efficiency in the combustion of the liquor in the regenerating boilers, the combustion air can be preheated up to 130–150°C with heat recovered from the exhaust gases.

The heat contained in clinker from cement factories can be recovered by using drum coolers to produce hot water for heating plant.

Combustible waste is produced in all branches of industry, much of it capable of being used in suitable boilers. The largest quantities of combustible waste are produced in the chemical industry and in wood processing.

In the chemical industry, the greatest amount of water is produced in plants manufacturing butadiene and styrene rubber, phenol, acetone, and artificial fibres. The surplus hydrogen obtained in electrolysis can be used as a raw material or as fuel.

The wood-processing industry produces sawnwood waste which can be used in steam and hot-water boilers of suitable design.

The preparation of coal for coking results in two grades of coal waste, middlings and slurry, which should not be dumped on the spoil heaps since they can be used, with satisfactory efficiency, as fuel in electrical power stations.

Two more, newer technologies for ISER recovery may be here briefly mentioned: natural gas expansion turbines and ORC (organic Rankine cycles).

With increasing use of natural-gas high-pressure transport, there are consumers at whose location a substantial difference appears between the arriving pipeline pressure and the utilization pressure. Depressurization can be, especially for large gas consumers, used in gas expansion turbines to produce electricity. For example in a combined-cycle gas/steam power plant with 2 X 76.5 MW gas turbines and a 72 MW steam unit, the natural gas (20 000 to 70 000 m^3/h) arriving with 38–68 bar/6–18°C enters, after preheating to 65–130°C, a gas expansion turbine which it leaves at 14–18 bar/15°C for further supply of the gas turbines. The maximum produced electric power is 1690 kW, i.e. 0.7% of the installed capacity of the main units [8.20].

In addition to the low-temperature ISER recovery technology described in chapter 5, there are two alternatives, specifically designed for industrial purposes, where higher energy levels for utilization are required. These are the so-called high-temperature heat pumps, i.e. piston compressors which may compress steam from a low to a high pressure (1 up to 150 bar) in a combined gas motor/gas compressor set and the ORC [8.21].

ORC systems use cycles with organic fluids, fed with low-grade ISER between 90–300°C, to produce mechanical/electrical energy. For petroleum refineries and chemical plants, where major quantities of ISER are involved, even special ORC turbo-machinery has been designed with standard units between 750 and 2500 kW(e) [8.22].

8.2.2.3. Economic aspects of ISER recovery

The recovery of ISER belongs to the most economic conservation actions, since it refers to utilization of resources which are synchronously available with, in general, a demand located nearby, not affected by a previous conversion efficiency charged already to the industrial process and, as such, free of all other

TABLE 8.IV. THE ECONOMICS OF THE RECOVERY OF INDUSTRIAL SECONDARY ENERGY RESOURCES (ISER)

Branch of industry	Cost of 1 tce recovered heat (from combustible gases, exhaust gases, and cooling water) (US$/t)	Payback time for investment costs incurred for energy recovery by primary fuel savings (years)
Iron and steel industry	20–24	1–1.5
Chemical industry	25–32	1–2.5
Petroleum refineries	12–20	0.8–1.5
Non-ferrous metals industry	32–42	1.5–3
Building materials industry	30–35	1.5–2.5
Wood industry	18–24	1–2
Food industry	28–40	2–4
Glass and porcelain industry	26–36	1–2.5
Combined heat and district power plant [a]	20–25	1–2
Engineering industry	24–35	1.5–3

Source: Table H1, Ref. [8.17].

[a] Hot water for district heating and glasshouse heating.

expenses regarding the primary resource stage. In particular, the following two aspects should be taken into account:

(a) One tce of ISER recovered corresponds to more than one tce of primary energy, since it avoids all losses that would otherwise be incurred in the previous converting (burning) processes
(b) One tce of ISER recovered needs less investment than would have been necessary to extract the saved amount of primary energy from the earth.

For these reasons, up to certain rather wide limits, the recovery of ISER appears extremely advantageous, the payback time for the investment costs incurred by primary energy savings lying between 0.8 and 2.5 years – see Table 8.IV [8.17].

8.2.2.4. Final remarks

Many of the comments presented above were drawn from the special ECE study summarized in Ref. [8.17], which offers an excellent overview on the subject. The only caveat the current author feels obliged to mention regards the terminology. He believes the ISER denomination reflects more genuinely the character and nature of the energies involved. ISER are not "secondary forms" of energy in the general sense of electricity, artificial gases, etc. – between which no distinction is made – since they are not freely producible but bound to the industrial process [8.23]. They represent "temporary" resources, since, if not used when they become available, they are lost. However, as the text progresses, the study mentions "secondary energy resources from industrial plants", which is exactly what ISER is intended to express.

8.2.3. Combined energy supply

In addition to combined production of two or more forms of energy, an improved energy husbandry can also be realized by a combined, complementary supply of two or more forms of energy to the same energy converter or consumer.

The first case is well known. It can be represented as a simple, individual steam boiler fuelled with various fuels, for example fuel oil and natural gas, or coal and fuel oil or natural gas, etc., depending on fuel availability and costs. The most complicated example is the electric system, where the total electricity demand is met with the optimal combination of different types of power plants, i.e. of primary energy resources.

A characteristic example of the second case has been discussed in chapter 2, that of a fuel-oil-fired boiler and an electrically driven heat pump, supplying heat for space heating and domestic hot water.

8.3. Energy conservation

Energy conservation includes all action geared to meet a given need for useful energy with the least expenditure, or the economically optimal expenditure, of available and/or desirable primary energy. It could either combine or exercise separately the effect of an absolute saving of energy and/or the effect of substitution of more valuable and scarce energy resources, for example petroleum, by a more readily available but still satisfactory resource.

8.3.1. The dual concept of energy conservation

Since doubts are sometimes raised about considering energy substitution as part of energy conservation or simply regarding it as fuel switching, it may help to define from the very beginning the term 'energy conservation' as used in the present framework.

Firstly, the term implies that energy should be conserved so as to preserve resources for future use. The most efficient means to achieve this entails the avoidance of profligate consumption and waste, and the reduction to a rational minimal level of all losses inevitably associated with the supply and consumption cycle. The result will be an energy saving in that a given energy demand would be met with less expenditure of primary energy. At a global level, the effect would be that the availability of primary non-renewable energy supplies could then be extended for a longer period.

Secondly, even with a stepped-up saving of energy, certain special, scarce and valuable primary energy resources, i.e. petroleum, could be further preserved by substituting other equivalent resources for them, either totally or in part. Although meeting the same final energy demand, substitution may result in less convenience and possibly also higher costs. In such circumstances, the resulting unused energy is then 'conserved' for applications where substitutes cannot be used.

Consequently, both aspects are further dealt with, energy saving as a new quantitative approach to energy husbandry in general, and petroleum substitution as an imperative qualitative constraint to conserve a fast declining valuable energy resource.

8.3.2. Main merits of energy conservation

Briefly summarized, energy conservation has the following main attributes and unique merits:

(1) Energy conservation is an immediate, renewable energy resource, obtainable within certain technical and economic limits, with less effort and costs than extracting an equivalent amount of depletable fossil primary energy from the soil or harnessing some other renewable source.

(2) Saving energy implies by no means curtailing real final needs, but only better energy husbandry by meeting the needs with less primary energy expenditure, i.e. avoiding squandering and waste of energy and improving the efficiencies of all involved conversion processes.

(3) Substituting scarce and valuable energy resources, i.e. petroleum, aims to conserve declining resources for applications where substitutes cannot be used, while the same final energy needs are met by more readily available energy carriers.

(4) Energy conservation promotes employment both by creating new jobs as well as by switching manpower demand to more qualified skills compared to those usually encountered in elementary primary energy extraction activities.

(5) Last but not least, one may add to the above-mentioned energetic advantages the energy ethic consideration of extending by energy conservation the availability of primary depletable energy reserves for future generations.

TABLE 8.V. AVERAGE EFFICIENCY[a] OF ENERGY RESOURCE USE IN THE ECE AREA – PRESENT SITUATION AND LONG-TERM PROSPECTS [8.24]. (ORDERS OF MAGNITUDE)

The various stages of the flow of energy	*Levels of efficiency attained in the early 1970s*		*Practically possible level* [b] %
	Level %	*Main causes of low efficiencies*	
1. Extraction	46	primary extraction techniques for oil; room-and-pillar mining of coal	59
2. Upgrading and conversion	78	classical power generation	70 [c]
3. Transport, distribution, storage	98	electric power transmission losses, losses in transformers, compressors, underground gas storage	96 [c]
4. Utilization			
(*a*) transport sector	20-25	gasoline-powered internal combustion engine; modal transport pattern; sub-urbanization	25
(*b*) industry sector			
i. iron and steel	55	waste heat and waste gases	65
ii. chemicals	50-70	leaks	55-75
iii. aluminium	30	losses of electrodes	35
iv. other industries	40-45	low price elasticity	45-50
i-iv. weighted average	45-50		56
(*c*) agricultural sector	30	gasoline and diesel powered internal combustion engine	33
(*d*) households and other consumers sector	45	inefficient ampliances, heat dissipation	50-55
(*a*)-(*d*) weighted average	42		51
5. Energy sector as a whole	15		20

[a] Useful output as percentage of input or availabilities.

[b] Taking into account the present high level of energy prices (exemplified by oil prices at about $11 a barrel), geological, economic, operational, environmental, behavioural, technical constraints, and lead and penetration times.

Levels of efficiency which might be attained in the early 1990s		*Change in %*	
Maximum level attainable %	*Main sources for improvement* (a) *Measures fully exploited by the early 1970s* (b) *Measures not fully exploited by the early 1990s*	*From*	*To*
71	(*a*) shift towards secondary and tertiary oil extraction, long-wall face mining of coal; reassessment of hydropower potential; (*b*) tertiary methods of oil extraction	+28	+54
76 [c]	(*a*) concentration of electric power generation; combined electricity/steam production; replacement of old equipment (*b*) new technologies such as MHD, fuel cells, gas turbines, advanced HTR, breeders, fusion reactors	−10 [c]	−3 [c]
98	(*a*) higher voltage, better insulation (*b*) increased use of direct current in long-distance transmission; cryogenic and supra-conducting cables	−2 [c]	±0
30	(*a*) smaller cars; shift of traffic from road and air to rail; dieselization; better traffic flow (*b*) new transportation and propulsion techniques; urban planning; substitution of transport by telecommunications, nearby recreation, etc.	+20	+30
65	(*a*) recovery of waste gases and low-grade heat; upscaling of plant size; partial integration of steel works with nuclear power stations (*b*) continuous casting	+20	+20
60-80	(*a*) leak prevention, insulation, recycling, new technologies, plant integration into steam supply systems, concentration of operations in greater units	+10	+20
35-40	(*a*) increased scrap and waste heat recycling (*b*) new electro-chemical and chemical processes	+15	+25
55-60	(*a*) assessment of real needs; insulation; better equipment; better maintenance; recovery of waste heat; shifts in energy mix; total energy schemes	+10	+30
60		+18	+25
36	(*a*) improved production structure, capacity use and integration; dieselization; recycling of waste; total energy systems (*b*) recycling of agricultural waste, changed demand structure	+10	+20
60-65	(*a*) insulation of appliances and buildings; total energy systems; recycling of waste and trash; district heating, reduced consumption levels; redesigned energy mix (*b*) heat pumps; solar collectors; energy-conscious design of buildings	+15	+40
55		+20	+30
30		+33	+100

[c] The decrease is attributable to a further penetration of electricity whose conversion and transmission efficiencies lie below efficiencies of direct use; higher efficiency of electricity use is taken care of under 4.

8.3.3. Technical and economic limits of energy saving and substitution

However attractive the merits, energy saving and petroleum substitution have their technical and economic limitations.

The range, limits and merits of energy conservation may be accurately assessed only in relation to the totality of effect, both inside and outside the energy supply system in which it is to be applied. Decisions affecting energy conservation must, like all other decisions on energy development, be dovetailed with the goals of society as a whole. In consequence, any decision on whether or not to apply energy conservation should be measured in relation to how the system behaves as a whole, under different alternatives, when judged by technical, economic, environmental and social criteria.

There are hardly any new basic technical approaches in the area of energy conservation capable of bringing about fundamental changes in the rational utilization of energy. However, there is an enormous potential to improve known energy technologies and extend their application. In this respect Table 8.V provides an excellent overview on the present stage and long-term prospects of improving energy efficiencies in the ECE region [8.24].

The now almost classical technical approaches to energy conservation, i.e. demand management and improved efficiencies along the entire supply chain, and selection of especially efficient supply chains either according to the primary energy base or the technology involved – for example co-generation of heat and power, heat pumps, etc. – have been previously discussed or are consolidated in chapter 13.

Once the technical aspects have been outlined and their marginal limits explored, an economic evaluation has to be carried out for the different alternatives, to determine both economic limits and optimal range.

The economic evaluation of energy conservation measures should be made in accordance with the methods employed for the evaluation of alternative energy projects – see subsection 10.3 – on the basis of a discounted cash flow. Seen from the viewpoint of the national economy, any alternative for which the discounted potential social benefits of energy saving or substitution exceed its discounted cost stream is economic. Among several alternatives which meet this condition, the most economic is the one with the highest present net worth figure, i.e. for which the difference between discounted cash flow of revenues[8] and expenditures reaches the maximal positive value. However, shortage of capital could eliminate the optimum solution in favour of less efficient, but more practicable alternatives.

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[8] It is a specific feature of energy conservation investments, compared to other productive investments, that the former do not increase the revenues but reduce the expenditures.

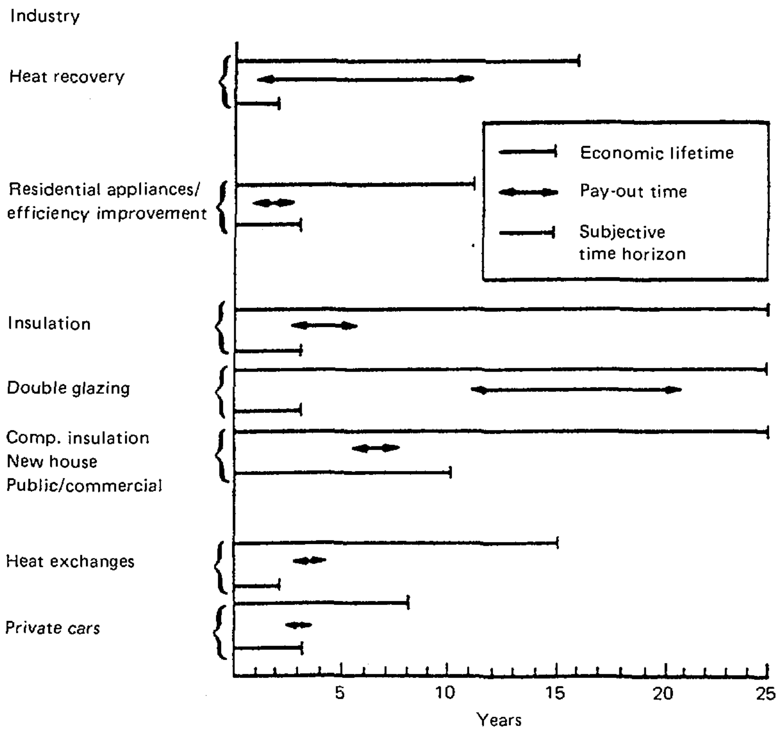

FIG.8.18. Comparison of economic lifetime, actual payback time and typical consumer's subjective payback time (source: Shell Petroleum, 1979) [8.25].

There are cases in which preliminary judgement on the cost-effectiveness of an energy conservation proposal can be made simply by comparing the specific investment needed to create a certain amount of savings or substitution capacity with the specific investment otherwise required for installing new capacity for producing or extracting the same amount of energy. While such a comparison is appropriate for the investment capital involved, it does not reflect the comparative situation for the maintenance and operation cost component, which could sometimes strongly bias the comparison.

Another rather popular, simplified first approach for evaluating the cost-effectiveness of energy conservation measures is the payback time. This is the ratio of the investment cost to the present worth of the net annual savings, indicating over which time period the energy savings, suitably discounted to their present worth, are equal to or larger than the initial capital investment.

Although the payback time is an attractive criterion, and very simple to calculate, caution is recommended in its utilization since under certain conditions, economic solutions with too long payback periods might be excluded – see subsection 10.3.6.

Both the aforementioned indicators – the specific investment for replacing one t/a additional primary energy producing capacity and the payback period of an investment for saving the same amount of energy – are used, individually or combined, as criteria for energy conservation promotion by government incentives.

Decisions on energy conservation measures would particularly depend on their micro-technical-economic merits, since better husbandry of energy can only favourably affect environmental and social conditions. However, for some time to come, social reservations will persist until individual inertia or old energy-consuming habits are gradually replaced by a new attitude where 'energetics' will become synonymous with 'energy ethics'.

An example of how personal action is taken in implementation of energy conservation measures is illustrated by Fig. 8.18, in which economic lifetime, actual payback time and typical consumer's subjective payback time are compared for different objectives. In general, the consumers are ready to accept only much shorter payback periods, with the exception of improved appliances and new houses.

8.3.4. Measures and incentives for promoting and financing energy conservation projects

Before 1973, the main energy policy goal of government was to ensure sufficient supply to meet energy demand, i.e. a supply-oriented policy. No official practical priorities for efficient energy husbandry existed, except the actions which energy-conscious consumers initiated randomly in their own interest. Nowadays, many authorities are actively and successfully intervening in this area. Governments are increasingly promoting energy conservation since it is recognized to be important for the economy as a whole and not merely for specific sectors or consumers. Their interventions include: mandatory energy conservation standards for buildings and norms for industrial production; heating and lighting standards and driving speed limits; energy taxes and price regulations; economic incentives such as tax deductions, soft loans or even flat subsidies. In addition, impressive information campaigns have been launched and free advisory services offered to develop public interest and voluntary co-operation in energy conservation.

Since 1973, a considerable effort has been made promoting energy conservation in the world. This effort was first initiated, organized and co-ordinated in the industrialized countries and was approached accordingly in the group of countries with centrally planned economies. The developing countries followed more slowly, the more advanced among them quite efficiently.

It is not possible to describe in detail in this volume, nor even summarize, the avalanche-like advance of activities in the energy conservation area. Nevertheless, it is hoped that the following short presentation of the main energy-conservation-promoting measures illustrated by a series of tables, readily available for IEA countries in a consolidated form [8.26], will supply sufficient examples to give a fair overview on the subject.

(1) The residential and commercial sector: financial or fiscal incentives in the form of taxes, discount on taxable income, subsidies, grants and loans, concentrating heavily on retrofitting programmes, building-codes for new homes, generally applying to insulation; labelling of household appliances, air-conditioners, etc., in order to encourage buying and manufacturing energy-efficient products. District heating and co-generation of heat and power were early identified as efficient energy-saving and petroleum-substituting possibilities.

    Table 8.VI illustrates the main conservation measures implemented in the various IEA countries.

(2) Industry: fiscal and financial incentives to encourage investment in energy saving and substitution techniques. Projects with a longer payback period or a high risk are generally given priority assistance; reporting and auditing schemes, often in combination with mandatory or voluntary target setting, information activities, including advisory services, in particular directed to small and medium-sized industries.

    Table 8.VII illustrates the energy conservation measures implemented country by country in the IEA area.

(3) The transportation sector: speed limits, programmes to increase automobile efficiency, e.g. fuel economy standards and weight, horsepower or displacement taxes, support of public transport and car pooling, taxes and motor fuel pricing.

    Table 8.VIII presents the energy conservation measures implemented in the transportation sector in various countries. Of particular interest in this respect are the government automobile fuel economy programmes in major automobile-producing countries presented in Table 8.IX[9].

As far as practical results of implemented energy conservation measures are concerned, Fig. 8.19 illustrates the decreasing energy input per GDP and share of petroleum in the total energy demand, between 1973 and 1990 in the IEA countries. Between 1973 and 1979 the energy required to produce a unit of GDP fell by 8% and the relative share of petroleum used on the same base declined by 11%. Between 1979 and 1990 the overall efficiency of energy use, as measured by the same indicators, is expected to increase by a further 14%. The TPE/GDP elasticity would be about 0.6 over this period. The share of petroleum in total primary energy use is expected to fall from 50% in 1979 to 40% in 1990. The share of net oil imports would decline from 33% in 1971 to 27% of total energy

[9] The figures have been kept expressed in kcal/km, and not converted to kJ/km, since reproduced from an official document.

TABLE 8.VI. IMPLEMENTATION OF ENERGY CONSERVATION MEASURES IN THE RESIDENTIAL AND COMMERCIAL SECTOR[a] [8.26]

	Fiscal/financial incentives			Building codes					Efficiency labelling of appliances		
				New buildings		Existing buildings					
	Discount on taxable income	Subsidy grant	Loan	Mandatory	Voluntary	Mandatory	Voluntary	Prohibition of bulk metering	Mandatory	Voluntary	Information advice
Australia	–	–	–	–	–	–	–	–	–	P	x
Austria	x	x	–	P	x	–	–	–	P	x	x
Belgium	–	x	–	P	–	P	–	–	P	–	x
Canada	–	x	x	x	–	x	–	x	x	–	x
Denmark	x	x	–	x	–	x	–	–	P	–	x
Germany, F.R.	x	x	x	x	–	x	–	P	P	x	x
Greece	x	–	P	x	–	P	–	–	P	–	x
Ireland	x	x	–	x	–	–	x	–	P	–	x
Italy	–	–	–	x	–	x	–	x	x	x	x
Japan	P	P	x	x	–	x	–	x	x	–	x
Luxembourg	–	x	–	x	–	P	–	–	P	–	x
Netherlands	–	x	–	x	–	x	–	–	P	–	x
New Zealand	x	x	x	x		x			P		x
Norway	–	–	x	x	–	x	–	–	P	–	x
Portugal	–	–	x	P	–	P	–	–	–	–	x
Spain	x	x	x	x	–	x	–	x	P	–	x
Sweden	–	x	x	x	–	x	–	P	x	–	x
Switzerland	x	–	x	x	–	x	–	–	–	–	x
Turkey	P	P	–	P	–	P	–	–	P	–	x
United Kingdom	x	x	–	x	–	–	–	x	P	–	x
USA	x	x	x	P	–	–	–	P	x	–	x

Source: Country Submissions for IEA 1977, 1978, 1979 and 1980 Reviews of National Energy Policies.

[a] They are described in more detail in the country chapters of the annual publication *Energy Policies and Programmes of IEA Member Countries.* Some specific examples are given in Section III.

x: exists
P: in preparation
–: does not exist

TABLE 8.VII. IMPLEMENTATION OF ENERGY CONSERVATION MEASURES IN INDUSTRY[a] [8.26]

	Financial/fiscal incentives			Reporting/auditing			Information advice/assistance			Other measures	
	Grant/ subsidy	Loan	Tax incentive	Target setting	Reporting	Auditing	Information/ publication	Meeting/ seminar	Advice for small & medium-sized firms	CHP	Waste/ waste heat
Australia	–	–	x	–	–	x	x	x	x	x	x
Austria	x	x	x	–	x	x	x	x	x	x	x
Belgium	–	–	–	–	–	–	x	–	x	–	–
Canada	x	–	x	x	x	x	x	x	x	x	x
Denmark	x	x	–	–	–	–	x	x	x	x	x
Germany, F.R.	x	x	x	x	–	–	x	x	x	x	x
Greece	P	x	–	x	x	x	x	x	x	P	P
Ireland	x	P	–	P	P	–	x	x	x	x	x
Italy	P	P	–	–	x	–	x	x	x	xP	xP
Japan	x	x	x	x	x	x	x	x	x	–	x
Luxembourg	–	–	–	–	–	–	x	–	–	–	–
Netherlands	x	–	x	–	–	x	x	x	x	x	x
New Zealand	x	x	x	P	–	x	x	x	x	x	x
Norway	x	x	x	–	x	–	x	–	P	x	x
Portugal	x	–	–	–	–	x	x	–	x	P	–
Spain	x	x	x	x	x	x	x	x	x	x	P
Sweden	x	x	–	–	–	x	x	x	x	–	x
Switzerland	–	–	x	–	–	–	x	–	x	–	x
Turkey	–	–	–	–	–	–	x	–	P	P	P
United Kingdom	x	–	x	x	–	x	x	x	x	x	x
USA	x	x	x	x	x	x	x	x	x	x	x

Source: Country Submissions for IEA 1977, 1978, 1979 and 1980 Reviews of National Energy Policies.

[a] They are described in more detail in the country chapters of the annual publication *Energy Policies and Programmes of IEA Member Countries.* Some specific examples are given in Section III.

x: exists
P: in preparation
–: does not exist

TABLE 8.VIII. IMPLEMENTATION OF ENERGY CONSERVATION MEASURES IN THE TRANSPORTATION SECTOR[a] [8.26]

	Taxes		Speed limits km/h (for private cars)			
	on weight	on engine size	Motorways/ roads	Car pooling	Support for mass transport	Information campaigns
Australia	x	x	100	–	x	x
Austria	–	x	130/100	–	x	x
Belgium	–	x	120/90	P	x	x
Canada	x	–	100/90	x	x	x
Denmark	x	–	100/80	–	x	x
Germany, F.R.	–	x	(130)[b]/100	x	x	x
Greece	–	x	100	–	x	x
Ireland	–	x	88	x	x	x
Italy	–	x	90–140/110–80	–	x	x
Japan	x	x	80–100	x	x	x
Luxembourg	–	x	120/90	–	x	x
Netherlands	x	–	100/80	P	x	x
New Zealand	–	x	80	x	x	x
Norway	x	–	90/80	–	x	x
Portugal	x	x	120/90	–	x	x
Spain	–	x	100/90/80	–	x	x
Sweden	x	–	90–110/70	x	x	x
Switzerland	x	x	130/100	–	x	x
Turkey	x	x	90/80/70	x	x	–
United Kingdom	x	–	113/97	x	x	x
USA	–	–[c]	88	x	x	x

Source: Country Submissions for IEA, 1977, 1978, 1979 and 1980. Reviews of National Programmes.

[a] They are described in more detail in the country chapters of the annual publication *Energy Policies and Programmes of IEA Member Countries.* Some specific examples are given in Section III.

[b] Recommended on motorways.

[c] Tax on measured vehicle fuel efficiency.

x: exists

P: in preparation

–: does not exist

TABLE 8.IX. GOVERNMENT AUTOMOBILE FUEL ECONOMY PROGRAMMES IN MAJOR IEA AUTOMOBILE-PRODUCING COUNTRIES [8.26]

Country	Description
Australia	Voluntary new car fuel economy programme: 745 kcal/km (26.1 mpg) in 1983 and 662 kcal/km (29.4 mpg) in 1987.
Canada	Voluntary fuel economy programme: 921 kcal/km (20 mpg) in 1980 and 668 kcal/km (27.5 mpg) in 1985. Mandatory programme under development.
Germany, F.R.	Voluntary programme to improve new car fuel economy by 10 per cent to 12 per cent over 1978 levels by 1985 (no specific levels for absolute average consumption have been set).
Italy	Voluntary programme to improve new car fuel economy by 10 per cent by 1985. Present fuel economy averages 9.1 litres/100 km (25.8 mpg).
Japan	Mandatory new car fuel economy programme of 609 kcal/km (30.1 mpg) in 1985.
Sweden	Voluntary programme to improve fuel efficiency to 663 kcal/km (27.6 mpg) in the mid-1980s. Further reductions to 1990 are being discussed.
United Kingdom	Voluntary programme to improve fuel efficiency by 10 per cent by 1985. Current fuel economy is 790 kcal/km (23.5 mpg).
USA	Mandatory new car fuel economy programme beginning with model year 1978 of 1019 kcal/km (18 mpg) increasing to 667 kcal/km (27.5 mpg) by 1985.

Source: Country Submissions for IEA 1977, 1978, 1979 and 1980 Reviews of National Energy Policies.

Note: 1000 kcal/km is approximately equal to 12.8 litres per 100 km: mpg = miles per US gallon.

requirements in 1990 owing to an increase of IEA coal production by 50%, a tripling of nuclear power and some measurable contribution from renewable energy production by 1990.

The above consolidated figures for western countries would have appeared even more favourable if the performance of France, not an IEA member, but remarkably successful both in energy saving and petroleum substitution – especially due to its nuclear policy – had been included.

Additional information to the above global figures on energy conservation is offered by Fig. 8.20. It illustrates the diversity of the relationship between the efficiency of energy utilization (energy in 1000 toe) and the price of energy to users (US$/toe) in the industrialized countries. It also shows with few positive

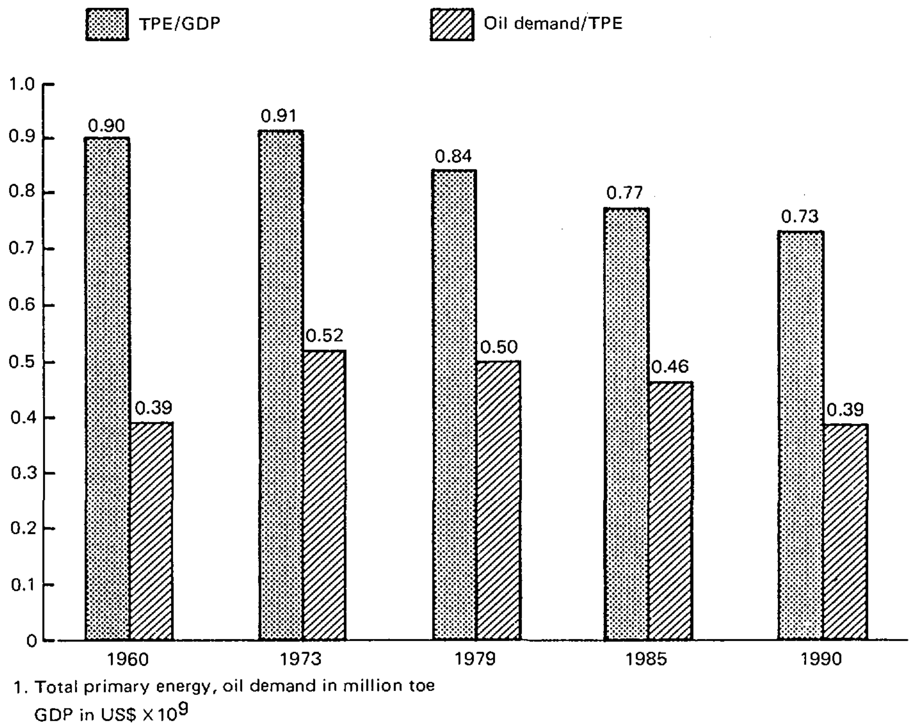

FIG.8.19. Energy demand ratio in IEA countries between 1960 and 1990 [8.25].

and negative exceptions, partly explained by geographical and structural conditions [8.27], the strong influence market prices exercise on energy consumption. Energy prices emerge convincingly as one of the most important factors of energy conservation. Further information on energy conservation measures in industrialized countries can be found in Refs [8.27–8.31], for centrally planned economies in Refs [8.25 and 8.32], the latter describing an interesting approach to the subject in the USSR.

As far as the developing countries are concerned, in the urban sector of their economy, the promotional problems encountered are similar to those in developed countries, occurring, however, at a substantially lower level of energy consumption. Consequently, similar, however more locally adapted psychological approaches are advisable. For the rural part of the energy supply, special approaches have to be devised stressing the built-in, embodied energy conservation component since this is invisible and, therefore, less challenging.

In any case, promotion of energy conservation has proved to belong to the group of the most difficult and sensitive marketing and public-opinion-forming campaigns, with alternatingly successful and frustrating results and requiring

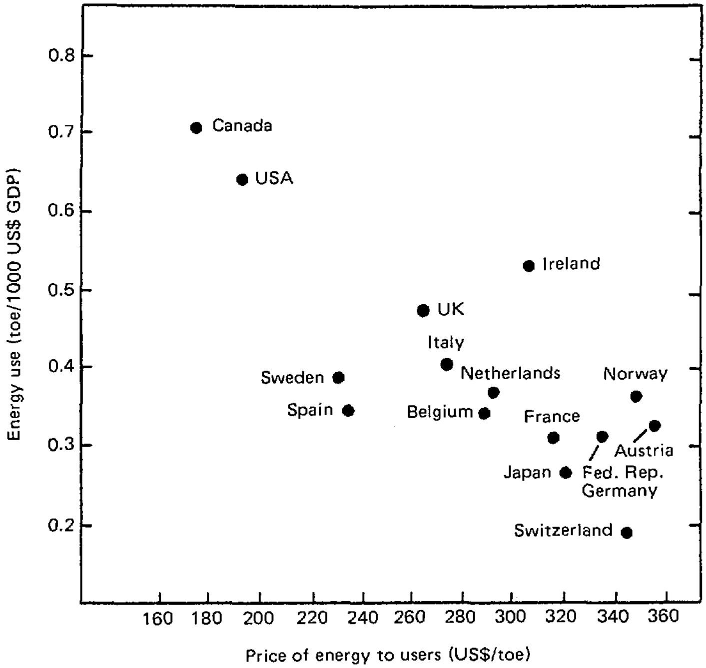

FIG.8.20. Relationship between inter-country differences in energy prices and energy intensity in 1978 (Source: The Economist, 1981) [*8.25*].

continuous, permanently renewed effort and motivation to fight both inertia and the dislike of human beings to change habits and attitudes [8.33]. However, some energy ethics are gradually penetrating public opinion, whereas the industrial and commercial sectors, with their cooler, professional attitude, learned quickly, under the pressure of rising energy prices, to appreciate both the advantages of promotional incentives and the direct benefits of improved energy husbandry.

8.3.5. Institutional framework for promoting energy conservation

Measures and incentives for promoting energy conservation as described in the previous subsection have to be systematically studied, researched, elaborated and publicized, and those entailing standards or regulations have to be officially implemented. Only an adequate institutional framework could, therefore, take over the complicated managerial activity involved and carry it out on a permanent operational basis, within the respective national economies [8.34].

Since energy conservation might be best approached embodied in the overall energy system, its management should ideally be integrated in an overall energy authority, usually an Energy Ministry or National Energy Authority. That is practically the case in a series of developed countries and possibly the line to recommend for developing countries as well, and which some of them have already embarked upon.

A particularly interesting example of well organized and successful national energy conservation effort is that of France. Implemented as early as the end of 1973, the former Agency for Energy Economy, since May 1983 the French Agency for Energy Management (AFME), has developed an intense, partly pioneering, activity in promoting energy conservation by saving and petroleum substitution in all end-use sectors. Its research and work programme, its annual reports, the ample documentation, the system of economic incentives as well as its regional decentralized structures and international co-operation programmes offer a rich source for innovative reflection on the subject. However, a series of similar organizations are operating in other industrialized countries, well worth contacting for further documentation and technical co-operation.

The experience of developed countries has also proved, that in addition to national energy conservation co-ordinating bodies, regional or superregional co-ordinating agencies or authorities – for example the IEA or the European Economic Commission (EEC) – could also be eminently efficient [8.26]. Similarly in the study area, the regional activity of the United Nations Economic Commission for Europe – ECE – and the worldwide work of the Energy Conservation Commission of the World Energy Conference are examples to be commended.

Chapter 9

ENVIRONMENTAL EFFECTS AND OTHER CONSTRAINTS TO ENERGY DEVELOPMENT

9.1. Energy and environment

9.1.1. General considerations

The history of societal development has been deeply marked by the human desire to achieve living and working conditions less and less dependent on environmental constraints. This desire led to actions of fundamental impact on nature and the environment. Energy development is certainly a category of action having major influence, and capacity for impairment.

In fact there is a close link between ecology, i.e. the branch of science concerned with the interrelationship of organisms (humankind) and their environment, and energy. Thermodynamics deals equally with irreversible processes depending on the direction of time, which determine also biological happenings. Everywhere on earth and in the universe where regular structures are created, they lead, according to the entropy principle, to a higher disorder of the environment [9.1]. This is the scientific base of the environmental effect of any energy conversion process.

All primary energy input has to be taken from nature, as primary energy input, processed, circulated and usefully consumed, to end the circuit released as heat into the environment. According to the first law of thermodynamics regarding the conservation[10] of energy, the evacuated heat as the sum of losses and used energy remains equal to the primary energy input.

The wide physical energy circuit from nature back to the environment has deep repercussions on overall energy development itself. The most global impact comes from the increasing quantity of heat which energy utilization releases into the environment.

However, the ecological equilibrium on earth has never been static. Humankind constantly intervened, using energy. The use of fire is the most important example and with the help of this source of energy and others, modern technology was finally created. Since the beginning, this has resulted in humankind changing its environment, e.g. clearing forests to obtain timber and arable land. For example, the karstic south European coasts were wooded at one time and Carthage, the former granary of Rome, was made into desert.

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[10] Here the author feels unhappy again about the coincidence of the term 'conservation of energy' in its initial physical meaning and its modern use in the sense of better energy husbandry.

The first fires brought the first environmental pollution and risks as seen today in the context of energy production: the air was contaminated by fumes containing, amongst other things, carcinogenic materials; fireplaces also represented a hazard due to the risk of forest fires being started.

The environmental effects of energy will be highlighted in the following according to the types of pollution transfer, the areas in which pollution sources occur, the pollution-causing primary energy sources and the pollution effects on various sectors.

(1) Types of pollution for which different media are responsible for transfer [9.2]:
  - contamination of the air by pollutants
  - contamination of water by pollutants
  - water pollution by waste heat
  - atmospheric pollution by waste heat
  - noise
  - surface requirement
  - aesthetic aspects: landscape disfigurement.

(2) Areas in which pollution sources occur:
  - industry
  - electrical power stations
  - households and small-scale consumers
  - transportation

(3) Primary energy resources causing pollution: coal, petroleum, natural gas, hydraulic energy (running water, dams), nuclear energy, biomass, direct solar energy.

(4) Effects on: materials (i.e. buildings), plants, animals, human beings.

9.1.1.1. Atmospheric pollution

Pollutant emissions represent the most important type of environmental pollution in energy production. In the case of natural gas – to begin with a 'clean' primary energy source – carbon monoxide (CO) and nitrogen oxides (NO_x) constitute the pollutant combustion products which are released from the stack. In the case of petroleum products, sulphur compounds and hydrocarbons are also produced, whilst coal combustion involves in addition the production of considerable quantities of dust which also contain radioactive substances. In nuclear installations, chemical pollutants are not produced, but the emission of radioactive substances is fundamental.

The pollutants released in the combustion of fossil primary energy sources also occur in nature, e.g. in volcano lava or as a degradation product from organic material. As long as they are chemical compounds, e.g. SO_2, or hydrocarbons, they are also degraded in the course of time by natural processes.

9.1.1.1.1. Carbon monoxide (CO) emissions

Carbon monoxide results from incomplete combustion, above all from the operation of motor vehicles and domestic heating systems. Its toxicity is based on the fact that it takes the place of oxygen in forming a very strong bond with the red blood pigment haemoglobin (200–300 times stronger than oxygen); it is only discharged again very slowly and, consequently, impedes oxygen transport in the blood. In greater concentrations, it leads to death through blocking vesicular breathing.

Technical measures can be taken which will partially prevent the production of CO in large firing systems; in the case of motor vehicles there are now official stipulations limiting the CO level in exhaust gases. In the case of the internal combustion engine, a certain CO proportion is always produced which could only be prevented with after-combustion. Precisely because of its considerably lower CO emission, the diesel engine is reputed to produce less environmental pollution.

A high number of fatal accidents used to happen in the past from leaks in town gas networks, this artificial gas containing a high share of CO. With the new steel pipelines, but especially with natural gas replacing the old town gas, this substantial risk has almost disappeared.

9.1.1.1.2. NO_x emissions

Nitrogen oxides (NO, NO_2, NO_3) are produced from the reaction of atmospheric nitrogen with atmospheric oxygen where combustion processes occur at high temperatures, i.e. in fossil-fuelled power stations (approx. 1800°C), in motor vehicle engines and, to a smaller extent, in domestic heating appliances. Nitrogen oxides attack the mucous membranes and respiratory organs and promote catarrh and infections (bronchitis, bronchial pneumonia) in these regions. Their effect is enhanced in the brain. Nitrogen oxides are also contained in photochemical smog; NO_2 reacts with ozone and air humidity to give nitric acid, HNO_3.

The aggressive nitric acid is present, as is the sulphuric acid from SO_2, in aerosol form.

Suitable execution of the combustion process can minimize NO_x production, but cannot prevent it. Processes for removal of nitrogen oxides from flue gases are being tested at the moment in Japan [9.3].

The last few years have seen increased efforts to reduce SO_2 and NO_2 emissions using a fluidized-bed firing system. This process, which also allows low-grade coal to be used, prevents the production of nitrogen oxides to a great extent as a result of low combustion temperatures (800–900°C). The coal sulphur content is already bound in the firing stage by the addition of limestone so that the flue gases are practically free of sulphur. However, some developments are still to be made before the process can be used on an industrial scale. To date it has not been clarified to what extent the emission of fine dusts capable of entering the lungs increases in this process as compared to large modern firing systems.

9.1.1.1.3. Sulphur dioxide (SO_2) emissions – acid rain

Coal and oil contain up to 4% sulphur which is reduced to 1–1.25% in hard coal by flotation. In combustion, sulphur is predominantly oxidized to give gaseous SO_2, which is considered to be the most important air pollutant in combustion. In this case, as has been proved in medical examinations in the last few years, SO_2 in dry respiratory air only has an effect at very high concentrations, causing irritation of the bronchi and lungs. In the presence of sunlight and air humidity, SO_2 is oxidized to sulphuric acid (photochemical smog).

SO_2 and the oxidation products, sulphurous acid (H_2SO_3) and sulphuric acid, can lead to diseases of the respiratory organs, the heart and the circulatory system. The ozone (O_3) produced irritates the respiratory tract and reacts with other air contaminants to produce new and, in some cases, aggressive pollutants.

It is possible in principle to remove SO_2 extensively (up to 90%) from power station flue gases by technical means. However, the processes are expensive and require relatively large quantities of energy. In Japan and the USA there are flue gas desulphurization plants which are already viable [9.4]. Three different flue gas desulphurization processes have been under examination in demonstration plants for some time in the Federal Republic of Germany [9.5]. A large flue gas desulphurization plant went into operation at Querscheid/Saar in summer 1979. Flue gas desulphurization is now a stipulated requirement in the Federal Republic of Germany for new large coal-fired power plants [9.6].

As flue gas desulphurization is too costly for small-plant operation, the fuel used in the plant must be desulphurized. Consequently, light fuel oil with a low sulphur content is specified for domestic heating appliances. In principle, extensive desulphurization can also be carried out for other kinds of oil and coal, but has only been carried out in limited instances.

The SO_2 emissions became a national and international popular theme of discussion only at the United Nations Conference on the human environment in 1972 after crossing the threshold of public awareness as the acid rain issue.

Acid rain refers loosely to a mixture of wet and dry acidic deposition from the atmosphere. The wet part may be rain, snow, hail, sleet, fog, dew or frost. The dry part, estimated to be about half the total, consists of gases and solid particles that settle to earth. Dry deposit can go into solution and begin behaving like acid rainfall as soon as it contacts surface moisture.

As soon as the acid rain issue entered public discussion, the forest dying was ranged under its effects, and environmentalists requested extreme measures against SO_2 emissions, especially originating from electric power stations, mainly coal-burning plants [9.7].

In the meantime, several comprehensive studies have been carried out regarding the atmospheric pollutants resulting from energy production and consumption and each time the acid rain issue received great attention, for example in Spain, the EMMA project [9.8] and the study organized by the International Electric Research Exchange, with two working groups of independent university researchers and utility scientists drawn from Canada, Europe, Japan and the USA [9.9]. The first group combined the disciplines of medicine, epidemiology, physics and mathematics, the second those of ecology, forestry, agriculture, soil science, aquatic biology, chemistry and physics.

Their remit was "to prepare an objective scientific assessment of existing knowledge of the effects of atmospheric SO_2 and its derivatives on human health, animals, natural ecosystems, agriculture and fisheries, to bring out inadequacies and to identify specific research requirements".

From the highly interesting conclusions it may be singled out that with regard to forestry, the situation facing the policy-maker is confused. Long-range effects on productivity due to acid rain have not been established. Insofar as damage reported in the Federal Republic of Germany is due to pollutants these may be of relatively local origin. An even more recent study of the VDI (the Association of German Engineers) carried out in the Commission for Clean Air Protection concludes that the concept of acid rain is not an acceptable simplification and that much more complex processes are involved. In any case, the acid rain cannot be made primarily responsible for the dying forests, although it may intervene in the framework of a larger combined action [9.10].

The conclusion is that in the presence of the noxious effects, energy action must be taken, but much caution is needed to find the real causes and allocate the high cost burdens to the real pollutant. It would be regrettable hastily to bias the nowadays so sensitive balance between energy supply and environment protection [9.7].

In this area the ongoing strong research effort on acid rain causes and effects, amounting to \$27 million in the USA in 1984 [9.11], to over \$10 million yearly in Canada and some \$5 million in Europe, is expected to soon bring some clarification. Such a co-operative effort, in fact corresponds to the international character of the subject, since energy use and its environmental side-effects do not respect political boundaries (for example southern Norway, Sweden and parts of Finland are affected by emissions from Great Britain and central Europe). It is in this spirit that in March 1983 an international agreement for clean air protection elaborated by the United Nations Economic Commission for Europe and signed by 24 Western and Eastern states became operational. Its terms of reference include, among others, drafting a concrete strategy for reducing the effects of atmospheric pollution, especially SO_2 emissions.

9.1.1.1.4. Hydrocarbons (C_mH_n) emissions

This term covers all organic compounds consisting of carbon and hydrogen. They are of great technical significance as fuels (petrol, benzene, natural gas, propane, etc.) and are principally emitted to the atmosphere from the oil processing industry and road traffic. Some hydrocarbons are carcinogenic, e.g. benzene and benzopyrene, constituents of car exhaust gases and exhaust gases from oil- and coal-firing systems.

Even the inhalation of very small concentrations of carcinogenic substances produces a long-term increase in the risk of contracting cancer.

9.1.1.1.5 Dust emissions

Dusts are produced in industrial facilities (e.g. cement works), above all in combustion processes and not only in the combustion of solid fuels. In industry and power stations today, approximately 99% of grit is removed using electrostatic filters. However, the majority of the fine dust particles of less than 3 μm pass through the filter. Unlike the grit, this fine dust can reach the lungs via the respiratory tract. The toxicological effect is predominantly based on the content of substances such as lead, vanadium, fluorine, nickel, arsenic, selenium, cadmium, beryllium and mercury, some of which promote cancer. In addition, other pollutants, e.g. hydrocarbons and sulphur or nitrogen compounds, accumulate on the surface of the fine invisible dust particles so that their effect, in the presence of dust, is augmented. Generally, dust increases the number of respiratory organ diseases, e.g. influenza, pneumonia, asthma.

9.1.1.1.6. Radioactivity

As radioactive substances are widely present in the earth as trace elements, coal also contains small quantities of radioactive substances from the naturally occurring decay series of uranium and thorium. Part of these substances is distributed in the environment with fine dusts via the power station chimney. When inhaled with dust, these radioactive substances – heavy metals such as lead and radium – can penetrate into the bloodstream; they primarily accumulate in the bones and lead to radiation exposure in that region. Radioactive substances are also emitted from nuclear power stations via vent stacks; in this case, these are predominantly radioactive fission and activation products, e.g. iodine-131, krypton-85, strontium-90 and tritium, which are taken up by the human body in different ways: iodine is chiefly concentrated in the thyroid gland, strontium in the bones, whilst a noble gas such as krypton cannot be incorporated into the body as it does not enter into chemical combination with any substance.

Nuclear power station emissions are measured very accurately; the radiation exposure produced as a result, even in the most unfavourable case – excluding thyroid gland exposure due to iodine – lies well under one millirem per year. In the case of reprocessing plants, it is higher and comparable to the radiation which can be received in the most unfavourable case in the vicinity of a coal-fired power plant.

As a result of radiation, radioactive substances increase the risk of cancer. They have an effect – although the biophysical and biochemical primary process is different – which is similar to that of certain hydrocarbons or heavy metal.

9.1.1.2. Water pollution

Water pollution is predominantly caused by industrial waste water and domestic sewage; agriculture can also contribute to pollution when artificial fertilizers are used excessively. In comparison, pollution caused in conjunction with energy production is of less significance.

Occasionally oil causes damage in that transport accidents on land can lead to groundwater contamination and transport accidents at sea directly affect humankind when the resulting oil slick contaminates coastal regions.

A certain amount of water pollution occurs when coal is washed (4.5 m^3 water for 1 t hard coal) and when oil is treated. Chemical pollutants are responsible in the latter case. Mine water can be contaminated with natural radioactive substances. On the other hand, effluents from fossil-fuelled power stations are of no significance. Waste water from nuclear installations contains radioactive substances. However, water pollution arising from energy production, conversion and consumption is small in comparison with the atmospheric pollution.

9.1.1.3. Heat pollution and CO_2 effects

All losses of energy conversion, transport and consumption processes, and finally the used useful energy itself, result in heat release in the environment, directly or via cooling water. The environment is the sink, required by the second law of thermodynamics. The environment is also the collecter of all effects of energy processes, which contribute to the general, increasing entropy.

The heat releases as a total have no detrimental effects, but could turn into heat pollution when discharged for example in a limited amount of cooling water or in very heavily populated centres.

Heat has, however, an indirect polluting effect, when originating from the burning of fossil fuels or biomass, namely CO_2 emissions.

Experience has shown that increasing CO_2 content in the atmosphere develops under insolation a 'greenhouse effect', resulting in an increase of the outdoor temperature. Atmospheric carbon dioxide acts as a heat trap. It does not interfere with incoming solar radiation, but it blocks some of the outgoing reflections of this heat into space, by absorbing infra-red radiation [9.12].

Systematic checking of the CO_2 content in the atmosphere has shown an increase from some 292 ppm at the end of the last century up to 333 ppm at present. In major cities and conurbations the figures could be much higher. In general, the rate of increase is now 1 ppm/year [9.13].

The outdoor-temperature could rise, according to model calculations, by some 2 K or 1.5–3 K if the present CO_2 content doubles. The temperature rise would not be uniform, but could reach 7–10 K at the poles. It is not possible to enter into further discussion on possible repercussions of such temperature rises, but further studies might look deeper into these aspects, since eventually they could impose some limitations on the CO_2 content increase, and indirectly on the energy production from the primary resources generating it.

9.1.1.4. Other pollution

Other, self-explanatory polluting effects are noise, surface requirements and landscape disfigurement, all of these, in one form or another and to different degrees, being associated with energy activities and installations.

9.1.2. Environmental effects of various energy chains and processes

A few typical examples are given to illustrate the amplitude, urgency and challenging character of an ecological approach to energy development.

(1) Coal. In the extraction phase in the chain of coal, especially by strip mining, one may mention alteration to landscapes, temporary influence on the water economy and loss of farming and forestry land areas. In the conversion to intermediate forms of energy or final consumption, the release of different products such as ash, dusts, exhaust gases and waste liquids, may influence or even damage the environment if they are allowed to escape. In addition to carbon dioxide, whose increasing concentration in the atmosphere amplifies the effects of the general heat release of combustion processes, exhaust gases may contain noxious sulphur dioxide, nitrogen oxides, carbon monoxide, and other volatile dangerous elements. To prevent such influences, large coal-burning power stations are constructed with efficient electrical filters for dust removal and costly sulphur removal equipment [9.14].

(2) Petroleum. In the petroleum chain impairment can occur to all four areas of the environment (air, water, soil and landscape) [9.15]. A major danger occurs when crude oil or derivatives leak out either during sea transport into the sea water or during land storage, transport and distribution into the ground.

A permanent impairment to the landscape arises along the entire energy chain due to the large scale of the technical installations.

The noxious effects of possible high sulphur contents of exhaust and flue gases are avoided by advanced sulphur removal of derivatives in the refineries or in the furnaces of power-station boilers. As in the case of coal, the released free carbon dioxide, although not strictly a pollutant, amplifies the greenhouse effect in the upper atmosphere.

Petroleum from oil shale and tar sands includes in addition the impairments of the mining and preparation phase, as described above for coal mining.

(3) Natural gas. The natural gas chain causes the least impairment to the environment of all the fossil fuels since gas can be transported and burned without harmful effects.

(4) Geothermal energy. The geothermal energy chain could impair the environment through possible noxious effects of mineralized, gas-containing water released from the plant or excessive amounts of waste heat, the disposal of which might be difficult at some geothermal sites [9.16]. Dry-rock geothermal resources might possibly exercise noxious effects on the subterranean zones, but it is too early to make predictions on this subject.

(5) Nuclear energy. Without doubt, the nuclear energy chain is the one with the major feared potential impact not only on the environment but on the population as well [9.17–19].

While the external problems created by uranium mining, processing and electricity production in nuclear power stations are the same as those from fossil fuel chains, the danger of ionizing radiation which permanently accompanies this chain makes it not only potentially although controllably dangerous, but also an explosive subject of public discussion and reaction. To complicate the situation, the chain does not end in the electricity-generating power station where the useful utilization takes place, but continues to exist dangerously for a long period of time, in the form of disposed nuclear waste. Nuclear energy development needs, therefore, to be eminently dominated, in addition to other environmental considerations, by the imperative: safety first!

(6) Renewable energy resources. Of the renewable energy resources group, hydro power and biomass could entail the greater impairments to the environment [9.20].

Hydro power may not only deeply affect the water balance of an area but may also lead to substantial landscape changes, for instance by large storage reservoirs. The latter could determine important population shifts, if human settlements are eventually submerged by storage lakes. On the other hand, beneficial environmental effects can be produced by flood control, soil erosion limitation and reforestation of the basin area [9.21].

Biomass energy utilization negatively affects the environment if its normal regeneration cycle is perturbed. Excessive wood burning for example easily leads to deforestation with all its disastrous effects on soil erosion and other environmental damage. The same applies to agricultural waste utilization, if the natural soil recovery circuit is not maintained by natural or artificial fertilizers. When biomass is burned for energy purposes, the same problems are involved as with fossil fuels, especially regarding CO and CO_2 emissions.

As far as other renewable energy resources are concerned, insufficient experience exists for evaluating the environmental effects or impairments of tidal, wave, OTEC, wind and direct solar energy.

(7) At the intermediate energy stage, electrical energy, although itself a perfectly clean energy form, has the most complex effects on the environment [9.22]. In its production phase in classical thermal and nuclear power plants it impairs the air by the already mentioned hot and possibly noxious and dusty gas effluents, the cooling water or air by massive waste heat release and the landscape by large-scale power plants, electrical substations and electrical lines. Its transport lines and distribution network, when aerial, certainly do not contribute to the landscape's beauty [9.23]. Finally, in its consumption phase, independent of what useful energy form it is converted to, it ends in heat released to the environment.

(8) Another intermediate energy form of very friendly environmental character is heat distributed directly through industrial and district heating networks [1.24]. If co-generated with electricity it offers the many advantages already commented on. Among those of environmental nature, the one relating to possible location of energy production outside the populated consuming centres, in sites where coal or nuclear energy can be substituted for fuel oil or natural gas, might appear of special interest.

(9) In the final consuming stage where used useful energy, wastage and losses return as heat to the environment, some of the final processes also spray noxious effluents into the atmosphere, for example the fleet of automotive vehicles. At the same time CO_2 and heat are evacuated. The latter might be undesirable in small spaces and has to be further removed to the outside atmosphere.

9.1.3. Improving the energy/environment relationship

The physical effects of energy on the environment could be basically improved by reducing the noxious effluents for the same quantity of useful energy needed, i.e. raising the overall efficiency of energy utilization. Ways and means to this purpose have been amply discussed in this framework. A typical example: since 1977 the average specific heat rate in the Federal Republic of Germany of a kW·h is 0.328 kgce, compared with 0.692 kgce in 1950, i.e. less than half. The environmental effects have been reduced at least in the same proportion (but meantime the environmental exigencies have increased too).

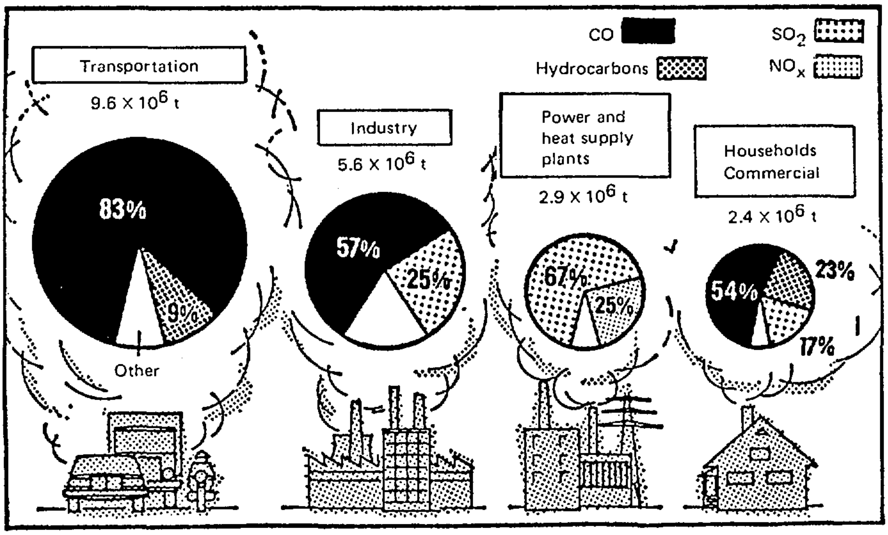


FIG. 9.1. Atmospheric pollution in the Federal Republic of Germany in 1978 [9.27].

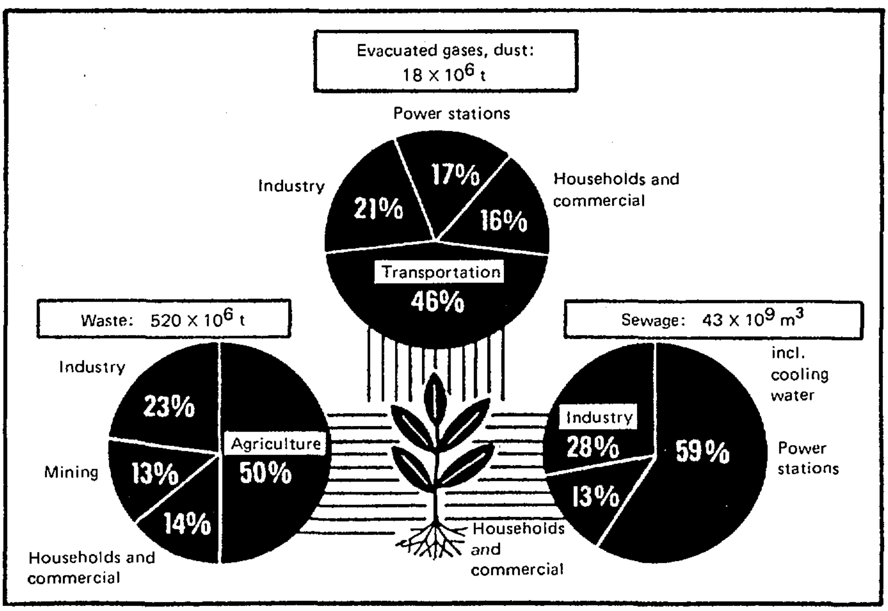


FIG. 9.2. Pollution in the Federal Republic of Germany in 1982 [9.28].

An additional possibility to reduce environmental effects is to use less pollutant energy resources, clean them before conversion or clean up the effluents as conversion products. All these alternatives involve higher, sometimes substantially higher, energy costs.

For example, environmental protection measures for an electric power station (700 MW) burning hard coal account for 26% of the total investment costs: the flue gas SO_2 treatment represents 16%, electrofilter and NO_X treatment 5% and noise and heat treatment another 5% [9.25]. In addition, the auxiliary services energy consumption for desulphurization may reach up to 5% of the total electricity production [9.26].

In conclusion, improved environmental preservation increases both costs and auxiliary energy consumption.

An overview on the contribution of the main energy consumption subsectors to the total air pollution in the Federal Republic of Germany in 1978 is presented in Fig. 9.1. According to this, transportation, industry and households are the main CO contributors (incomplete combustion) and the power stations and industry the main SO_2 polluters.

Figure 9.2 displays the share of the same four subsectors in air pollution, water pollution and waste and garbage. Annually, in the Federal Republic of Germany, 18×10^6 t of noxious effluents are blown into the air, 43×10^9 m^3 of polluted (including cooling) water are drained into the rivers and 520×10^6 t of garbage have to be disposed of. That is the bill of an affluent society [9.28].

9.2. Other constraints to energy development

Put in rather oversimplified fashion, the main constraints to energy development in industrialized countries appear to be environmental protection, public opinion and, in some measure, lead time, while in developing countries the factors could be capital, skilled manpower, management capability, time and environmental conditions (difficult in the large cities but amenable in the rest of the country).

In general, the above issues are commented on in the corresponding chapters and the environmental aspects have been given a lot of attention in the present chapter. A final comment would re-emphasize the manpower training and managerial aspects for the developing countries and the importance of environmental protection and public opinion in the industrialized countries. Also, the common issue of lead time constraints should be again underlined, although in a good planning exercise – see chapter 17 – they will be analysed and taken care of. However, it is a fact that certain phases of energy development take time, not only for technical and economic reasons, but simply because their speed of action or penetration is limited by human and/or administrative (bureaucratic) factors. For example, the development of an opencast mine can require up to five years and in the case of underground mining a time span of over ten years must be expected from the exploration phase to the attainment of full output. The average lead time from commitment to commercial operation for nuclear power plants now under construction in industrialized countries varies from 60 to 100 months and more. For developing countries entering upon nuclear power generation, a long initial preparatory period must be added – see chapter 18.

Without doubt, in the industrialized countries a deep and unanimous desire for environmental protection has developed, and people in the energy field were among the first to embark upon action, through the establishment of extensive standards and regulations, being well aware of the risks and consequences that could ensue in their absence.

However, regarding the latter, a contradictory situation gradually evolved. While the professionals studied risks and consequences with all the necessary objectivity [9.29, 30], public opinion reacted more and more emotionally [9.31], initially in relation to nuclear power, and of late extending to almost all energy-related projects, the acid rain issue being one of the newest areas.

Anyhow, a strange evolution is taking place, explained by the old saying that nature always hits back. Humankind, after aiming at becoming less and less dependent on the environment, finds, once its energy hunger is fairly satisfied, an amazingly rapid interest in preserving environmental conditions as close to natural as possible, even making potentially suicidal protests against changes caused by energy development.

Public opinion can intervene both positively and negatively in energy issues. An example of positive intervention is when public opinion is actively mobilized for energy conservation, another of negative effect is in mostly unreasonably fighting the introduction and development of nuclear energy. In both cases the results, to a large extent, derive from campaigning; in the latter case the energy managers and politicians probably underestimated the necessity of favourable public opinion and failed to supply all the required information from the very beginning. It will certainly not be easy to provide it at a late stage. However, there is little doubt that rational arguments will ultimately convince. But why delay and what is the social price paid?

Part II

ECONOMIC ASPECTS OF ENERGY DEVELOPMENT

Chapter 10

BASIC CONCEPTS OF ENERGY ECONOMICS

It is not intended nor would it be possible to present within this framework a consolidated overview of all economic aspects of the broad and complex energy economy. However, the main issues of energy development and planning cannot be approached without a minimal critical mass of economic knowledge of basic concepts and tools, which all non-economist professionals participating in such an endeavour should possess or urgently acquire. Accordingly, this chapter brings, not necessarily in the most systematic way, but otherwise closely target-related, basic comments on significant economic aspects of energy in general and, owing to their more sophisticated nature, of electricity and nuclear-generated electricity in particular.

10.1. Basic concepts and considerations

10.1.1. Energy and economic data

Information is one of the essential ingredients for development and planning. A realistic appreciation of the value of information and a committed effort to organize and use it properly is a fundamental condition for the efficient management of the financial and human resources of any country and for the best utilization of funds available for development.

Energy information undoubtedly belongs to the first group of information to be organized in a developing country, and according to the system concept of energy development, it should be approached in the form of an energy information system.

Energy information systems are bodies of data organized in a form suitable for analysis, gathering data under a unitary concept, placing them in common units, storing them and providing an easy access to them. According to the volume and level of available data, an energy information system can take the form of simple tables or elaborate interactive computer systems.

There are two current forms of energy information systems: those based on matrix representation of energy accounts and those based on a flow model of the energy system.

The design of a specific national system should be based on an appraisal of the purposes which the system is to serve and the data available to be incorporated into it. However, whatever system is adopted, it should be capable of representing all uses of energy as well as all primary energy resources, including non-commercial and renewable. In all information systems, decisions must also be made as to whether and how to include non-energy uses of fuels such as those for feedstocks and items such as animal power. Again, these issues will depend on local conditions and needs.

(a) Tabular energy accounting systems. A common approach to developing an energy information system is by use of a tabular accounting framework. Such frameworks are particularly popular with international institutions because they provide a convenient way of comparing data worldwide and of different regions and countries [10.1, 10.2]. They are also in their more simple forms very useful for developing countries [10.3].

(b) Reference energy systems. An alternative approach to energy information systems is represented by the reference energy system family of models. A reference energy system (RES) presents a flow model of energy supply, conversion and final use. A computerized version of the model has been developed for use in developing countries [10.4]. The RES approach to energy information systems emphasizes the analytical uses of energy data and in particular the construction of alternative projections of demand and supply in order to examine national energy strategies.

The most advanced information system based on the RES is the EDIS system, designed by the Institute for Energy Research at Stony Brook [10.5].

A particularly interesting energy information system perfectly fitting the purposes of IAEA courses is the Energy and Economy Data Bank of the IAEA [10.6]. Like the energy courses themselves, the data bank established in 1976 is geared to the role of nuclear energy in the wider energy development context and stores accordingly all pertinent information – technical and economic – relating both to nuclear and all other forms of energy. In addition, an impressive volume of data regarding population, environment and other socio-economic aspects is stored and readily available for analysis.

The data bank was designed to deliver three main categories of services:

(a) Current usage, i.e. to answer rapidly all questions regarding energy: consumption, production, commerce, resources and related economic aspects;
(b) Periodical publication of statistical bulletins and brochures summarizing in tabular and graphic form the present and future energy situation in different IAEA member countries and
(c) Support for energy demand projection, based on several mathematical models.

Figure 10.1 presents a simplified graphical structure of the encompassed data areas in the IAEA energy data bank.

There are, of course, other places where worldwide energy data is stored, probably duplicating, tripling and x-plicating the same parallel efforts. But they are almost everywhere of difficult access. It is therefore salutary and to be commended that in the United Nations Conference on New and Renewable Energy Sources held in Nairobi in 1981 there was a strong call for a worldwide systemization of energy information – understandably the accent was on new and renewable energy forms –, of easy and wide open access [10.7]. The IAEA, with its own data bank, co-operating with the United Nations statistical office in

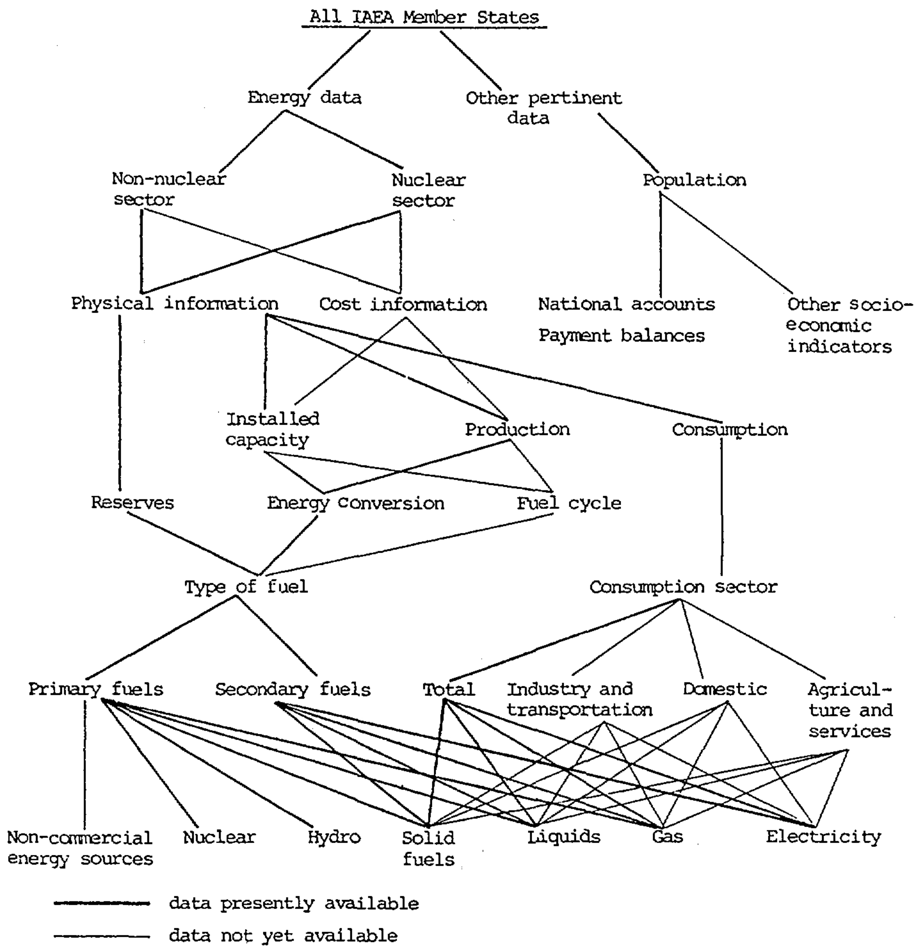


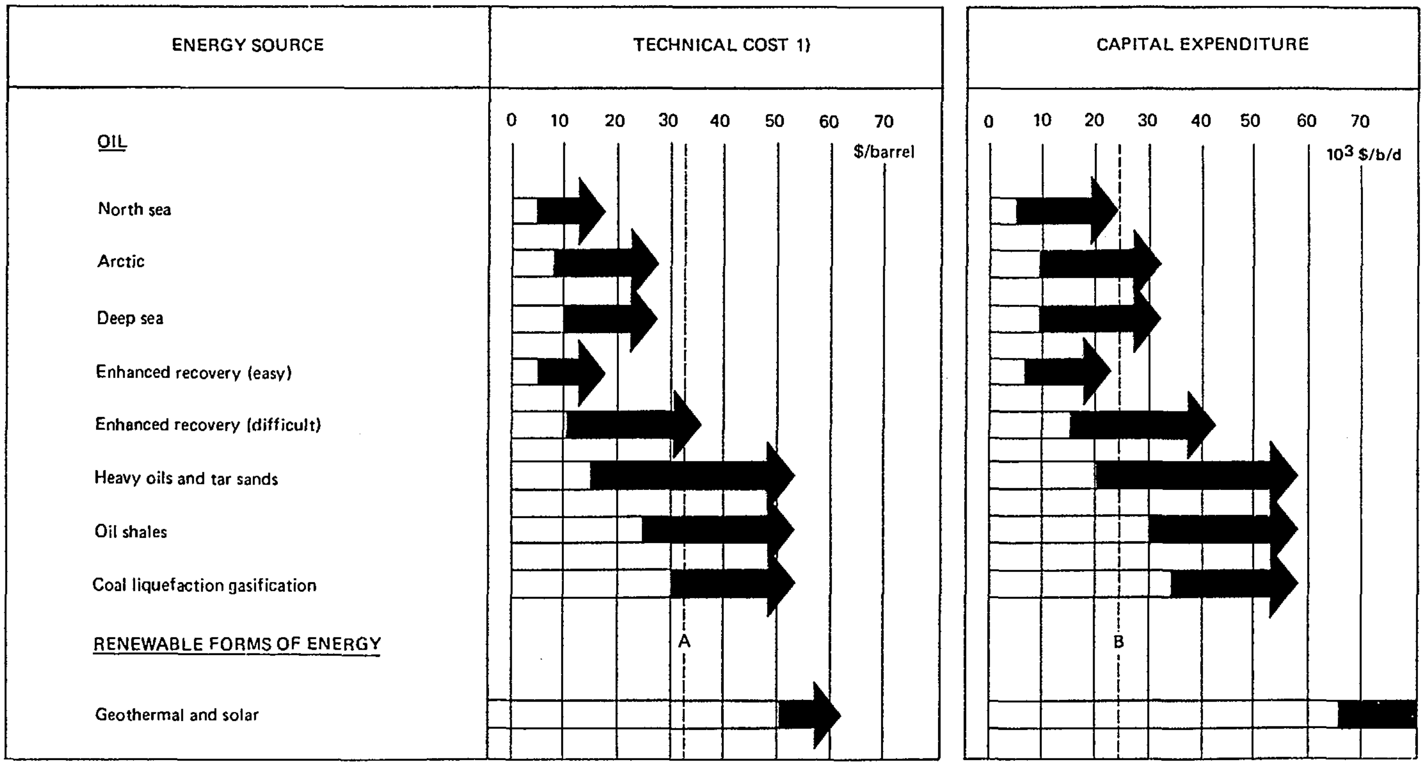
FIG.10.1. Structure of the IAEA Data Bank.

New York, the statistical division of IAE/OECD in Paris, the World Bank in Washington and the Energy Statistical Division of the Common Market in Luxembourg might well represent a core move in this direction.

10.1.2. Energy costs and prices

The total annual costs of energy-producing, -converting, -transporting and -consuming installations basically consist of:

(a) A fixed component, which does not depend on the amount of energy processed in the year of reference, and which represents the fixed annual costs: depreciation (amortization) of the invested capital and the related interest charges.



(1) Before tax
A Average cost of oil supplies in consumer countries
B Maximum development investment in North Sea approved in 1980

FIG.10.2. Capital expenditure and production costs of some primary energy resources.

(b) A variable component, which depends on the amount of energy processed, for instance the fuel costs of a thermal power station, and
(c) A category of costs of mixed character, i.e. depending both on the size of the installation, as well as on the amount of energy processed, as for example administration costs, maintenance and repair costs and direct operational costs, mainly labour costs.

While for existing installations the annual costs are determined from actual disbursement figures carefully accounted for in a well-organized system, for projected installations an evaluation approach is used, based mainly on available information system data and previous similar calculations.

In the latter case, simplifications are made, considering only two categories of costs: fixed and variable, the third category, mixed costs, being allocated according to their main component to one of the two retained groups. Further considerations and numerical examples follow this simplified approach, which is fully adequate for the purposes of this book.

10.1.2.1. Investment costs

Depending on the nature of the energy installations the fixed costs can have a light or heavy impact on the annual costs, as illustrated by a few following examples.

In general, the investment costs depend in addition to the nature of the energy installations on their size and sophistication, which naturally includes efficiency and ease of operation. In particular the effect of economy of scale on the specific investment costs could be very substantial.

Figure 10.2 illustrates the investment costs at the end of 1980 for creating a production capacity of one barrel per day of crude oil under different conditions of location and grade of recovery, as well as for heavy oils, tar sands and oil shales. The latter are in the same order of magnitude as coal liquefaction and gasification. For geothermal and solar energy, much higher figures are indicated [10.8].

Table 10.I gives in its first column a good comparative overview on the investment cost of electric power generation plants, depending on the various types of fuel used. The figures include costs of transmission and distribution [10.9].

10.1.2.2. Depreciation

Energy installations, like all production equipment, decrease in worth over time as they wear out physically or are replaced by newer or more economic facilities. The term depreciation generally refers to this decrease in worth. In terms of cost accounting, however, the fundamental concept of depreciation is that the capital invested in an energy facility must be recovered in some systematic fashion from the revenues it generates during its operating life. Therefore, from the

TABLE 10.I. OIL IMPORTING DEVELOPING COUNTRIES: COMPARATIVE COSTS OF POWER GENERATION BASED ON VARIOUS TYPES OF FUEL
(Delivered cost to major consumers)

Generator type		Investment cost 1980 (US \$/kW installed)[a]	Fuel cost 1980 (US¢/kW·h)	Power cost 1980 (US¢/kW·h)
Hydro power	Large, high head	1100	n.a.	2.4
	Low head mini hydro	3500	n.a.	12.7
Diesel	Large, heavy oil fuel coastal location	1000	4.2	6.7
	Small, light oil fuel inland location	800	10.9	13.2
Steam	Large, gas-fired	800	0.4	2.4
	Large, coal-fired	1000	2.7	5.2
	Large, (imported) oil-fired	800	5.5	7.5
	Small, heavy oil-fired inland location	1400	7.3	11.4
	Small, wood-fired	1500	3.0	10.0
Geothermal	Dry steam field	1400	n.a.	3.0
	Wet steam hot water field	2800	n.a.	6.0
Nuclear	Large multiple units	1600	1.0	5.1
	Single small unit	2200	1.0	7.4
Solar photovoltaic		20 000–30 000[b]	n.a.	100–300
Wind generator		5 000–15 000[b]	n.a.	30–100

Note: n.a. – not applicable

[a] Investment cost includes costs of transmission and distribution.

[b] Both solar energy and wind power are intermittent energy sources which require storage to make energy available on demand at all times.
Investment costs given above are system costs with storage included.

Source: World Bank staff estimates.

viewpoint of accounting, depreciation is defined as the annual charge against revenues that is used to repay the original amount of capital borrowed from investors. As such, depreciation does not account for the replacement value of an asset which, due to real escalation and inflation may increase substantially over time with respect to its original purchase price. While depreciation accounting is important for financial analyses, it is of interest in expansion planning primarily from the standpoint of calculating a salvage value for units that have expected lifetimes that extend beyond the end of the study period.

There are a variety of depreciation methods available for cost accounting. Some methods are designed to increase cash flow in the early years of an investment, while a number of others are designed for tax purposes. Regardless of the methods used, however, the sum of all annual depreciation charges over the life of the alternative must equal the initial investment (I) in the alternative less the salvage value (V) which is defined as the net sum to be realized from the disposal of an asset (net of disposal costs) at the time of its replacement, resale, or at the end of the study period.

There are four commonly used depreciation methods: (1) straight line, (2) sum-of-the-years digits, (3) declining balance, and (4) sinking fund [10.10]. All four methods are based strictly on time, i.e. an asset has the same depreciation charge whether it is used continuously or only occasionally (i.e. depreciation is independent of a power plant's electrical output). Each depreciation method has unique features, and the choice of a particular method is often influenced by factors such as income tax laws and regulations. In many instances specific depreciation methods are specified by regulatory agencies within a country.

(1) Straight-line depreciation is the simplest and one of the widely used methods of depreciation. The depreciation charged each year D_i is constant, and is determined as a fraction of the investment value minus the net salvage value (i.e., a future value) at end of asset's useful life (i.e., when $i = n$). Accordingly,

$$D_i = \frac{1}{n}(I-V)$$

and the book value of the asset is

$$B_i = I - \frac{i}{n}(I-V)$$

i.e. equal to the initial investment to be recovered minus all depreciation charges accumulated to date. When $i = n$ the book value is equal to the salvage value. The annual return on investment, which is a fixed fraction of the book value, also decreases linearly with time.

(2) Sum-of-the-years depreciation provides a larger depreciation charge in the early years of plant life (called accelerated depreciation) which may correspond more closely to the way an asset (e.g. a power plant) actually depreciates. The annual depreciation charge is

$$D_i = \frac{2(n-i+1)}{n(n+1)}(I-V)$$

(3) The declining-balance method is another accelerated depreciation option for amortizing an asset at an accelerated rate early in its life, with corresponding lower annual charges near the end of service life. In this method, a fixed rate is applied to the balance of the investment after the depreciation charges of previous years have been subtracted. When tax regulations permit (e.g. in the USA) a rate equal to twice the straight-line rate is used (i.e., 2/n); this is commonly called the double-declining-balance method. The formula for calculating the depreciation charge is:

$$D_i = I\left(\frac{2}{n}\right)\left(\frac{n-2}{n}\right)^{i-1}$$

Because this method will not lead to full depreciation in any finite time, a switch to some other depreciation method must be made. Typically, a changeover to straight line depreciation is made in the year in which the straight-line depreciation on the remaining balance is just equal to the double-declining-balance depreciation.

(4) Sinking-fund depreciation is a method which sets a constant annual charge for depreciation plus return on undepreciated investment at a value such that the net plant investment will be fully depreciated at the end of plant life. This method is analogous to establishing a fund by constant end-of-year annual deposits throughout the life of an asset. These deposits are then assumed to earn interest (z) so that at the end of plant life, the total fund will equal the cost of the asset minus its salvage value. The amount charged as depreciation in any year is equal to the sinking-fund deposit plus the interest on the accumulated fund. Therefore, unlike the straight-line method, charges for depreciation are lowest at the beginning of life and increase with time. Book values with the sinking-fund method are always greater than they would be with the straight-line method.

$$D_i = \left[\frac{z(1+z)^{i-1}}{(1+z)^n-1}\right](I-V)$$

A comparison of the four depreciation methods is shown in Fig. 10.3. The sinking-fund method has the slowest rate of capital recovery, while the sum-of-the-years-digits and double-declining-balance methods recover a large share of the initial investment early in the depreciable life. Combinations of these four methods are sometimes used by utility companies, although sum-of-the-years-digits and double-declining-balance methods, both accelerated depreciation options, are typically used for tax purposes.

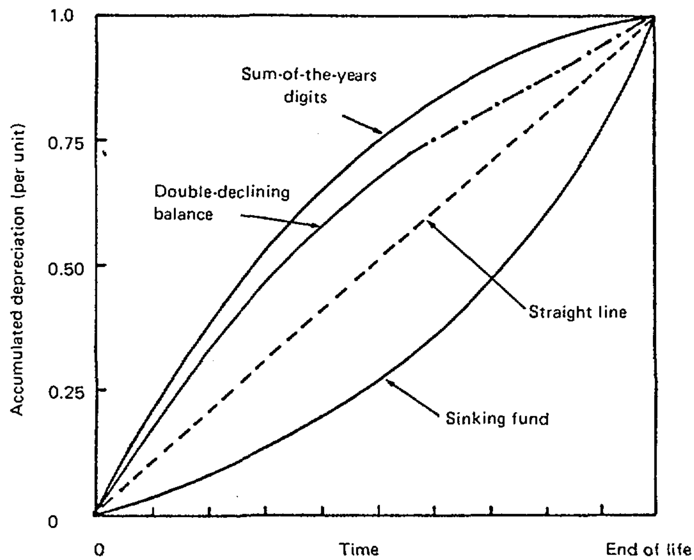


FIG.10.3. Comparison of depreciation methods.

10.1.2.3. Fuel costs

Fuel costs depend on so many conditions that it is impossible to prepare a compact coherent presentation. However, the range of variation of the comparative costs of domestically produced fuels from different sources as opposed to costs of equivalent imported fuels, displayed in Table 10.II, suggest a fair image of both, absolute values and their relative position in June 1980 [10.11].

10.1.2.4. Electricity generation costs

Because of their more complicated structure and also in view of the detailed comparison between conventional thermal and nuclear power generation in chapter 11, this subsection will deal with the general aspects of electricity generating costs as illustrative for energy production processes.

There are two distinct figures that are important when discussing or comparing the economics of electric power generation: (1) capital investment costs, for example in US dollars per kilowatt of installed capacity, which denote the capital outlay necessary to build a power plant, and (2) power generation costs, for example in US mills per kilowatt-hour, which represents the total cost of generating electricity. Power generation costs are comprised of three major categories of costs: (1) the costs associated with the initial capital investment in a power plant, which are called fixed investment charges, (2) fuel costs, and (3) operation

TABLE 10.II. COMPARATIVE COSTS OF DOMESTICALLY PRODUCED FUELS FROM DIFFERENT SOURCES[a]
(1980 US$ per barrel of crude oil equivalent)

	Range of domestic costs	Imported equivalent
Primary energy		
Crude oil	6.00 – 15.00	30.75[b]
Natural gas	2.25 – 11.00	27.00[c]
Coal	4.50 – 15.00[d]	14.00[e]
Secondary energy		
Derived from crude oil		
Gasoline – primary distillate	9.40 – 21.00	43.50
– cracking of fuel oil	11.00 – 21.00	43.50
Kerosene	11.30 – 25.40	46.00
LPG	10.00 – 25.00	42.50
Fuel oil	7.20 – 13.50	27.45
Derived from coal		
Gasoline	40.00 – 60.00	43.50[f]
Synthetic fuels		
Ethanol from molasses/sugar cane	25.00 – 45.00	43.50[f]
Shale oil	25.00 – 35.00	30.75
Renewable energy		
Firewood	8.00 – 20.00	46.00[g]
Charcoal	30.00 – 80.00	46.00[g]

[a] Based on delivered cost to major consumers.
[b] Based on posted price for Saudi-Arabian Light Crude, 1 June 1980.
[c] Based on imports of liquefied natural gas or fuel oil.
[d] Includes cost of infrastructure.
[e] Cost of imported steam coal delivered to a coastal location.
[f] Cost of imported gasoline.
[g] Cost of imported kerosene.

Source: World Bank staff estimates.

and maintenance (O&M) costs. For the purposes of discussion, these three categories of costs can be divided into two groups: fixed costs and variable costs. As Fig. 10.4 illustrates, fuel and O&M costs have both fixed- and variable-cost components [10.10].

Fixed costs are related to the expenditures for items that are used over an extended period of time, such as a boiler or reactor, and are independent of the

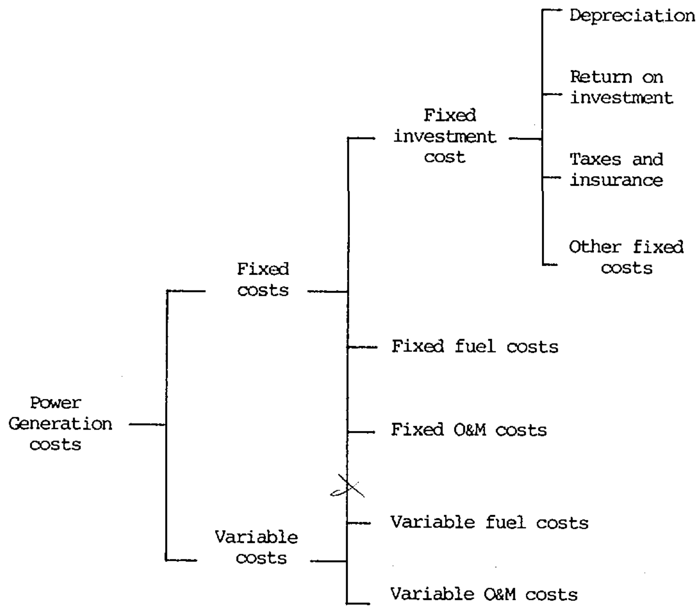


FIG.10.4. Principal categories of power generation costs.

amount of electricity generated, transmitted, or used. Classified as fixed costs are investment charges which include depreciation, return on investment (e.g. for private utilities, this includes interest paid to bondholders' debt and return to stockholders' equity), and (where applicable) taxes and insurance, interim replacement, and funds for decommissioning, all of which may be treated as proportional to the initial capital investment in plant and facilities. The annual fixed investment charges for a plant can be calculated as the product of the fixed charge rate and the plant capital investment costs. In the absence of tax and insurance complications (which are very important considerations in some countries), the annual fixed charge rate is essentially equal to the sum of the depreciation charges and the charges for the annual return on investment. Typical fixed O&M costs include wages and salaries, while fixed fuel costs could include, for example, the costs associated with stockpiling fuel, such as coal.

In contrast, variable costs, which are often called expenses, represent expenditures for goods and services that are consumed within a relatively short period of time (usually one year or less). Variable costs generally depend directly on the amount of electricity generated (i.e., they are expressed in terms of a monetary amount per kilowatt-hour production). Variable fuel costs and variable O&M costs are the two primary categories of variable costs.

From a broader perspective, the money received by a utility from its customers, called revenue, must in the long-run be sufficient to cover all costs of providing

TABLE 10.III. TYPICAL COSTS OF COAL-FIRED AND ALTERNATIVE POWER PLANTS (1982 US$)

Large systems, 300 MW units	Coal		Steam plants lignite	Fuel oil		Low speed diesel
Expected life, years	25		25	25		–
Capital costs, $/kW	1100		1200	900		–
Annual fixed costs, i=10%, $/kW	121		132	99		–
Annual O, M & R, $/kW	22		24	18		–
Annual costs, $/kW	143		156	117		–
Annual costs, 65% load factor ¢/kW·h	2.5		2.7	2.1		–
Overall efficiency, %	36		36	36		–
Fuel costs[a], ¢/kW·h	0.7	(2.9)[a]	0.8	4.7	(5.7)[a]	
Total costs, 65% load factor ¢/kW·h	3.2	(5.4)[a]	3.5	6.8	(7.8)[a]	

[a] maximum figure.

TABLE 10.III. (cont.)

Small systems, 30 MW units	Coal		Steam plants lignite	Fuel oil		Low speed diesel	
Expected life, years	20		20	20		20	
Capital costs, \$/kW	2200		2300	1800		1200	
Annual fixed costs, i=10%, \$/kW	258		270	211		141	
Annual O, M&R, \$/kW	44		46	36		36	
Annual costs, \$/kW	302		316	247		177	
Annual costs, 65% load factor, ¢/kW·h	5.3		5.5	4.3		3.1	
Overall efficiency, %	32		32	32		40	
Fuel costs[a], ¢/kW·h	0.8	(3.3)	0.9	5.3	(6.4)	4.3	(5.1)
Total costs, 65% load factor, ¢/kW·h	6.1	(8.6)	6.4	9.6	(10.7)	7.4	(8.2)

[a] Assumes that all delivered fuel costs (i.e., coal, lignite, fuel oil) will be equal to those used for large plants.

service. However, this may not be the case in countries where electricity production is subsidized.

Normally, the annual revenue requirement is simply defined as the sum of the annual fixed and variable costs associated with all plants in the utility system. Variable costs are usually paid directly from revenue while fixed costs must ordinarily be recovered over an extended period of time because revenues would normally be insufficient to cover large capital expenditures. In addition, fixed costs represent money spent for items whose usefulness continues for an extended period of time (e.g. a power plant), thereby producing benefits for both present and future customers.

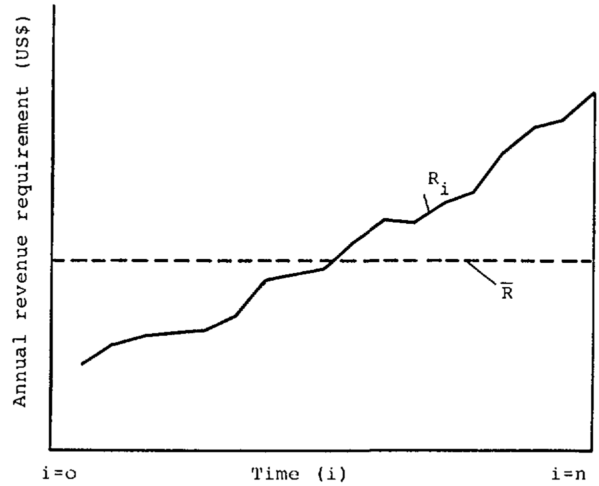
The combined effect of fixed and variable costs on the total and specific costs of an intermediate energy carrier, i.e. electricity, is presented in Table 10.I for a large range of primary energy resources and partly for large and small generating plants. Table 10.III displays a more detailed comparative calculation of the kW·h generating cost in large electric systems with 300 MW units, burning coal, lignite or fuel oil. Alternatively, conditions in small systems – 30 MW units – are examined for the same fuels and compared also with low-speed diesel plants [10.12]. A deeper analysis of this table permits comparison of the relative weight of the fixed and variable costs in the cost of the final product and also observation of the effect of economy of scale in the larger units.

10.1.2.5. Lifetime 'levelized' cost of electricity generation

The electricity generation costs as described in the previous subsection are valid for a given year and given conditions, possibly a typical year. However, these costs vary from year to year; variable costs, such as variable fuel costs, may change over time due to price escalation, while fixed costs, such as those related to capital investment costs, may also vary due to decisions about tax and depreciation schedules. Depending on prevailing economic conditions and the specific characteristics of the operating utility, these yearly changes in fixed and variable costs may occur uniformly or in a highly irregular fashion.

In addition to changing costs, the amount of electricity generated by a power plant or utility system varies from year to year due to factors such as scheduled and unscheduled maintenance and changes in unit operating performance. Varying load patterns caused by variable customer demands can also significantly affect power plant operation.

These year-to-year variations in costs and electric generation cause the unit cost of electricity for a plant or system to vary from year to year, making cost comparisons with other generation alternatives extremely difficult. It is therefore convenient to use present value analysis (further described in subsection 10.3) to calculate a fictitious unit cost (in mills/kW·h) that is representative of the generating characteristics of the plant or system under consideration and the time varying costs actually incurred. If kept constant over the life of the alternative, this



R_i = Revenue required in the i^{th} year to defray all costs of generating electricity in that year (US$).

$\bar{R}$ = Levelized annual revenue requirement, constant over the life of the alternative (US$)

FIG.10.5. Comparison of annual revenue requirements and levelized revenue requirement.

fictitious cost, called a 'levelized' cost, would have exactly the same effect on a utility's finances as would the actual, time-varying costs.

The concept of cost levelization is illustrated in Fig. 10.5. Shown as a function of time for a power-generating alternative are the varying annual revenue requirement R_i, and an equivalent levelized revenue requirement $\bar{R}$. Instead of collecting revenue R_i in year i to pay for all fixed and variable costs incurred in that year, the operating utility could defray these costs by receiving revenue of $R_i/(1+a)^i$ at time i = 0 and investing it to obtain a return at the ratio a per year for i years. The revenue $R_i/(1+a)^i$ is simply the present worth value of the revenue requirement in the year i, where a is the discount rate (see subsection 10.3.2).

More generally, all costs occurring over the lifetime (n years) of an alternative could be defrayed by receiving revenues in the amount of

$$\sum_{i=1}^{n} \frac{R_i}{(1+a)^i}$$

at time zero. This sum is the present worth of all yearly costs incurred during the life of the alternative.

If a constant revenue requirement, $\bar{R}$, were received each year during the entire life of the alternative (i.e. for n years), then the present worth of its revenues, namely,

$$\sum_{i=1}^{n} \frac{\bar{R}}{(1+a)^i}$$

would have to equal the sum of the present worths of the actual annual revenue requirements. The levelized revenue requirement can therefore be determined as

$$\bar{R} = \frac{\sum_{i=1}^{n} \frac{R_i}{(1+a)^i}}{\sum_{i=1}^{n} \frac{1}{(1+a)^i}}$$

On the same basis a levelized annual bus-bar cost in mills/kW·h can be calculated, which accounts for both the year-to-year variations in costs and electric generation. If a generation alternative produces E_i kW·h of electricity in year i, then the unit cost of electricity b_i (mills/kW·h) in that year can be determined as $b_i = (1000 \times R_i)/E_i$ where R_i (monetary amount) is the revenue requirement in year i. As noted previously, b_i varies from year to year because both R_i and E_i change over time. If a uniform (i.e. constant) price for electricity, $\bar{b}$, in mills/kW·h, is charged each year over the life of the alternative, then the present worth of its revenues (monetary amount) would be:

$$\sum_{i=1}^{n} \frac{\bar{b} \times E_i}{1000(1+a)^i}$$

This permits determination of the levelized bus-bar cost of the kW·h during the life of alternative. By similar procedures, an annual levelized electric generation, levelized annual fixed cost and levelized annual variable cost (fuel and O&M) could also be calculated – see Ref. [10.10], Chapter 5.

10.1.2.6. Energy prices

Although the price formation for energy obeys the same basic market law of supply and demand, it is not possible to generalize its action upon the different energy carriers. The production of each of them responds to a different logic: the costs structure, the financing conditions, the competitive situation and the specific production conditions act and interact differently on the price mechanism. The energy market as a whole is characterized by its huge volume, its sensitive stability including political risks and influences, and by the dominant role of petroleum.

As far as the relationship between production costs and selling prices is concerned, for certain energy carriers it has lost any reasonable meaning. Such is the case with petroleum; in some of the great basins of the Middle East, it costs 30 to 40 cents to produce a barrel of crude, which sold at 30 to 35 dollars per barrel, after having reached even US \$40 and more on spot markets a few years ago. But this discrepancy is not general. As Fig. 10.2 shows, in other regions of the world or under other conditions the production cost of an oil barrel could be much higher, even prohibitive currently, when relating to unconventional petroleum resources.

Historically the selling price of petroleum increased from \$2.40 a barrel at the end of 1972 to over \$32 a barrel in 1980 – see Fig. 11.4. However, in constant 1972 prices, the increase corresponds to only \$10 (1972) a barrel. In the meantime, for the reasons which will be further commented upon, the price has stabilized around \$29 per barrel.

It followed further downstream, the prices of petroleum derivatives are substantially increased by transport, refining, distribution, the profit of the distributor and heavily affected by taxes. Figure 10.6 displays, for example, the price evolution of petroleum derivatives compared to the crude oil price between 1962 and 1979; in 1979, at a fob price of \$15 to \$16 a barrel, almost the same amount was added in taxes in the consuming countries. Of course, in the meantime, the crude oil price level increased again and so did the other components, especially taxes. Figure 11.4 also shows the evolution of natural uranium prices since 1973 compared to the price of petroleum, in current and constant dollars [10.13].

10.1.3. Average, marginal and social costs

Average costs are mathematically deduced costs for a product or a service which produced in different quantities and at different points of time has different costs for each of these conditions. The best example is the kW·h in an electrical system, where its average cost is simply determined by dividing the total system costs by the number of kW·h produced – or consumed –, i.e. $C_{av} = C/E$ where C_{av} = average cost of a kW·h, E = electricity produced – or consumed – in a given period of time, and C = total costs in the given period.

Marginal costs are the costs of an additional produced unit, i.e. $C_m = \Delta C/\Delta E$ or at limit $C_m = dC/dE$.

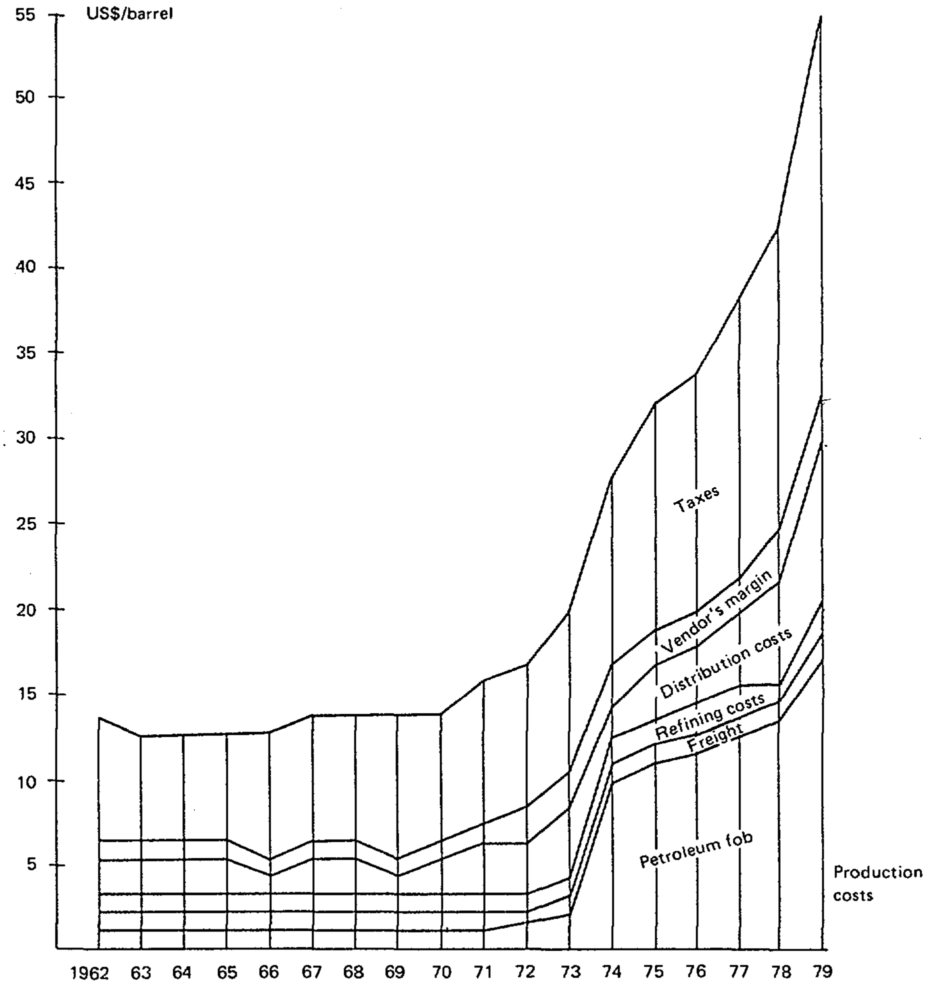


FIG.10.6. Structure of final price of a barrel of petroleum products in western Europe.

The basic question is how the costs C vary dependent on the production E, and what are the subsequent variations of the average and marginal costs. As a main element in energy costing the above kW·h example is further commented upon in subsection 10.2, Fig. 10.7, with additional considerations as to marginal cost, price and tariffs.

Social costs are costs engendered at the level of the economy as a whole by any action generating physical or economic impacts outside its own sphere. An example from the energy sector would be harmful environmental effects of even desulphurized flue gases from a thermal coal-fired power station. Another example would be foreign exchange expenditure at a time when the economy of a country is severely constrained by a balance of payments deficit.

10.1.4. Current, constant, subsidized and shadow prices

Whereas the term 'current prices' is self-explanatory, constant prices are adjusted current prices, in the sense that independently of the date of their validity, they are all referred to a common time base of reference and are, therefore, directly comparable.

The adjustment tries to take into consideration progressing monetary erosion, which mades a certain given amount of money lose a part of its buying power from one year to the next. Although this evolution is a fact, it is difficult to evaluate it quantitatively because the progression varies not only from country to country: even within the same country the annual rate of increase depends on very many factors.

The rate of monetary erosion (inflation) is in general determined from the average value of wholesale and retail prices or from the price index of the gross national product. Although not entirely correct, since the above indices also include variations of productivity components, this method is, however, unanimously accepted.

To convert, for example, current dollars into constant dollars referred to in a certain year of reference, for each year of the time period a reduction with the ratio $1/1{+}e$ is applied, where e represents the rate of monetary erosion (inflation).

Consequently, an amount S_i in current dollars in the year i becomes in constant dollars in the reference date year: $S_c = (S_i/(i{+}e))i$.

Subsidized prices intervene when, for whatever economic or political reasons, the prices to be paid by local consumers, or a special singled-out category of consumers, are fixed lower than the normal economic domestic, import or international prices. Almost classical examples in this respect are gasoline and kerosene prices in a series of developing countries. Further examples are provided by Mexico, with the following domestic prices as a percentage of the 1980 export price: natural gas 9.8%, heavy fuel 13.3%, or as a percentage of prices in the USA: diesel fuel 18.7%, regular gasoline 38.8%, premium gasoline 50.3%, LPG 20.0% [10.14].

Shadow prices are a useful analytical concept to be used in such situations when the market prices do not properly reflect the social costs (or benefits). The shadow price is the price – a management or planning price – which reflects at the margin the social value of goods or services; as such it may substantially differ from the actual prices paid on the market.

10.1.5. Economic incentives

Energy development is promoted both by official and private initiative and financing. Depending on the economic system and the level of the national economy, the proportion varies from country to country.

While the investments for public projects are in any case optimized from the point of view of the national economy, i.e., including social costs and benefits, private projects in the energy sphere are governed by the rate of return on private investment.

Such projects might practically intervene at all stages of the energy system, i.e. primary energy production, conversion, transport and particularly in the final consumption stage. Given the integrated structure of the overall energy system, any private energy project interferes – positively or negatively – with the economy of the energy system and subsequently with the whole national economy.

The most obvious examples can be encountered in the field of energy conservation, where an enormous number of private consumers might take private action. As already commented on in chapter 2, an industrial or domestic consumer might be prepared to invest in an energy-saving measure given a rewarding rate of return or an advantageous pay-back period. However, he would hesitate to push his investment higher although additional energy savings might be secured. While unattractive for the private consumer, such potential marginal savings could be highly interesting for the country's economy when less expensive than petroleum imports.

Therefore, in the energy conservation potential of a country, a zone exists in which conservation measures are no longer privately attractive but socially still advantageous. However, since scattered over so many consumption areas, they are not physically accessible for public action. They could, instead, prove of value if the private consumer would extend his own action and the marginal costs for the community would certainly be favourable. The necessary funds would then be provided as an incentive for such action.

The above circumstances ideally apply to the energy-conscious consumer, who would take action in any case on his own behalf. However, the great majority of consumers, from habit and inertia, would not normally move in this direction. Attractive incentives might then be necessary.

The most interesting field for public incentives is doubtless the one bridging the gap existing between private and social beneficial rate of return. Its exploitation in the national interest involves serious study and managerial expertise.

A practical, real example might better illustrate the area of action of an incentive in the public interest:

Consider a city landlocked at high altitude in an equatorial developing country, supplied with hydroelectricity from outside but generating in addition a significant amount of electricity from its own diesel plants. There is no need for space heating. The consumers using electricity for water heating are not interested, at the prevailing tariffs, in replacing electricity by solar energy for this purpose. No solar equipment is locally available and high investment costs prevail. However, if such substitution were to take place once solar equipment was installed, the consumer would then enjoy an equivalent service with zero fuel costs, and the national economy would benefit by a substantial fuel saving. The economics of such a substitution could be evaluated by comparing the investment costs of the solar device with those saved by the liberated equivalent electric capacity plus the extraction and refining capacity needed to supply it with fuel. Such a substitution would probably prove economic, but would raise the question of how to implement it.

In such cases, various financing solutions could be considered, ranging from simple incentives for the consumer in the form of soft loans and/or outright subsidies, up to the most complicated financial schemes with support from the community or state, or even from the interested electricity utility.

One may even think a step further and expect that when energy conservation projects need partly financing in hard currency, international support may be made readily available since the goal of meeting energy demand partly by saving or substituting scarce energy is equivalent to an extension of the primary energy resource base, and for such proposals major international loans are available.

10.2. Electricity tariffs

The selling prices of energy depend basically on its quality, the quantities acquired and the place of delivery. For storable primary and intermediate energy forms, the trade conditions are not very different from other wholesale operations.

However, for non-storable energy forms, such as natural gas – only limited storage, heat – hardly storable in larger quantities, and electricity, – with the exception of relatively limited storage batteries, absolutely not storable, to the above selling conditions, it is essential to add a further condition: the time of consumption.

When time intervenes in the selling process, the conditions become more complicated and in the interest of both suppliers and consumers, a systematic, transparent and fair-price base with clear descriptions of the conditions of supply must be offered. This is the costing-pricing system, the tariff of rates.

Since the tariffs and conditions of supply for electricity are both the most elaborated and the most exposed to public criticism, these have been selected as the main subject of this subsection.

10.2.1. Electricity costing

The problems of electricity costing are very complex and call for the close collaboration of the accountant/economist and the engineer, each of whom should acquire some measure of the other's outlook on the subject.

The main difficulty consists in the fact that an electricity utility supplies each of its consumers with two services: the actual electrical energy he consumes (kW·h) and the readiness to supply the energy he wants whenever he wants it [10.13].

Thus it comes about that the gross costs incurred by an enterprise in supplying its consumers with electricity fall into two main components, the variable and fixed. The variable component represents the cost of the actual energy supplied,

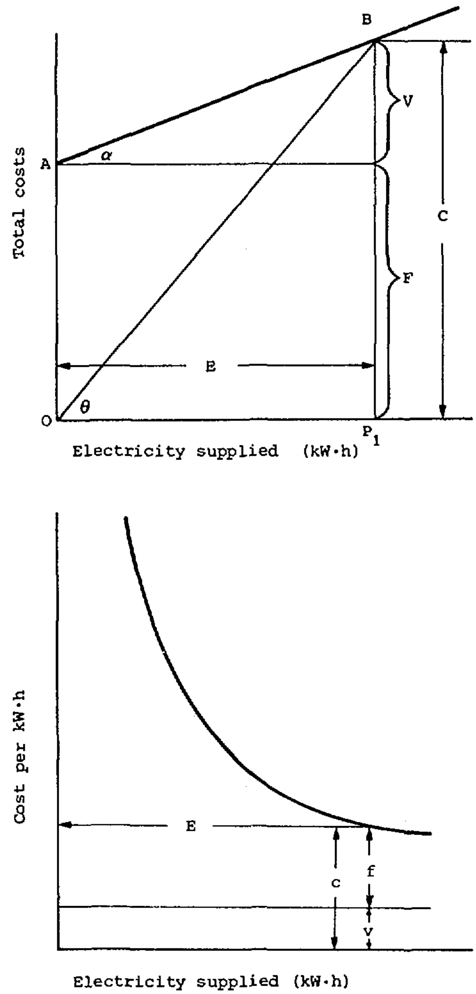


FIG.10.7. Structure of total electricity supply and kW·h costs.

while the fixed component represents the cost of always being ready to supply energy whenever it is wanted. For some consumers, readiness of supply may cost more than the actual energy supplied.

In subsections 10.1.2.1 and 10.1.2.4 the structure of the electricity supply costs, consisting of two main components, the fixed and the variable costs, was explained. This is simply illustrated by Fig. 10.7, which could equally apply to a single consumer, a group of consumers or to a whole enterprise. The total costs of supply are represented by the line AB which does not pass through the origin;

that is to say, the total costs are by no means directly proportional to the amount of energy supplied. For even if no energy whatsoever were supplied, the costs would not fall below a certain irreducible minimum, F, which represents the fixed component of costs. The total costs, C, will depend upon the amount of energy supplied, E, and will exceed F by the variable component of costs, V, which is directly proportional to E.

The total cost of supply (C) is the sum of the cost of readiness to supply (F) and the cost of electrical

$$C = F + V = F + vE$$

energy actually supplied (V).

The terms C, F, V and E may refer to an annual, quarterly or monthly basis according to convenience, however, they must all of course be computed on the same basis. The term v, however, will generally be independent of any time element (though not always independent, as when E is supplied at different times by different plants).

The diagrams in Fig. 10.7 should not be taken too literally or as mathematically precise. They are ideal diagrams in that they illustrate in simple mathematical form a logical way of expressing electricity costs. The direct proportionality between the variable costs and the energy supplied, and the maximum kilowatt demand, is more of a convenient hypothesis than a statement of absolute fact.

10.2.2. Marginal costs of electricity supply

Depending on the conditions for an additional supply of electricity, there are two different concepts of marginal costs to refer to [10.15]:

(a) The short-run marginal cost of supply is the additional generation, transmission and distribution costs which arise from an additional supply of electricity in a given year, for unchanged generation, transmission and distribution capacity.
(b) The long-run marginal cost of supply is the additional cost engendered by an additional supply of electricity in a given year where the electrical utility can allow for the corresponding investment in the appropriate generation, transmission and distribution capacity.

As far as the short-run marginal cost is concerned, in case (a), i.e. when an electricity supplier cannot extend his supply capacity, two situations might occur:

(a1) The additional electricity demand can be completely met without any negative repercussions on the existing consumers. In this case the marginal cost consists of the costs of the additional electrical energy supplied, which in the case of Fig. 10.7 is supposed to be supplied from an already operating unit. Within the limits of the generating capacity – for example P_1 – the marginal cost is the incremental cost $v\Delta E$. More generally, for example when non-operating units have to be started up, the marginal cost corresponds to the additional costs incurred in supplying a consumer (or group), by comparison with what the costs would have been if the consumer (or group) were not supplied at all.

(a2) If the additional electricity demand cannot be met in full, the supplier is either compelled to resort to exceptional methods (voltage reduction, imports, etc.) or to temporarily cut off other consumers. Accordingly, the calculation of the short-run marginal cost requires the use of a concept of the cost of curtailment to reflect the social costs stemming from the inability of the supplier to meet the total electricity demand from his own facilities.

The long-run marginal cost usually arises from an anticipation of an investment which normally would have been due later.

Practically, the calculation of the marginal cost of supply is based on the following essential property, which is characteristic of large electrical production, transmission and distribution systems in which indivisibilities can be neglected: in an optimized system, the short- and long-run marginal costs of supply are equal.

This property can be explained as follows:

- If the short-run marginal cost is higher than the long-run marginal cost, the electricity supplier is interested to extend his facilities and would herewith meet the demand, reducing the total costs.
- If, on the other hand, the short-run marginal cost is lower than the long-run marginal cost, that means the supplier would have had the chance to avoid certain investments and meet the electricity demand with lower costs.
- If, finally, the marginal costs are equal, the supplier cannot reduce his costs by changing his facilities, i.e. the latter are able to meet the demand at the lowest level, and the system is, therefore, optimal.

Expressed in a mathematical form, demand for and availability of the various equipment units bearing random variables, the efforts of the supplier to minimize the expectation of the supply costs, results in mathematical expectations for equal short- and long-run marginal costs [10.15].

The above situation allows us to calculate the long-run marginal costs of equipment using the short-run marginal costs and, therefore, enables us to allocate the various capacities to different hourly and seasonal periods, which is of great assistance in price (tariff) setting.

However, while in practice the marginal costs calculation for generation and interconnection is based on short-run marginal costs, transmission and distribution marginal costs are determined as long-run marginal costs using a statistical approach [10.15].

10.2.3. Electricity tariff design

The basic problem of tariff setting consists in apportioning the total costs plus benefit of electrical utilities to their individual clients according to their participation in the cost-generating electricity supply process, from generation to transmission and distribution up to final consumption. However, since it is in a monopoly situation, a public electricity utility has to ensure optimal operation of the electrical sector.

The theory of optimal production states that if all other prices in the production sector correspond to an optimal production, an enterprise can achieve optimal production respecting the following three basic requirements: meeting demand, minimizing production costs and selling at marginal cost.

Marginal cost pricing has a simple intuitive justification: by setting a price signal reflecting the cost to the community of a marginal increase in demand, an enterprise leads it customers to set their demand at a level which corresponds to the collective advantage, although they are taking their decisions solely on the basis of their own interest [10.15].

In practice, the quest for optimal covering of the whole production sector is purposeless, since the prices reached on various markets do not necessarily correspond to an optimum, for many and different reasons. Nonetheless, the endeavour to reach an optimum, at least in part of the production sector, remains meaningful. In this direction the marginal cost pricing implemented in France by EDF (Electricité de France) and aimed to obtain optimum output in the electrical sector alone, deserves special mention [10.15]. It successfully uses prices as signals giving incentives to consumers conducive to usage of their electrical appliances which is in their own and in the public interest.

Consistency between load forecasts, investment decisions and pricing policy is a prerequisite for marginal tariff studies. The same system of prices used for investment and operation purposes should be used for tariff design. In particular, the investment costs entering into the calculation of tariffs must be expressed in present values, using the same discount rate as in investment planning. In addition, a marginal cost tariff can only be effective if calculated in respect to an optimal generation mix. Finally, the tariff signal should secure consistency between the expectations of the electricity supplier and his customers in regard to changes in the level of structure of electricity tariffs. Bringing forward into the tariff the structure of costs anticipated some years in the future by the electricity supplier could be an incentive for customers to take rational long-term decisions.

Once the annual marginal costs of electricity supply, i.e. generation, transmission and distribution are determined, the next step is their allocation to the great and varied mass of consumers.

This problem would be insurmountable if the consumers were not classified into groups or classes, so that the total costs may in the first place be allocated to the various classes according to some reasonable process, and the costs so charged to each class and then suballocated to the various individual consumers within that class.

The system of classification must be such that all consumers within any one class have common characteristic tendencies, apart from mere size, insofar as they affect costs. It must be recognized that there will in fact be wide individual differences between consumers within any one class. All that can be expected is to ensure that all consumers of a class are likely to show similar inherent trends.

There is a principle almost universally adopted by electricitiy supply enterprises, and one that is often enforced by legislation. This is that once consumers have been classified into various categories, every individual consumer within the same category must be offered the same rates. Apart from ethical considerations it would clearly be impolitic for an enterprise to do otherwise. If there are good grounds for believing that certain consumers within an existing category possess inherent characteristics to which sound reasons can logically be attributed for allocating a lower share of costs than to others within the same category, then there could be justification in subdividing the category into two groups, newly defined, and charging each at different rates.

Thus, there is really no practicable alternative to classifying consumers according to the rate structure and to allocating costs to each class in accordance with its inherent characteristic trends.

The costs – which will determine the rates – allocable to each class of consumer and to each individual consumer within any class will depend upon the quantity of energy supplied and upon the maximum power demand. It is because of this that scientific costing must be applied on a two part (or three part) basis. However, it should not be inferred that these two factors – energy and maximum demand – are the only two that influence the allocation of costs. There are in fact a series of other important factors which determine the sharing of costs between the various classes of consumer and between the individual consumers of each class. Some of them will affect the fixed component of costs, some the variable component, and some both components. These additional important factors are: load and plant factor, diversity factor, location, time of load incidence, seasonal variations of load, power factor, interruptibility.

There may also be secondary factors, such as whether the utility or the consumer pays for service connections or whether the consumer takes supply at high or at low voltage. Such points as these really amount to variants of the location factor.

Mention should also be made of scale factor, but this may logically be considered under the first two of the factors listed above.

The problem of distributing the total annual costs among the consumers is even more difficult than the correct identification of every consumer's contribution to the engendered costs. While for the costs a metering base could be referred to, the tariff's structure and rates design involve a high level of expertise, since in addition to the dual structure of costs to be accommodated and reflected

TABLE 10.IV. ELECTRICITY SUPPLY COSTS OF ELECTRICITE DE FRANCE (EDF) IN 1978
(in cents of January 1980 FF, inflation corrected)

Generation		Produced TW·h	c/kW·h
Hydro		62.6	13.2
Thermal		90.0	13.0
Nuclear		25.7	10.8
Purchased		24.9	12
	Total	203.2	12.7
At delivery voltage		**TW·h**	**c/kW·h**
225 kV		19.8	12.6
60 to 150 kV		34.8	14.7
under 60 kV		62.2	20.8
low voltage		70.4	37.4

in the rates, the determination of the latter may sometimes call for imaginative deviations from only substantive arguments; thus in favour of commercial considerations of what certain categories of consumers can bear rather than what they should bear and, not seldom, to bow somewhat to public opinion and political pressures. Therefore, as management in general, tariff setting may turn sometimes from an objective science to partly an imaginative art.

10.2.4. Examples of electricity cost structure and tariffs

As a consolidated example of kW·h costs at generation level and at different delivery voltage levels, the following figures (cents of 1980 FFr) are presented in Table 10.IV from the yearly results of Electricité de France (Edf) in 1978 [10.16].

In addition to the average kW·h generation costs, the first part of the table gives valuable information on the average generating costs of the different power plant categories and their production in 1978. In the second part, the structure of delivery at the different voltage levels is shown and for each level the average kW·h cost, which evidently increases with growing 'electrical distance' to the consumer.

It is not possible to enter into more detail on the structure of tariffs. However, an illustration is given using the example of PLN – the National Public Electricity Corporation of Indonesia – with the basic tariff, valid in February 1983, reproduced in Table 10.V.

TABLE 10.V. PLN (NATIONAL PUBLIC ELECTRICITY CORPORATION OF INDONESIA) TARIFF SCHEDULE 1983
US$1 = Rp 970.00

No.	Code of tariff	Contracted power	Demand charge Rp/kVA	Energy charge Rp/kW·h	Projected average revenue Rp/kW·h
1	S_1	to 200 VA	[a]		
2	S_2	200 – 250 VA 250 VA to 200 kVA	1600	35	48.22
3	R_1	250 VA to 500 VA	1600	56	68.21
4	R_2	501 VA to 2200 VA	1600	67	79.12
5	R_3	2201 VA to 6600 VA	2800	97	121.78
6	R_4	>6600 VA	2800	117.50	137.50
7	U_1	250 VA to 2200 VA	2800	99.50	121.04
8	U_2	2200 VA to 200 kVA	2800	108.50	137.37
9	U_3/MV	>200 kVA	1750	P = 111 OP = 70	89.28
10	U_4	–	–	221	221.00
11	I_1	3.8 kVA to 99 kVA	1750	P = 81.50 OP = 51	76.65
12	I_2	100 kVA to 200 kVA		P = 77 OP = 48	67.15
13	I_3/MV	>200 kVA	1600	P = 68.50 OP = 43	56.40
14	I_4/HV	>5000 kVA	1500	P = 58 OP = 37	44.12
15	G_1	250 VA to 200 kVA	2800	71	89.06
16.	G_2/MV	>200 kVA	1500	P = 72 OP = 47	64.02
17	J	–	–	56.50	56.50
		Average			74.72

[a] Tariff S_1 100 VA = Rp 2010/month
150 VA = Rp 3015/month
200 VA = Rp 4020/month

Note: P = Peak hours (18:00 – 22:00)
OP = Off-peak hours (22:00 – 18:00)

The tariff has the following categories according to the type of consumers:

S_1 – small consumers (low voltage)
S_2 – social consumers: schools, mosques, churches, hospitals, etc. (low voltage)
R_1–R_4 – households of different sizes (low voltage)
U_1–U_2 – small and medium commercial consumers (low voltage)
U_3/MV – large commercial consumers connected to medium-voltage system
U_4 – temporary service (low voltage)
I_1–I_2 – industrial and hotels (low voltage)
I_1–I_2 – small and medium industries
I_3/MV – hotels and large industries connected to medium voltage
I_4 – industry connected to high voltage
G_1 – office (government, public enterprises, foreign missions, etc.)
G_2/MV – offices connected to medium voltage
J – street lighting

All categories pay a demand charge and an energy charge or a surcharge, the latter depending on the fuel costs; in addition certain types of consumers pay a different energy charge depending on the consumption during peak hours (6 p.m. to 10 p.m. local time) or off-peak hours. The same rates apply for all PLN regions throughout Indonesia [10.17].

10.3. Evaluation of alternative energy projects

10.3.1. The cost/benefit analysis

Energy is not the only scarce resource to be taken into account when projecting long-term socio-economic development. Land, capital, other materials and skilled manpower are not abundant either. Therefore, not one of these resources, and energy is certainly included, should be developed to an extent which would either waste the others or create undue demand for them. Instead, an optimal balance of the whole economy should be aimed at, with optimal shares apportioned to every one of these production factors [10.18].

It is of course not possible that in searching to optimize energy development in a developing country, all the above factors can be duly considered. However, no effort should be spared to try and include in the optimization process as many reciprocal influences and effects as possible.

The tool to be used for this purpose is cost/benefit analysis. Its basic concept assumes that every project, if implemented, exercises a series of effects which must be thoroughly anticipated as regards form and intensity and as point of time of action, and which can be measured and expressed by a cash flow. Beneficial events are represented as revenues, costs are expressed as payments from the standpoint of a central cashier, who impersonally represents the effects of the project. In any case, only the cash flows through the central cashier are of interest, i.e. only events directly connected with the project and contributing to it are retained. That means a totally selfish position is taken, but of no harm so far as it remains within the legal regulations. Under these conditions the effects on outside factors, including environmental ones, must be introduced as cash flows, when not directly determinable, rather than as social costs calculated with shadow prices, for example.

The cost/benefit analysis method also adopts a certain perspective for the project, i.e. a planning horizon and confines its analysis from the beginning – the year zero – to this horizon. The cashier operates only during this time period. No past operations, nor any beyond the planning horizon are accepted.

The cash flow – every effect – has to be registered both in terms of money and at a point of time, and possibly represented in a cash flow diagram.

Since any alternative solution of energy supply – production of primary energy, conversion to intermediate energy, including electricity and distribution – has to satisfy completely the given requirements, i.e. deliver the same final output, the selection decision will be based on the economic comparison of the cost inputs.

However, there could appear for example solutions with higher initial cost inputs – higher investment costs – and lower later annual operation costs – and vice versa, solutions with lower investment and higher operation costs. Also, the construction time needed might be different. An arbitration between present and future therefore appears necessary.

The need for arbitration originates from the permanent competition between satisfaction of immediate consumption needs and satisfaction of more important consumption in the future. It reflects the basic concept of an investor: to invest means to engage an amount of resources today in order to obtain in coming years a flow of goods and services with a higher value – for the community in macro-economic terms, for the enterprise in micro-economic terms – than the amount of resources engaged [10.19]. This means that one dollar now does not have the same value that one dollar in n years has, even if no monetary erosion exists or if such is not considered.

Accordingly, one present dollar appears equivalent to $(1 + a)$ dollars in one year's time whilst one dollar in one year appears equivalent to $1/(1+a)$ dollars now. If the coefficient a is constant over the years, then more generally one dollar in n years is equivalent to $1/(1+a)^n$ now.

To be compared, the cash flows of the different alternative solutions have, therefore, to be referred to a common point in time; this is done by a mathematical process by which different monetary amounts can be moved, either forward or backward, from one or more points in time, taking account of the 'time value of money' during interim periods as explained below.

10.3.2. Present value analysis

Present value is a simple and effective economic concept, permitting the direct comparison of alternative solutions each able to perform the same output but each having a different cost input. To this purpose the current values are reported – discounted – to a given common date, in general to the present and their so-determined present values homogeneously compared [10.20].

The general expression for the present value or present worth B_{oi} of the balance of a project in the year i becomes:

$$B_{oi} = \sum_{i=1}^{i=n} \frac{R_i - C_i}{(1+a)^i}$$

where:
R_i = revenues in the year i, C_i = costs in the year i, a = discount rate, i = year variable, n = duration of the installation.

The above relation assumes that there is no money erosion (inflation) during the life of the project. Should, as is now common, inflation progress, the calculations have to be made in constant dollars, i.e., the current values first deflated and then discounted with the discount rate a, which is the discount rate for constant money.

In general the project with the highest B_o is the most economic of the group compared – see Fig. 10.8. If all alternative solutions have the same final revenue, for example electricity supply, only the cost cash flow can be compared and selected as the best solution with the lowest discounted cost.

10.3.3. The discount rate

The selection or acceptance of a specific discount rate is one of the most complex issues of the cost/benefit analysis approach. For public investment projects it should reflect the community's view of the value of extra consumption (in the sense of an increasing general living standard) in the future as compared with the present. For private investment projects it is the view of the investor which is decisive. Accordingly, there are two rates of time preference present, the social and the private discounting rate. The first will be chosen by administrative or political decision – as a common figure for the whole economy or possibly with higher rates for branches involving faster changes. The private investor will decide depending on his assessment of the money market situation, i.e. the rate at which he can borrow to invest or, with his own financing, the rate he would receive for the money he could use otherwise.

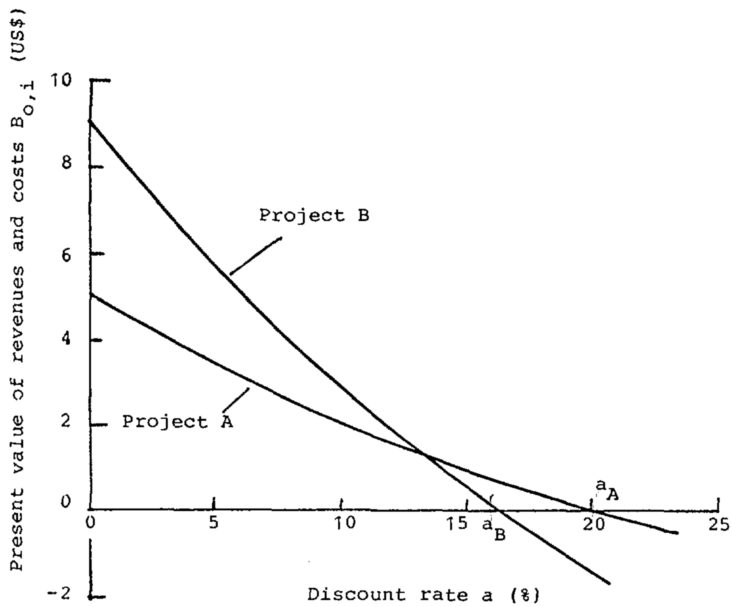


FIG.10.8. Dependence of present value on balance of revenue and cost cash flows from the discount rate a.

For investment optimization analysis the discount rate relates to constant money, i.e. to real term calculations. It varies, but within rather narrow limits from country to country. For example, it was 7% for the fourth and fifth and 9% for the seventh five-year plan in France for constant francs, it was 10% in 1979, in the USA 10% in general and 8% for energy, 8% in the UK and 6% in the USSR [10.17]. The World Bank calculates with 10%.

As regards the prices to be used, although the analysis is carried out in constant money, they must be current market prices, i.e. taking into account the evolution of the structure of relative prices. For developing countries where the market prices only imperfectly play the role of social indicators, shadow prices should be used instead. For some developing countries, for example India, Algeria, Ivory Coast, Tunesia, etc., such prices might be calculated with mathematical programmes [10.18]. Another approach would be to take the prices as they are, and try to correct up- and downstream effects in relation to the country's economy.

In addition to the identification of the maximal present value (worth) of the discounted revenues and costs or the least discounted costs (when applicable) solution as relatively the best of the alternatives compared, some further investigations are necessary for analysing performance.

10.3.4. Benefit/cost ratio

The benefit/cost ratio represents the ratio between the present value of the discounted revenue and the cost cash flows. It obviously has to be greater than 1 for projects which are absolutely economic (profitable).

However, the relative profitability of the alternatives cannot be deduced from this ratio alone. The most profitable alternative is surely the one with the highest present value of the balance $B_{o,n}$ which must not necessarily be that with the maximal benefit/cost ratio. The highest benefit/cost ratio confirms only an absolute profitability with the highest benefit per invested money unit.

10.3.5. Rate of return

Both the present value of the balance of revenue and cost cash flows and the benefit/cost ratio depend on the value of the discounting rate, a.

If it is assumed that all costs are paid with the present value $C_{o,n}$ at the reference time zero, the final balance in the year i = n can be written as

$$B_{o,n} = R_{o,n} - C_{o,n} = Z((1+a)^n - 1/a(1+a)^n) - I$$

where $E_{o,n} = I$ the total investment, discounted at the reference time basis and

$$R_{o,n} = Z((1+a)^n - 1/a(1+a)^n$$

with Z representing the equal yearly revenue during n years to be discounted according to its yearly payment. With $n = \infty$ $B_{o,n}$ becomes $B_{o,\infty} = (Z/a) - E_{o,n}$.

The dependence of $B_{o,i}$ on the discount rate a can be followed in Fig. 10.8.

$B_{o,i}$ becoming equal to zero, for the value a_B or a_A, means that for this discount rate value, the project is self-sustaining. For 'a' values greater than a_B or a_A the project is not economic, for lower values the project is profitable. The value a for which $B_{o,i} = 0$ and the benefit cost ratio = 1 is called the internal rate of return of the project.

10.3.6. Payback or capital recovery time

There are further possible checks on the selected alternative solution, as for example annual benefits and costs, risk analysis, etc., which cannot be commented on in detail within this framework. However, an often applied criterion, especially in simpler energy conservation projects, should be mentioned briefly.

If the cost stream E_i is broken down into an investment (I) that is made at one point in time, and variable costs V_i covering, for instance, fuel and operation and maintenance costs in the case of a power plant, this equation can be written in the following form:

$$I = \sum_{i=1}^{i'} (E_i - V_i)$$

In this form time i' clearly appears as the time required for net operational revenues to pay back the capital investment. The corresponding criterion consists of ranking alternative solutions by their payback times and choosing only those whose time of capital recovery does not exceed a preselected value i'_o.

The criterion of payback time may be attractive for its relative simplicity, although the selection of a reference payback time involves the same problems as that of the choice of suitable rate of discount. The main objection, however, lies in the fact that this criterion ignores to a large extent the time distribution of costs and revenues within the payback period. Thus, two investment projects with the same investment cost but with net revenues consisting of a series of ten equal annual amounts for one case and a single amount in the tenth year for the second would both have the same payback time of ten years and be considered as economically equal, an obviously questionable ranking [10.10].

Chapter 11

ELECTRICITY GENERATION COST OF NUCLEAR AND FOSSIL-FUELLED POWER PLANTS

The proper way of assessing nuclear power generation within a country is through an optimization study based on the particular characteristics of its energy system. The nuclear power plant is integrated into the grid and the overall costs and benefits of the system are studied in depth. The result is then compared to an alternative energy source which will supply an equivalent amount of electricity. In this way, the economic effects of the power programme on the energy supply market, as well as on the national industrial and manpower infrastructures, would be properly assessed. Such a global assessment is very difficult to achieve, so normally a more modest approach is used, consisting of the economic analysis of the electric-power-generating subsystem expansion. Although less comprehensive, this approach can provide a reasonably consolidated image of the economics of nuclear power in the country.

An even simpler approach, consisting of a direct comparison between the economics of nuclear power plants and their competitors, namely fossil-fuelled power plants for base-load power generation, could only provide limited indications regarding the economic competitiveness of nuclear power. Although such an analysis would disregard the effects between the nuclear (or coal- or oil-fired) plants and the whole power-generating system and associated transmission facilities, experience has found it satisfactory for preliminary investigations.

The following comparison between the electricity generation costs of nuclear and fossil-fuelled power stations must, therefore, be judged accordingly in its much narrower framework. In addition, like any comparison of alternative energy solutions, it has still to be submitted to the evaluation criteria of the present-worth analysis – see subsection 10.3. On a pro rata basis, a levelized energy cost (levelized cost of kW·h) can be calculated assuming that the electric energy generated by the plant produces, in all alternatives, revenues (priced at levelized unit cost of the kW·h) whose present-worth value equals the present-worth value of all expenditures incurred in the implementation and operation of any alternative solution. The latter approach is the one normally followed by the IAEA.

Although the main scope of this chapter is to present a comparative calculation of the kW·h generation costs of different alternative solutions, it will also comment on some characteristic aspects. Since the calculation for the nuclear power plant generating costs has some more complicated aspects, for example the fuel cycle cost component, it will for the most part be just referred to, the fossil-fuel alternative being both simpler and better known. The presentation makes extensive use of the already often mentioned IAEA Guidebook on the Introduction of Nuclear Power, Ref.[11.1], but includes in addition more recent material, mostly also originating from the IAEA.

11.1. Components of nuclear power generation costs

The main components entering into the calculations of nuclear power generation costs are the following:

(a) Basic elements: capital investment, nuclear fuel cycle and operating maintenance (O&M) costs
(b) Additional elements: infrastructure development costs such as R&D and transfer of technology, domestic industrial and manpower development associated with a nuclear power programme
(c) Plant construction and performance: reflected in its construction duration, load factor, net power rating and economic life
(d) Outside economic influences: interest and escalation associated with the fuel cycle and O&M costs during plant life as exogenous parameters.

11.2. Capital investment costs

The capital investment cost of a nuclear plant (or in general, of any power plant) is the sum of all expenditures incurred in the design, licensing, manufacture and erection, construction and commissioning of the plant.

Several accounting systems are used to split the capital investment cost into its principal parts; the breakdown shown in Table 11.I is the one employed in the IAEA. It shows the cost structure and defines direct and indirect, base, fore and total capital investment costs. The fore cost as defined here does not include the effects of inflation (escalation) of prices to be paid for labour, equipment, material and services, nor does it include interest on capital borrowed during the construction period. All of these items are included in the defined total capital investment cost. Items such as taxes and fees have been excluded from the present definition of total capital investment costs. There are other accounting methods which do include these items along with others, or which include all or some of the infrastructure development costs.

The contribution of capital investment costs to the bus-bar power generation costs is the result of the annual fixed charge which includes depreciation of and interest on the total capital investment cost. The capital recovery factor is normally used as the fixed charge factor when depreciation of investment is carried out using the sinking fund method. For nuclear power plants, the annual capital charge is the largest contributor to the unit power generation cost. Items excluded in the IAEA accounting system from the total capital investment cost, of course, do contribute to the power generation cost; they are accounted for in the fuel or O&M costs.

The estimated and real (experienced) capital costs of power plants — no matter whether fossil, nuclear or hydro — show a very wide range of values. A scattering of capital cost values can be observed at a country level, but the range

TABLE 11.I. STRUCTURE OF THE POWER PLANT CAPITAL INVESTMENT COST

Direct cost

Structures and site facilities

Reactor/boiler equipment

Turbine plant equipment

Electric plant equipment

Miscellaneous plant equipment

Cooling system, etc.

Indirect cost

Construction management, equipment and services

Home office engineering and services

Field office engineering and services

BASE COST = DIRECT + INDIRECT COST

+ Owner's costs

+ Spare parts

+ Contingency

------------------------------ = FORE COST

+ Interest during construction (IDC)

+ Escalation

+ Interest on escalation

------------------------------ = TOTAL CAPITAL INVESTMENT COST

Items not considered above:	Initial fuel loading
	Heavy-water inventory
	Cost of land
	Taxes and fees
	Infrastructure development costs

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is especially wide in worldwide comparisons. An example of cost data for nuclear and fossil power stations is given in Fig.11.1, which shows the evolution of capital investment costs in the USA, expressed in mixed years dollars, which means adding up the current expenses when they occur, on a yearly basis.

A generally valid explanation of this dispersion in capital costs is difficult to find, although changing economic factors, plant design, project management,

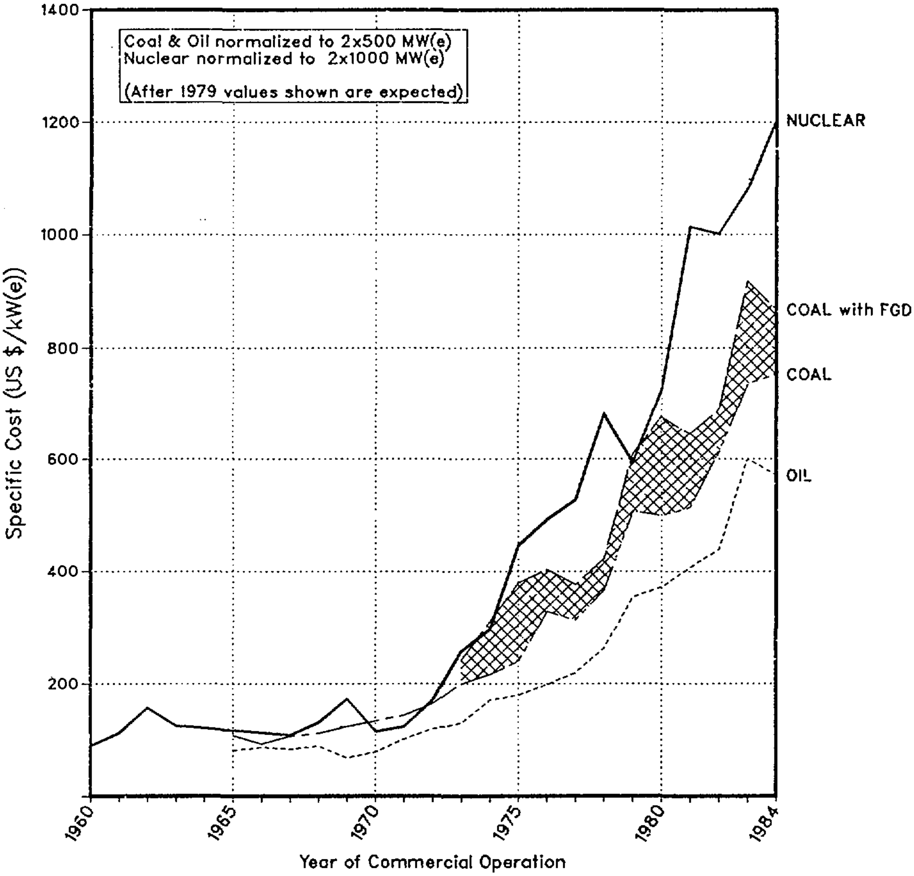

FIG.11.1. Average total capital investment cost (mixed years dollars per kW(e)) in the USA.

different approaches and general policy factors have substantially contributed to this development.

For the purpose of evaluating plant capital investment cost trends, it is therefore necessary to remove from reported values the distortion introduced by escalation of prices in the power plant construction industry and focus only on the fore costs expressed in constant currency of a selected year. Such an exercise has been performed using data available for the USA for large nuclear and coal-fired power plants. The results are presented in Fig.11.2. In constant January 1980 prices, fore costs increased from around 400 US$/kW(e) for construction start in mid-1967 to over 700 US$/kW(e) for construction start in mid-1971, an increase of over 75% in real terms within a four-year span. Coal-fired plants experienced a less dramatic increase in costs as can be seen in Fig.11.2.

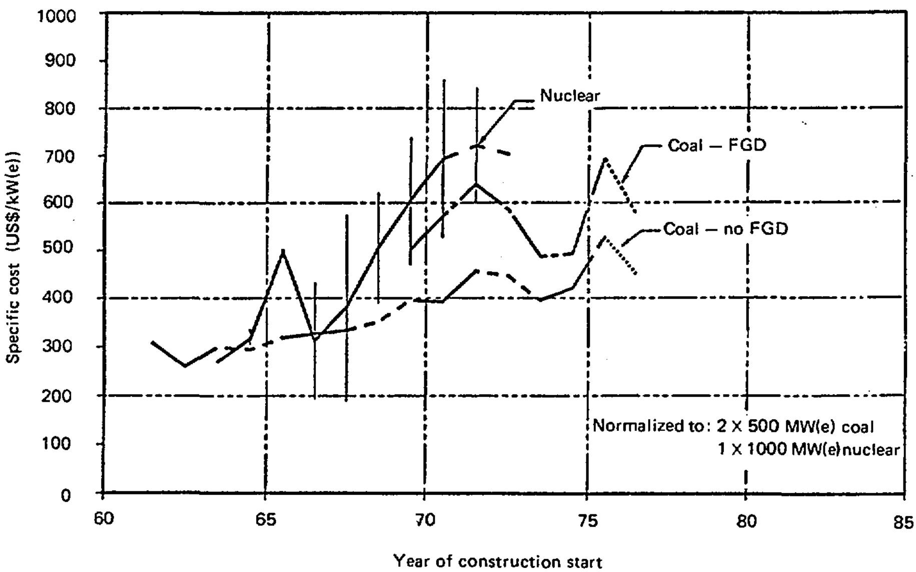

FIG.11.2. Fore costs in constant (1980) US dollars in the USA.

For coal-fired plants, equipped with flue gas desulpherization (FGD) systems, fore costs increased from an average of about 500 US$/kW(e) for a mid-1969 start of construction date to about 690 US$/kW(e) for a mid-1975 start of construction date, an approximate 40% increase in six years. For coal-fired plants without flue gas desulphurization (FGD) equipment, fore costs experienced a relatively modest increase of approximately 65% over a ten-year span (1965–1975) or less than 30% over a comparable six-year period (1969–1975).

The licensing and construction period for nuclear plants in the USA has steadily increased up to about 13 years. As a consequence, most nuclear units committed after 1971 are not yet in commercial operation and their total capital investment costs, containing considerable amounts for escalation and interest during construction, are still unknown.

Estimated fore costs for LWR power plants in France, provided by Electricité de France (EdF), are based on a 1992 commercial operation date. For the 900 MW(e) nominal units, construction duration is given at approximately 5–5½ years while for the 1300 MW(e) nominal units, construction duration is given at 6–6½ years.

At mid-1982 prices, fore costs for a 2 X 910 MW(e) station amount to about 5000 FF/kW(e) and for a 2 X 1290 MW(e) station amount to about 4950 FF/kW(e).

However, the above fore costs are only projected figures based on past EdF experience and not actual experienced costs. Cost drift in constant prices is also excluded.

TABLE 11.II. RANGE OF FORE COST OF ELECTRIC POWER PLANTS

	Plant capacity (MW(e))					
	100	200	300	600	900	1200
	Cost (constant 1980 US$/kW(e))					
Nuclear plants						
Low	–	–	–	1700	1200	1000
High	–	–	–	2000	1500	1200
Coal-fired plants						
Low	–	1400	1200	950	850	750
High	–	1800	1500	1200	1050	950
Oil-fired plants						
Low	1400	1100	950	750	650	–
High	1700	1350	1250	900	800	–

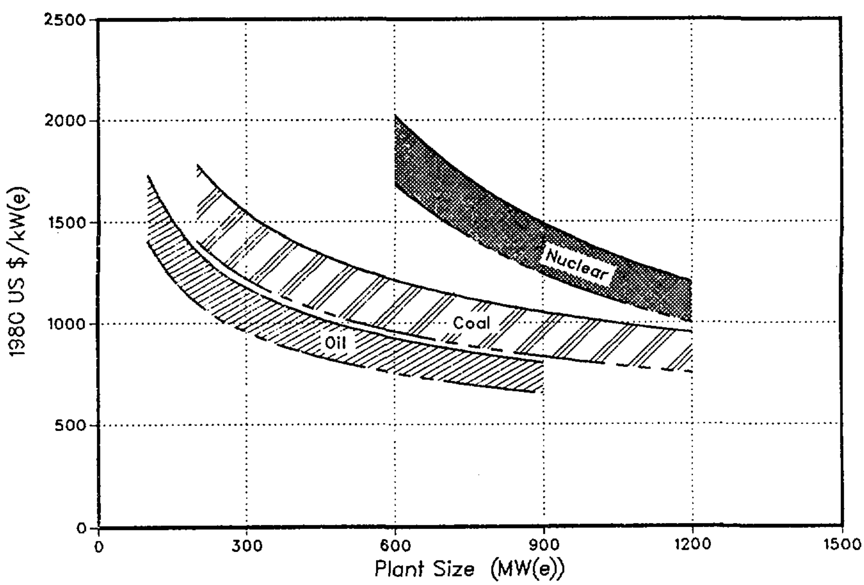

FIG.11.3. Range of electric power plant fore costs.

TABLE 11.III. STRUCTURE OF THE NUCLEAR FUEL CYCLE COST

Natural uranium reactor	Enriched uranium reactor
Front-end costs	*Front-end costs*
Natural uranium	Natural uranium
–	Conversion to UF_6
–	Enrichment
Fuel fabrication	Fuel fabrication
Transportation	Transportation
Back-end costs	*Back-end costs*
Storage and transportation of irradiated fuel	Storage and transportation of irradiated fuel
Reprocessing	Reprocessing
Credit for plutonium	Credit for plutonium
–	Credit for uranium
Disposal of wastes	Disposal of wastes

Direct cost	=	Front-end + back-end costs
Indirect cost	=	Interest on direct costs
Total nuclear fuel cycle cost	=	Direct + indirect costs

Interest during construction and escalation in France are estimated to be lower than in other countries, where more time is needed to put a large nuclear plant into commercial operation.

In Canada, dry fore costs (the cost of D_2O is excluded) for a 4 X 750 MW(e) PHWR plant of the CANDU type and Ontario Hydro experience, range between 650 and 950 Can \$/kW(e) in January 1983 prices, excluding cost drift. Including cost drift and heavy-water costs, fore costs amount to approximately 2000 Can \$/kW(e). For other Canadian utilities as well as for single or dual unit plants, fore costs are considerably higher. Table 11.II and Fig.11.3 display the fore cost range for nuclear, coal- and oil-fired electric power plants.

11.3. Nuclear fuel cycle costs

Lower nuclear fuel cycle cost as compared to fossil-fuel costs is the key factor in the competitive position of nuclear power plants.

Chapter 4 discussed the main technical aspects of the various options available for the nuclear fuel cycle. The complexity of nuclear fuel cycle economics stems

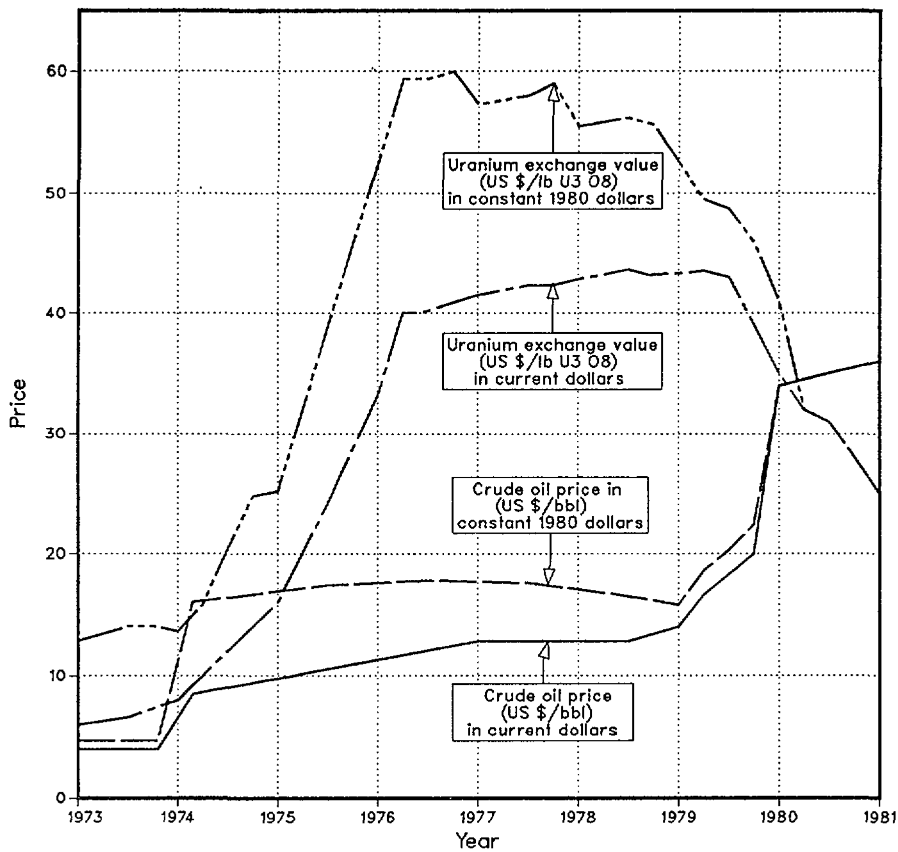

FIG.11.4. Historical evolution of natural uranium and crude oil prices.

from the fact that it involves numerous expenditures made at different points in time before the fuel is actually loaded into the reactor and energy production begins, as well as other disbursements made a long time after the spent fuel has been unloaded from the reactor for ultimate disposal or for reprocessing, production of new fuel with recovered fissionable materials and disposal of radioactive wastes.

The front-end processes of the nuclear fuel cycle include the costs incurred in the exploration, mining and milling of uranium, conversion into UF_6 and enrichment in the ^{235}U isotope (in the case of reactors fuelled with enriched uranium) and finally, fabrication of fuel elements. Of course, all costs for transportation between processes and dispatch to the reactor site are included as well.

The back-end processes of the nuclear fuel cycle include the expenditures incurred in storage and transportation of irradiated fuel, reprocessing for extraction

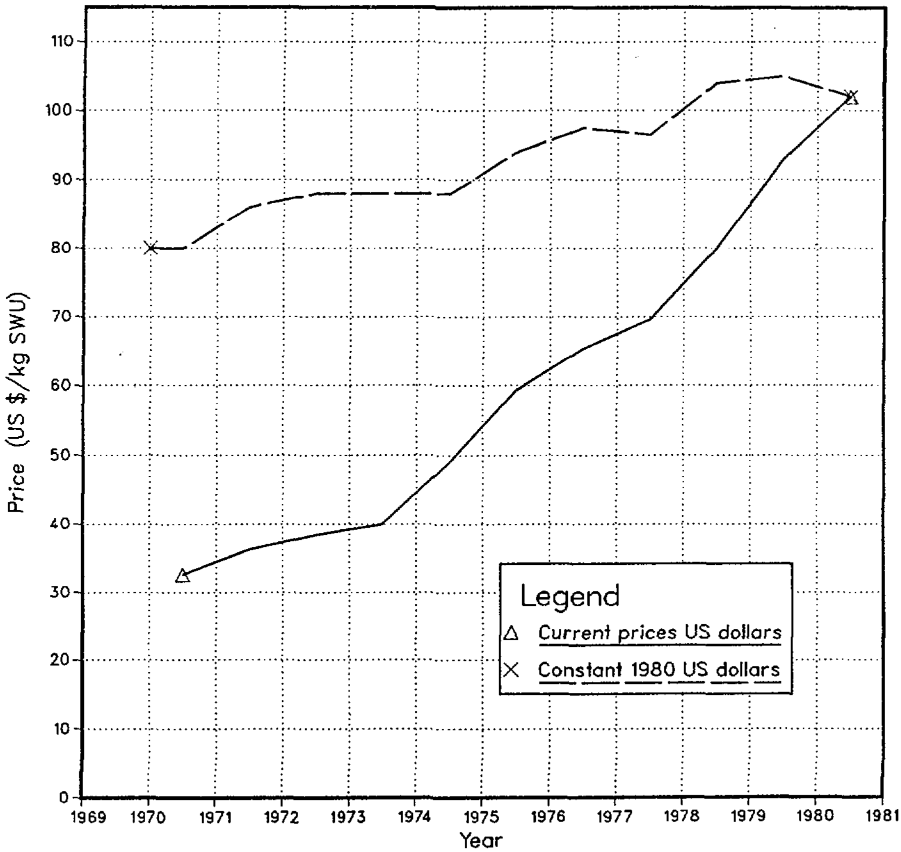

FIG.11.5. Enrichment service price (USA contracts).

of plutonium and uranium, and the separation, concentration and final disposal of radioactive wastes in the case of a closed fuel cycle. The economic effect of recycling the recovered plutonium and uranium (closed cycle) is to add a credit to the nuclear fuel cycle costs. Interest on the expenditures incurred at the front-end as well as the back-end of the fuel cycle constitutes the so-called indirect cost of the nuclear fuel cycle. Direct plus indirect costs determine the total nuclear fuel cycle cost component of the energy produced by the fuel burnt in an enriched uranium reactor – see Table 11.III. In the case of a natural uranium reactor the items conversion to UF_6, enrichment and credit for uranium are waived.

Since many fuel batches of different composition may be used during the life of the reactor, it is customary to calculate the levelized cost of the energy produced by the nuclear plant throughout its lifetime.

The historical evolution of both uranium and crude oil prices is shown in Fig.11.4, expressed in current US$ and also is constant 1980 US$. Most of the

TABLE 11.IV. REFERENCE FUEL COST DATA
In constant 1980 US$

Fuel		Range	Reference value
Nuclear			
Natural uranium	\$/kg U_3O_8	48 – 120	88
Conversion to UF_6, LWR	\$/kg U	4–6	5
Enrichment, LWR	\$ SWU	120–200	160
Fabrication, LWR	\$/kg U	150–200	175
Fabrication, HWR	\$/kg U	80 – 100	85
Shipping	\$/kg U	10–20	15
Back-end cost (net)	\$/kg U	300 – 500	400
Discount rate, %/a		8–14	10
Annual load factor, %		60–80	70
Total fuel cycle cost, LWR	10^{-3} US\$/kW·h	9.5–10.5	10
Total fuel cycle cost, HWR	10^{-3} US\$/kW·h	5–7	6
Fossil			
Hard coal, mine mouth	\$/t	30–40	
Hard coal, away from mine	\$/t	50–90	
Crude oil	\$/bbl	30–50	
Total fuel cost	10^{-3} \$/kW·h		
* Coal	(30 – 60 – 90 \$/t)	12 – 24 – 36	
* Oil	(30 – 40 – 50 \$/bbl)	44 – 58 – 72	

Note: It is assumed that all values remain unchanged indefinitely, in constant value currency.

increase in the natural uranium price in current dollars occurred during the period 1974–1977, reaching values in the range 88 to 97 US\$/kg of U_3O_8 (40 to 44 US\$/lb). If the price of U_3O_8 is expressed in constant 1980 US\$, the increase occurred in the period 1974–1976 when the price reached a peak value close to 130 US\$/kg (60 US\$/lb), i.e. almost five times the U_3O_8 price existing at the beginning of 1973 (also expressed in constant 1980 US\$). Starting from 1977, the U_3O_8 price in constant 1980 US\$ began a steady decrease towards values in the range of 62–66 US\$/kg (28–30 US\$/lb) in the year 1980. The recent U_3O_8 price decrease is apparently due to (natural) uranium production exceeding demand, combined with high levels of stocks maintained by the consumers.

TABLE 11.V. STRUCTURE OF THE POWER PLANT OPERATION AND MAINTENANCE COST

Cost category	Description
Wages and salaries	Power plant staff and administrative staff
Operation and maintenance materials and equipment, repair costs, etc.	Maintenance materials and equipment required to repair or replace plant equipment; repair costs; consumable materials and expenses, etc.
Insurance	Property and nuclear liability insurance fees
Inspection	Routine inspection fees
Purchased services	Maintenance services and repair performed by off-site staff
Other costs	All other relevant O&M costs not included in the above categories
Items not considered:	National and local taxes and fees Cost of water

Comparing the uranium and oil price curves, it is interesting to observe that the 1973–74 major oil price increase was immediately followed by a major uranium price increase. After these increases, the price of both uranium and oil remained almost constant (in constant currency values) for several years. In 1979, a second major oil price increase occurred but this was not accompanied or followed by a uranium price increase in 1980–81.

Regarding enrichment of uranium, as shown in Fig.11.5, the USA price of a separative work unit (SWU) in current dollars has steadily increased in the last ten years from 32.5 to 102 US$/SWU, i.e. an increase of more than 210%. However, when the price of separative work is expressed in constant 1980 US$, the actual increase in the last ten years has been only about 27%.

Another important contributor to the nuclear fuel cycle cost is the price of fabrication of the fuel elements. Its average value (for LWRs) has increased from about 80 US$/kgU in 1970 to about 150 US$ in 1980, i.e. an increase of about 90% in current dollars, but a decrease of 25% in constant dollars. The reason for this trend in the cost of this service is to be found in technological development and mass production of fuel.

Table 11.IV displays ranges and reference values in constant 1980 US$ for nuclear fuel, coal and oil both per unit and per kW·h.

TABLE 11.VI. OPERATION AND MAINTENANCE COST OF THE ELECTRIC POWER PLANTS

	Plant capacity (MW(e))					
	100	200	300	600	900	1200
	Cost (constant 1980 US$/kW·a)					
Nuclear plants						
LWR	–	–	–	22.0	15.0	12.0
HWR	–	–	–	29.0	–	–
Coal-fired plants	–	40.0	32.0	25.8	21.5	19.0
Oil-fired plants	17.2	16.6	16.0	15.3	14.7	–

11.4. Operation and maintenance costs (O&M)

Table 11.V lists the components of the O&M costs as used by the IAEA in order to compare cost experience from different sources and different types of plants. Some of the O&M costs are fixed costs (e.g. wages and salaries, insurance and other fees), while others have fixed and variable components. The variable costs depend on the number of operating hours (e.g. consumables and maintenance materials, repair costs, maintenance services performed by off-site plant staff).

Table 11.VI contains the reference (O&M) data used by the IAEA in its current general analysis.

11.5. Infrastructure development costs

There are many tasks and activities involving certain expenses, which are needed for the implementation of a nuclear power project and a nuclear power programme, but which are usually not included in the power generation costs. Such activities are: planning, studies, scientific research and development in support of a nuclear power programme, manpower development at all levels, except regarding the training of the operations staff, which is included in the owner's cost, development of national infrastructure (governmental, regulatory, industrial, education), national participation promotion, technology transfer, regulatory and licensing costs.

These infrastructure development costs are difficult to evaluate and express; it is also questionable whether they should be charged to a single nuclear power plant or to a long-term nuclear power programme. It must also be considered that they can produce benefits by promoting the country's overall development. The usually accepted procedure is to assume that infrastructure development costs and the benefits resulting from them balance out.

11.6. Other factors influencing electricity generation costs

In addition to the previously discussed main components of electricity generating costs, the following factors can influence to a greater or lesser degree the total generating costs:

(a) The duration of plant construction is important both for minimizing the interest and escalation costs accruing during this time period and for avoiding additional costs as a result of replacement power. This latter shortfall in energy production between scheduled and actual commissioning has to be either purchased or produced by other, less efficient power plants at the utility's disposal, which results in substantially higher opportunity costs.

(b) The annual plant capacity factor is defined by the IAEA as the ratio between actual energy produced and energy that the plant could have produced at its rated capacity under continuous operation during the whole year. The projected plant capacity factor is possibly the most uncertain parameter since, in addition to planned shutdown periods for scheduled refuelling and maintenance, which nevertheless cannot be a priori exactly defined, forced outages always occur owing to unexpected events. Accordingly, both the available power balance between supply and demand as well as the amount of electricity generated annually, and hence the capacity factor, are negatively affected.

(c) The plant net electric power rating similarly influences the power and electricity production, both quantitatively and qualitatively, and is a yardstick for efficient operation and plant management.

(d) The plant economic life plays a role in the determination of the annual fixed charges due to depreciation of and interest on the capital investment; the economic life and the discount rate will define the capital recovery factor to be used for calculating the annual fixed charges on capital investments.

(e) The interest rate on money borrowed to meet the cash flow requirements during the construction period has a great impact upon the interest to be paid during construction (IDC) of the plant. Moreover, escalation of prices during construction will increase capital costs. Altogether, high interest and escalation rates compounded with lengthy construction periods will lead to substantial additions to the fore costs.

(f) Inflation: In an economic analysis, the assumption is usually made that inflation will affect power generation costs for all alternatives in the same way and, consequently, all cash flows can be expressed in constant value currency. However, for financing purposes, assumptions regarding future inflation rates should be made in order to determine the expected flow of payments.

(g) Cost drift: This is a parameter which affects fore costs and through them total generation costs. It is associated with price increases in constant money due to increased scope, increased content, improved design, QC/QA, etc.

(h) The discount rate: The opportunity cost of money (i.e. discount rates) in the country (or region) where the plant is built and operated plays an important role in the economic analysis of power plants. The national discount rate to be used in the analysis is affected by the inflation rates, which are related to interest rates. The national discount rate is used in the economic analysis of nuclear power at the country level. The commercial interest rate on the other hand is used in economic analysis at the electrical utility level, in order to arrive at total capital investment costs and bus-bar generation costs.

11.7. Limitation and uncertainties of cost estimates

Cost estimates should be made for a particular country and site, accounting for all relevant factors and conditions, such as local infrastructure, current international economy, site characteristics, etc. Moreover, a distinction should be made between cost estimates intended for economic comparisons and cost estimates needed for analysis of payment schedules (cash flow studies). Economic comparisons should be made, whenever possible, by removing from the costs the inflationary effects of the national and international economies, i.e. costs should be expressed in constant money of a selected base year. However, expected future price increases of a particular item above expected average inflation of the economy should be accounted for by means of a differential (real) escalation rate applied to the price of that particular item. Whereas it is important to remove the distortion introduced by inflation from economic comparisons, it is relevant to include inflationary effects on payment schedules when estimating future financial needs. This matter is particularly important when construction cost estimates are prepared for power plants with long construction and lead times.

It is emphasized that the owner's cost component of the capital investment cost requires careful evaluation, especially for the first nuclear power plant to be built in a country. Owner's cost should carefully scrutinize amounts of money for infrastructure development, part of which might remain for further use beyond the immediate purpose of the nuclear plant.

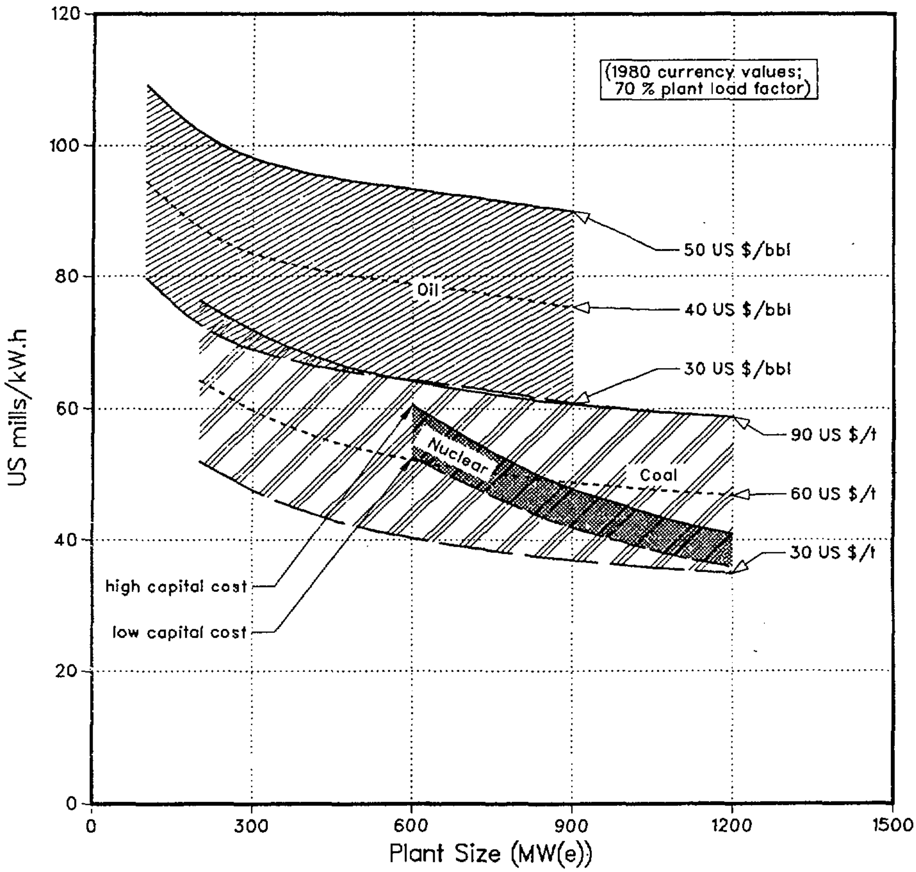

FIG.11.6. Estimated cost of electricity generated by nuclear, coal- and oil-fired plants starting operation in 1990.

11.8. Alternative power generation costs and competitiveness of nuclear power

According to the above considerations, the total annual power generation cost for the power plant consists of a fixed charge on capital investment, an annual fuel cost and annual O&M expenses. In addition, and according to the criteria adopted, there might be an annual charge for infrastructure development costs.

Based on the average figures, all expressed in 1980 constant US$ – for electrical power plant fore cost in Table 11.II and Fig.11.3, for fuel cost in Table 11.IV and for operation and maintenance in Table 11.V – the range of kW·h costs generated by nuclear, coal- and oil-fired plants are comparatively displayed in a synthesis, Fig.11.6.

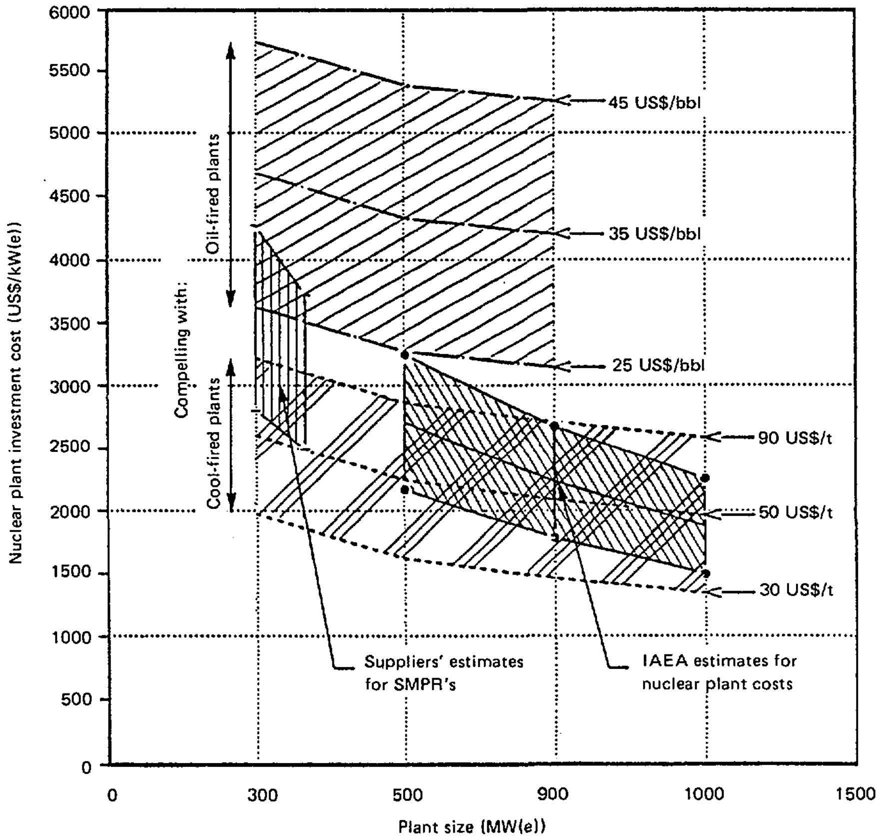

FIG.11.7. Investment costs at which nuclear power plants can compete with oil- and coal-fired plants.

However, in spite of its convincing bases and calculation techniques, Fig.11.6 presents an overview valid only at the time of its elaboration. As time goes on, changes intervene and because of its paramount importance, such an overview has to be kept continuously up-to-date. This task is included in the IAEA ongoing programme of advising and assisting Member States in the evaluation of their energy planning studies in general and their nuclear power programme in particular.

Accordingly, a revision of the comparative evaluation presented was carried out in March 1983 as referred to 1982 conditions with costs expressed in constant (1982) US$ compared to the former constant (1980) US$ [11.2, 3]. The total investment costs for coal- and oil-fired plants were obtained from estimates calculated for 1980 conditions and applying and escalation factor of 1.16 (approximately 8% escalation rate per annum). The comparison capacity range for nuclear power plants was lowered to some 100 MW(e) with capital investment

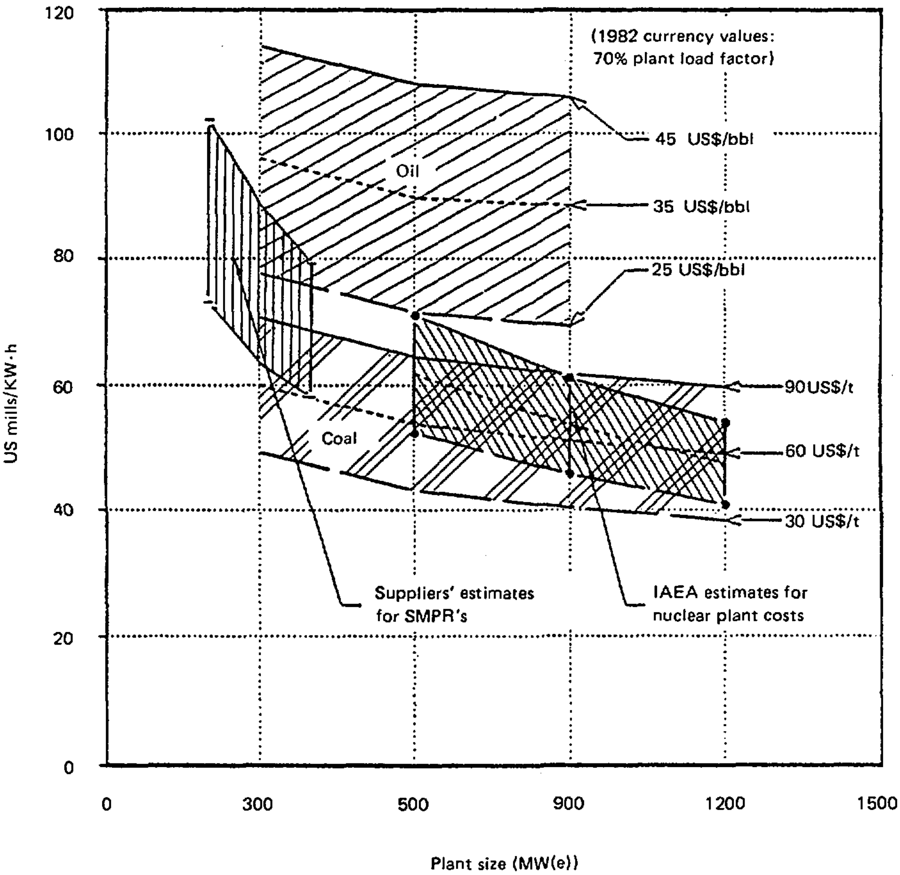

FIG.11.8. Estimated cost of electricity generated by nuclear, coal- and oil-fired plants starting operation in 1990 (revised).

costs indicated by suppliers. For unit capacities in the range from 600–1200 MW(e), IAEA estimates based on cost experience reported to the Agency have been used. Taking into account the latest evolution, a lower curve for an oil price of US $25/bbl has been introduced for the oil-fired plant alternative.

Figure 11.7 displays the investment costs at which nuclear power plants can compete with oil- and coal-fired plants (including interest during construction) while Fig.11.8 presents the comparison of the kW·h costs, in US mills/kW·h between the same alternative solutions.

Whatever the reservations expressed in the IAEA Guidebook [11.1] regarding the very limited applicability and validity of the general economic analysis presented, which is obvious if referred to very specific single cases, it nevertheless gives an excellent overview on the relative positions of nuclear, coal- and oil-fired large electricity generation plants. Therefore, the main facts and conclusions regarding the competitiveness of nuclear power stations are reproduced below and provide one of the main answers to the basic question of the competitiveness of nuclear energy.

In Figs 11.6 and 11.8, where the costs of kW·h generated by nuclear, coal- and oil-fired plants are displayed, they are expressed as a function of plant size and for indicating the ranges, two variables were used:

(a) Capital investment cost of the nuclear plants;
(b) Fuel cost of the fossil-fired (coal and oil) plants.

These are the two principal factors affecting the competitiveness of nuclear power with fossil-fired plants, and they are also the two factors most difficult to determine not only in a general analysis, but also for a particular study.

As shown in Fig.11.8, the cost of electricity produced by a nuclear plant is in general substantially lower than the cost of electricity produced by oil-fired plants in the size range of 600 to 1200 MW(e), even at fuel oil prices as low as 25 \$/bbl. The competition of nuclear plants with coal-fired plants in the same size range is close, depending fundamentally on the coal price and the nuclear plant investment cost assumed. For the size range below 600 MW(e), nuclear power plants could only compete favourably with oil plants in the upper level of the oil price range and assuming that the estimated investment costs of SMPRs will be effectively achieved.

In addition to the two main parameters (investment cost of nuclear plants and fossil fuel costs), those which may strongly affect the competitive position of nuclear power are the annual discount rate, and the plant load factor. The cost of electricity produced by a nuclear power plant is only slightly affected by even large changes in the components of the nuclear fuel cycle cost. The cost of electricity of coal-fired plants is affected by the quality of coal to be burned and by the environmental protection requirements, in addition to the price (including transport) of coal.

As far as nuclear power plants are concerned, the economy of scale is particularly important for the capital investment costs. A 600 MW(e) nuclear plant has about 75% higher unit capital cost than a 1200 MW(e) one, whereas for fossil-fuelled plants the specific cost increase is only about 30%. The same peculiarity can be noticed for O&M costs. Fuel costs on the other hand are practically independent of plant size. Total capital investment costs for nuclear plants of sizes lower than 600 MW(e) (SMPRs) are very uncertain and the range given here should be interpreted as indicative values of costs that are expected to be achieved.

Looking at the past evolution of nuclear power costs, it can be observed that ever since commercial nuclear power plants started to penetrate the electricity generation market, they have maintained an economically competitive position vis-à-vis available alternative energy sources. Individual projects have shown some deviations with respect to strict competitive conditions, but such deviations were always marginal and attributable to specific situations or unexpected factors. In effect, nuclear power could never have penetrated the energy market to the extent it did without, in general, achieving economic competitiveness.

When in 1973–74 the price of oil was suddenly raised far above its earlier level, the economically competitive status of nuclear power could have been considerably improved. This, however, did not happen. Nuclear power costs followed the trend of oil costs with a very short delay, rising to attain a very similar competitive level to the one they were holding before the oil price increase. Incidentally, coal followed a similar trend.

With its second substantial price increase in 1979, oil attained a price level which placed it substantially above the competitive range for electricity production. This left nuclear power and coal as the main competitors in the bulk commercial electricity generation market. In spite of the recent decrease of oil prices, this position has not been altered, nor is it likely that significant changes will occur in the future.

Economic competition between available alternative energy sources is a powerful force which acts on each of these sources. Consequently, the cost trends of nuclear power cannot be considered in isolation. It seems reasonable to assume that the future evolution of nuclear power costs will follow the overall pattern of evolution of the whole energy market, where each available alternative source tends to maintain its competitive position. This seems to hold especially for a regulated market such as the energy market.

In addition to, and in parallel with, the updating work outlined above, a cost methodology has been developed in the IAEA and a computer program named BACON, standing for Base Code Normalization of Power Plants, has been written which updates, revises or expands the data needed for carrying out investment cost studies and analyses of nuclear and coal-fired plants in various countries, on a regular basis [11.4]. A methodology for cost and price escalation identification has also been recently elaborated [11.5].

11.9. International comparison of alternative power generation costs

More information on the specific conditions in various countries can be gained from the Proceedings of the International Conference on Nuclear Power Experience, held by the IAEA in September 1982 [11.6] which contain an overview [11.7] and six detailed country reports [11.8–13] on nuclear power generating costs including comparisons with fossil-fuelled conventional power plants.

Reference [11.7] presents highlights on nuclear power costs around the world. The capital investment costs, i.e., fore or overnight costs and total capital investment costs (TCIC) of the nuclear and thermal power plants originate from IAEA studies while the UNIPEDE (Union of Electricity Producers and Distributors) has examined the total generation costs, both with a view to discover a general

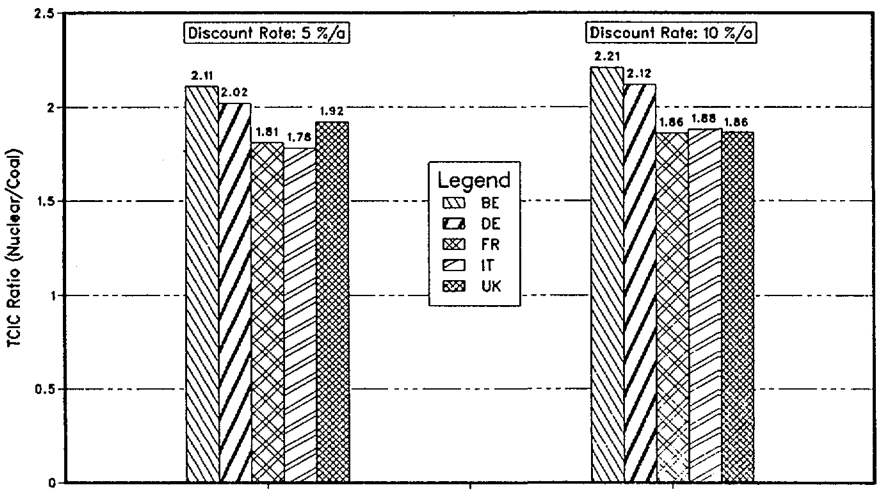

FIG.11.9. Relative TCIC of nuclear and coal-fired plants in various countries.

trend in the European context and to establish a basis for comparison of generating costs between the various countries.

In addition to the figures and tables referring to the conditions in each country, the consolidated comparisons in Figs 11.9 and 11.10 are of special interest.

The figures are self-explanatory, however, it is worth emphasizing that at discount rates of both 5% and 10%, the kW·h costs vary in favour of nuclear energy, the variation range being 53% up to a maximum of 93% of the coal-generated electricity, for comparable plant sizes. More details on the competitiveness of nuclear energy in a series of countries are summarized below:

For Canada generation costs reported for 1980–1981 were in the range of 13–16 Canadian mills/kW·h for nuclear plants and 20–25 Canadian mills/kW·h for coal-fired plants. In the past several years total generation costs for the nuclear Pickering A plant are about 60% of the total generation costs of a comparable coal-fired plant (Lambton) assuming a load factor of over 80% to match the nuclear station. Even considering that the Bruce A investment costs are higher than for Pickering A, the generation costs for Bruce A are still only about 75% of those for Lambton [11.8].

In France the kW·h generating costs for base-load operation were in 1978 15.8 1982 centimes for nuclear as against 24.2 for coal (without flue gas desulphurization) and 26.9 1982 centimes for coal with flue gas desulphurization. The figures in 1982 were 19.4 for nuclear against 32.0 and 35.5 centimes respectively. Nuclear generation cost, therefore, some 55 to 60% that of coal generation in base-load operation, still maintains an important advantage when partly operating in higher zones of the daily load curve [11.9].

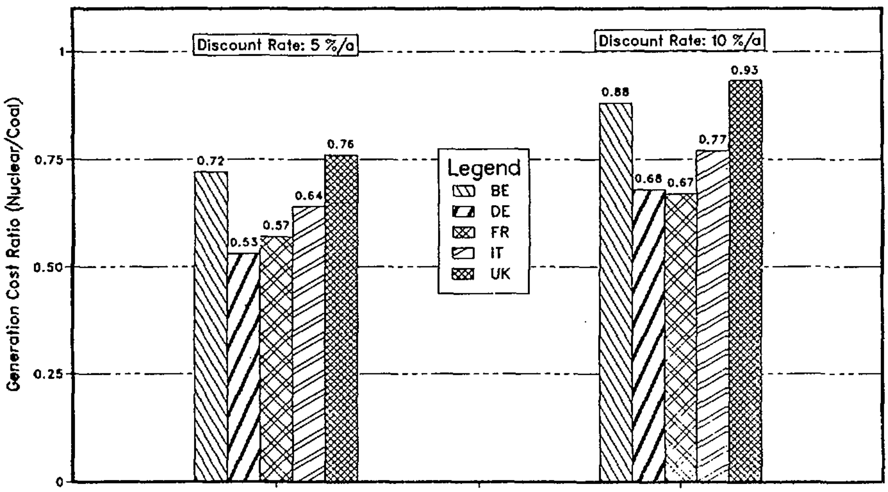

FIG.11.10. Relative cost of electricity generated by nuclear and coal-fired plants in various countries.

In the Federal Republic of Germany the relationship between nuclear and coal generation in the base-load region is 20 Dpf/kW·h (one Dpf = 0.01 Deutsche Mark (DM)) for nuclear against 30 Dpf/kW·h for coal with a duration of 6500 h/a utilization. The figures move to 29 against 36 Dpf/kW·h with 4000 h/a, i.e. at lower load factors [11.10].

In India nuclear generation cost is competitive with thermal generation where coal has to be transported over more than 800 km from coal reserves. In addition, the intrinsic compactness of nuclear fuel makes it easy to carry, thus reducing transport costs and strain on transportation networks. Nuclear generation cost will further decline when the capacity of nuclear power generating units is increased from the existing 235 MW(e) to a larger size such as 500 MW(e). Specifically, figures of 40.1 US mills/kW·h for the nuclear and 47.1 US mills/kW·h for the thermal power plant are indicated [11.11].

The Republic of Korea reported actual total generation costs for the KNU-1 station of 15.9 mills/kW·h (1978), 25.0 mills/kW·h (1979), 21.2 mills/kW·h (1980) and 32.8 mills/kW·h (1981), expressed in currency values of the respective year. Compared with average conventional thermal power generation costs, nuclear generation costs were less than half.

For the second Korean nuclear unit, KNU-2, with commercial operation scheduled in early 1983, total generation costs are projected at about 48 mills/kW·h compared with 51.4 mills/kW·h for a coal-fired plant and 83.5 mills/kW·h for an oil-fired plant [11.12].

In the USA total generation costs of nuclear plants in the past have generally been lower than coal generation costs, the ratio being in the range of 0.7 to 0.9.

Recent trends indicate that the nuclear advantage is eroding due to large increases in capital costs of the nuclear plants [11.13].

In addition to the presented figures, the following general conclusions emerged:

(a) Everywhere, except in certain regions where coal is abundant and cheap, nuclear plants are more economic than coal-fired power plants.
(b) Nuclear power plant capital investment costs have been increasing considerably everywhere but there are significant differences in this development between various countries. In France, for example, cost increases have been more manageable, amounting to about 50% in constant money terms over ten years, while in other countries (USA and Federal Republic of Germany) they represented a factor of about five over the same time span.
(c) The capital cost is the major contributing factor to the final generating cost of nuclear power plants, amounting to 50–80%. In comparison, the capital cost contributes 40–55% to the generating cost of a coal-fired power plant.
(d) One of the major contributions to the increases in the capital costs (in constant money) was quoted as having been the changes in regulatory requirements in some countries and the consequently required or perceived changes in designs, increases in scope of supply, and backfitting during execution of projects. All will cause delays and this effect of lengthened project times has multiplied through cost escalation and very much higher charges for interest during construction, especially with the high interest rates which prevailed during the late 1970s and early 1980s.
(e) Plant standardization would be one way to approach this problem and it has been quite successfully used in France, as demonstrated by decreasing construction and commissioning times for later units in a series of standardized plants. The Federal Republic of Germany also reported on a recently launched effort of co-operation between utilities and the regulatory authority to produce a series of standardized plants in a 'convoy' system which will cut down the number of licensing steps and thus shorten the licensing time.
(f) The cost savings which can be attained through several identical units at the same site were reported by Canada and France as amounting to 10–15% or even as high as 20–25% of the total cost of the multi-unit station.
(g) With the high contribution of the capital investment to the generating cost of nuclear plants, the availability for producing base-load generation becomes a most important parameter for their economic assessment. Availability has also been significantly different between various countries.

Chapter 12

FINANCIAL ASPECTS

As part of their central responsibility for the economic and social development, the initiative and responsibility for energy development rests with national governments. Accordingly, the responsibility for planning, co-ordination of development activities and financing such activities is the responsibility of each country. However, the international community in a spirit of common interest should be and actually is willing to assist developing countries in their effort to accelerate their energy development.

12.1. Financial energy investment requirements of developing countries

The petroleum price increases in 1973 and subsequently in 1979 and 1980 caused major changes in the financing of energy investments all over the world.

The industrialized countries were strongly affected, but finally learned, despite recession, to live with the new situation. However, the petroleum-importing developing countries were more severely hit. They subsequently got into an extremely uncomfortable financial position, since in addition to higher prices for imported petroleum, they had to pay higher prices for imported industrial goods and higher real and nominal interest rates on international borrowing but realized substantially lower export income. Table 12.I quantifies the situation described, with % figures referring to GDP, for the period 1973–1980.

The immediate liquidity problems have been solved as a whole but the outstanding foreign debt of the developing countries, outside Europe, at the end of 1982 had reached the enormous figure of 730×10^9 US$.

Although the industrialized countries are not exempt from investment difficulties, the investment situation of the developing countries is so much more dramatic, that it behoves this chapter to concentrate all further considerations on its analysis and possible solutions.

Indeed, in the last decade a substantial effort has been concentrated on finding practical means and ways to adapt the petroleum import bill of the developing countries to a manageable energy development and investment strategy. The basic idea, almost the basic dilemma, was that petroleum-importing countries, in particular, not only have to find the resources for energy investments that are more costly than before; they also have to finance imports of petroleum until these investments for enlarging national production and those to increase the efficiency of energy use begin to pay off.

TABLE 12.I. DIRECT IMPACT OF OIL PRICE INCREASES ON OIL IMPORTING COUNTRIES
(10^9 current US$) [3.8]

	1973	1974	1979	1980
Cost of oil imports	8.3	27.3	56.2	91.1
as % of GDP	1.4%	3.7%	4.0%	5.3%
as % of export earnings	10.1%	23.8%	22.5%	28.8%
Total debt outstanding	97.3	120.6	322.8	370.1
as % of GDP	16.7%	16.4%	23.0%	21.6%
as % of export earnings	89.3%	81.0%	102.3%	93.3%
Total dept service	16.1	17.5	60.5	75.2
as % of export earnings	24.8%	14.6%	32.6%	23.7%

Source: International Monetary Fund, World Economic Outlook 1982 (Washington, D.C., 1982).

With this goal in view, a series of remarkable studies have been carried out and some published, see Refs [12.1–6]. In general, the financial aspects involved energy development alternatives and options which had been well scrutinized previously and realistically checked for consistency with general GDP development strategies. Even extreme alternatives have been examined to avoid the 'scissors effect' by the year 2000 arising from too heavy a strain on accumulated capital and a persistent commercial deficit [12.6].

While some of the energy development issues will be further discussed in the next chapters, the following conclusions of the World Bank analysis are retained:

Developing countries can reduce energy costs, i.e. oil imports, by investing to improve energy efficiency and to produce more energy for export or for economic import substitution. Such an effort would require an average annual investment of about $\$130 \times 10^9$ (in 1982 dollars) over the next decade. This commitment would be required to achieve the commercial energy demand and production projected for 1995. The projections take into account economic growth and energy demand prospects as well as institutional and technical constraints. This effort will be necessary and justified under a wide range of plausible scenarios concerning future oil prices.

Table 12.II displays the investment structure and the distribution of funds for low-income, oil-importing and oil-exporting countries, as well as the subtotals

for each energy form. The cumulated investment requirements for the 1982–1983 decade amount to US 1426×10^9.

Table 12.III presents the foreign exchange component of the total investment requirements displayed in Table 12.III.

The magnitude of the required energy investments poses a major financing problem and it underlines the need for a greater effort to mobilize energy financing from all possible sources. About half, or $64 million per year, of the projected investment requirement is in foreign exchange. This compares with an estimate of US 25×10^9 for the actual 1982 flow of external capital to finance energy investment in developing countries. These flows would need to expand by about 15% a year in real terms to meet the projected foreign exchange financing requirements.

The financing constraints are most severe for the low-income countries. These countries are estimated to require 16% of the foreign exchange flowing to all developing countries, but receive only 9% of publicly guaranteed external credits and an even smaller share of other external capital. It is essential that greater support from official sources be provided, particularly in the form of concessionary credit consistent with these countries' overall debt servicing capacity.

A determined effort needs to be made by official and commercial financial institutions to encourage the use of project, or non-recourse, financing techniques in the oil and gas sector. Developing countries should do everything possible to draw on the resources of international oil companies.

Domestic resource mobilization for energy investment will be equally important. Appropriate pricing policies will be critical to ensure a reasonable degree of internal cash generation. Strengthening operational efficiency and the financial structure and procedures of energy enterprises should also make a substantial contribution.

The great effort assessed for the next decade becomes even more evident when compared to past investment figures: during the period 1960–75 the developing countries invested an average of $12 $\times 10^9$ (1980 US$) a year in energy development, i.e. in commercial energy, mostly electricity. This represented about 5% of total investment and 1.3% of GNP.

In 1980 energy investment reached $34 $\times 10^9$, almost triple the average of the earlier period, 10% of total investment and 2.5% of GNP.

12.2. Investment financing sources

Energy projects need for their realization both a financing component in national currency for the part of the investment activities to be paid for locally and a financing component in foreign currency for payments abroad for imported goods and services. According to the World Bank, the internally financed part of the energy projects submitted to the bank varied between 15 and 40% [12.7].

TABLE 12.II. COMMERCIAL ENERGY INVESTMENT REQUIREMENTS IN DEVELOPING COUNTRIES 1982–1992 (10^9 US$ (1982) [12.2]

	Low income countries	Middle income countries: Oil importers	Middle income countries: Oil exporters	All developing countries	Annual average, 1982–92
Electric power					
Hydro	74.4	132.2	31.8	238.4	21.7
Nuclear	6.3	40.8	6.1	53.2	4.8
Geothermal	0.1	4.3	2.1	6.5	0.6
Thermal	43.2	75.8	39.7	158.7	14.4
Transmission and distribution	49.9	101.8	49.9	201.6	18.3
Subtotal	173.9	354.9	129.6	658.4	59.8
Oil					
Exploration	21.2	48.9	99.1	169.2	15.4
Development	43.2	32.4	195.9	271.5	24.7
Other[a]	2.5	6.0	16.7	25.2	2.3
Subtotal	66.9	87.3	311.7	465.9	42.4
Refineries[b]	30.8	52.8	39.7	123.3	11.2

Natural gas					
Exploration, development, transmission and maintenance	17.5	16.8	30.2	64.5	5.9
Domestic distribution[c]	4.3	4.7	7.4	16.4	1.5
Exports	0.0	3.0	6.2	9.2	0.8
Subtotal	21.8	24.5	43.8	90.1	8.2
Coal	55.2	27.2	6.3	88.7	8.1
Total	348.6	546.7	531.1	1426.4	129.7

Note: These estimates are for the investments required during 1982–92 to achieve the energy production levels set out.

Some additional investments amounting to $13 billion per year will be required in the 1993–95 period to complete the projects for 1995 production. Expenditures shown in this table do not include investments for fuel storage and retail distribution (except for pipeline investments for domestic distribution of natural gas) and for infrastructure associated with energy imports.

[a] Includes maintenance of old fields, enhanced and secondary oil recovery, pipelines, and infrastructure.

[b] Estimates include investments in refinery modifications necessary to achieve a balance between petroleum product supply and demand within developing countries, as well as investments in refinery rehabilitation and replacement of old plant and in energy conservation measures. These estimates could vary by as much as 20 per cent, depending on assumptions concerning the refinery mix in China, and on the extent to which product imbalances in the developing countries are met through direct trade in refined products. Estimates exclude investments in infrastructural development, which amount to about $10 billion.

[c] Distribution of gas from major transmission pipelines to residential and commercial users.

Source: World Bank estimates.

TABLE 12.III. FOREIGN EXCHANGE REQUIREMENTS FOR COMMERCIAL ENERGY INVESTMENTS IN DEVELOPING COUNTRIES 1982–92
(10^9 US \$ estimated annual average) [12.2]

	Electricity	Coal	Oil and gas	Total commercial energy
Middle income countries				
Oil exporters	6.5	0.3	22.8	29.6
Oil importers	10.2	0.9	5.3	16.4
Low income countries	3.2	1.0	4.4	8.6
All developing countries	19.9	2.2	32.5	63.9[a]

[a] Includes \$9.3 billion for refineries, which is not included in country group or individual fuel totals.

Source: World Bank estimates.

12.2.1. National investment financing sources

The national or local financing sources are:

(1) Own resources
- equity capital
- cash flow

(2) Debt capital
- domestic bonds
- local bank credits
- donations and credits from public entities
- contributions for future services of the project
- leasing.

It is expected that the major difficulties which developing countries will encounter in financing their energy development will be for the internal part of the investments. The funds in national currency can only be generated by increased national savings or a re-allocation of savings, while funds in foreign currency originate from the much larger reservoir of world savings.

Developing countries will therefore need to develop a policy framework for attracting the private and public capital needed, as well as for improving the mobilization of domestic public resources, particularly by sector energy companies.

The mobilization of domestic resources for energy investment has been constrained by several factors, some specific to the energy sector and others relating to the more general problem of low domestic savings rates in the developing countries. Clear limits on the ability of LDCs to borrow from private and public sources and the important local cost element in total investments, particularly in coal and hydro projects, make domestic resource mobilization of critical importance. The energy sector in developing countries is dominated by public sector companies. In the power sector, public utilities operate in a highly regulated environment. During the early 1970s, most power utilities were able to generate a portion of the needed investment from internal resources. Inadequate tariff increases, coupled with rising unit investment and fuel costs, have severely drained power sector finances. Financial performance has also been weakened by low capacity utilization and slow collections, particularly from municipalities and other government agencies.

The most important problem, however, has been the widening gap between electricity tariffs and real investment and operating costs. Efforts to reduce domestic inflation and maintain consumer satisfaction have made many governments reluctant to approve regular electricity tariff increases. The increases which have been granted tend to be on an ad hoc basis, limiting the ability of the utility to control and plan for its financial operations. In many cases, the impact of tariff increases has been reduced by inflation and accelerating investment costs for the development of power facilities, including costly hydro sites, and high capital costs of switching from oil to other energy sources for power generation. An additional problem is the absence of any domestic long-term capital markets in the developing countries. Because power utilities have not been able to finance the local cost component of investment programmes internally, they have been forced to borrow foreign exchange.

All of these factors have made it difficult for national power companies to generate internal and external funds for investment programmes. In the World Bank's experience, most national power companies in the developing countries have not been able consistently to meet self-financing ratios of 20–30% over time. Shortfalls in local cost financing have led some governments to create new sources of medium- to long-term local financing, as well as increase contributions from the public budget for project financing and direct equity injections to the national companies.

National oil companies also operate in a regulated environment. Most are integrated through exploration, development, refining, and marketing, including imports of crude oil and products. In general, their record of generating investment funds has been mixed. In cases where exports of domestic oil and gas are based on international prices and domestic prices both cover costs and provide an adequate per barrel net return to the company, self-financing has contributed to new investment. Where the national oil company (NOC) supplies the domestic market at regulated prices which do not cover total costs, the potential for self-financing is limited.

NOCs are also an important source of tax revenue for the national budget through their generation of export earnings, royalties, other production-related taxes and corporate income taxes. While natural resource taxation is appropriate, particularly because of the high rent element inherent in oil and gas development, in some cases taxation levels have been excessively high and inflexibly applied.

The issues for coal are somewhat different. Most coal projects in the developing countries are not export-based but are designed to produce coal for domestic markets, including power generation. Thus, it is difficult to attract foreign equity investment and/or private commercial interest.

Insofar as domestic sources cannot meet the local investment financing requirements, the balance has regretfully to be drawn from international financing sources.

12.2.2. International investment financing sources

The international financing sources for investment projects in developing countries can be divided into the following categories:

(1) Multilateral development institutions
- (a) The World Bank Group
  - – The International Bank for Reconstruction and Development (IBRD)
  - – The International Development Association (IDA)
  - – The International Finance Corporation (IFC)
- (b) Regional and subregional development banks and organizations
  - – The African Development Bank/Fund (AFDB/AFDF)
  - – The Asian Development Bank (ADB)
  - – The Inter-American Development Bank (IDB)
  - – The European Economic Community (EEC)
  - – The European Development Fund (EDF)
  - – The European Investment Bank (EIB)
  - – The European Non-Associated Country Programme (EC-NACP)
  - – The Special Action Account (EC-Special)
- (c) Other institutions
  - – The Arab Bank for Economic Development in Africa (BADEA)
  - – The Arab Fund for Economic and Social Development
  - – The OPEC Fund for International Development
  - – The International Fund for Agricultural Development (IFAD)
  - – The Islamic Development Bank (ISDB)
- (d) United Nations Funds
  - – United Nations Development Programme (UNDP)
  - – United Nations Revolving Fund for Natural Resources Exploration
  - – United Nations Capital Development Fund

(2) Bilateral financing sources
   – Member countries of the Development Assistance Committee (DAC) of the Organisation for Economic Co-operation and Development (OECD)
(3) International markets
   – Loans
   – International bonds (Eurobonds)
   – Foreign bonds
(4) Export credit
   (a) Export credit agencies:
      For example: – Export-Import Bank – USA
      – Export Credit Corporation – Canada
      – Kreditanstalt für Wiederaufbau (KfW) Federal Republic of Germany
   (b) Equipment suppliers' credit.

As can easily be recognized from the above enumeration, there are wide possibilities for developing countries to secure financial support for their foreign currency needs provided that the proposed projects are solidly founded and well serving the countries' socio-economic development.

In the past the foreign capital flows originated almost half and half from official multi- and bilateral sources and from private sources [12.2]. Although an increase of the official flows would be desirable, especially because of their softer amortization conditions, it seems that the additional funds will have to come in the future mainly from international markets now in expansion, from which in the past only a few developing countries succeeded in obtaining loans on favourable conditions.

Under these conditions it appears highly advisable that developing countries make all efforts to appear as reliable borrowers on the private international money market, both by studying their loan conditions well and developing in their countries the managerial framework and expertise to use them best and service them punctually.

12.3. The main international financing sources

In this subsection, the main international financing sources will be dealt with in more detail. Their origin, nature, functions and operations regarding the energy sector will be summarized and compared.

12.3.1. The World Bank Group

The World Bank Group consists of three international financial institutions: The World Bank, i.e. the International Bank for Reconstruction and Development (IBRD) and its two affiliated institutions: the International Development

Association (IDA) and the International Finance Corporation (IFC). Each of these institutions has a specific role, but all promote the same general goal: economic development.

The World Bank is the oldest institution. It was created in 1944, together with the International Monetary Fund. It lends money to governments or, with the guarantee of the concerned country, to autonomous organizations or private enterprises, at conventional interest rates.

The International Development Association, created in 1960, finances the same type of projects as the World Bank and selected on the same criteria, however, on easier conditions for the foreign currency balance of the borrowing country. Its intervention is limited to developing countries with a GNP per capita of less than US \$300 and which cannot obtain the foreign money they need by conventional loans.

IDA has no personnel of its own; all staff members of the World Bank embody automatically the same functions at IDA. As of March 1978, IDA had awarded 720 credits – the term 'loan' for a World Bank operation and 'credit' for an IDA operation allows a simple distinction between the two activities – to 66 countries, totalling some US \$13 $\times 10^9$.

The International Financial Corporation (IFC), created in 1956, complements the operations of the World Bank, promoting and financing investment by private productive enterprises in developing countries, at commercial interest rates. In March 1978, IFC had 108 members and its total financing amount of US \$1.8 million was distributed over 302 enterprises in 63 countries.

Essentially, both the World Bank and the IDA operate in the same way. Selection, evaluation and financing of projects are practically alike. The basic difference between them can be found in the origin of their funds and, subsequently, in the conditions under which loans or credits are granted.

The World Bank started its operations with a paid-in capital representing 10% of its members' subscriptions, i.e. US \$2.3 $\times 10^9$. However, in the meantime, borrowings from the international financial markets became the Bank's main source of funds in addition to its interest reserves of some US \$2.2 $\times 10^9$, resulting from its profits. The obligations issued by the Bank are guaranteed by the share of the not-paid-in capital, totaling 27.782 $\times 10^9$ dollars. These important guarantees and the solid reputation of the Bank allow it to borrow and relend money on very reasonable conditions. This is the main advantage offered by the Bank to the borrowing countries. The Bank can supply them with loans on better conditions than they could normally obtain on the international capital market.

On the contrary, the IDA credits bear no interest charges, but an administrative charge of almost 0.75%. The pay-back period of the credits is much longer, normally 50 years as compared to 15 to 20 years for World Bank loans. IDA is in the position to offer these advantageous conditions since its funds originate mainly from donors or from loans without interest made by a group of 21 initiator countries. However, it has always been more difficult for IDA to reconstitute its necessary resources than for the World Bank to obtain supplementary funds by loans from the capital market. From an initial subscription of 780 million dollars in 1960, IDA has reached in the meantime US \$4.2 $\times$ 10^9, including a transfer of 915 million dollars from the World Bank from its net revenues.

Until 1976 the World Bank intervened little in the area of fossil fuels, providing 750 million dollars for oil and gas pipelines and coal exploitation. No petroleum loans have been granted, either because petroleum development in the majority of developing countries was only marginally economic as long as the international petroleum prices were low and the supply potentially high or, when economically justified, there were no difficulties in obtaining financing from other sources.

At the end of 1973, the situation changed and Bank studies identified among the 70 oil-importing developing countries, 40 to 50 which could produce petroleum. The new petroleum prices now justify exploitation in a series of areas regarded before as not economically attractive. However, the majority of these countries with petroleum potential have neither the technical expertise nor the financial resources for exploiting it. Therefore, the Bank acted by increasing its role in this critical area, serving as a catalyst for providing financial resources and technology transfer for petroleum exploration and development in these countries.

As far as the electricity sector is concerned, the Bank has in the past focused its aid on improving investment decisions with a view to minimizing the costs of long-term development of electrical systems, improving the management of existing ones or implementing new institutions in this sector and ensuring early on the necessary financing to avoid any slow-down in the construction plans or interruptions in service. In recent years, the Bank has extended its activities to rural electrification and it tries to be present from the very beginning in order to contribute to an optimal conception of the projects.

Regarding nuclear energy, the Bank has attentively watched its development and in 1974 reached the conclusion that technically and economically, nuclear power projects could be dealt with using its normal procedures. The World Bank seems ready at present to consider limited participation in the financing of nuclear power in developing countries, should the corresponding projects be the 'least cost' alternative for supplying the growing demands for electric power and should such participation attract other foreign sources of finance.

In initial preparatory phases, the Bank could assist, with its considerable management experience, the developing countries – either directly or through the substantive aid of the IAEA – in their endeavour to build up the institutional framework and technical expertise necessary for nuclear energy introduction. Later, for actual projects, besides participating to a limited extent in the financing which would mobilize other financing sources (official or private), the Bank could assist by watching over the quality and timing of the project [12.8].

Because of the relative unfamiliarity of both the Bank and the developing countries with new and renewable sources of energy, as well as the early state of

TABLE 12.IV. WORLD BANK ENERGY LENDING (10^6 US$) [12.3]

	1976	1977	1978	1979	1980	1981	1982	Totals FY76–82
Electric power	949.3	951.5	1146.2	1354.9	2392.3	1323.0	2131.2	10 246.4
Oil and gas	60.0	150.0	–	112.4	385.0	649.5	539.3	1 896.2
Coal	–	–	10.0	–	72.0	10.0	227.0	319.0
Other	–	–	–	58.0	29.0	364.0	460.4	911.4
Total	1009.3	1101.5	1156.2	1525.3	2878.3	2346.5	3357.9	13 375.0

knowledge concerning the effective strategies for development of the respective technologies, the Bank, as yet, has moved slowly and cautiously in the financing of projects other than large-scale hydro-electric power generation and fuelwood production.

The amount and structure of World Bank energy lending 1976–1982 is illustrated by Table 12.IV.

While power lending accounted for 77% of the total programme (64% of the 1982 programme), the rapid growth in the World Bank's oil and gas lending programme is unique among the multilateral institutions. From the inception of the oil and gas programme in 1977, projects have been identified in over 50 countries. Since the approval of an expanded lending programme in 1980, 43 projects have been approved for more than US \$1.6 $\times$ 10^9 in loans and credits. In 1979, the Bank also initiated a programme to accelerate coal exploration and development, focusing on 25 countries with good geological potential. Since then, the Bank has made four loans totalling US \$289 $\times$ 10^6 for projects with a total cost of US \$1.8 $\times$ 10^9. Twelve new projects are in preparation.

The Bank's overall lending activities in the energy sector also include programmes for refinery conversion, energy conservation, and renewable and new energy resources. To encourage energy conservation, the Bank has supported a wide range of activities, including plant energy audits and the financing of retro-fitting equipment to improve energy utilization. Bank lending in this area, including fuelwood, was US \$278 million at the end of 1982.

As World Bank lending in the energy sector has expanded, its share in total project costs has declined. In 1981, for example, the Bank financed only about 16% of total project costs, with cofinancing providing 20%, and the balance provided by the borrower. As in the case of the ADB and IDB, to ensure that

TABLE 12.V. WORLD BANK ENERGY LENDING PROGRAMME 1982–86

	Five-year total (10^9 US\$)	Annual average (10^9 US\$)	% of total
Electric power	12.9	2.58	42.6
Coal	2.3	0.46	7.6
Oil and gas	10.1	2.02	33.3
Other (fuelwood, retro-fitting, etc.)	5.0	1.0	16.5
TOTAL	30.3	6.06	100

The above figures are project commitments (disbursed over periods of 2–6 years) in current dollars, i.e. they have been increased for expected inflation.

developing countries will be able to mobilize financing for high priority energy projects, the World Bank intends to promote co-financing actively, particularly for energy projects, and to encourage the financial strengthening of national oil companies to increase internal and external resources available for energy investment.

The World Bank energy lending programme 1982–1986 are presented in Table 12.V. It amounts to US \$30 $\times$ 10^9 over five years with 33%, i.e. US \$10.1 $\times$ 10^9 in the petroleum and natural gas sectors. It confirms herewith the World Bank's decision substantially to enhance its intervention in these sectors [12.2, 12.9].

12.3.2. Regional and subregional development banks and organizations

The regional and subregional development banks in Africa, Asia and Latin America are active in the financing of energy projects. They have also taken an interest in promoting activities in the field of new and renewable sources of energy in their member states and provide resources for project preparation. These banks have the advantage of proximity and closely knit relations with their member states and have detailed knowledge of local conditions, resources, priorities and needs in the field of new and renewable sources of energy. While maintaining close links with the World Bank and its technical expertise, they have a potential to make available their own resources as well as additional funds gathered in their member states.

TABLE 12.VI. EUROPEAN INVESTMENT BANK LENDING FOR ENERGY PROJECTS IN DEVELOPING COUNTRIES (10^6 US $) [12.3]

	1975	1976	1977	1978	1979	1980
Power production	26.1	89.7	–	45.4	141.6	285.8
Thermal	26.1	41.6	–	10.5	60.4	141.8
Hydro	–	48.1	–	34.9	81.2	144.0
Nuclear	–	–	–	–	–	–
Transmission	–	–	40.7	2.6	46.5	61.6
Total energy	26.1	89.7	40.7	48.0	188.1	347.4
Energy as % of total lending	23.5	73.2	22.2	11.4	21.7	43.6

Source: Annual Reports of the European Investment Bank 1975–1980. Loans converted from the European Currency Unit (ECU) to current dollars.

Regional and subregional development banks also act as lead agencies for co-financing operations. A priority task already being undertaken by these banks is the surveying of the new and renewable sources of energy potential and needs by region and subregion, as well as by category of new and renewable sources of energy; also assessing the availability of local structures and resources and technical/operational capacities with a view to studying, promoting and implementing investment projects in this field. In this connection, they can have an important catalytic role in the development of national absorptive capacity, including institutional building and training of national energy management [12.10].

Reference [12.3] provides more detailed information on the lending activities of the Asian, African and Inter-American Development Banks, as well as on lending figures and lending structures.

The European Investment Bank (EIB) responded to the mid-1970 increase in oil prices by placing new emphasis on its energy-lending activities. Before 1975, energy represented only 6.4% of the total EIB lending programme in the developing countries and was confined mainly to the power sector. During the 1975–81 period, energy lending rose to an average of 32% of the total programme. Table 12.VI summarizes the EIB's energy-lending activities, which have focused on the development of domestic energy resources, particularly hydro- and coal-based power generating facilities. In 1981, the EIB made its first loans for petroleum and nuclear projects. US 17.4×10^6 were provided for the development of a nuclear plant, and US 8.7×10^6 went for oil and gas exploration activities, including projects in Senegal and Tanzania. EIB loans were often combined with the more concessional lending of the European Development Fund. Interest subsidies granted by the EDF are managed by the EIB and integrated into the loan process.

Table 12.VII brings an overview of the multilateral commitments for energy, 1975–1981, totalling US $\$17.1 \times 10^9$, out of which the World Bank alone accounted for over US $\$10 \times 10^9$.

12.3.3. The United Nations

The United Nations assistance is channelled through the United Nations Development Programme (UNDP), which also operates other United Nations funds which have as part of their mandate the financing of activities in the field of energy.

UNDP activities in the energy field which are eligible for UNDP assistance include identification of potential sites for hydro power development; exploration for coal, uranium, geothermal energy, petroleum and natural gas (excluding exploratory drilling); assessment, research and development of various renewable energy sources; energy planning, including planning for rural electrification and the promotion of small/low-cost energy sources at the village level; legislation, and training. Actual projects may consist of a combination of activities and may be integrated in larger development activities. UNDP resources for energy are expected to be US $\$5 \times 10^9$ in the 1982–86 programme cycle.

On an interim basis, voluntary contributions in cash or in kind are being sought for the UNDP Energy Account to undertake activities designed to meet urgent needs for assistance, especially in the poorest developing countries, for financing high-risk, capital-intensive projects. The Energy Account is meant to complement the World Bank's increased lending programme in the energy field over the next five years, to lead to project identification which may lead to subsequent bank capital financing.

The United Nations Fund for Natural Resources Exploration is concerned with pre-investment studies in minerals, water and energy development. Since it has limited resources, the Fund's activities are focused mainly on exploration for solid minerals. Governments are expected to reimburse the Fund at a rate of 2% of the annual value of actually produced commodities over a period of 15 years, up to a ceiling of 15 times the original investment.

12.3.4. Bilateral financing from DAC countries

Member countries of the Development Assistance Committee (DAC) of the Organisation for Economic Co-operation and Development (OECD) recognize the importance of the efforts of developing countries for reducing their dependence on oil imports and meeting, at the same time, the rising energy requirements associated with their expanding and modernizing economies, and regard them as a

TABLE 12.VII. MULTILATERAL COMMITMENTS FOR ENERGY 1975–1981, in 10^6 US$ [12.2]

	1975	1976	1977	1978	1979	1980	1981	Total
Asian Development Bank	153	147	217	249	325	385	480	1950
African Development Bank	19	13	27	28	64	52	32	235
Inter-American Development Bank	270	288	407	923	397	416	935	3636
European Investment Bank	26	90	41	48	188	348	140	881
Subtotal	468	538	692	1248	974	1201	1687	6702
World Bank	584	1009	1102	1156	1467	2849	2233	10400
Total	1052	1547	1749	2404	2441	4048	3820	17102

Source: Annual Reports.

TABLE 12.VIII. COMMITMENTS OF BILATERAL CONCESSIONARY ASSISTANCE FOR ENERGY 1975–1980 [12.2]

Donor	(10^6 US$)	(%)	Energy as percentage of donor's total
Canada	366	5	23
France	249	3	8
Germany, Fed. Rep.	879	12	11
Japan	2125	28	25
United Kingdom	41	1	7
USA	1057	14	7
OPEC bilateral	1622	22	12
Other	1162	15	..
Total	7501	100	..

.. Not available.

Source: World Bank Debt Reporting System. Figures may differ from those of other sources as a result of differences in project and financing classification.

major challenge for international co-operation. They are also aware of the fact that the investment and associated planning, training, research and financing needs are enormous and that developing countries need assistance in developing their energy potential. Therefore, DAC countries are ready to provide increased financial support – mainly through co-operation. They regard expanded co-operation in this area as a matter of mutual interest since it is essential for sustained development and contributes to better balanced international energy markets.

Consequently, the DAC countries committed in 1978 close to US $\$1 \times 10^9$ as official development assistance (ODA) to the energy sector in developing countries. These commitments rose to US $\$1.4 \times 10^9$ in 1979 – some 5% of the total ODA commitments in that year. Table 12.VIII totals the commitments over the 1975–1980 period.

In addition, DAC countries' export credit commitments for energy development in developing countries amounted to roughly US $\$10 \times 10^9$ annually in 1978 and 1979. Foreign direct investment, bank lending and lending through the bond market to the energy sector may have amounted to another US $\$3.5 \times 10^9$ per year.

Around half of DAC assistance to the energy sector was extended to the least developed and other low-income countries, whereas these countries received only some 3% of bilateral non-concessionary flows for the energy sector. Within DAC financial support for the energy sector, around 75% of bilateral ODA flows and about 90% of non-concessionary flows financed electricity production, transmission and distribution. Other commercial and non-commercial renewable sources of energy received a marginal share of external financing support.

12.3.5. OPEC financing

The OPEC Fund for International Development is funded by contributions from member countries of OPEC amounting to US $\$4 \times 10^9$. It is one of the significant financing sources for developing countries, especially low-income countries. The fund undertakes both programme and project lending as well as financing of technical assistance. The terms vary from grants to non-concessionary loans. Although the fund's project financing has been concentrated on projects in agricultural production and energy, the fund's financing is not restricted to these areas. In addition, the fund has co-financing and technical assistance arrangements with organizations such as the World Bank, UNDP and the World Food Programme.

OPEC countries' bilateral and multilateral aid commitments to energy development were around US $\$850 \times 10^6$ in 1978 and US $\$530 \times 10^6$ in 1979 (16% of their total assistance programmes). Both figures include US \$230 to 250×10^6 petroleum credits. The bilateral commitments totalize US $\$1.6 \times 10^9$ in the period 1975–1980 – see Table 12.VII.

12.3.6. The international market

The major instruments available for financing from this market are loans secured in the international credit markets (Euroloans), or bonds which are either issued in the international capital market (Eurobonds) or in the foreign capital markets (foreign bonds).

The main characteristics of Euroloans are that they are extended by banks using borrowed funds, are usually non-negotiable and large amounts are usually available. Electric utilities, particularly those involved in nuclear power, have raised in this market US $\$7.7 \times 10^9$ in 1978 (80 loans) and US $\$5.2 \times 10^9$ (35 loans) during the first half of 1979, among which is a loan of US $\$732 \times 10^6$ obtained by a developing country, namely the Republic of Korea.

For electric utilities, maturities for loans obtained on this market ranged from 10 to 12 years (exceptionally 15 years) with three to seven years' grace periods. The interest rates are usually floating. For example, the base rate of the London International Bank offered 'LIBOR' varied between a low of 6% and a high of 14% during the 1970s.

12.3.7. The export credit agencies

Another most important foreign source of financing consists of export credit agencies such as the Export-Import Bank in the USA, the Export Credit Corporation in Canada or the Kreditanstalt für Wiederaufbau in the Federal Republic of Germany. Export credits represent one of the principal borrowing instruments in particular for developing countries, through which were financed the majority of plants which have been built or are under construction in these countries. The main advantages provided by export credits are:

(1) Funds are available in substantial quantities even during internationally tight money situations, and particularly during the present period of low economic growth.
(2) Financing usually covers up to 85% (sometimes up to 100%) of the cost of services and equipment from the exporting country. .
(3) Maturities are generally longer than in the conventional financial markets. For nuclear plants, export credit maturities are usually 12 to 15 years from the date of completion of the project, thus providing about 20 years overall maturity and the period can be even longer in specific cases.
(4) There is an extended grace period on repayments, which usually covers the entire construction period.
(5) A subsidized interest rate is offered, which is lower than commercial rates.

In spite of some variations from one country to another, most export credit schemes share the following additional characteristics:

(1) They generally involve two levels of intervention: specialized governmental entities which deliver the appropriate credit insurance or guarantees, and official financial institutions or commercial banks which provide the funds.
(2) The currency in which they are transacted is generally the national currency of the exporting country. However, some countries are increasingly lending in Eurodollars by borrowing the required amounts in the international market and relending them to the borrower under the guarantee of their export credit insurance agency.

12.3.8. Financing of nuclear power plants

The financing of integrated nuclear energy projects, i.e. including all installations up- and downstream of the nuclear power plant, is too complicated to be dealt with at this stage; in addition, in many cases, the problem is limited to the power plant alone. Therefore, as example, only the latter will be considered below.

In the past, in industrially advanced countries, local sources of financing have been largely used by state-owned private or mixed-capital utilities. However, over

TABLE 12.IX. NUCLEAR POWER PLANT OR NSSS EXPORTS (June 1981) – IN OPERATION OR UNDER CONSTRUCTION [12.14]

From	USA		Federal Republic of Germany		Canada		France		Sweden		United Kingdom		USSR	
To	No. of units	Total net capacity (MW(e))	No. of units	Total capacity (MW(e))	No. of units	Total capacity (MW(e))	No. of units	Total capacity (MW(e))	No. of units	Total capacity (MW(e))	No. of units	Total capacity (MW(e))	No. of units	Total capacity (MW(e))
(a) Developing countries														
Argentina	–	–	2	1027	1	600	–	–	–	–	–	–	–	–
Brazil	1	626	2	2490	–	–	–	–	–	–	–	–	–	–
Bulgaria	–	–	–	–	–	–	–	–	–	–	–	–	5	2632
Czechoslovakia	–	–	–	–	–	–	–	–	–	–	–	–	6	2480
Cuba	–	–	–	–	–	–	–	–	–	–	–	–	1	408
Hungary	–	–	–	–	–	–	–	–	–	–	–	–	2	816
India	2	396	–	–	2	413	–	–	–	–	–	–	–	–
Korea, Rep. of	6	4905	–	–	1	620	2	1800	–	–	–	–	–	–
Mexico	2	1308	–	–	–	–	–	–	–	–	–	–	–	–
Pakistan	–	–	–	–	1	125	–	–	–	–	–	–	–	–
Philippines	1	620	–	–	–	–	–	–	–	–	–	–	–	–
Romania	–	–	–	–	1	660	–	–	–	–	–	–	–	–
Taiwan	6	4921	–	–	–	–	–	–	–	–	–	–	–	–
Yugoslavia	1	632	–	–	–	–	–	–	–	–	–	–	–	–
Subtotal	19	13411	4	3517	6	2426	2	1800	–	–	–	–	14	6336

(b) Industrially advanced countries														
Belgium	4	2 796	–	–	–	–	3	2675	–	–	–	–	–	–
Finland	–	–	–	–	–	–	–	–	2	1320	–	–	2	840
German D.R.	–	–	–	–	–	–	–	–	–	–	–	–	9	3 338
Germany, Fed. Rep.	2	252	–	–	–	–	–	–	–	–	–	–	–	–
Italy	5	3 231	–	–	–	–	–	–	–	–	1	150	–	–
Japan	10	7 012	–	–	–	–	–	–	–	–	1	158	–	–
Netherlands	1	51	1	450	–	–	–	–	–	–	–	–	–	–
South Africa	–	–	–	–	–	–	2	1842	–	–	–	–	–	–
Spain	12	9 655	1	990	–	–	1	480	–	–	–	–	–	–
Sweden	3	2 630	–	–	–	–	–	–	–	–	–	–	–	–
Switzerland	4	1 962	1	920	–	–	–	–	–	–	–	–	–	–
Subtotal	41	27 589	3	2360	–	–	6	4997	2	1320	2	308	11	4 178
TOTAL	60	41 000	7	5877	6	2426	8	6797	2	1320	2	308	25	10 514

Grand total: 110 units 68 242 MW(e)

Note: Nuclear power plant exports to Austria and Iran are not included.

the last several years, the capability of utilities in most industrially advanced countries to finance large new investments (such as those encountered with nuclear power plants) with their own resources, has been declining. The utilities' internal cash flow generation capability has been substantially jeopardized by major investment expansions, the higher unit cost of new facilities, higher operating costs (particularly fuel) and interest rates and depreciation provisions generally based on non-revalued assets. The combination of declining earnings with insufficient depreciation resulted in cash flow growing more slowly than the new investments which they were supposed to finance.

Utilities have attempted to fill this financing void with equity capital provided by the state for state-owned utilities or raised in local capital markets by private utilities by tapping local sources of debt-financing such as domestic bond issues, local bank credits and credits from public entities and even entering leasing arrangements [12.11]. They have also been increasingly using international sources of financing over the past ten years due to increasing scarcity in local debt capital markets.

Even in industrialized market economies, government interventions via taxes can be cited to ease the financing situation. For example the so-called 'coal-cent' was introduced long ago in the Federal Republic of Germany as a tax on each consumer kW·h, in support of the further utilization of partly uneconomic hard coal production for electricity generation or in 1981 in Spain, a tax of 5% of the national average kW·h cost, for every kW·h supplied. The revenue from this tax will serve for the development and maintenance of the infrastructure of zones where coal-, hydro- or nuclear power plants (i.e. non-hydrocarbon-fired) are implemented [12.12].

Another relevant example is the nuclear programme in Egypt. There is no doubt that Egypt is in no position to cover all the required financing for the eight nuclear units it is intending to build from now to the year 2000. However, the Egyptian Government decided to allocate a portion of the oil revenue surplus to cover part of the foreign component requirements of the nuclear programme. This oil revenue surplus is placed in a special fund only for that purpose. More than US $600 million is already available in that fund. Of course this is added to the local component [12.13].

As far as exported nuclear power plants are concerned, with rare exceptions, the foreign currency component – up to the level required – has been secured and financed through bilateral arrangements.

When requested, the terms of financing have, as a matter of fact, been an essential ingredient of the bids submitted by the various vendors. They were in most cases equivalent to substantial rebates, the extent and value of which were a decisive factor in the final selection of the supplier, even though the concessionary elements did not lend themselves easily to quantitative comparisons. As a result, financing was usually related to projects and prevailing market conditions, and there was no guarantee that similar terms would be offered again in the future, although at present, nuclear equipment manufacturers in most supplier countries are eager to export, faced by lagging nuclear development programmes in their own countries and fierce international competition in those countries which continue their construction programmes.

The volume of the export transactions for nuclear power stations has been considerable: 110 units with a total capacity of about 68 000 MW(e) have been exported by seven supplier countries. Table 12.IX shows the number of units and their capacity which were exported from each of the supplier countries to the various developing and industrially advanced recipient countries; 45 of these units were exported to 14 developing countries.

In addition to the international development organizations presented in the first part of this subsection also active in the energy field but not currently involved in nuclear power financing, two more organizations should be named which, however, also include this field in their operations. They are the European Investment Bank (EIB) and the European Atomic Community (EURATOM), both specialized agencies of the European Economic Community (EEC).

12.4. Energy lending procedures

All lending organizations display a profound prudence in the selection of borrowers in order to make sure they will get their money back. In addition, official credit organizations which, according to their by-laws, have to serve specific purposes, for example financing of development, have to stick closely to these rules. That is particularly the case with World Bank loans.

It is, therefore, understandable that in order to comply with the aforementioned conditions, these organizations exercise a control of the proposed investment projects which goes far beyond the checking of the purely financing requests and reimbursement guarantees.

Undoubtedly, the most demanding in this respect is the World Bank. Since it is the major lending institution for developing countries, it is imperative to be informed in advance on the requirements a project and the borrower have to fulfil in order to apply successfully for a financing loan.

Although each lending organization has its specific conditions, once those of the World Bank have been described, little need be added.

It is not possible to give here more than a brief summary of the lending conditions and control of the World Bank. They are amply described in papers presented by World Bank Staff in previous IAEA courses, [12.7, 8, 15 and 16]. However, for general information, the following basic principles and aspects, presented in a project's chronology from the first phase of identification to the last retrospective evaluation may be noted:

(1) Identification. In this first phase Bank and borrowers select projects capable of contributing to development strategy and complying with

realization criteria of the Bank. These projects are then included in the Bank's lending programme for the given country.

(2) Preparation. The borrowing organization carries out pre-investment and feasibility studies on the project, the Bank participating with advice and possibly financing this phase or helping the borrower to find other financing sources. For energy projects, depending on their nature, this phase lasts one to two years, or even longer, for example for large hydro power plants.

(3) Evaluation. The Bank's staff proceeds with an in-depth examination of the project, both in the field and at Headquarters.

As mentioned, this analysis is not confined to the financial aspects only; rather it extends to all other significant aspects such as technical, economic, institutional and managerial. The Bank feels obliged to check that there is a positive impact of the project on the national economy and for this reason surveys the latter's whole framework. It would, if relevant, include shadow-prices for this examination. On the other hand it goes so far for example as marginally to check, in the case of an electricity generation investment, not only opportunity alternatives for the same investment amount, but also to compare the costs engendered for the national economy if the project is not carried out at all. However, such a comparison serves more to identify extreme economic limits than to question an investment required for technical and possibly political reasons, and basically also acceptable from the economic point of view. In this respect and for further refined considerations of the analysis methodology, Ref. [12.7] supplies first-hand information.

The analysis ends with an evaluation report, which serves as a basis for negotiation with the borrower.

(4) Negotiations. In this phase the Bank studies with the borrower the measures to be taken for successful implementation of the project. The agreements arrived at will constitute an integral part of the loan documents. The project is then submitted for approval by the Bank administrators. If it is approved, the two parties sign the loan agreement and the implementation of the project begins.

(5) Implementation and supervision. The borrower is responsible for the execution of the project. The Bank supervises the execution through the advance reports submitted by the borrower and periodical visits in the field. Procurement of goods and services for the project must follow the Bank's official procedures in a spirit of efficiency and economy.

(6) Retrospective evaluation. Once the last payment of the loan amount has been made, a separate, independent department of the Bank prepares its own evaluation report, in general based on the documentation existing at headquarters and only if necessary are field visits included. This retrospective evaluation offers a final balance of past experience and possible suggestions for improving the project's cycle.

TABLE 12.X. ESSENTIAL ELEMENTS OF FINANCIAL ANALYSIS IN WORLD-BANK-FINANCED PROJECTS

Accounting system

Accounting data

Past financial performance

Present financial position

Financing plan for the proposed projects

Financial projections based on financial objectives – income statement, cash flow, balance sheet, working capital, investment programme

Detailed assumptions used – The Bank should suggest assumptions to the extent possible, e.g. minimum financial objectives

Sensitivity analysis for key variables

Management/efficiency indicators:

- % Population served
- Per head consumption
- % system loss
- Days accounts receivable
- Employees/1000 consumers
- % Contribution to investment
- % rate of return
- Debt service ratio
- % Debt (debt and equity)
- Real tariff increase
- Salary/employee/month
- Operating ratio
- Operating expenses/unit sold

During the first phase of the described project-related procedures, additional information is collected regarding the borrower's organization, as for example, status of entity (autonomous or under strict governmental control), management (centralized or decentralized), accounting system and practices in force, corporate planning, budgeting and budgeting control, financial regulations, internal control and audit systems, data processing, competence and training of financial staff, etc. A special analysis is devoted to the accounting system, checking its capacity and competence in general and in relation to the project under consideration.

As far as the financial analysis is concerned, the main issues and items checked are those enumerated in Table 12.X.

TABLE 12.XI. ESTIMATED TERMS FOR FUTURE MEDIUM- AND LONG-TERM LOANS[a]

Loan category	Interest rate (%)	Maturity (years)	Grace period (years)
Concessional loans from:			
DAC	2.6	32	9
OPEC	2.3	17	5
CPE	2.3	17	4
Other bilateral sources	3.5	15	4
IDA[b]	0.75	50	10
ADB	1.0	39	10
IDB	1.9	37	10
AFDB	1.8	26	6
AFDF	0.73	47	10
FED	1.2	38	10
EIB	2.3	33	9
IMF Trust Fund	0.5	11	6
Other multilateral sources	1.8	29	7
Loans at market terms			
Official export credits	8.9	13	4
Suppliers' credits	8.9	14	2
Financial markets and others	13.5	9	4
IBRD[b]	8.7	17	4
ADB	8.7	20	4
IDB	8.4	20	5
AFDB	7.1	17	5
EIB	8.5	16	4
Other multilateral sources	7.7	12	4

[a] Based on average terms in 1979–81.

[b] Beginning with FY83, IBRD loans are at variable rates, reviewed and set in July and January. Currently, loans negotiated after July 1, 1982 will be 11.43%. In addition, IBRD loans include a $\frac{3}{4}$% commitment charge and 1–$\frac{1}{2}$% front-end fee. IDA loans remain at $\frac{3}{4}$% service charge on the disbursed amount and $\frac{1}{2}$% commitment charge on the undisbursed.

Source: World Bank.

After the above description and some experience with projects financed by the World Bank, the question arises as to whether the involvement of the Bank in other than purely financial aspects goes too far, eventually ending into a too close scrutiny of the borrower's activities. The question is certainly worth a debate. As usual, the answer might emerge as a compromise. Definitely useful, to some extent absolutely necessary for developing countries in their initial development phases, a point is probably reached somewhere in the zone of advanced developing countries, where this close scrutiny is not only unnecessary but possibly retards initiative and free efficient action of borrowers with sufficient technical economic and managerial expertise.

However, this tendency to over-involvement in aspects not strictly concerning financing is encountered in almost all major lending organizations, and probably deserves as such an optimization analysis.

As far as future medium- and long-term loans are concerned, Table 12.XI gives some estimates of interest rates, maturity and grace periods for different categories of loans. It also shows new, variable IBRD rates and commitment and front-end fees.

12.5. Financing energy conservation measures

In chapters 8 and 10, energy conservation measures were identified as particularly attractive investments up to certain limits, both from the energetic as well as the economic point of view. The payback time of the invested capital is often very short, a few years, and once paid back, these measures generate a positive cash flow. For these merits, as already mentioned, they enjoy financial incentives, or in some countries even particularly favourable financing conditions.

However, in developing countries, when such measures include some imported equipment and hence a foreign currency cost component, difficulties may occur in financing the latter. The World Bank may cater for such financing, but in general only for more important projects, dealt with case by case. In reality, a whole series of small projects would need, and qualify for, such financial assistance.

Under these conditions, it could be helpful if some general international banking arrangement would provide for such projects a simple procedure enabling fast implementation, for example, for an energy-conserving window. In fact, it would make little sense to negotiate a loan to run longer than the payback time from evident savings. Here time is not only money, but also energy saved or petroleum substituted.

An alternative could be to establish in developing countries with more energy conservation potential an internal mechanism, financing both foreign and local components and managing a special energy conservation fund. The latter could rotate and snowball if, after short-term loans were reimbursed, a percentage of the savings achieved after a few years were contributed to its expansion. Such national centres could possibly be affiliated to a central international focus, providing both advice and initial temporary funds.

Part III

WORLD ENERGY DEVELOPMENT STATUS AND TRENDS

Chapter 13

WORLD ENERGY DEVELOPMENT

This chapter aims to present a succinct overview on world energy development, with a minimum of statistics as supportive background and a greater accent on salient facts and issues which decisively determined past evolution and possibly offer keys and clues for assessing further patterns of development. Integrated in this approach, the supporting data material has been selected both for its topicality and for its significance.

13.1. Present status and past evolution of world energy consumption

Energy demand and supply depend on many factors, including population, climate, the level of socio-economic development, natural resources including energy resources, etc. For better understanding of the past evolution, the present situation and the future trends of worldwide energy consumption, it is useful to undertake the analysis both integrated at world level and for major groups of countries.

13.1.1. An introductory overview

The following four-way classification of countries which is currently used by the United Nations Conference on Trade and Development – UNCTAD – for purposes of statistical convenience, appeared best suited for an introductory overview:

(1) Developed market economy countries: Australia, Austria, Belgium, Canada, Denmark, Finland, Federal Republic of Germany, France, Greece, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, United Kingdom, United States of America, Yugoslavia.

(2) Socialist countries of Eastern Europe: Bulgaria, Czechoslovakia, German Democratic Republic, Hungary, Poland, Romania, Union of Soviet Socialist Republics.

(3) Socialist countries of Asia: China, Democratic People's Republic of Korea, Mongolia, Viet Nam.

(4) Developing countries: all other countries of Africa, Asia, Latin America and Oceania not specified above.

Table 13.I presents a broad overview on figures and %-structure of world population, gross domestic product (GDP) and commercial energy consumption. Selected for its wide overview, Table 13.I has to be read accordingly, i.e. the original data consist of estimates derived from differing sources and using different methods. In particular, it should be noted that conversion of GDP of most

TABLE 13.I. WORLD AND MAJOR GROUPS OF COUNTRIES: POPULATION, GDP AND COMMERCIAL PRIMARY ENERGY CONSUMPTION IN 1975 [13.1]

	Population (10^6 inhabitants)	GDP (10^9 US \$)	Commercial energy consumption (10^6 tce)	Per head: GDP (US \$)	Per head: Commercial energy consumption (kgce)	Ratio commercial energy consumption per US \$ of GDP (kgce)
World	3967	6207	8002	1570	2028	1.29
		%				
World	100	100	100			
Developed market economy countries	20	66	58	5140	6094	1.14
Socialist countries of Eastern Europe	9	15	24	2660	5412	2.04[a]
Developed regions	29	81	82	4355	5699	1.31
Developing countries	48	14	10	460	401	0.90
Socialist countries of Asia	23	5	8	330	734	2.05[a]
Developing regions	71	19	18	417	500	1.20

Sources: United Nations World Energy Supplies 1971–1975; UNCTAD, Handbook of International Trade and Development Statistics Supplement 1977.

[a] The relatively high ratio generally reflects the energy-intensive nature of heavy industry, which predominates in these countries.

TABLE 13.II. EVOLUTION OF WORLD POPULATION IN 10^6 INHABITANTS [13.2]

	600	1400	1800	1925	1950	1978
North America	2	3	5	125.5	166.1	242
Europe, without USSR	22	52	208	305.3	392.1	480
Japan – Oceania	6	11	27	68.2	95.1	126
USSR	10	13	49	154	180	261
China and Asian planned economies	49	70	330	440	569.8	930
Africa	24	68	102	139.2	217	436
Latin America	12	33	19	97.8	161.9	344
Asia (without China and Japan)	81	124	277	515	722.5	1389
Total world	206	374	954	1890	2504.6	4219
Industrialized countries	40	79	279	653	847.3	1140
Developing countries	166	295	675	1237	1657	3079
Developing countries % of total	81.6	78.8	70.7	65.4	66.2	72.9

of the countries into dollars was done using official exchange rates rather than reflecting purchasing power parities, and the estimates for the socialist countries (taken from World Bank Atlas) are GNP derived from net material product. For these reasons, all the estimates contain a wide margin of error.

The figures show a strong concentration of the consumption of commercial primary energy resources in the developed regions – the developed market economy countries and the socialist countries of Eastern Europe, which with about 29% of the total world population account for more than 80% of global consumption. The other 70% of the population of the developing regions, comprising the developing countries and the socialist countries of Asia, consumed less than 20%.

The heavy concentration of commercial energy consumption in the developed regions generally reflects a more advanced level of development, these regions accounting also for slightly more than 80% of the total world output. Their per head commercial primary energy consumption lies at 5700 kgce, almost 12 times higher than the world's average of around 2000 kgce per head. However, these figures do not completely reflect the real energy consumption level in the developing countries since they refer only to the commercial primary energy consumption concentrated in the urban areas, where energy is consumed more or

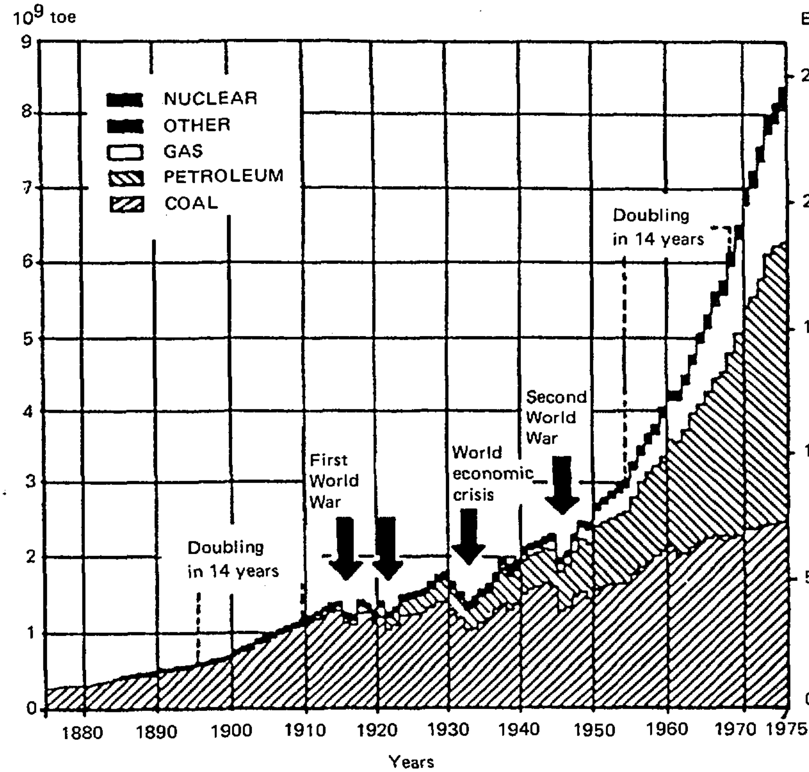

FIG.13.1. World commercial energy consumption 1875–1975 [*13.3*].

less as in developed countries, although on a smaller scale. In addition, in these countries extensive use is made in rural areas of non-commercial energy such as fuelwood, vegetable waste, animal manure, as well as human and animal power. This non-commercial energy consumption might reach up to 90% of the total energy consumption (as in Nepal) or still participate with 48% in the global energy balance of such a large and relatively advanced country as India [13.1]. On the contrary, consumption of non-commercial energy in the developed regions is relatively low.

Consumption of non-commercial primary energy resources cannot be included in regular statistics, since hardly any overall energy balances include them regularly. Some surveys have been carried out to evaluate them occasionally. The only recent existing evaluation including both commercial and non-commercial primary energy resources in a world energy balance assessed the situation in 1976 as follows: the total world energy consumption of 6.74×10^9 toe consisted of 5.08×10^9 toe (75.4%) consumed by the developed regions and 1.66×10^9 toe

TABLE 13.III. GEOGRAPHICAL DISTRIBUTION OF WORLD COMMERCIAL PRIMARY ENERGY CONSUMPTION, 1960–1980 [13.4]

	(%)			
	1960	1970	1974	1980
Western Europe (OECD)	20.0	21.2	20.6	20.7
EEC group of nine	16.7	16.6	16.2	16.6
North America	37.3	35.9	35.6	33.8
USA	34.9	31.0	30.7	30.5
Japan	2.8	5.4	6.0	7.5
Australia and New Zealand	1.0	1.1	1.1	1.2
Total industrialized countries	61.1	63.6	63.3	63.2
South and West Asia	2.9	3.8	4.1	5.2
Africa	1.6	1.5	1.9	1.9
Latin America	3.2	3.6	4.2	4.4
Total developing countries	7.7	8.9	10.2	11.5
Planned economies	31.2	27.5	26.5	25.3
Total (10^6 tce)	4369	7023	8186	12113

Source: OECD Oil report 1973.

(24.6%) by the developing regions. While non-commercial energy is implicitly included for the developed regions, a separation appears for the developing regions: 0.58×10^9 toe represents the share of non-commercial energy, i.e. 35%, or worldwide about 8.6%.

13.1.2. Evolution of world population

One of the most important elements in the determination of the world energy consumption is the world population, its geographical distribution and its economic structure. Table 13.II presents, starting as early as the year 600, the evolution of world population, its geographical distribution and the % share of developing countries. The latter, after a minimal figure of 65% in 1925, increased its share to 72.9% in 1978 and is continuing this trend.

13.1.3. Past evolution of world consumption of commercial primary energy

Figure 13.1 presents the evolution of the consumption of commercial energy since 1875, i.e. the year when total coal consumption reached some

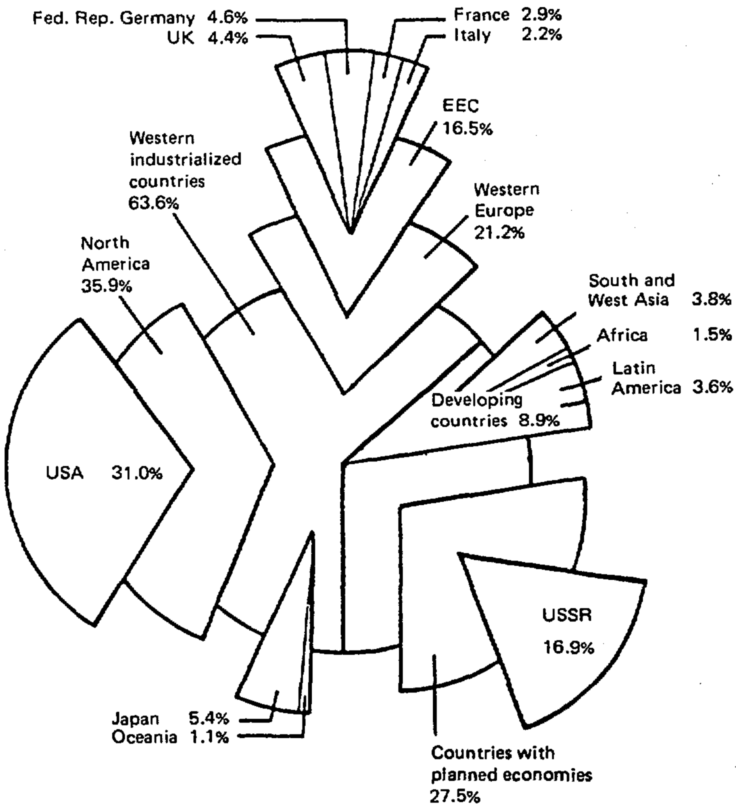

FIG.13.2. Shares of main regions and countries in world commercial primary energy consumption in 1970, in % [13.4].

200×10^6 t. Despite the interruptions caused by two world wars and the world economic crisis in the '30s, total energy consumption increased steadily with a doubling period of 14 years, both at the beginning of the century and in the late '50s and '60s [13.3].

Going into more detail, Table 13.III displays the % geographical distribution of world commercial primary energy consumption for the year 1960 (4369×10^6 tce), 1970 (7023×10^6 tce), 1974 (8186×10^6 tce), almost double that in 1960, and 1980 ($12\,113 \times 10^6$ tce), almost triple that of 1960.

Figure 13.2 shows the above described geographical distribution of the world commercial primary energy consumption for different economic groups while Fig.13.3 shows the breakdown of world energy consumption 1965–1982 according to participating primary energy resources [13.5].

The substantial differences in the per head primary energy consumption of the different groups are self-explanatory, as shown in Tables 13.IV and 13.V. In

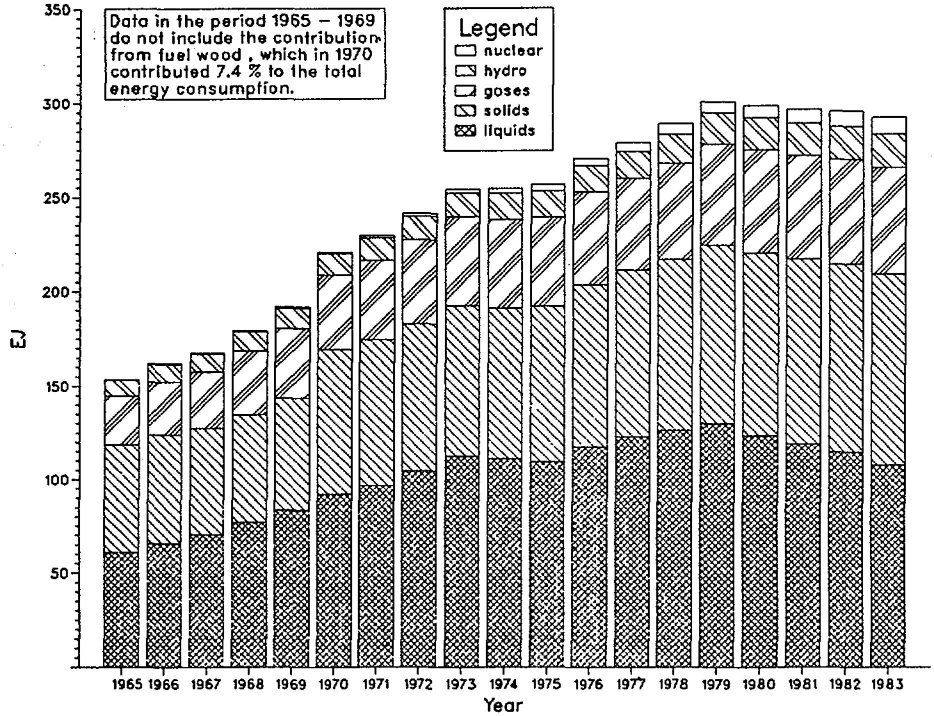

FIG.13.3. Breakdown of world energy consumption 1965–1983 by primary energy resources [13.5].

TABLE 13.IV. PER HEAD COMMERCIAL PRIMARY ENERGY CONSUMPTION IN 1960, 1970 AND 1980 [13.4]

	(tce per head per year)		
	1960	1970	1980
Europe	2.6	4.0	6.3
North America	8.1	11.1	16.0
Japan	1.3	3.7	7.9
OECD countries	4.1	6.3	9.7
Rest of world	0.7	0.9	1.3
World	1.4	1.9	2.7

Source: OECD Oil Report 1973.

TABLE 13.V. PER HEAD COMMERCIAL PRIMARY ENERGY CONSUMPTION IN 1973 IN tce/a AND AS COMPARED TO DEVELOPING COUNTRIES [13.4]

	tce per head per year	developing countries = 1
USA	11.3	26.9
UK	5.8	13.8
USSR	5.7	13.6
Fed. Rep. Germany	5.5	13.1
EEC	4.8	11.4
France	4.2	10.0
Japan	3.3	7.9
Italy	2.9	6.9
World average	2.0	4.8
Latin America	1.04	2.5
Developing countries	0.42	1.0
Africa	0.35	0.8
South and East Asia	0.28	0.7

addition to the absolute figures, the latter also shows the relative figures referred to the level of developing countries average per head consumption.

The study [13.6] which the author presented at the 11th World Energy Conference in Munich in 1980 and which brings a very detailed retrospective analysis (1960–1976) of the primary energy consumption in the world may prove particularly helpful for further reading.

13.1.4. Recent status of world consumption of commercial primary energy

The recent status (1981) of world commercial energy consumption is displayed in Table 13.VI, which also shows the corresponding figures for 1979 and 1973. Figure 13.4 presents the specific per head conventional consumption figures and adds the specific production figures for the main geographical regions of the world [13.7].

Table 13.VI shows that the world conventional energy consumption in 1981, almost 8700 $\times$ 10^6 tce (254.2 EJ) and production of 9088 $\times$ 10^6 tce (266 EJ), are 2% and 5% lower respectively than the 1979 figures. The per head consumption shows even more clearly the effects of better energy husbandry and economic recessions.

TABLE 13.VI. RECENT STATUS OF WORLD COMMMERCIAL PRIMARY ENERGY CONSUMPTION [13.7]

	1973			1979			1981		
	10^6 tce	PJ	%	10^6 tce	PJ	%	10^6 tce	PJ	%
Petroleum	3 669	107 535	48.2	4 091	119 910	46.2	3 800	111 369	43.8
Natural gas	1 525	44 682	20.0	1 842	53 979	20.8	1 906	55 860	22.0
Coal	2 235	65 502	29.4	2 637	77 296	29.7	2 652	77 724	30.6
Hydro	162	4 747	2.1	212	6 210	2.4	220	6 447	2.5
Nuclear	24	716	0.3	76	2 231	0.9	97	2 842	1.1
Total	7 615	223 182	100	8 858	259 626	100	8 675	254 242	100
Primary energy consumption in Western Europe									
Petroleum	940	27 540	60.6	944	27 661	56.1	810	23 739	52.1
Natural gas	192	5 636	12.4	281	8 241	16.7	273	8 001	17.6
Coal	366	10 712	23.5	378	11 087	22.5	383	11 225	24.6
Hydro	45	1 307	2.9	57	1 656	3.4	55	1 612	3.5
Nuclear	9	264	0.6	22	648	1.3	34	996	2.2
Total	1 552	45 459	100	1 682	49 293	100	1 555	45 573	100
Primary energy consumption in North America									
Petroleum	1 224	35 864	46.4	1 280	37 514	46.2	1 125	32 971	42.8
Natural gas	875	25 629	33.2	828	24 261	29.9	800	23 446	30.4
Coal	467	13 672	17.7	564	16 521	20.3	600	17 585	22.8
Hydro	58	1 697	2.2	65	1 908	2.3	65	1 890	2.5
Nuclear	12	352	0.5	36	1 040	1.3	39	1 149	1.5
Total	2 636	77 214	100	2 773	81 244	100	2 629	77 041	100
Primary energy consumption in Central and South America									
Petroleum	246	7 195	75.7	305	8 939	70.9	325	9 525	70.7
Natural gas	51	1 503	15.7	78	2 286	18.1	85	2 491	18.5
Coal	14	407	4.3	23	665	5.4	23	674	4.9
Hydro	14	396	4.3	24	706	5.6	27	791	5.9
Nuclear	–	–	–	●	10	●	●	9	●
Total	325	9 501	100	430	12 606	100	460	13 490	100

TABLE 13.VI (cont.)

	1973			1979			1981		
	10^6 tce	PJ	%	10^6 tce	PJ	%	10^6 tce	PJ	%
Primary energy consumption in Africa									
Petroleum	67	1 967	50.4	89	2 611	49.7	94	2 784	50.3
Natural gas	4	111	3.0	9	261	5.0	11	322	5.8
Coal	58	1 712	43.6	74	2 160	41.4	75	2 198	39.7
Hydro	4	114	3.0	7	205	3.9	8	220	4.2
Nuclear	–	–	–	–	–	–	–	–	–
Total	133	3 904	100	179	5 237	100	188	5 524	100
Primary energy consumption in the Middle East									
Petroleum	104	3 039	75.4	130	3 804	72.6	122	3 605	68.7
Natural gas	25	724	18.1	34	982	19.0	42	1 231	23.5
Coal	8	243	5.8	13	384	7.3	11	322	6.1
Hydro	1	23	0.7	2	70	1.1	3	73	1.7
Nuclear	–	–	–	–	–	–	–	–	–
Total	138	4 029	100	179	5 240	100	178	5 231	100
Primary energy consumption in South/East Asia, Australia, Oceania									
Petroleum	535	15 685	67.7	592	17 359	62.2	552	16 178	57.8
Natural gas	24	695	3.0	63	1 832	6.6	75	2 198	7.9
Coal	209	6 122	26.5	260	7 605	27.3	285	8 353	29.8
Hydro	20	571	2.5	27	783	2.8	30	865	3.1
Nuclear	2	47	0.3	10	296	1.1	13	366	1.4
Total	790	23 120	100	952	27 875	100	955	27 960	100
Primary energy consumption in Eastern Europe, USSR and China									
Petroleum	554	16 245	27.1	751	22 022	28.2	770	22 567	28.4
Natural gas	354	10 384	17.3	550	16 116	20.6	620	18 171	22.9
Coal	1 114	32 634	54.4	1 326	38 874	49.8	1 275	37 367	47.0
Hydro	22	639	1.1	30	882	1.1	34	996	1.3
Nuclear	2	53	0.1	8	237	0.3	11	322	0.4
Total	2 046	59 955	100	2 665	78 131	100	2 710	79 423	100

Source: Yearbook of World Energy Statistics. United Nations 1982.

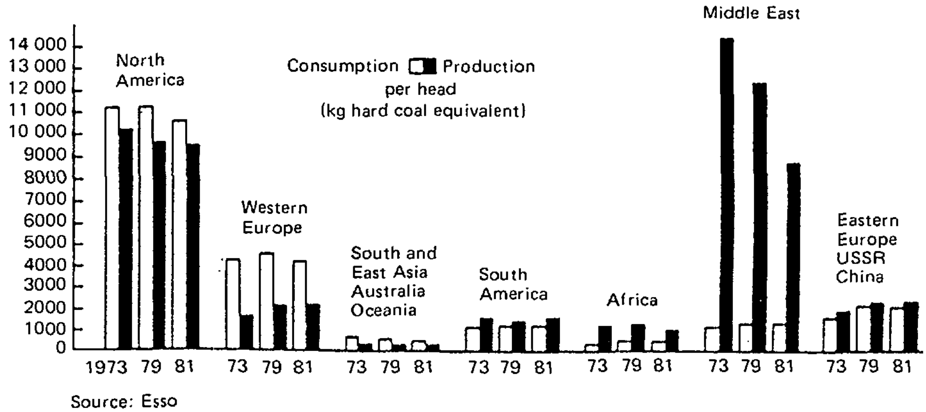

FIG.13.4. Commercial energy consumption and production, per head figures in the world [13.7].

Whereas the worldwide average per head commercial energy consumption exceeded for the first time in 1978 the 2000 kgce/head figure and reached in 1979 with 2064 kgce/head a record level, it then decreased in 1981 to 1956 kgce/head. The specific energy production figure decreased in 1981 to 2049 kgce/head and was 8% lower than in 1975.

The specific commercial energy consumption per head decreased in Western Europe in 1981 more than 8% compared with 1979, in North America by some 7%. However, with 10 600 kgce/head the Americans and Canadians still remain the largest primary energy consumers in the world, although the 1981 figure is somehow lower than the 1970 figure.

As far as the structure of world conventional energy consumption is concerned, between 1973 and 1981 energy conservation efforts and the economic recession reduced the share of petroleum from 48.2% to 43.8%, increasing the natural gas share from 20% to 22%, the share of coal slightly from 29.4% to 30.6%, hydraulic energy from 2.1% to 2.5 % and nuclear from 0.3% to 1.1%. Interestingly enough, the larger effects intervened between 1979 and 1981 rather than before, confirming the typical long penetration time of new energy-husbandry-improving measures.

In contrast to the decreasing share of petroleum in the world and in the different world regions since 1973 – see Table 13.VI – , Table 13.VII displays the historical increase of the petroleum share in total conventional energy consumption from 1925 to 1975, in the world from 13.3% to 44.1%, in the developed market economies from 12.2% to 50.1% and, more dramatically, in the developing countries up to 61%.

TABLE 13.VII. WORLD AND MAJOR GROUPS OF COUNTRIES: CHANGES IN PATTERNS OF COMMERCIAL PRIMARY ENERGY CONSUMPTION 1925 – 1975 [13.1]

	Year	Total commercial energy consumption	Percentage of total commercial energy consumption			
			Solid fuels	Liquid fuels	Natural gas	Hydraulic and nuclear electricity
World	1925	1 485	82.9	13.3	3.2	0.7
	1950	2 492	61.5	27.0	9.8	1.7
	1960	4 243	52.0	32.0	14.0	2.0
	1970	6 876	35.2	42.7	19.9	2.2
	1975	8 002	32.8	44.1	20.4	2.8
Developed market economy countries	1925	1 321	83.7	12.2	3.4	0.7
	1950	1 864	56.9	28.9	12.1	2.1
	1960	2 608	40.2	38.3	18.9	2.6
	1970	4 312	26.0	49.0	22.4	2.6
	1975	4 635	23.9	50.1	22.5	3.6
Socialist countries of Eastern Europe	1925	80	82.9	15.2	1.7	0.1
	1950	447	84.1	12.5	2.9	0.5
	1960	900	71.2	19.7	8.3	0.8
	1970	1 538	49.9	28.4	20.6	1.1
	1975	1 965	43.2	32.1	23.8	1.0
Socialist countries of Asia	1925	24	94.0	6.0	–	–
	1950	43	99.3	0.5	–	0.2
	1960	447	96.4	2.9	0.2	0.5
	1970	449	91.5	6.9	0.5	1.1
	1975	625	82.2	15.9	0.8	1.1
Developing countries	1925	59	59.2	37.6	2.5	0.8
	1950	139	38.9	55.4	4.3	1.4
	1960	286	30.1	58.7	8.7	2.5
	1970	578	20.6	61.7	14.4	3.3
	1975	777	19.8	61.0	15.3	3.9

13.2. Trends of future world energy development

Concerning the future evolution of world energy supply, several worldwide studies with different time horizons have been published in the last decade [13.8–12].

In relation to the 12th Congress of the WEC in New Dehli (1983), revised, new, and independent forecasts appeared [13.5, 13.13–16].

It is not possible to discuss in detail the different studies and forecasts, nor would this be useful since the first estimates were in general reduced to lower figures.

Since UN representatives have been participating in the work of the Energy Conservation Commission of the World Energy Conference since its creation in 1975, preference will be given to its documentation regarding both the prospects of world energy demand and supply till 2020 and the potential for energy conservation during this period.

However, it should be recalled that the Commission Report published in 1978 was not supposed to present an energy demand and supply forecast up to the year 2020, but merely analyse scenarios of development possibly ending in balanced solutions given reasonable constraints and/or promotion conditions.

Among the analysed scenarios, a balance based on a global primary energy production of 1 000 exajoules (22.7×10^9 toe or 34.1×10^9 tce) appeared acceptable to meet a reasonably constrained demand by the year 2020. To attain this goal on both balance ends, considerable efforts would have been necessary to promote production and managing demand, as well as to improve conversion and transport efficiencies and assure adequate substitutions throughout the energy system.

In its further work, the Conservation Commission reviewed the situation, also in the light of the discussions at the 11th World Energy Conference and, without giving up the targets set in 1978, focused from 1981 on an energy supply in 2020 of 880 EJ, i.e. 20×10^9 toe or 30×10^9 tce. At the same time, it stressed even more strongly the necessity of immediate measures to increase supply and manage demand [13.10].

Taking into account the trend in recent years, the Conservation Commission again revised its previous figures and presented at the 12th WEC Congress in New Delhi the following consolidated forecast, resulting from detailed studies of the ten regions into which the world had been divided for this purpose [13.13, 14].

Table 13.VIII presents an overview of the premises and consolidated results of the study. Compared with the 1981 forecast [13.10] the estimate of total world energy consumption in the year 2000 has been reduced from 12.90×10^9 toe to 11.744×10^9 toe in scenario I or 10.104×10^9 toe in scenario II. From 20.10×10^9 toe in the year 2020, the new figures decline to 17.957×10^9 toe in scenario I and to 13.766×10^9 toe in scenario II, i.e. a reduction of 10.7 and 31.5% respectively.

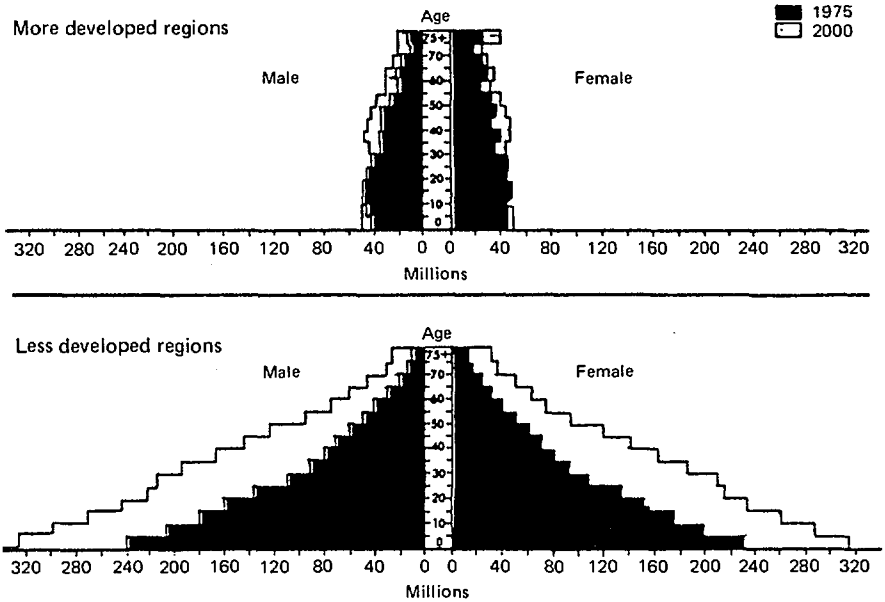

FIG.13.5. Age/sex composition of the world's population, 1975 and 2000 [*13.17*].

TABLE 13.VIII. WORLD ENERGY DEVELOPMENT TO THE YEARS 2000 AND 2020 [13.13, 14]

	1960	1978	2000 I	2000 II	2020 I	2020 II
World population, 10^6 persons	3015	4261	6039		7722	
Rates of growth, %		1.94	1.6		1.2	
GNP levels, G$ (1978)	3707	8885	19592	15859	34875	23765
Rates of growth, %		5.0	3.65	2.65	2.0	2.0
GNP per head, $ (1978) p.c.	1229	2085	3244	2626	4516	3078
Rates of growth, %		3.0	2.0	1.05	1.7	0.8
Total primary energy consumption, 10^6 toe	3308	6818	11744	10104	17957	13766
Of which						
commercial energy	2748	6083	10820	9053	17067	12674
non-commercial energy	560	735	924	1051	890	1092
Energy consumption, toe per head per year	1.1	1.6	1.94	1.67	2.33	1.78

TABLE 13.IX. STRUCTURE OF WORLD ENERGY DEVELOPMENT TO THE YEARS 2000 AND 2020 [13.13]

	(10^9 toe)					
	1960	1978	2000		2020	
			I	II	I	II
Coal	1.20	1.70	3.24	2.79	5.68	4.39
Petroleum	0.96	2.68	3.40	2.79	3.58	2.43
Natural gas	0.42	1.16	2.16	1.78	3.16	2.40
Nuclear energy	–	0.15	0.98	0.80	2.30	1.66
Hydro	0.46	0.39	0.71	0.62	1.36	1.00
Fuelwood	0.40	0.49	0.61	0.71	0.54	0.68
New energy sources	–	–	0.33	0.27	1.0	0.80
Vegetable and animal wastes	0.16	0.25	0.32	0.34	0.35	0.41
Total	3.30	6.82	11.75	10.10	17.97	13.77

In order to reflect the two basic alternatives under which the future till 2020 might be considered, two development scenarios have been investigated: Scenario I, the so-called 'rose', and Scenario II, the 'grey' version of the future respectively correspond to a 'normative co-operation' alternative with a generally peaceful world and to an alternative of 'increasing tensions'. The first scenario is based on rather optimistic, the second on more pessimistic, assumptions of a future, that one way or another will not be easy to master. Accordingly, GNP growth rates have been differently assessed.

Population growth plays a major part in the growth of world energy needs. In fact, it explains 60% of demand growth over the whole forecasting period under scenario I, even 90% of growth up to 2000, and 75% for the period 2000–2020, under scenario II, versus only 50% for 1960–1978. The population figure selected for the year 2000, 6×10^9 inhabitants, corresponds well with other estimates, for example also with the figure of 6.35×10^9 in Ref. [13.17]. Figure 13.5 shows the expected structure. Most of the population growth up to the year 2000 (92%) will occur in developing countries, where 5.0×10^9 people will live in 2000. The age structure for the industrialized nations becomes more column-shaped (characteristic for a mature and slowly growing population); the structures for the developing countries remain pyramid-shaped (characteristic of rapid growth) [13.17].

As far as world primary energy consumption growth according to Table 13.VIII is concerned , one may note the following salient features which best emerge from comparing future development with the reference period 1960–1978:

- Total world energy consumption increased from 3.3 Gtoe in 1960 to 6.8 Gtoe in 1978. It could reach 10.1 Gtoe (II) or 11.7 Gtoe (I) in 2000 and 13.8 Gtoe (II) or 18 Gtoe (I) in 2020. In fact, total world consumption could double or even treble between 1978 and 2020.
- Demand growth will slow down considerably: 1.8% (II) or 2.5% (I) up to 2000, and 1.6% (II) or 2.1% (I) for the period 2000–2020, compared to more than 4% between 1960 and 1978. Average annual growth rates will actually be halved.
- Growth of consumption per head will be very slow: 1.7–1.9 toe in 2000, and 1.8–2.3 toe in 2020, compared to 1.1 toe in 1960 and 1.6 toe in 1978.

Regarding the energy supply – see also Table 13.IX – the following aspects deserve attention [13.14]:

- Non-commercial sources covered 17% of world energy demand in 1960, representing 560 Mtoe. They covered only 11% in 1978, representing 735 Mtoe. The decrease of their share of world demand will continue: 8% in 2000, and 5% in 2020, under Scenario I, 10% and 8% respectively under Scenario II, though they will represent increasing volumes: 900 Mtoe (I) or 1100 Mtoe (II) in 2020. At the same time, non-commercial energy consumption per head will gradually decrease from 0.17 toe in 1978 to 0.12 toe (I) or 0.14 toe (II) in 2020.
- The share of coal in world energy demand decreased sharply between 1960 and 1978 (from 36% to 25%), though representing an increase in volume from 1.2 Gtoe to 1.7 Gtoe. This tendency will be reversed in the future: 28% in 2000 (2.8–3.2 Gtoe), and 32% in 2020 (4.4–5.7 Gtoe). In fact, as from 2000, coal will again become the world's leading source of energy.
- Nuclear power will also massively replace oil in the future. Its part in total world supplies could grow from 2% in 1978 to 8% in 2000 (0.8–1.0 Gtoe), and 12–13% in 2020 (1.7–2.3 Gtoe).
- Hydropower production will increase from 0.4 Gtoe in 1978 to 0.6–0.7 Gtoe in 2000, and 1.0–1.3 Gtoe in 2020, that is, it would maintain its part in total world supplies at 6–7%.
- The share of new and renewable energy in world supplies will grow gradually to 3% in 2000 (300 Mtoe), and 6% in 2020 (0.8–1.0 Gtoe).
- In the long run, natural gas will maintain its present share of 17% in world supplies, because world demand will grow considerably: from 1.2 Gtoe in 1978 to 1.8–2.2 Gtoe in 2000, and 2.4–3.2 Gtoe in 2020.
- Finally, petroleum's share of world supplies will decrease from about 40% in 1978 to about 30% in 2000, and about 20% in 2020. Under Scenario II,

TABLE 13.X. WORLD COMMERCIAL PRIMARY ENERGY CONSUMPTION*, 1970–1995 [13.16]

	10^6 toe[a]			Growth rate (% per year)	
	1970	1980	1995	1970–80	1980–95
Oil	2.311	3.067	3.355	2.9	0.6
Coal	1.475	1.825	2.821	2.2	2.9
Natural gas	889	1.241	1.930	3.4	3.0
Primary electricity[b]	328	611	1.423	6.4	5.8
Total	5.003	6.744	9.529	3.0	2.3
	% of total			% of increase	
	1970	1980	1995	1970–80	1980–95
Oil	46.2	45.5	35.2	43.4	10.3
Coal	29.5	27.1	29.6	20.1	35.8
Natural gas	17.8	18.4	20.3	20.2	24.7
Primary electricity[b]	6.5	9.0	14.9	16.3	29.2
Total	100.0	100.0	100.0	100.0	100.0

* Energy consumption includes bunkers.

[a] toe = tons of oil equivalent.

[b] Primary electricity comprises electricity generated from hydropower, nuclear energy, or geothermal resources. Throughout this report, primary electricity is converted into tons of oil equivalent (toe) at thermal replacement value, assuming an average conversion efficiency of about 34%.

Sources: United Nations J Series and World Bank estimates.

world oil demand could reach a ceiling of 2.8 Gtoe in 2000, decreasing to 2.4 Gtoe in 2020 (1978: 2.7 Gtoe). Under Scenario I, oil substitution will be less successful.

Consequently, world demand could increase to 3.4 Gtoe in 2000, and 3.6 Gtoe in 2020.

In conclusion, the future challenge seems not to be, as some claim, coal instead of nuclear energy, but coal and nuclear energy, with quite an accent on the latter as well.

TABLE 13.XI. ESTIMATES OF TOTAL WORLD ENERGY CONSUMPTION (EJ), PERCENTAGE USED FOR ELECTRICITY GENERATION, AND PERCENTAGE SUPPLIED BY NUCLEAR ENERGY [13.5]

Country group	1983			1990[b]			1995[b]			2000[b]		
	Total energy consumption	% used for elect. gener.	% supp. by nucl.	Total energy consumption	% used for elect. gener.	% supp. by nucl.	Total energy consumption	% used for elect. gener.	% supp. by nucl.	Total energy consumption	% used for elect. gener.	% supp. by nucl.
North America	75.9	34.9	4.2	90	37	8	96	39	8	103	41	8
				92	38	8	103	40	8	113	41	8
Western Europe	47.1	35.1	7.3	51	39	14	57	40	15	63	40	15
				57	38	14	63	39	18	70	41	18
Eastern Europe	73.1	24.7	1.9	87	28	5	97	30	6	105	31	8
				91	28	6	105	30	8	118	31	12
Industrialized Pacific	17.1	38.2	5.3	20	41	8	22	42	10	25	44	12
				22	40	8	25	42	12	28	43	16
Asia	43.2	16.2	0.7	55	20	1	63	23	2	71	26	3
				61	20	1	75	23	2	90	26	3
Latin America	20.8	21.0	0.1	27	25	1	32	28	1	37	30	2
				30	24	1	37	27	1	45	30	2
Africa and Middle East	18.8	18.0		24	21	0.2	28	24	0.3	33	27	1
				26	21	0.4	33	24	1	42	27	2
World Total	293.9	27.9	3.1	354	31	6	396	33	6	438	34	7
				378	31	6	441	32	7	505	34	9

TABLE 13.XI (cont.)

Country group	1983			1990[b]			1995[b]			2000[b]		
	Total energy consumption	% used for elect. gener.	% supp. by nucl.	Total energy consumption	% used for elect. gener.	% supp. by nucl.	Total energy consumption	% used for elect. gener.	% supp. by nucl.	Total energy consumption	% used for elect. gener.	% supp. by nucl.
Industrialized countries	197.8	32.2	4.4	217	37	9	237	38	10	258	40	11
				229	37	9	259	38	11	286	39	14
Developing countries												
In CPE-Europe[a]	14.4	20.8	1.3	17	25	3	19	27	5	20	29	6
				18	24	3	20	27	6	22	29	7
Others	81.8	20.8	0.4	120	21	1	140	23	1	160	26	2
				130	20	1	162	23	1	197	26	2
Total of DCs	96.1	19.0	0.6	137	21	1	159	24	2	179	26	2
				148	21	1	183	24	2	219	27	3

[a] Developing countries in the Centrally Planned Economies (CPE) in Europe: Albania, Bulgaria, Czechoslovakia, Hungary, Poland and Romania.
[b] The top and bottom figures for total energy consumption are low and high estimates, respectively.

TABLE 13.XII. ESTIMATES OF TOTAL ENERGY AND ELECTRICITY CONSUMPTION PER HEAD (units: energy GJ; electricity MW·h) [13.5]

Country group	1983		1990		1995		2000	
	Energy	Electricity	Energy	Electricity	Energy	Electricity	Energy	Electricity
North America	293	10.4	328–338	12.2–12.8	342–367	13.5–14.5	358–391	14.6–16.0
Western Europe	117	4.2	123–136	4.8–5.1	134–148	5.3–5.8	145–160	5.8–6.5
Eastern Europe	178	4.4	199–209	5.5–5.9	214–233	6.3–7.0	227–255	7.1–8.0
Industrialized Pacific	124	4.8	137–150	5.7–6.1	150–169	6.3–7.1	164–187	7.2–8.0
Asia	18	0.3	20–22	0.4–0.4	21–25	0.5–0.6	22–28	0.6–0.7
Latin America	53	1.1	60–65	1.5–1.6	64–74	1.8–2.0	68–83	2.1–2.5
Africa and Middle East	28	0.5	31–34	0.7–0.7	33–38	0.8–0.9	34–43	0.9–1.1
World average	63	1.8	68–72	2.1–2.2	70–78	2.3–2.5	72–83	2.5–2.8
Industrialized countries	188	6.2	197–208	7.2–7.7	209–228	8.0–8.7	222–246	8.8–9.7
Developing countries								
In CPE-Europe[a]	147	3.1	165–174	4.1–4.2	175–191	4.8–5.1	182–206	5.3–6.0
Others	23	0.4	30–32	0.6–0.7	32–37	0.7–0.9	33–41	0.9–1.1
Total of DCs	27	0.5	33–36	0.7–0.8	35–40	0.8–1.0	36–45	1.0–1.2

[a] Developing countries in the Centrally Planned Economies (CPE) in Europe: Albania, Bulgaria, Czechoslovakia, Hungary, Poland and Romania.

Reference [13.13] further analyses the North-South dynamics, i.e. the major changes that would occur in the world energy picture, due to the different evolution of the industrialized and developing countries. Some of these changes will be further commented on in Chapters 14 and 15.

The WEC forecasts refer to two long-term horizons, the years 2000 and 2020 only, with no shorter-term sections and no time series. They highlight strategic objectives. A stringent need exists, however, for short- to medium-term energy development forecasts, based on which actual economic planning and policy decision could be based and made in good time.

To the latter category belong the already mentioned World Bank and IAEA forecasts with time horizons of 1995 and 2000 respectively, prepared for specific purposes, but embracing the world development. In addition there are forecasts referring to the industrialized countries only, which will be discussed in chapter 14.

The World Bank forecast for 1995 is based on the reference period 1970–1980 and is presented in Table 13.X [13.16].

The IAEA estimates of total world commercial energy consumption with sections for the year 1983 (reference) and 1990, 1995 and 2000, explicitly include the share used for electricity generation and the share supplied by nuclear energy [13.5]. It also includes two estimates for future years, a low and a high figure. They are presented in Table 13.XI.

The IAEA estimated total commercial primary energy consumption figures are in general higher than the WEC totals for the year 2000, i.e.: the low IAEA figure of 438 EJ (10.47×10^9 toe)[11] is 8% lower than the Scenario I WEC figure (11.75×10^9 toe minus 0.34×10^9 toe non-commercial energy consumption) and some 3.5% higher than the Scenario II figure of 10.10×10^9 toe). The IAEA high figure of 505 EJ (12.07×10^9 toe) is substantially higher than both WEC forecasts.

The share of the developing countries in the total consumption increases from 32.7% in 1983, to 38.7% in 1990 to 40.1% in 1995 and to 40.8–43.3% in the year 2000.

Table 13.XII displays the specific consumption figures for energy (GJ/head) and electricity MW·h/head in the different time horizons.

13.3. Summary presentation of world energy resources and reserves

After having previously dealt with the various primary energy resources, both commercial and non-commercial, one by one, it appears interesting to consider them grouped together for an overview on energy reserves and potential yearly production. To this purpose, Table 13.XIII presents the consolidated figures for total world primary energy reserves as critically summarized in [13.18] from IIASA,

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[11] 1 EJ = 23.9×10^6 toe.

TABLE 13.XIII. ESTIMATED WORLD PRIMARY ENERGY RESERVES AND POTENTIAL DEVELOPMENT OF YEARLY PRODUCTION [13.18]

Resources	Reserves (EJ)	Reserves (10^9 tce)[a]	Potential yearly production (EJ/a)	Potential yearly production (10^9 tce/a)
Coal	50 000	1 705	315–440	10.7–15
Petroleum and gas	43 000	1 465	250–380	8.5–13
Nuclear energy				
Thermal reactors	2 000	68	380 (in 2020)	13
Breeder reactors	300 000	10 230	540	18.5
Fusion			60–90 (in 2020)	2.1–3.1
Biomass			79	2.7
Hydro			32–47	1.1–1.6
Solar energy				
Decentralized			30–60	1–2
Centralized			60–90 (in 2020)	2–3

[a] 1 EJ = 34.1 × 10^6 tce.

WEC and IAEA studies and publications, as well as estimates on potential development of yearly production.

There are no major differences between these summarizing figures and the detailed components presented in previous chapters.

13.4. Worldwide evolution of electrical energy development

Electricity is a relatively new energy form in the long history of world energy consumption. Hardly a century has passed since the first local lighting networks and electric motors started operation. However, once started, electricity rapidly embarked on the multilateral development which made it the versatile energy vector so praised in this book, as elsewhere.

Here are a few landmarks in its world wide evolution: world production was 270 TW·h in 1930, 465 TW·h in 1940, 960 TW·h in 1950, 4910 TW·h in 1970, 8100 TW·h in 1980 and 8253 TW·h in 1982 and reached 8498 TW·h in 1983. Table 13.XIV shows intermediate figures on world electricity development and the distribution between industrialized, developing and planned economy countries [13.19, 20]. When reading Table 13.XIV, attention should be paid to the fact that according to the available statistical data, the developing countries in Eastern Europe are included here under planned economy countries, while usually they appear under developing countries. For this reason, the % share of developing countries in the world electricity generation appears low. Nevertheless it is increasing continuously.

Text continued on p. 547.

TABLE 13.XIV. EVOLUTION OF WORLD ELECTRICITY GENERATION 1930–1979 [13.19, 20]

Year	World	Industrialized countries		Planned economies		Developing countries	
	(TW·h)	(TW·h)	(%)	(TW·h)	(%)	(TW·h)	(%)
1930	270						
1940	465						
1950	959	772.5	80.5	140	14.5	46.4	5.0
1955	1545	1206.6	78.0	260	16.8	78.5	5.2
1960	2300	1695	73.7	475	20.6	130.5	5.7
1965	3380	2405	71.2	760	22.4	211	6.4
1970	4910	3490	71.0	1085	22.0	350	7.0
1973	6100	4270	70.0	1390	22.8	470	7.3
1975	6500	4375	67.0	1600	24.6	550	8.4
1979	7965	5220	65.6	1965	24.7	780	9.7

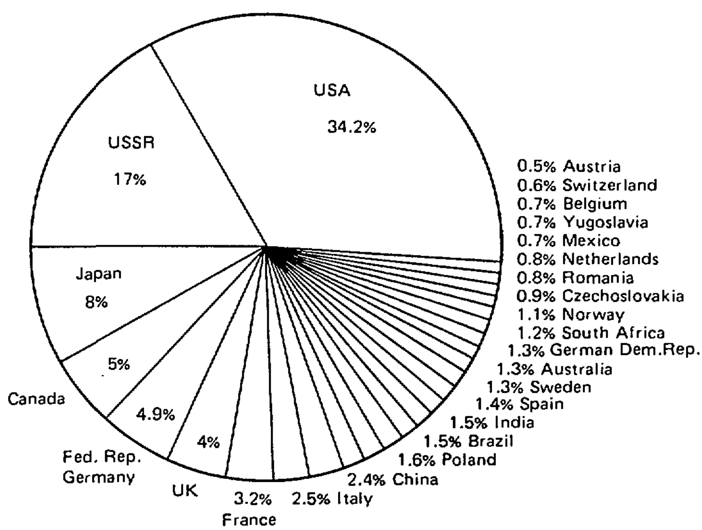

FIG.13.6. World ranking of countries for net electricity generation in 1978 [13.4].

TABLE 13.XV. ESTIMATES OF TOTAL ELECTRICITY GENERATION AND CONTRIBUTION BY NUCLEAR POWER [13.5]

Country group	1983			1990[b]			1995[b]			2000[b]		
	Total elect.	Nuclear[c]		Total elect.	Nuclear[c]		Total elect.	Nuclear[c]		Total elect.	Nuclear[c]	
	(TW·h)	(TW·h)	(%)	(TW·h)	(TW·h)	(%)	(TW·h)	(TW·h)	(%)	(TW·h)	(TW·h)	(%)
North America	2 745	327.3	11.9	3 464	719	21	3 920	771	20	4 356	828	19
				3 628	719	20	4 236	822	19	4 785	961	20
Western Europe	1 715	356.4	20.8	2 079	763	37	2 341	871	37	2 604	981	38
				2 210	802	36	2 574	1 054	41	2 927	1 328	45
Eastern Europe	1 875	147.0	7.8	2 494	404	16	2 961	600	20	3 427	843	25
				2 655	531	20	3 256	906	28	3 852	1 408	37
Industrialized Pacific	678	94.6	14.0	843	163	19	966	224	23	1 134	308	27
				910	184	20	1 088	304	28	1 263	463	37
Asia	725	30.3	4.2	1 163	77	7	1 535	119	8	1 929	189	10
				1 263	78	6	1 785	159	9	2 403	303	13
Latin America	448	2.5	0.6	710	17	2	929	40	4	1 159	57	5
				743	18	2	1 031	40	4	1 387	88	6
Africa and Middle East	314			520	5	1	707	9	1	923	36	4
				559	11	2	818	40	5	1 163	100	9
World total	8 498	958.1	11.3	11 273	2 147	19	13 361	2 634	20	15 531	3 241	21
				11 968	2 343	20	14 785	3 326	22	17 780	4 650	26

Industrialized countries	6 599	902.2	13.7	8 276	1 996	24	9 447	2 379	25	10 651	2 847	27
				8 748	2 179	25	10 271	2 981	29	11 707	4 001	34
Developing countries												
In CPE-Europe[a]	310	19.4	6.3	434	58	13	522	87	17	600	124	21
				452	62	14	564	115	20	676	159	24
Others	1 590	36.5	2.3	2 563	93	4	3 392	168	5	4 279	270	6
				2 767	102	4	3 949	230	6	5 397	490	9
Total of DCs	1 900	55.9	2.9	2 997	151	5	3 913	255	7	4 880	395	8
				3 220	164	5	4 514	345	8	6 073	649	11

[a] Developing countries in the Centrally Planned Economies (CPE) in Europe: Albania, Bulgaria, Czechoslovakia, Hungary, Poland and Romania.

[b] The top and bottom figures for total electric and nuclear generation are low and high estimates, respectively.

[c] The nuclear generation data presented in this table and the nuclear capacity data presented in Table 13.XIX cannot be used to calculate average annual capacity factors for nuclear plants, as Table 13.XIX presents year-end capacity and not the effective capacity average over the year.

TABLE 13.XVI. NUCLEAR POWER REACTORS IN THE WORLD (END OF 1983) [13.5]

Group and country	Operating		Under construction[a]		Electricity supplied by nuclear power reactors during 1983	
	Number units	Total MW(e)	Number units	Total MW(e)	TW·h	Percent of total electricity
North America						
Canada	15	8 303	8	5 925	43.12	11.0
United States of America	80	62 307	50	55 929	284.20	12.1
Western Europe						
Belgium	6	3 473	2	2 012	22.91	46.6
Finland	4	2 206	–	–	16.71	44.6
France	36	26 903	25	29 200	137.15	49.0
Germany, Federal Republic of	16	11 110	11	11 908	62.56	18.0
Italy	3	1 286	3	1 999	5.59	3.2
Netherlands	2	504	–	–	3.38	6.0
Spain	6	3 760	9	8 369	10.15	9.2
Sweden	10	7 355	2	2 100	39.16	37.6
Switzerland	4	1 940	1	942	14.80	28.5
United Kingdom	35	8 364	7	4 252	43.95	17.2
Eastern Europe						
Bulgaria	4	1 632	2	1 906	11.38	28.8
Czechoslovakia	2	762	9	4 354	5.70	8.2
German Democratic Republic	5	1 694	–	–	10.90	11.9
Hungary	1	395	3	1 230	2.30	10.2
Poland	–	–	2	880	–	–

Romania	–	–	2	1 320	–	–
USSR	42	19 721	42	38 951	113.00	8.0
Yugoslavia	1	632		–	3.72	6.1
Industrialized Pacific						
Japan	28	19 024	10	10 022	94.63	17.5
Asia						
India	5	1 030	5	1 100	2.90	2.1
Korea, Republic of	3	1 790	6	5 622	8.27	17.0
Pakistan	1	125	–	–	0.19	1.0
People's Republic of China	–	–	1	300	–	–
Philippines	–	–	1	621	–	–
Taiwan, China	4	3 110	2	1 814	18.90	40.0
Latin America						
Argentina	2	935	1	692	2.36	6.0
Brazil	1	626	1	1 245	0.16	0.1
Cuba	–	–	1	408	–	–
Mexico	–	–	2	1 308	–	–
Africa and Middle East						
South Africa	–	–	2	1 842	–	–
World total	316	188 987	210	196 251	958.10	11.3

TABLE 13.XVI (cont.)

Group and country	Operating		Under construction[a]		Electricity supplied by nuclear power reactors during 1983	
	Number units	Total MW(e)	Number units	Total MW(e)	TW·h	Percent of total electricity
Industrialized countries	292	177 950	172	173 451	902.20	13.7
Developing countries						
In CPE-Europe[b]	7	2 789	18	9 690	19.38	6.3
Others	17	8 248	20	13 110	36.51	2.3
Total of DCs	24	11 037	38	22 800	55.89	2.9

[a] Nuclear programmes in Austria and Iran have been interrupted, and the reactors are not included.

[b] Developing countries in the Centrally Planned Economies (CPE) in Europe: Albania, Bulgaria, Czechoslovakia, Hungary, Poland and Romania.

TABLE 13.XVII. NUMBER OF COUNTRIES WITH NUCLEAR POWER REACTORS IN OPERATION, UNDER CONSTRUCTION, OR PLANNED (END OF 1983) [13.5]

Country group	Number of countries in group	Countries with nuclear power reactors			
		In operation	Under construction[c]	Planned[d]	Total[e]
North America	2	2	2	2	2
Western Europe[a]	23	10	8	5	11
Eastern Europe	9	6	6	8	8
Industrialized Pacific	3	1	1	1	1
Asia	43	4	5	6	7
Latin America	46	2	4	2	4
Afric and Middle East[a]	70		1	4	5
World total	196	25	27	27	38
Industrialized countries	27	15	13	8	16
Developing countries					
In CPE-Europe[b]	6	3	5	5	5
Others	163	7	9	14	17
Total of DCs	169	10	14	19	22

[a] Nuclear programmes in Austria and the Islamic Republic of Iran have been interrupted, and the reactors are not included.

[b] Developing countries in the Centrally Planned Economies (CPE) in Europe: Albania, Bulgaria, Czechoslovakia, Hungary, Poland and Romania.

[c] May include countries having reactors already in operation.

[d] May include countries having reactors already in operation or under construction.

[e] Total number of countries in each group that have nuclear power reactors in operation, planned or under construction.

Going into more detail than the distribution between the large economic world groups, Fig.13.6 displays the ranked share of countries in the 1978 total electricity net productions. Since the presentation's cut-off limit is 0.5% of the world total figure, only a few, large developing countries were ranked.

Some specific high electricity production figures (kW·h per head per annum) were for example in 1978: Canada: 12 140, USA: 9600, Federal Republic of Germany: 5176, Japan: 4390, EEC: 4062, USSR: 3952, France: 3872, Italy: 2700,Spain: 2240, world average: 1650.

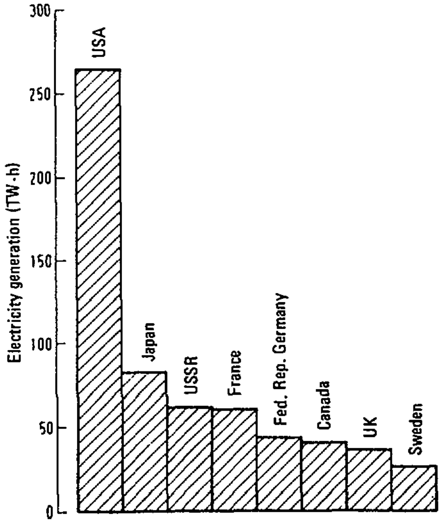

FIG.13.7. Nuclear electricity generation in 1980 [13.23].

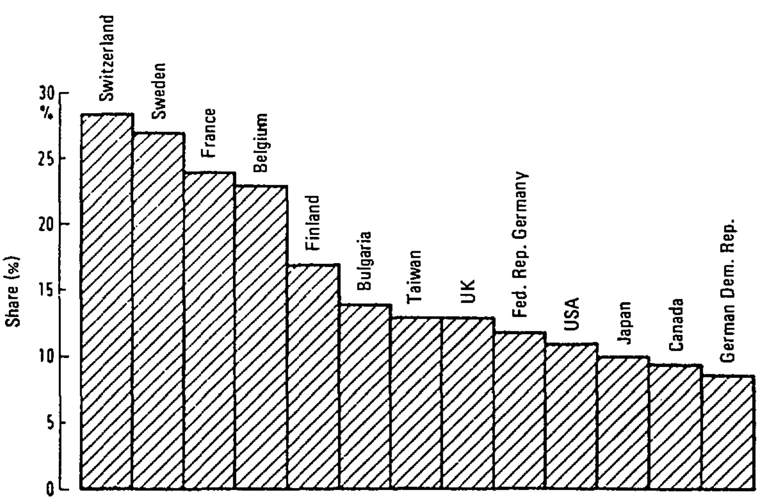

FIG.13.8. Nuclear share in national electricity generation 1980 [13.23].

TABLE 13.XVIII. EVOLUTION AND PROSPECTS OF WORLD ENERGY DEVELOPMENT 1950–2000 [13–22, 5]

Year	Energy consumption (EJ)	Electricity generation (EJ)	Electricity generation (TW·h)[a]	Electricity/ energy share (%)	Nuclear/ electricity share (%)
1950	76.2	9.62	1045	12.6	0.0
1960	131.0	23.2	2520	17.7	0.13
1970	228.0	50.1	5440	22.0	1.72
1974	265.0	64.0	6950	24.1	4.36
1980	320.0	81.0	8797	25.3	7.9
1985	354–378	103.8–110.2	11273–11968	27.5–29.1	19–20
2000	438–505	143–164	15531–17780	32.4–32.5	21–26

[a] 1 EJ = 1 Exajoule = 277.8 $TW \cdot h_t$ = 108.6 TW·h(e). There are some slight differences between the TW·h figures recalculated from the EJ figures and the TW·h official statistics. However, these are not significant for the illustrative purpose here intended.

Future forecasts, as is the case for energy overall, are continuously being scaled down: from the first WEC (1977) estimates of some 27 500 TW·h in the year 2000 and 66 000 TW·h in 2020, the latest IAEA estimates descend to 11 300–12 000 TW·h in 1990 and 15 500–17 800 TW·h in the year 2000 – see Table 13.XV. The United Nations projections lie slightly higher than the 1984 IAEA estimates, i.e. 12 300 TW·h for 1990 and 18 500 TW·h for the year 2000 [13.21].

For the years 1982, 1985, 1990 and 2000 the per head electricity figures are shown in Table 13.XII.

13.5. The start and increasing share of nuclear energy

The history of peaceful utilization of nuclear energy for electricity generation purposes is very short. Not even three decades have passed since the commissioning of the first commercial nuclear power station of 5 MW(e) (USSR). A boom period followed, bringing in 1967 the nuclear installed capacity to 7000 MW(e). By the end of 1983, there were 316 nuclear power units with a total capacity of 189 000 MW(e) in operation in 25 countries – see Table 13.XVI[12].

These nuclear units represented over 8% of worldwide electrical power capacity and provided 11.3% of the total electricity generated during 1982. A further 210 nuclear units with a total capacity of 196 GW(e) were under construction at the end of 1983.

TABLE 13.XIX. ESTIMATES OF TOTAL AND NUCLEAR ELECTRICAL GENERATING CAPACITY [13.5]

	1983			1990[c]			1995[c]			2000[c]		
	Total elect.	Nuclear		Total elect.	Nuclear		Total elect.	Nuclear		Total elect.	Nuclear	
	(GW(e))	(GW(e))	(%)	(GW(e))	(GW(e))	(%)	(GW(e))	(GW(e))	(%)	(GW(e))	(GW(e))	(%)
North America	748	70.6	9.4	910	133	15	1 005	135	13	1 089	135	12
				954	135	14	1 085	144	13	1 196	160	13
Western Europe[a]	469	66.9	14.3	547	126	23	600	144	24	651	162	25
				582	144	25	660	185	28	732	230	31
Eastern Europe	418	24.8	5.9	556	60	11	660	89	14	764	126	17
				592	82	14	726	138	19	859	214	25
Industrialized Pacific	188	19.0	10.1	224	27	12	249	37	15	283	50	18
				241	32	13	280	51	18	316	76	24
Asia	186	6.1	3.3	295	14	5	387	21	6	482	29	6
				320	15	5	449	29	6	601	49	8
Latin America	123	1.6	1.3	188	5	3	239	7	3	290	9	3
				196	6	3	265	8	3	347	15	4
Africa and Middle East[a]	81	–	–	132	2	1	178	3	2	231	5	2
				142	2	1	206	8	4	291	16	6
World total	2 212	189.0	8.5	2 852	367	13	3 318	437	13	3 790	516	14
				3 027	415	14	3 672	563	15	4 341	760	18

TABLE 13.XIX (cont.)

	1983			1990[c]			1995[c]			2000[c]		
	Total elect. (GW(e))	Nuclear (GW(e))	Nuclear (%)	Total elect. (GW(e))	Nuclear (GW(e))	Nuclear (%)	Total elect. (GW(e))	Nuclear (GW(e))	Nuclear (%)	Total elect. (GW(e))	Nuclear (GW(e))	Nuclear (%)
Industrialized countries	1 725	178.0	10.3	2 074	338	16	2 319	388	17	2 565	450	18
				2 192	383	17	2 521	497	20	2 817	646	23
Developing countries												
In CPE-Europe[b]	89	2.8	3.1	114	10	9	132	18	13	147	24	17
				119	11	9	142	22	16	165	33	20
Others	398	8.2	2.1	664	20	3	867	31	4	1 079	42	4
				717	21	3	1 008	44	4	1 359	82	6
Total of DCs	487	11.0	2.3	779	30	4	998	48	5	1 225	66	5
				836	32	4	1 150	66	6	1 524	115	8

[a] Nuclear programmes in Austria and the Islamic Republic of Iran have been interrupted, and the reactors are not included.
[b] Developing countries in the Centrally Planned Economies (CPE) in Europe: Albania, Bulgaria, Czechoslovakia, Hungary, Poland and Romania.
[c] The top and bottom figures for total electric and nuclear capacity are low and high estimates, respectively.

Table 13.XVII presents an overview on the number of countries with nuclear power reactors in operation, under construction, or planned by the end of 1983. From the world total of 196 countries – 27 industrialized and 169 developing – 16 industrialized and 22 developing countries had nuclear energy projects active or in progress.

Figure 13.7 presents the nuclear electricity generation in 1980 in the various countries, while Fig.13.8 illustrates its share in the country's electrical energy production [13.23].

According to the planned completion dates of the units under construction, by 1985 nuclear power may be producing about 15% of the world's electricity – see also Table 13.XVIII.

However, a negative aspect of nuclear power development in some countries during the last few years has been the lack of new orders for additional nuclear units and even the cancellation or postponement of units which were ordered earlier, including some already under construction. In general, the reasons are: lower than expected growth in electricity demand, ongoing political and public constraints and financing problems. Due to this slow-down in initiation of new nuclear power projects, an inevitable flattening of the curve of nuclear capacity growth may be foreseen in the second half of this decade.

Nonetheless, during this period, the nuclear share of electricity generation in some countries will reach very impressive levels. In particular, France is planning to satisfy 70% of its electricity needs in 1990 through nuclear power. Estimated nuclear shares of electricity generation in other countries in 1990 are: over 50% in Belgium; over 40% in Bulgaria, Sweden and Taiwan; over 30% in the Federal Republic of Germany, Hungary, the Republic of Korea and Spain and between 20% and 30% in Finland, Switzerland and the USA [4.3].

In the longer term up to the year 2000, there are expectations that a resumption in economic growth will stimulate growth in energy and electricity needs, and that nuclear plant ordering will be resumed in countries where it has been suspended. Additional incentives for an increased demand for nuclear energy would include: a growing recognition that nuclear energy is increasingly able to replace fossil fuel not only for electricity generation but also for heat applications; a restored public and political confidence in nuclear energy as a reliable, economic and environmentally acceptable source of energy; and the foreseeable need to replace a significant amount of older generating capacity.

With the above view, Table 13.XVIII displays the evolution of nuclear-produced electricity and its increasing share in the world electricity balance. This table incidentally also provides an excellent overview on the evolution of world energy

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[12] For more details see the yearly published IAEA brochure Ref. [13.22], which in addition to other updated information brings a complete list of all nuclear reactor units connected to the grid, their parameters and performances.

and electricity consumption between 1950 and 1980, the prospects for 1990 and 2000, as well as percentage shares.

Table 13.XIX illustrates the total and nuclear electrical generating capacity which corresponds to the electricity generation figures of Table 13.XV. Accordingly, the total installed world electrical capacity of some 2212 GW(e) in 1983, of which 189 GW(e), i.e. 8.2% is nuclear, will possibly increase to 4350 GW(e) with 760 GW(e) i.e. 18% nuclear in the year 2000 [13.5]. That would correspond to a share of nuclear-based electricity generation of 26% in the total world electrical energy production or of some 8.5% in the world total energy balance.

However, the above figures, relating to thermal reactor systems only, represent a temporary contribution to meet the energy requirements of the world on a time-scale comparable to the oil period. A long-term contribution of nuclear energy far beyond this century presumes the development and timely introduction of commercial advanced systems, first of all fast breeders which provide a nuclear economy whose fuel resources would become practically unlimited [13.25].

13.6. Summary and conclusion

For better understanding the energy dilemma of the next decennium and somehow as a conclusion to the aforegoing considerations, it might serve, in line also with the views expressed in Ref. [13.26], to submit the following summary:

- The world population, at some time reaching 10 to 12 $\times$ 10^9 inhabitants, will develop a demand for primary energy no lower than some 38 $\times$ 10^9 tce (i.e. 27 $\times$ 10^9 toe or 1125 EJ).
- The fossil energy reserves of category 1, according to IIASA estimates and totaling 34 000 EJ, i.e. 17 700 EJ coal costing less than US \$35 (1980) per tce, 8300 EJ petroleum and 8400 EJ natural gas with costs both less than US \$17 (1980) per boe, would last, if used for a world population of 10 $\times$ 10^9 inhabitants, for some 30 years.
- The fossil energy reserves of categories 2 and 3, i.e. 32 000 EJ coal with costs (cat. 2) between US \$ 35 – 70 (1980) per tce, 6300 EJ petroleum (cat. 2) and 11 700 EJ (cat. 3) and 4500 EJ natural gas (cat. 2) and 4100 EJ (cat. 3) with costs (cat. 2) between US \$17 – 28 and (cat. 3) between US \$28 – 35 (1980) per boe representing additional 42 800 EJ of cat. 2 and 15 800 of cat. 3, could intervene only at much higher costs, with increased environmental and social impacts, and based on improved and new large-scale technology.
- The renewable energy resources (fuelwood and hydro) are considered limited to some 126 EJ annually, i.e. 11% in a 10 $\times$ 10^9 population scenario.
- The nuclear energy reserves if only used via thermal reactors would represent only 2.2% of the total fossil energy reserves of 93 000 EJ. Utilized via breeder reactors, nuclear energy reserves would triple the fossil ones (coal, petroleum and natural gas).

– Solar energy is expected to reach only a share of 11% of the total annual energy consumption by the middle of the next century.

It appears that difficult problems have to be solved in order to meet the long-term energy demand. They are less related to the availability of primary energy resources than imposed by the time delay necessary to develop to commercial application the new and improved technology required for the utilization of continuously more demanding and costly energy input.

The main problems relate to the considerable increase of coal production to some 12×10^9 t/year and the development of its liquefaction technology, to the development of new techniques for petroleum extraction from oil-shale, tar sands, heavy oils and deep off-shore reserves, and to further development of nuclear energy utilization. For the latter the challenges are the commercial breeders and some time later energy from nuclear fusion.

In the light of the above considerations, it is hardly necessary to stress the importance of the development of nuclear energy, since in addition to being imperatively necessary it represents and energy resource with a mature technology, which is commercially competitive and in spite of objections, safe and clean in its application. However, because of its demanding technology and great economic dependence on the advantages of scale, caution is recommended regarding the timing of its implementation in smaller electrical systems.

Chapter 14

ENERGY IN INDUSTRIALIZED COUNTRIES

14.1. The group of industrialized countries

The next chapter, Energy in Developing Countries, begins with a brief review of the various existing methodological classifications of the world's countries for analytical and study purposes. It subsequently explains the reasons for adopting the recent World Bank definition of the group of developing countries [15.1] as framework for the energy analysis which is the subject of the chapter.

The present chapter deals with the remaining countries, the group of industrialized countries with the following subgroups:

(a) North America
(b) Western Europe
(c) Industrialized Pacific
(d) Eastern Europe (USSR and the European CPE (centrally planned economies))
(e) The high-income oil exporters and South Africa.

Subgroups (a) to (c) are also members of the OECD – the Organisation for Economic Co-operation and Development; subgroup (d) comprises members of the CMEA – the Council for Mutual Economic Assistance. With the exception of France, Finland and Iceland, all other countries from subgroups (a) to (c) are members of IEA – the International Energy Agency. A number of European countries are members of the EEC – the European Economic Community.

The basic difference between the above grouping and the other more usual ones is that it includes the European CPE countries (Bulgaria, Czechoslovakia, the German Democratic Republic, Hungary, Poland and Romania), which elsewhere are statistically ranged under the developing countries. However, the IAEA statistics provide separate data for developing countries in CPE-Europe, others and consolidated total of developing countries.

Since according to the above classification a simplified bipolar energy world could be contemplated, a simplified and, it is to be hoped, successful scenario of long-term world energy development could also be evolved. It might evolve by consolidating the following two trends: the industrialized countries' determination to reduce substantially the specific energy input per per cent GNP growth and to cover it with a primary energy mix containing less petroleum; and the developing countries' aim to utilize all the primary energy resources needed for their socio-economic development, without, however, repeating the wasteful historical patterns of energy development of the now industrialized countries, while basing their development on wise energy husbandry.

The availability of petroleum would remain a key problem in this scenario, since for years to come the developing countries would need increasing quantities of this resource, especially for their rapidly expanding transportation needs. Subsequently, petroleum will not only have to be saved as much as possible, but also massively substituted for. Here only coal and nuclear energy possess the needed potential, the latter also the necessary speed for development of capacity.

14.2. The energy evolution

The figures and comments in chapter 13 on the world energy situation emphasized the concentration of gross national product and energy consumption in the group of industrialized countries. In the graphical presentation of the relationship between per head energy consumption and per head GNP it is precisely these countries which fill the upper right corner of the diagram, where both indices reach their maximum values.

Given the described situation, the following considerations will not go into involved additional data analysis but will address directly the basic structural aspects. For deeper quantitative analysis adequate statistical sources are indicated at the end of the chapter.

14.2.1. Past energy evolution

The history of energy, as far as larger-scale and centralized supply and consumption are concerned, is hardly two centuries old and practically confined to industrialized countries. These could only start their industrial development when coal and later electricity and petroleum derivatives became available and hydro power was introduced on a larger scale.

After a long initial time period with coal constituting by far the main primary energy source for industrial heat production and transport purposes and, together with hydro power, for electricity generation, by the early nineteen-thirties petroleum entered the energy market; an incredible boom started for this new primary energy resource with excellent technical qualities and extremely low prices. Its appearance undeniably represented a great contribution to energy development. However, its profligate consumption and waste-favouring supply conditions led relatively soon to a terrible petroleum dependency which became a major source of trouble in the seventies. Fortunately, natural gas, which developed almost in parallel, although not necessarily associated with petroleum production, had a certain alleviating influence. Nevertheless, it appears in the long run less economically helpful since its price asymptotically moves towards the opportunity level of petroleum prices.

With the petroleum price explosion in 1973 and the further increasing prices of petroleum and of other energy carriers as well, the industrialized countries entered an era demanding a fundamental change in the structure of their energy economy.

14.2.2. Recent development and present status

All industrialized countries reacted by improving energy husbandry. The concept, effort, means and dedication applied were very dependent on the economic system, the pressure from consumers to import petroleum and the supply and consumption structure which affected differently the penetration rate of energy-saving and substitution measures.

Due to the different basic approaches, reaction and action to the petroleum challenge will be separately analysed for the western and the eastern group of countries.

14.2.2.1. The new energy strategy of the western countries

According to their concurring interests, the western industrialized countries met early on at the highest levels and established a common energy strategy, repeatedly spelled out and strengthened in their national and international organizations dealing with energy and even confirmed at summit meetings.

The common energy strategy, described in more detail in subsection 14.3.1, can be summarized as follows:

(1) To reduce excessive dependence on petroleum through energy conservation, i.e. saving and substitution
(2) To develop alternative energy resources
(3) To loosen the relationship between economic and energy development, i.e. using less energy for a given economic growth rate
(4) To co-operate in a strong energy research and development programme
(5) To co-operate with petroleum-producing and other petroleum-consuming countries with a view to developing a stable international energy trade as well as the rational management and use of world energy resources in the interest of all countries
(6) To participate in a common plan to prepare the western countries for the risk of a major disruption of petroleum supplies and to share available stored petroleum reserves in the event of an emergency.

The above goals, although concurrent in the various industrialized countries and commonly agreed upon, are approached differently in the various countries. Accordingly, the rate of success differs and in recent years there has been critical evaluation within the international organizations in which the countries are members and have participated in common decisions.

14.2.2.1.1. Recent developments and present status

The overall results of the implemented common energy strategy can be judged from the figures of Table 14.I, which compare the key IEA energy

TABLE 14.I. IEA KEY ENERGY INDICATORS [14.1]

	(10^6 toe)			
	1973	1980	1981	1983[a]
Total primary energy (TPE)	3303.4	3512.9	3437.6	3319
Non-oil requirements	1589.4	1846.1	1879.2	1840
Oil requirements	1714.0	1665.8	1558.2	1479
% of TPE	51.9	47.4	45.3	44.6
Net oil imports	1173.9	1050.0	909.7	773
% of TPE	35.5	29.9	26.5	23.3
Indigenous production:				
– Total energy	2194.4	2542.7	2570.7	2565
– Oil	620.0	710.6	709.1	921
TPE/GDP[b]	0.89	0.80	0.77	0.75
TFC/GDP[b]	0.67	0.58	0.55	n.a.

	Growth rates (per cent per annum)		
	1973–80[c]	1980–81	1981–82
TPE	0.9	–2.1	–3.5
GDP	2.4	1.6	–0.6
Total final consumption (TFC)	0.3	–3.0	n.a.
Net oil imports	–1.6	–13.4	–15.0
Oil requirements	–0.4	–6.5	–5.1
TPE/GDP[b]	–1.5	–3.7	–2.6
TFC/GDP[b]	–2.0	–5.2	n.a.

[a] Preliminary.
[b] toe per US $1000 (1975) of GDP.
[c] Annual average growth rates.

Sources: Energy Balances of OECD Countries 1971/81, Paris 1983, and Country Submissions to the IEA Secretariat (subsequently referred to as OECD Energy Balances and Country Submissions).

indicators from 1973, 1980, 1981 and 1982 [14.1]. From the self-explanatory figures the following features are particularly remarkable:

- The petroleum share in the total primary energy consumption decreased from 51.9% in 1973 to 44.6% in 1982;
- The share of net oil imports went down from 35.5% to 23.3%;
- Indigenous energy production increased from 2194.4×10^6 toe to 2565×10^6 toe and of indigenous oil from 620.0×10^6 toe to 721×10^6 toe.
- The TPE/GDP ratio went down from 0.89 to 0.75 toe for US $1000 (1975) of GDP.

The above and following figures do not include French energy data, since France is not an IEA member country. However, from previous comments – see subsection 8.3 – the excellent results of the French energy husbandry policy are well known.

Decreasing oil demand had marked effects on prices in 1982. The average price paid for crude oil by member countries of the IEA declined from $36 a barrel in the first quarter of 1981 to just over $32 a barrel by the end of 1982.

During February and March 1983, crude oil prices fell substantially as both non-OPEC and OPEC producers reduced contract and official prices. The average contract price in March 1983 was estimated at $29 a barrel, some $7 a barrel less than its peak in the first quarter of 1981. Spot crude oil prices have continued to run below official prices following the March 1983 OPEC agreement to realign official prices on the basis of a market crude price of $29 a barrel and to set a production quota of 17.5×10^6 b/d for the remainder of 1983. This tendency continued throughout 1984.

Figure 14.1 compares the structure of the IEA total primary energy requirements (TPE) for 1973 and 1981: it shows a small increase of TPE (3303 to 3437×10^6 toe), the increasing shares of hydro/geothermal (6.8% from 6.0%), solid fuels (22.9% from 20.1%) and nuclear energy (4.2% from 1.3%), a stagnant share of natural gas (20.7%) and a decrease of the petroleum share from 51.0% down to 45.3%.

The intended weakening of the historical links between economic growth and energy consumption made good progress between 1973 and 1981. Table 14.II shows the decline in both the broad measures of energy intensity, total primary energy requirements per unit of GDP (TPE/GDP) and total final consumption per unit of GDP (TFC/GDP). This trend has accelerated since the oil price shock of 1978. For example, TFC/GDP in member countries of the IEA decreased at an average rate of 1.3% per year from 1973 to 1979, but at 5.4% per year from 1979 to 1981.

As far as individual industrialized countries are concerned, although all are industrialized, these operate in the field of energy husbandry and management at different levels of performance and efficiency. Whilst not universally valid,

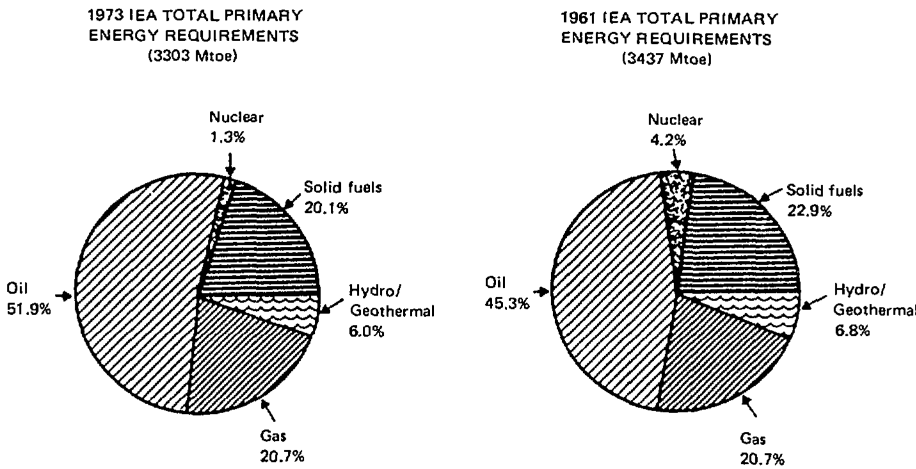


FIG.14.1. IEA total primary energy requirements (TPE) in 1979 and 1981, in 10^6 toe [14.1].

since national conditions retain their share of uncertainty, Fig.14.2 offers a general comparison of the specific GDP in 1975 US$ generated with the consumption of one tonne oil equivalent in a group of selected industrialized countries. France and the Federal Republic of Germany are leading the field, with France showing a higher acceleration in performance between 1973 and 1979. Progress has, however, been registered in all the countries, although at very different paces.

As regards nuclear energy, at the end of 1981, 109.7 GW of nuclear plant was operating in IEA countries, with 58.5 GW in the USA. During the year, 7.7 GW of new nuclear capacity was commissioned – 3.9 GW in North America, 0.6 GW in Japan and 3.2 GW in Europe. Total nuclear capacity under construction in IEA countries at the end of 1981 was 135.3 GW, of which 80.7 GW was in the USA, 10 GW in Canada, 9.5 GW in Japan and 35.1 GW in Europe.

14.2.2.1.2. Energy outlook and projections

In addition to its part in world energy development studies, the western world engendered a series of studies typically tailored to its areas and spheres of interest, as for example:

- Fuelling Europe in the Future – the Long-term Energy Problem in the EEC Countries: Alternative R&D Strategies – IIASA [14.3].
- World Energy Outlook, an IEA study, 1977.
- World Energy Outlook (WEO), the IEA study, revised edition, 1982 [14.4]. WEO is not a forecast of what will happen. It is an assessment of what

TABLE 14.II. HISTORICAL ENERGY AND OIL REQUIREMENTS PER UNIT OF GDP [14.1]

					Average annual change (%)	
	1973	1979	1980	1981	1973–79	1979–81
TPE/GDP[a]						
IEA Total	0.89	0.83	0.80	0.77	−1.2	−3.7
North America	1.11	1.04	1.01	0.97	−1.1	−3.4
Europe	0.71	0.66	0.63	0.61	−1.2	−3.9
Pacific	0.69	0.64	0.60	0.58	−1.2	−4.8
TFC/GDP[a]						
IEA Total	0.67	0.62	0.58	0.55	−1.3	−5.8
North America	0.83	0.76	0.73	0.69	−1.5	−4.7
Europe	0.53	0.49	0.46	0.44	−1.3	−5.2
Pacific	0.50	0.48	0.42	0.40	−0.7	−8.7
Oil/GDP[a]						
IEA Total	0.46	0.42	0.38	0.35	−1.5	−8.7
North America	0.50	0.47	0.43	0.40	−1.0	−7.8
Europe	0.41	0.35	0.32	0.30	−2.6	−7.4
Pacific	0.49	0.42	0.36	0.34	−2.5	−10.0

[a] Measured in toe per US $1000 of GDP at 1975 prices and exchange rates.
Sources: OECD Energy Balances and OECD National Accounts.

might happen to energy supply and demand during the rest of the century on the assumption that the OECD area resumes a modest rate of economic growth.

– The annual reviews of energy policies and programmes of IEA countries, the latest here cited being the 1982 review [14.1].

In addition, the comprehensive study of the United Nations Economic Commission for Europe (UNECE): An Efficient Energy Future – Prospects for Europe and North America [14.5], although not including the industrialized Pacific countries, provided impressive study material for the western zone, as well as for the eastern countries which form part of the ECE.

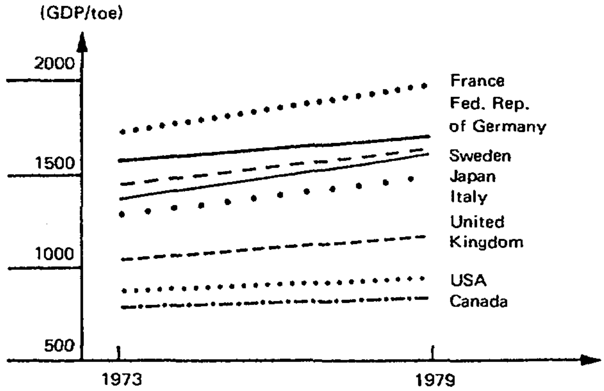


FIG.14.2. GDP/toe in some industrialized countries [14.2].

Finally, the yearly updated estimates of the IAEA on world energy consumption, electricity generation and share of nuclear energy represent another permanently topical source of information on energy prospects of both western and eastern countries [13.5].

As for recent developments and the present status, because of their topical character and for the sake of consistency, the IEA forecasts will be taken as representative for the western countries' future development, although for strictly correct quantitative purposes, the French data should be added. However, since the interest of this analysis is more in trends and the energy trends in France are more favourable than the IEA average, the aggregated IEA data would perfectly serve the purpose.

(a) Total energy development

Table 14.III and Fig.14.3 show historical data and forecasts of TPE requirements by fuel and region.

Solid fuel use is expected to increase steadily in all three regions to 1995. The Pacific region is expected to increase its coal use at the fastest rate but its share of total use in TPE requirements will remain the lowest (Pacific: 25%; Europe: 29%; North America: 30%).

Oil requirements are expected to increase from 1981 to 1985 but the total requirements for oil will remain below the 1980 level in all three regions. The decline in oil use is expected to continue to 1995 in North America and Europe, but a slight increase is expected in the Pacific region after 1985.

There are substantial regional differences in gas demand. Demand in North America is forecast to remain almost constant throughout the decade and

TABLE 14.III. PROJECTED IEA ENERGY REQUIREMENTS (TPE) [14.1] (10^6 toe)

	1980	1981	1985	1990	1995	Annual average growth rates 1981–85	1985–90	1990–95
IEA Total								
TPE	3512.3	3437.6	3825	4229	4593	2.7	2.0	1.7
Oil	1665.8	1558.2	1616	1596	1567	0.9	–0.3	–0.4
Solid fuels	764.9	786.5	936	1126	1316	4.5	3.8	3.2
Gas	717.0	712.2	735	796	806	0.8	1.6	0.3
Nuclear	131.3	146.1	252	379	481	14.6	8.5	4.9
Hydro and others	233.4	234.5	285	332	426	5.0	3.1	5.1
North America								
TPE	2034.3	1992.7	2183	2374	2535	2.3	1.7	1.3
Oil	872.1	816.0	838	818	785	0.7	–0.5	–0.8
Solid fuels	425.9	435.8	535	640	754	5.2	3.7	3.3
Gas	530.7	527.6	507	528	529	–1.0	0.8	0
Nuclear	75.8	82.7	141	210	240	14.3	8.3	2.7
Hydro and others	130.0	130.7	162	178	227	5.5	1.9	5.0
Pacific								
TPE	453.1	451.1	535	637	733	4.4	3.6	2.8
Oil	272.9	261.3	268	280	286	0.7	0.9	0.4
Solid fuels	97.8	104.3	130	161	183	5.7	4.4	2.6
Gas	30.4	32.3	55	78	85	14.2	7.2	1.7
Nuclear	20.2	21.5	39	63	95	16.1	10.1	8.6
Hydro and others	31.7	31.7	43	56	83	7.9	5.4	8.2
IEA Europe								
TPE	1024.9	993.9	1106	1218	1328	2.7	1.9	1.7
Oil	520.9	480.9	510	498	496	1.5	–0.5	–0.1
Solid fuels	241.2	246.4	270	325	379	2.3	3.8	3.1
Gas	155.8	152.3	173	190	192	3.3	1.9	0.2
Nuclear	35.3	41.8	72	107	145	14.7	8.3	6.3
Hydro and others	71.7	72.0	81	98	116	2.7	3.9	3.4

Source: OECD Energy Balances and Country Submissions.

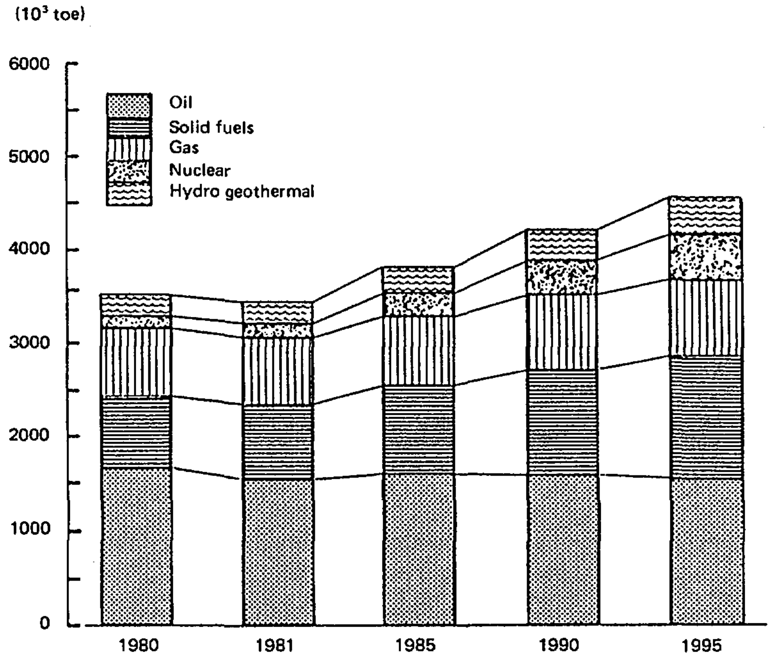


FIG.14.3. Total IEA energy requirements, 1980–1995 [*14.2*].

beyond. In Europe, gas demand is expected to increase in line with TPE requirements and the share of gas in TPE is expected to be 14% in 1995. The most rapid increase in gas demand is likely in the Pacific region. It is expected almost to triple between 1980 and 1995, but the share of gas in TPE requirements will remain the lowest (Pacific: 12%; Europe: 14%; North America: 21%).

The growth of nuclear power is conspicuous in all IEA regions. The share of nuclear power in TPE requirements is expected to increase to 13% in 1995 in the Pacific, to 10% in North America and 11% in Europe.

In all regions hydro power and other renewable energy resources are expected to grow at an annual average rate of 2.9% between 1981 and 1995. The largest increases are foreseen in North America and the Pacific region, where there are still undeveloped hydro-electric resources.

At this point an interesting comparison of the latest IEA forecasts with some former figures is instructive. Figure 14.4 illustrates the differences between the 1977 IEA forecast for OECD primary energy demand, the figures of the IEA steam-coal study (1978) and the figures of the 1982 IEA World Energy Outlook, the latter using a high and low case assumption compared to a reference case (1980).

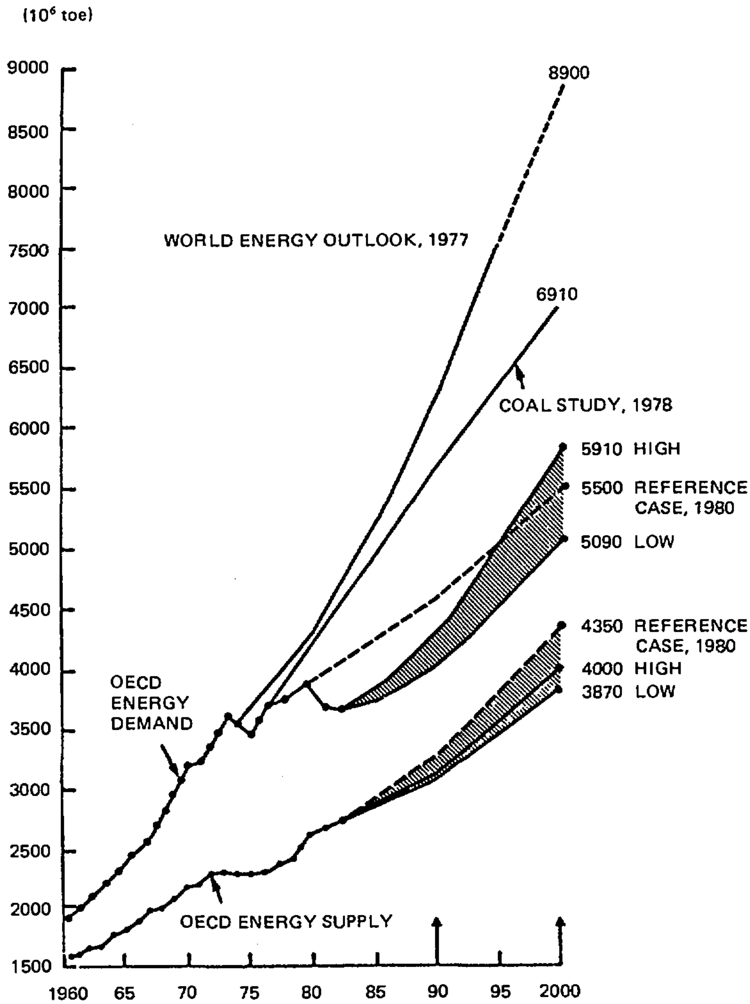


FIG.14.4. OECD primary energy demand and supply history and projections [14.4].

The high demand case assumes constant oil price/high growth, i.e. 1980–1985 real oil price –3.9%, economic growth +2.6%, and figures for 1985–2000 of ±0% and +3.2%. The low demand case assumes rising oil price/lower growth, i.e. real oil price –3.3%, economic growth +2.4%; and for 1985–2000 +3% and +2.7%. The latest figures lie between the low and high curves, well below the previous forecasts, but also significantly higher than the OECD energy supply potential curves.

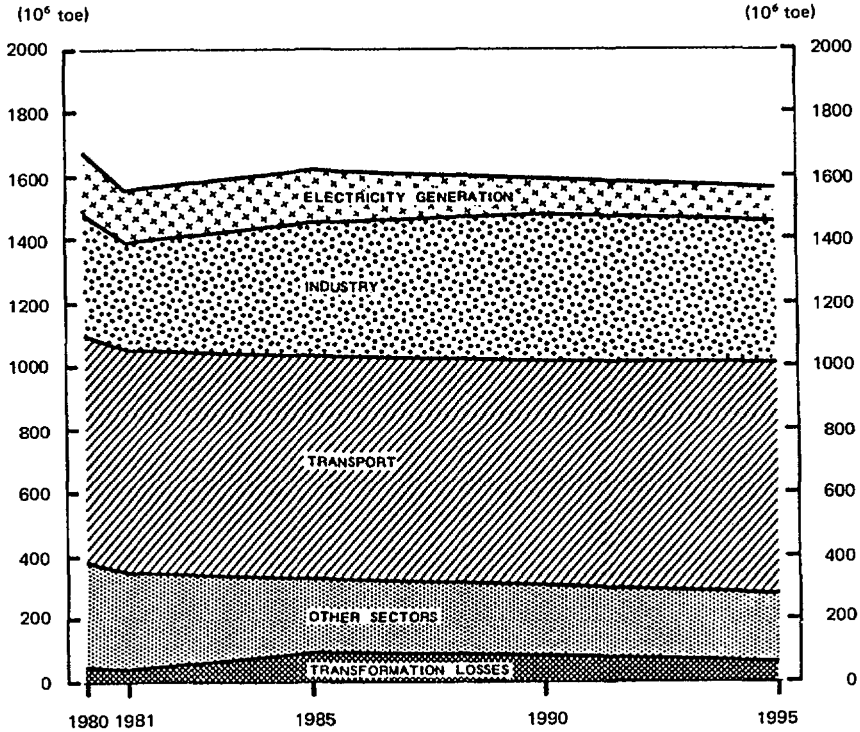


FIG.14.5. Total IEA oil consumption by sector [14.1].

(b) Improved energy efficiency

Projections by IEA member governments of future energy and oil requirements assume continued improvements in the efficiency of energy use and an acceleration of the rate of decline in the oil intensity of their energy economies, compared with results actually achieved from 1973 to 1981.

If the projected improvements in the TPE/GDP ratio do not occur and energy efficiency remains at 1981 levels, total energy use would reach a level of 660×10^6 toe higher than is now projected for 1995. Similarly, if the intensity of oil use in the economy were not to decrease from 1981 levels, oil use would reach a level of 820×10^6 toe higher than is now projected for 1995.

(c) Total petroleum consumption by sectors

Figure 14.5 illustrates the evolution of IEA petroleum consumption in total and by sectors between 1980 and 1995.

(d) Synthetic fuels

Canadian production of liquid fuels from oil sands is projected to increase considerably, from 5.7×10^6 toe in 1981 to 12×10^6 toe in 1990 and 18×10^6 toe in 1995. The USA projects production of liquid products from oil shale of the order of 4×10^6 toe in 1990 and 12×10^6 toe in 1995, and from coal liquefaction of the order of 4×10^6 toe in 1990 and 8×10^6 toe in 1995. Coal gasification in the Netherlands is projected to be 1.7×10^6 toe by 1990. In the USA, non-conventional gas contributions are projected to increase from 5×10^6 toe in 1985 to 31×10^6 toe in 1990 and 44×10^6 toe in 1995.

(e) New and renewable primary energy resources

The share of hydro and geothermal power in the energy supplies of IEA countries was 7% of total primary energy requirements in 1981. It is expected to increase to 8% by 1995.

Total production from renewable energy sources other than hydro power and geothermal sources was negligible in 1981. It is projected to be 15×10^6 toe in 1985 and 71×10^6 toe in 1995, or 0.4% and 1.5% respectively of the TPE requirements of IEA countries. Not included are biomass and small-scale hydro.

(f) Electricity generation and nuclear share

Electricity is both a major source of energy for final consumption and a major consumer of primary energy supplies. In the former role, electricity has a part to play in restructuring the energy economies of the IEA countries away from oil by directly displacing that fuel and thus indirectly providing further market opportunities for coal and nuclear energy. In the latter role, it plays a key part in promoting increased use of coal and nuclear energy.

In 1981, 5005 TW · h of electricity were generated in IEA countries, the energy equivalent of 430×10^6 toe. The generation of this electricity required the equivalent of 1200×10^6 toe of primary energy, of which 165×10^6 toe was petroleum and petroleum products, primarily heavy fuel oil.

Table 14.IV displays the electricity generation figures of the OECD countries, the total annual amount for 1982 and 1983 and estimated figures for 1985, 1990, 1995 and 2000. Nuclear energy generation has a separate column for TW · h contribution and % share of total generation [14.6].

Table 14.V presents an overview of the nuclear power plants in OECD countries, according to their status: operable, under construction and planned.

Table 14.VI displays by country the distribution of operable nuclear power plants by reactor type, within the OECD.

The evolution of nuclear share in total electricity generation is illustrated by Figs 14.6 and 14.7. Between 1974 and 1983 the nuclear share in total OECD

TABLE 14.IV. ESTIMATES OF TOTAL AND NUCLEAR ELECTRIC ITY GENERATION IN OECD COUNTRIES TO 2000 (during year – net TW·h) [14.6]

	1982			1983			1985			1990			1995			2000		
	Total	Nuclear	% Nuclear	Total	Nuclear	% Nuclear	Total	Nuclear	% Nuclear	Total	Nuclear	% Nuclear	Total	Nuclear	% Nuclear	Total	Nuclear	% Nuclear
Australia[a]	100.3	0	0	105.8	0	0	108.7	0	0	139.1	0	0	158.0[b]	0	0	177.0[c]	0	0
Austria	42.9	0	0	42.6	0	0	43.3	0	0	48.8	0	0	54.6	0	0	61.0[b]	0	0
Belgium	48.0	14.8	30.8	50.1	23.0	45.9	52.6	33.0	62.7	59.6	35.1	58.9	67.4	42.0	62.3	76.7	42.0[b]	54.8
Canada	384.5	36.5	9.5	401.3	46.4	11.6	435.4	65.3	15.0	493.4	91.6	18.6	560.3	108.9	19.4	628.4	112.5	17.9
Denmark	22.1	0	0	20.4	0	0	25.9	0	0	29.1	0	0	32.1	0	0	35.3	0	0
Finland	39.4	15.8	40.1	40.2	16.7	41.5	46.0	15.4	33.5	53.0	15.4	29.1	59.0	22.4	38.0	66.0	22.4	33.9
France	266.0	103.0	38.7	283.0	137.0	48.4	295.6[d]	185.2[d]	62.7	340.0[e]	243.0[e]	71.5	360.0[b]	279.0[b]	77.5	380.0[e]	315.0[e]	82.9
Germany, F.R.	345.0	60.0	17.4	351.0	63.0	17.9	372.0	82.0	22.0	420.0	130.0	31.0	467.0	170.0	36.4	510.0	200.0	39.2
Greece	23.2	0	0	23.9	0	0	26.8	0	0	36.2	0	0	44.8[b]	0	0	53.3[c]	0	0
Iceland	3.6	0	0	3.9	0	0	4.4	0	0	5.5	0	0	7.5	0	0	9.7	0	0
Ireland	9.8	0	0	10.0	0	0	10.6	0	0	12.3	0	0	14.5	0	0	16.6	0	0
Italy	175.9	6.6	3.8	174.4	5.1	2.9	195.8	7.7	3.9	248.3	19.9	8.0	301.2	71.8	23.8	365.0[b]	87.0[b]	23.8
Japan[a,f]	522.5	101.8	19.5	551.0	113.0	20.5	589.0[b]	135.0[b]	22.9	685.0	190.0	27.7	805.0	285.0	35.4	950.0	370.0	39.0
Luxembourg	0.5	0	0	0.5	0	0	0.5	0	0	0.5	0	0	0.5	0	0	0.5	0	0
Netherlands	50.9	4.3	8.4	50.6	3.5	6.9	51.6	4.3	8.3	49.2	4.2	8.5	50.4	4.2[b]	8.3	51.6	4.2[b]	8.1
New Zealand	24.3	0	0	25.5	0	0	27.5	0	0	31.4	0	0	34.0	0	0	36.6	0	0
Norway	92.8	0	0	106.2	0	0	94.0	0	0	106.0	0	0	115.0	0	0	123.0	0	0
Portugal	14.5	0	0	16.4	0	0	20.1	0	0	25.0	0	0	33.0	0	0	42.0	0	0
Spain[b]	114.7	8.8	7.7	117.2	10.7	9.1	125.1	29.2	23.3	145.5	41.3	28.4	169.0	50.5	29.9	191.7	59.6	31.1
Sweden	96.6	37.3	38.6	105.8	39.1	37.0	114.0	48.0	42.1	130.0	58.0	44.6	130.0	58.0	44.6	130.0	58.0	44.6

Switzerland	44.1	11.9	27.0	44.6	12.4	27.8	49.2	16.9	34.3	51.7	18.7	36.2	56.8[b]	21.8[b]	38.4	61.8	24.9	40.3
Turkey	26.6	0	0	27.1	0	0	42.0	0	0	68.9	0	0	129.0	9.7[b]	7.5	179.1	16.8	9.4
United Kingdom	243.8	38.7	15.9	248.4	43.9	17.7	267.8	50.0[b]	18.7	272.0	63.0	23.2	293.0[b]	80.0[b]	27.3	313.0	97.0	31.0
USA	2 257.0	282.2	12.5	2 304.0	292.1	12.7	2 593.0	387.0	14.9	3 082.0	595.0	19.3	3 376.0[b]	677.0	20.1	3 670.0[c]	740.0	20.2
OECD total rounded	4 949	722	14.6	5 104	806	15.8	5 591	1 059	18.9	6 533	1 505	23.0	7 318	1 880	25.7	8 128	2 149	26.4

[a] Data for fiscal year.
[b] Secretariat's estimate.
[c] Data from IEA.
[d] "Programmes and Prospects for Electricity Sector" – 13th issue (UNIPEDE, Sept. 1983).
[e] Low projection.
[f] Gross numbers.
[g] Mid-range projection.
NB. Imports are excluded.

TABLE 14.V. STATUS OF NUCLEAR POWER PLANTS IN OECD COUNTRIES (as of 31 December 1983) [14.6]

			Units – net GW(e)
	Operable[a]	Under construction	Planned
Belgium	5–3.5	2–2.0	0–0
Canada	14–7.6	10–7.5	1–0.6
Finland	4–2.2	0–0	1–1.0
France	36–27.2	25–29.2	3–3.9
Germany, F.R.	16–11.2	11–11.9	2–2.4
Italy	3–1.3	2–2.0	10–10.0
Japan[b]	28–19.1	11–10.3	7–5.9
Netherlands	2–0.5	0–0	0–0
Spain	6–3.8	9–8.5	3–3.0
Sweden	10–7.3	2–2.1	0–0
Switzerland	4–1.9	1–1.0	2–2.0
United Kingdom	35–8.3	7–4.0	1–1.2
USA	80–65.7	58–64.3	2–1.1
OECD Total	243–159.6	138–142.8	32–31.1

[a] Including plants under test operation after their first connection to the grid.
[b] Converted to net figures.

electricity generation increased from 6% to 15.8% together with coal from 34% to 40%. The share of oil dropped from 24% to some 11%.

Figure 14.7 displays by country and the OECD total for the share of nuclear energy in 1983 and estimates for 1985. While in some countries spectacular figures are presented by 1990, for example 72% in France, 58% in Belgium, 45% in Sweden, the OECD average lies around 23%.

(g) Net petroleum imports

Projected net oil imports for IEA countries are shown in Table 14.VII. Total net oil imports in 1990 and 1995 are projected to remain below the level of 1980. A delay in any area of alternative energy development could, however, change the picture.

TABLE 14.VI. DISTRIBUTION OF OPERABLE NUCLEAR POWER PLANTS BY REACTOR TYPE (Units – net GW(e)) [14.6]

	LWR		GCR	HWR	FBR	HTR	Others	Total
	PWR	BWR						
Belgium	5–3.5							5–3.5
Canada				14–7.6				14–7.6
Finland	2–0.9	2–1.3						4–2.2
France	28–24.6		7–2.3		1–0.2			36–27.2
Germany, F.R.	7–6.6	6–4.5		1–0.05	1–0.02	1–0.01		16–11.2
Italy	1–0.3	1–0.8	1–0.2					3–1.3
Japan[a]	12–8.5	14–10.3	1–0.16	1–0.16[b]				28–19.1
Netherlands	1–0.45	1–0.05						2–0.5
Spain	4–2.9	1–0.4	1–0.5					6–3.8
Sweden	3–2.6	7–4.7						10–7.3
Switzerland	3–1.6	1–0.3						4–1.9
United Kingdom			26–4.1	1–0.09	1–0.18		7–3.9[c]	35–8.3
USA	51–43.6	27–20.9				1–0.30	1–0.85[d]	80–65.7
OECD Total	117–95.6	60–43.3	36–7.3	17–7.9	3–0.4	2–0.3	8–4.8	243–159.6

[a] Converted to net figures.
[b] Advanced Thermal Reactor (ATR) (D_2O/H_2O).
[c] AGR.
[d] Hanford – 850 MW(e) (graphite/H_2O).

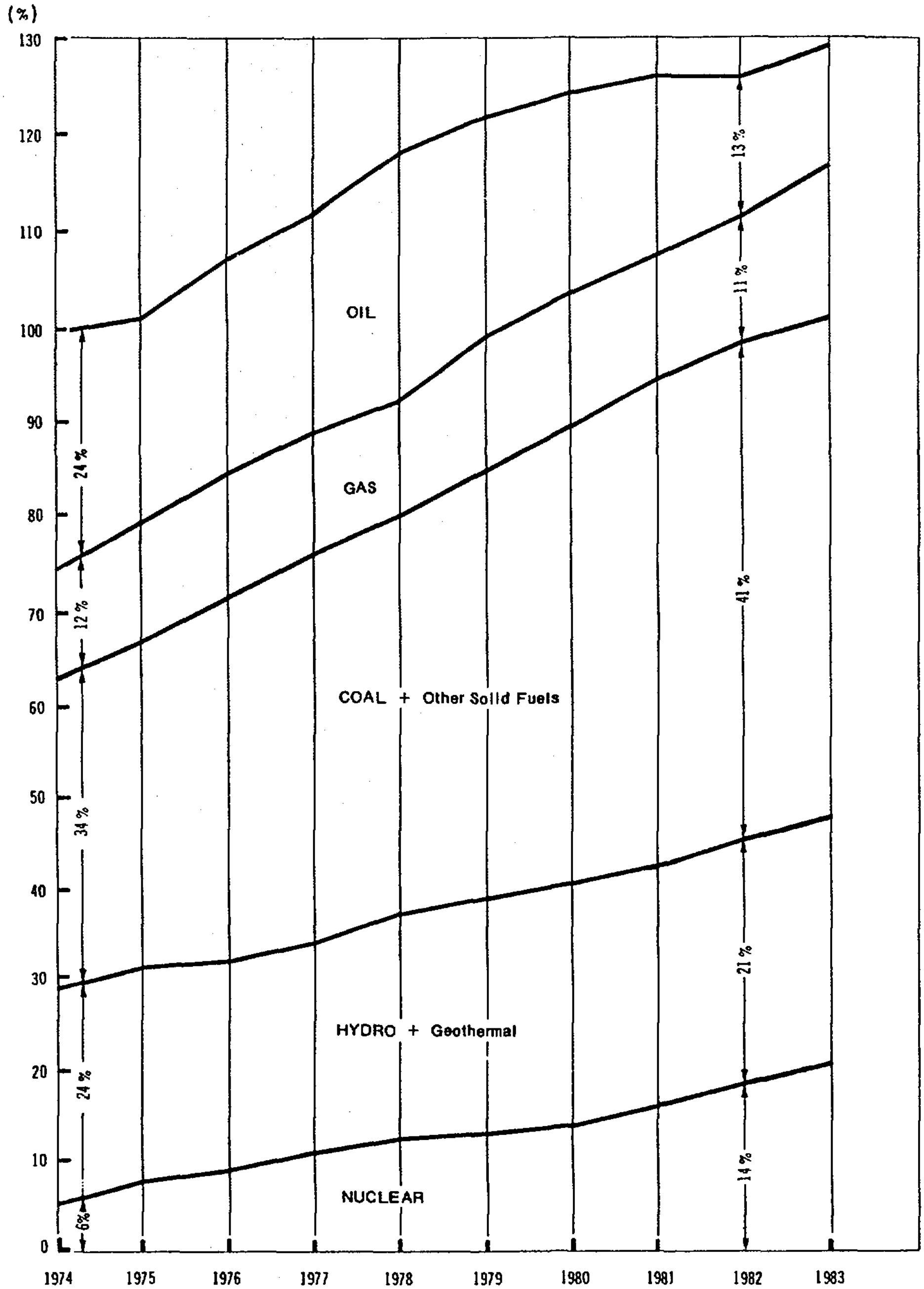


FIG.14.6. OECD electricity generation (gross) 1974–1983 (% breakdown by fuel type) [14.6].

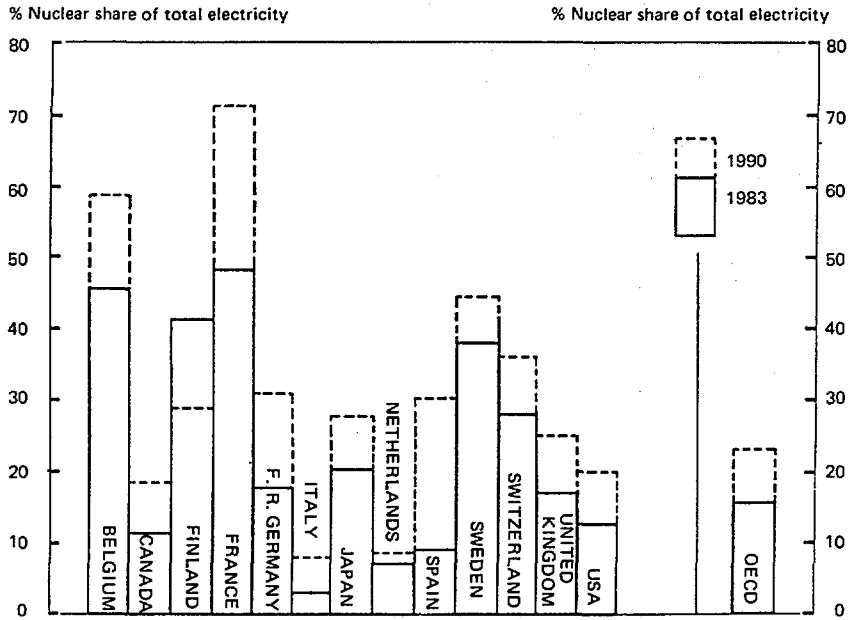


FIG.14.7. Nuclear energy's share of electricity generation in OECD countries [14.6].

14.2.2.2. Present status and future energy developments in the Eastern European countries

The industrialized countries of Eastern Europe – the USSR and the six European CPE countries – have an active co-operation in the energy area within the large economic framework of the Council for Mutual Economic Assistance (CMEA). A long-term, purpose-oriented programme of co-operation for meeting the economically substantiated needs of the CMEA member countries for the basic types of energy, fuel and raw materials, aimed at the optimization of general energy development, broadly co-ordinates the long-term orientation and the 5-year energy plans of the countries [14.7].

While basic orientation and main energy objectives are agreed upon in the council at highest levels, the current work is carried out in specialized commissions such as the CMEA standing commission for the coal industry, the commission for the oil and gas industry and the standing commission for electric power and the peaceful uses of atomic energy.

Table 14.VIII displays an overview of the structure and evolution of total primary energy production and consumption of the USSR and the East-West energy trade [14.12].

TABLE 14.VII. NET OIL IMPORTS[a] (10^6 toe) [14.1]

	Actual			Forecasts[c]		
	1980	1981	1982[b]	1985	1990	1995
Canada	8.6	9.0	−2.3	7	−2	−3
USA	335.8	287.1	220.1	320	330	298
North America	344.4	297.1	217.8	327	328	295
Australia	11.1	10.8	12.3	8	7	8
Japan	253.9	235.3	209.1	245	260	265
New Zealand	4.0	3.4	3.1	3	3	4
Pacific	269.0	249.5	224.5	257	270	277
Austria	11.3	9.8	8.7	11	11	12
Belgium	25.8	21.2	21.6	21	21	20
Denmark	13.2	10.5	9.0	7	6	6
Germany, F.R.	133.2	111.1	104.9	124	117	111
Greece	13.3	12.1	10.4	10	11	12
Ireland	5.8	5.0	4.4	7	6	7
Italy	96.5	92.1	88.8	103[d]	91[d]	87[d]
Luxembourg	1.1	1.0	1.0	1	1	1
Netherlands	38.1	31.8	31.2	37	40	42
Norway	−14.8	−15.5	−15.7	−19	−25	−12
Portugal	9.3	8.4	9.3	11	11	12
Spain	49.4	48.5	43.0	43	47	50
Sweden	26.0	21.4	19.3	25	19	15
Switzerland	13.1	11.8	11.0	12	12	12
Turkey	13.4	13.5	14.0	18	18	24
United Kingdom	1.9	−18.6	−29.8	−24	−3	10
IEA Europe	436.6	364.1	330.9	387[d]	384[d]	404[d]
IEA Total	1050.0	909.7	773.2	972	982	960

[a] Includes requirements for marine bunkers.
[b] Preliminary.
[c] In the case of some countries, forecasts pre-date recent oil price decreases and economic growth trends and revised forecasts now being developed may indicate lower oil import requirements.
[d] Secretariat estimates.

Source: OECD Energy Balances and Country Submissions.

TABLE 14.VIII. TOTAL PRIMARY ENERGY PRODUCTION AND CONSUMPTION OF USSR AND EAST-WEST ENERGY TRADE [14.12]

	Coal trade (10^6 toe)			Oil trade (10^6 toe)			Gas trade (10^{18} J)			Total[a] (10^6 toe)		
	1973	1980	1990	1973	1980	1990	1973	1980	1990	1973	1980	1990
USSR – Production	469	483	675	432	603	645	8.3	15.3	26.4	1057	1435	1955
consumption[b]	449	474	625	328	443	513	8.5	13.7	22.2	943	1228	1684
Net exports	20	9	50	104	160	132	−0.2	1.6	4.2	−114	207	271
Imports and stock charges	9	10	10	13	0	0	0.5	0.4	0.2	30	16	12
Gross exports	29	19	60	117	160	132	0.3	2.0	4.4	144	223	283
Eastern Europe (exc. USSR)												
Exports (net)	19	7	14	–	–	–	–	–	–	13	5	10
Imports (net)	–	–	–	57	81	95	0.2	1.0	1.5	62	105	133
– from USSR				(55)	(70)	(80)	(0.2)	(1.0)	(1.5)	(60)	(94)	(118)
– from other countries				(2)	(11)	(15)	(–)	(–)	(–)	(2)	(11)	(15)
Total Eastern exports to												
– other regions	22	11	20	14	24	27	–	–	–	29	24	42
– Western Europe	26	15	54	48	66	25	0.1	1.0	2.9	68	100	133
* share in consumption	7%	4%	9%	6%	10%	3%	2%	13%	28%	5%	8%	8%
* share in total west exports	49%	20%	29%	6%	12%	4%	25%	78%	71%	9%	15%	17%

[a] Including electricity exchanges.
[b] Including marine bunkers.

With its high primary energy production and consumption figures, the USSR has a heavy weight in the energy economy of the Eastern European group of countries: it produces in total some five times more primary energy and consumes three times more than the other CMEA countries.

The net energy trade balance of the USSR to the year 2000 shows the USSR as a net exporter for all primary energy carriers, coal, petroleum, natural gas and also for electricity.

The insufficient primary energy base of the group of the six CMEA Eastern European countries obliged them to make large energy imports, especially petroleum and natural gas, mainly from the USSR.

As a group, the CMEA European group, i.e. the USSR and the six CPE countries, is self-sufficient in energy and even an energy exporter – USSR and Poland (for coal) – to the world market.

Both the energy self-sufficiency and the energy export potential of this group, and specifically the latter, are very important elements for the present and future energy balance of the world economy.

Present petroleum production levels enable the USSR to both cover most of the CMEA petroleum needs and to earn hard currency by selling petroleum on the world market. In fact, returns from energy exports account for more than half of the USSR earnings from trade with Western countries. In 1980, they were estimated at US \$16–17 $\times$ 10^9 of which US \$14–15 $\times$ 10^9 came from oil. While there will undoubtedly be efforts to maintain oil as a source of hard currency income, the outlook for increased returns from natural gas sales is likely to place the oil option second. As a result, priority might be given to using the remaining oil surplus for intra-CMEA purposes. Conversely, Soviet oil exports to the West would tend to disappear in the late 1980s.

With roughly 40% of proven world reserves of natural gas, the USSR will continue to be the largest producer and probably the only exporter of natural gas among the CPE countries. A potential for increased natural gas production exists also in some of the Eastern European countries but virtually all of that production will be consumed domestically. Therefore, export could only rely on USSR gas reserves and production potential.

In 1980 the USSR natural gas production was 435 $\times$ 10^9 m^3, the 1985 plan target is 630 $\times$ 10^9 m^3. The reserve situation suggests that natural gas output can grow to higher levels of 760 $\times$ 10^9 m^3 in 1990 and 965–1030 $\times$ 10^9 m^3 by 2000.

Due to a favourable resource situation, the prospects for future production of natural gas are in fact considerably brighter than for the extraction of other fuels. The development of resources is at an earlier stage than in the oil sector and the USSR gas industry can tap almost untouched reserves. According to official USSR figures, proven natural gas reserves amount to 25 500 $\times$ 10^9 m^3, but other estimates run as high as 30 600 $\times$ 10^9 m^3. The static lifetime of reserves would thus range comfortably between 60 and 70 years and allow for definite accelerations of production. Moreover, additional recoverable resources are estimated at around 60 000 $\times$ 10^9 m^3.

Proven reserves have been identified in extremely large accumulations. Virtually all of Western Siberia's gas production, which accounts for slightly more than one-third of total output, comes from three fields: Medvezhye (70 $\times$ 10^9 m^3), Urengoy (50 $\times$ 10^9 m^3) and Vyngapur (15 $\times$ 10^9 m^3). The super giant Urengoy field in particular, which alone has proven reserves of

6200×10^9 m^3, but may hold up to $10\,000 \times 10^9$ m^3 of ultimately recoverable reserves, is projected to carry the brunt of Western Siberian gas expansion. Its annual production was planned to grow to 83×10^9 m^3 in 1981 and to as much as 180×10^9 m^3 during the current five-year plan period; but USSR officials have now mentioned figures of up to 270×10^9 m^3 for future capacity of Urengoy.

Against this favourable background, pipeline construction will be the main restriction on USSR gas production in the foreseeable future. In fact, the USSR gas industry has to cope with problems tied to the remoteness and the climate of Western Siberia. The major gas fields are located near the Arctic Circle and this poses problems of labour and transport infrastructure. However, the USSR has embarked upon a general expansion of its large-diameter transcontinental pipeline system – see also Fig.7.7.

USSR natural gas exports in 1980 were about 55×10^9 m^3 on a gross basis. As shown in Table 14.VI, about 30×10^9 m^3 went to Eastern European countries and 25×10^9 m^3 to the West. At the same time the USSR imported $4–5 \times 10^9$ m^3 from Iran and Afghanistan to supply bordering areas with natural gas. As gas imports from Iran have fallen from an earlier level of 10×10^9 m^3, it can be assumed that the Soviet Union would be interested in increasing imports again if the occasion arises. However, given their border trade character, the size of these imports would not affect the potential for Soviet gas exports to other countries.

Total exports of natural gas by the USSR are projected to grow to levels of $175–195 \times 10^9$ m^3 by the year 2000, provided that recipient countries in Eastern and Western Europe can, and are willing to, absorb such growing deliveries.

Soviet natural gas exports to its CMEA neighbours virtually doubled between 1978 and 1980 as a result of the completion of the Soyuz pipeline. The pipeline, which links the Orenburg gas-producing area with consumption centres in Eastern Europe, was built with labour and equipment input from the CMEA partners and Soviet gas deliveries are partly designed to pay for those contributions. Total Soviet gas supplies to Eastern European countries are now equal to more than a third of their natural gas consumption of roughly 80×10^9 m^3, with the remainder being covered by domestic gas production.

The USSR potential for gas exports to the West could grow threefold and even more over the next two decades. The actual size will depend on the extent to which Western countries consider this supply option desirable. In fact, the USSR has approached several Western European countries offering an additional 40 to 50×10^9 m^3 of natural gas per year from the mid-1980s onwards. The amounts under discussion are shown in Table 14.IX.

So far, the gas utilities of two countries have signed supply contracts with the USSR export agency. According to these contracts, the Federal Republic of Germany would receive 10.5×10^9 m^3 annually over 25 years with an additional 0.7×10^9 m^3 per year earmarked for West Berlin, and France is to be

TABLE 14.IX. USSR EXPORTS OF NATURAL GAS IN 10^9 m^3 [14.4]

	1980 Actual	Additional quantities under consideration[a]	1990 assumed
Austria	2.9	–	6
Belgium	–	–	5
Finland	1.0	–	1
France	4.0	8.0	12
Germany, F.R. (incl. West Berlin)	10.7	11.2	22
Italy	7.0	–	14
Netherlands	–	3	3
Sweden, Spain, Switzerland	–	2.5	2
Japan	–	–	5
Total OECD	25.6	–	70
Bulgaria	4.6		
Czechoslovakia	7.3		
German Democratic Republic	5.7		
Hungary	3.5		
Poland	5.9		
Romania	1.0		
Total CMEA	28.0		60
Yugoslavia	2.0		5
Gross exports	55.6		135
Afghanistan	−2.0		−3
Iran	−1.0		−2
Net exports	52.6		130

[a] Initially envisaged figures. Present estimates are $30 - 40 \times 10^9 m^3$ for total volume of new supply contracts.
Sources: OECD figures from Annual Oil and Gas Statistics and direct communications to the Secretariat; figures for Eastern Europe adjusted from ECE data.

supplied with an annual 8×10^9 m^3. While the exact terms of the contracts are not known, the pricing formula appears to be linked mainly to internal energy price levels in recipient countries , and is based on a formula whereby oil products prices and crude oil prices are weighted in a proportion of 80:20 [14.4].

Most CPE countries, and in particular the USSR, have a potential for increasing their coal production. But rapid large-scale realization is unlikely and coal will be an option for the 1990s rather than for the present decade. Likewise, there is only a limited outlook for additional coal exports from Poland and the USSR before the 1990s. USSR coal production in 1981 was 716×10^6 t.

The USSR-CMEA6 group early on organized an excellent co-operation in the electricity sector, which had a high rate of growth: between 1965 and 1980 electricity production increased in the USSR by approximately three times, from 507 TW·h to 1295 TW·h, and is expected to reach 1900–2050 TW·h in 1990. In the six CMEA countries, electricity production amounted to 420 TW·h in 1980 and is expected to rise to 570 TW·h in 1990 [14.12]. Nuclear energy accounted in 1982 for only 3% of USSR electricity production and 2% in the CMEA6 electricity balance. The figures estimated for 1990 are 12% and 14% respectively. The group is now completely interconnected as described in chapter 7. Figure 7.11 allows us to follow the direction and magnitude of the exchanged electricity flows.

The energy co-operation of the Eastern European countries was certainly favoured by their self-sufficiency in energy as a group, and especially in its incipient period, by the data availability of their planned economies. However, starting from an appreciably lower technological and managerial level than in the Western countries, the industrial effort needed for their energy development was very much more demanding.

14.3. Western organizations for international energy co-operation

The industrialized countries early on recognized the need for and the advantages of having international organizations for co-operation and exchange of experience in areas of fast-growing development and ever-enlarging public activities. First started in the area of technical co-operation, such organizations rapidly followed for economic issues and, naturally, the larger they grew, the less could they escape being attracted into the sphere of political influence and activities.

Very much could be written on the organizations' activity in the energy field, where the 'interconnection'-minded electrical engineers were among the first to seek standardization and exchange of experience and electricity supply. However, in the available space only a few organizations can be mentioned. They have been selected for their general interest for overall energy issues, the excellent work, technical as well as economic, performed in their geographic area and for their readiness to share experience or even extend technical assistance to developing countries in the field of energy. Only a brief basic description and some highlights on the most relevant features and activities are given for each organization.

14.3.1. The International Energy Agency (IEA)

The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme [14.8].

It carries out a comprehensive programme of energy co-operation among twenty-one[13] of the OECD's twenty-four member countries. The basic aims of the IEA are the elements of the western countries' common energy strategy enumerated in the introduction to subsection 14.2.2.1. France is not a member country but co-operates within the OECD.

Major decisions of substance are made by the Governing Board, which is composed of Ministers or their high-ranking representatives from each of the participating countries.

The Agreement on an International Energy Programme and the Long-Term Co-operation Program of the IEA state in broad terms that future energy policy must focus on strong energy conservation and rapid development of alternative energy sources in order to reduce petroleum imports. In October 1977, the Governing Board emphasized once again the importance of energy conservation as a vital element of an effective energy policy. This policy was reconfirmed later at the summit meeting in the Declaration of Venice in July 1978.

The objective set for the group of IEA countries was to hold their total petroleum imports to not more than 1300×10^6 t/a in 1985 and to establish similar group objectives for further successive periods. The corresponding principle agreed upon reads:

"Strong reinforcement of energy conservation, on a high priority basis with increased resources, for the purpose of limiting growth in energy demand relative to economic growth, eliminating inefficient energy use, especially of rapidly depleting fuels, and encouraging substitution measures in various sectors along lines which include the following elements:

- pricing policies (including fiscal measures) which give incentives to conservation;
- minimum energy efficiency standards;
- encouragement and increase of investment in energy saving equipment and techniques" [14.8, 9].

Among the four standing groups, each dealing with a principal area of the IEA's programme, and a high-level Committee on Energy Research and Development (CRD), the Long-Term Co-operation Standing Group (SLT) provides the

[13] IEA member countries: Australia, Austria, Belgium, Canada, Denmark, Federal Republic of Germany, Greece, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, USA.

overall framework for three subgroups: Energy Conservation, Accelerated Development of Alternative Energy Sources, and Nuclear Energy.

The SLT holds an annual periodic review to analyse national energy programmes and policies of member countries, each country being subjected to a comprehensive review by a team composed of experts in energy conservation, accelerated development of alternative energy resources and nuclear energy. Similar reviews are held concerning the research and development programmes on the three areas for each country.

The reviews are designed to provide a systematic assessment of the evolving national energy programmes, identify areas in which programmes might be improved and promote co-operation in the area of conservation and accelerated alternative resources development through exchange of information, experience and expertise.

The conservation subgroup of the SLT organizes expert meetings for close examination of energy conservation problems by in-depth analysis of key issues. Information and resources are pooled from the academic, business and government communities to ensure an effective review.

The great differences which occur among IEA countries in the use of energy in the various consuming sectors and which are reported periodically not only indicate the flexibility of energy utilization but are also useful examples when designing energy programmes and policies for developing countries.

It is not possible within this framework to enter into more detail regarding the evolution of energy utilization in the different IEA member countries[14]. However, an overview of the economic and energy evolution of the past years has been given in subsection 14.2.2.1 – see also Tables 14.I to 14.III and Figs 14.1 to 14.4.

Later on, the Governing Board meeting at ministerial level in May 1980 agreed, after national petroleum import goals were set by each country, to reduce the group objective from 1300×10^6 t/a to 1230×10^6 t/a in 1985. The Ministers also agreed that efforts to reduce petroleum imports will be continued beyond 1985, expecting to reduce the ratio between the rate of increase of energy consumption and the rate of economic growth for IEA countries as a group over the coming decade to about 0.6 and the share of petroleum in total energy consumption from 52% at present to about 50% by 1990.

IEA Ministers met again in May 1982 and reconfirmed the importance they attach to making progress towards appropriate pricing practices. They noted several areas of national pricing policies which impede the reduction of oil dependence. In spite of some positive decisions – oil prices deregulation

[14] The interested reader can follow it in the yearly IEA reviews – for example in Refs [14.1 and 14.8], where after an overview analysis, each country is presented in detail in separate chapters.

in Norway and the Netherlands – the lack of price transparency weakens the effectiveness of market signals and can prevent consumers and producers of energy from making economically efficient decisions.

14.3.2. The Organisation for Economic Co-operation and Development (OECD)

The Organisation for Economic Co-operation and Development (OECD) was set up under a convention signed in Paris on 14 December 1960, which provides that the OECD shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and rising standard of living in member countries, while maintaining financial stability, and thus to contribute to the development of the world economy
- to contribute to sound economic expansion in member as well as in non-member countries in the process of economic development
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The members of OECD are 24 countries: the above 21 IEA members and Finland, France and Iceland.

Since the OECD is the older organization, having been active also in the field of energy, the IEA has been established as an autonomous body within its framework.

14.3.3. The European Economic Community (EEC)

The European Economic Community, or "Common Market", is an association of countries seeking "a continuous and balanced expansion" of Europe's economy, established on 1 January 1958, which has undergone many changes during the years. The European Council, formed by Heads of States, decides on major policies, the Council of Ministers makes the current decisions and the Commission of the European Communities is the operational organization. The European Parliament supervises the three institutions.

The EEC showed an early interest in the energy sector, which gradually increased till 1973, when in a December meeting in Copenhagen the Council of Ministers was requested by the member countries to take measures to reduce the consumption of energy and to organize a global programme to develop alternative energy resources.

Accordingly, in the following years, several programmes for rational energy utilization, i.e. energy conservation, both by saving and petroleum substitution, were elaborated and gradually implemented. Although formally in different frameworks, the energy conservation measures within the OECD, IEA and EEC were developed as complementary and reasonably consolidated.

Based on the Third Report on the Community's Energy Saving Programme and on the Report on New Community Actions in the Energy Saving Area, and taking into consideration the previous decisions on the extended 1985 energy saving targets, the EEC Council decided in June 1980 that 1990 targets should be established for the Community's Energy Saving Programme and that each member country should contribute to the common goals on a comparable scale. To this purpose, national energy-saving programmes should be designed according to the particular conditions of each country. More specifically, the Council [14.10]:

- Approved that till 1990 the average community ratio between the rate of increase of energy consumption and the rate of economic growth should gradually be reduced to 0.7 or even less.
- Agreed that the member countries should adapt, if necessary, their energy-saving programmes till the end of 1980 to cover all main energy-consuming sectors and have an adequate energy price policy. For better comparison, these programmes should follow, while carefully respecting national priorities and particularities, the price policy and measures recommended in the basic programme, annexed to the decision.
- Agreed on the need to accelerate, especially in the international organizations, the technical elaboration of methods to measure energy consumption and of efficiency standards, especially for heat production equipment and domestic devices. The brochure [14.10] includes the annex mentioned, together with a comparison of the energy-saving programmes of the member countries with the recommended basic programmes. The activity of the EEC in the conservation area is of special interest also for developing countries, since it represents considerable technological knowhow and experience which might appropriately serve energy conservation projects in these countries, since the Community and its member states awarded in 1979 almost 20% of the world aid to the energy field of developing countries. About 60% of this aid in 1979 were grants [14.11]. A favourable share is enjoyed in this respect by the 57 developing countries which participate with the EEC in the special co-operation based on the Lomé Conventions.

14.4. The United Nations Economic Commission for Europe (UN-ECE)

The United Nations Economic Commission for Europe (ECE) is one of the five regional economic commissions of the United Nations in the world. ECE has served, since its inception in 1974, as a major instrument for co-operation in economic and related fields among member countries with different economic and social systems: the western countries and the Eastern European countries. The Commission carries out programmes in the fields of trade, transport, energy, environment, agriculture and timber, industry, statistics and economic projections.

Energy questions have assumed a prominent role in the programme of the Commission and a unique competence has been developed in the sectors of coal, gas and electric power. Meetings or seminars are held annually concerning these sectors for the purpose of assessing supply and demand balances, national policies, trade, technological developments and possibilities for international co-operation.

An impressive body of knowledge and experience has been developed through meetings of experts, special studies and seminars. Member countries of the Commission consequently are better informed of policies and developments throughout the region, which in turn provides the framework for policy formulation and concrete co-operative projects [14.12].

Since 1973, the ECE has devoted increased attention to general energy questions in order to develop a more comprehensive approach to energy policies, prospects and strategies in the region.

Reference [14.12] presents in more detail some of the energy activities of the ECE, the afferent studies and documents providing very valuable sources of information. Among them, of particular interest is the already mentioned major study on energy conservation in the region [14.5], which referring to the industrialized countries dealt with in this chapter, offers an excellent consolidated conclusion in relation to their future energy development: Two scenarios (cases) have been analysed for energy development in the region up to the year 2000: the "trends continued case" and an "energy conservation case". The latter was based on the utilization of the most efficient technology and practices commercially now available. The conclusions of the study point to the possibility for substantial savings over the next two decades. The energy conservation case reflects demand reduced by 19% as compared with the trends continued case and 17% as compared with government forecasts in the year 2000.

Energy savings could amount to 25% in buildings, 21% in industry and 10% in transport. While there are differences among countries, in every case the largest savings are expected from end-use heat demand. Demand for substitutable fuels (coal, gas, oil) could be 29% lower than currently forecast.

Energy demand, according to the conservation case, would be lower than the trends-continued case by 16% in the USSR; 20% in the other Eastern European countries; 19% in Western Europe; 22% in the USA; and 19% in the ECE region as a whole [14.5].

14.5. Energy co-operation between industrialized and developing countries

Doubtless there have been some underlying constraints to achieving better progress in international co-operation between the industrialized and the developing countries. No historic review will be made here – but see Ref. [14.13] – and only some salient constraints will be mentioned: lack of trust between the two major actors, the industrialized countries and the developing oil producing countries; lack of stronger potential will and the limited ability of the industrialized countries to render more assistance to the developing countries, especially in the energy field; the linkage of energy to other issues, insisted upon by the developing countries [14.13].

However, some new realities are facing international energy co-operation. For the industrialized countries the understanding that they have to live with modest economic growth for the immediate future and that even if the short-term energy situation seems relatively stable, if no action is taken, the medium and long-term energy (petroleum) market will certainly tighten.

The developing countries must understand that it would be virtually impossible for them to repeat the energy-intensive economic growth pattern that the industrialized countries were able to achieve during the 1950s and the 1960s with their low energy prices. Some newly industrialized countries have shown that less energy-intensive development patterns are both desirable and possible. Despite falling real oil prices, many of the oil importing developing countries continue to have difficulties to pay their oil import bills, while oil exporters, because of their dramatically lower revenues, have to review their domestic development plans. Faced with these realities, it is getting harder for the developing countries to link energy with North-South issues. The decoupling of energy from other economic and political issues is imperative if energy is to be taken up and its problems solved on its own merits [14.13].

The consequence of the above described basic changes is the rising conviction that energy is a problem common to all countries, and that there is a need for a global consensus covering the cross-sections of North and South, which, identifying energy development as a common task, recognizes the convergence of interests.

It is from the described position that many governments of industrialized countries are now revising their bilateral technical assistance programmes and international co-operation organizations of industrialized countries are reaffirming and refocusing their co-operation with developing countries [14.14, 15].

For example: the IEA carries out centrally and assists in collecting and organizing energy data [14.16], energy assessment and planning activities, actions for improving energy efficiency and expanding indigenous energy production, etc.

The EEC, an active technical assistance donor in the past, promotes with priority energy programmes in developing countries as a key phase of energy development [14.15]. In addition, the European Parliament, referring to the European Community as the world's largest purchaser of oil, which succeeded in cutting its imports of oil from 60% of the energy requirements in 1973 to only 38% in 1981, firmly recommends the industrialized countries to economize in their use of oil for the benefit of the Third World and help the LDCs in fighting deforestation. The EEC itself is allocating 2.4% of the GDP to energy policy.

Last but not least, the decades-long unselfish and objective position and action of the United Nations, its regional commissions and its main energy-related family organizations such as the IAEA, World Bank, etc., in the service of international energy co-operation, should be mentioned for the record.

It remains an open question as to whether multilateral co-operation efforts could ever integrate a world body for energy development in developing countries which could, as recently suggested [14.17], offer effective financial, technological and managerial assistance to the energy projects implemented in these countries.

Chapter 15

ENERGY IN DEVELOPING COUNTRIES

15.1. Ambiguous definitions of developing countries

The group of developing countries is very heterogeneous, showing great discrepancies in the countries' geographical size, climate, population, natural resources including energy resources, level of socio-economic development, culture and life habits – in brief, the main factors which determine energy consumption both in absolute figures as well as per head [15.1].

While the basic concept is clear, its limits are less well established. Depending on interpretation, the group of developing countries can include or exclude important subgroups of countries. For example:

(1) In the introduction to chapter 13, it was explained that for the convenience of being able to use corresponding statistics, the UNCTAD definitions of world economic groups of countries were adopted, namely: developed market economy countries, socialist countries of Eastern Europe, socialist countries of Asia and 'developing countries'.

(2) Recent IEA and OECD statistics and publications maintain the first group, combine the second and third under CPE, i.e. centrally planned economies, and leave the last as 'developing countries'.

(3) IAEA statistics takes geographical regions, but when grouping, selects industrialized countries and 'developing countries', the latter including those in CPE-Europe.

(4) The WEC Conservation Commission divided the world into ten regions, above all taking geographical situation (climate) and predominating economic systems into account, and studied energy problems region by region. After considering north-south dynamics it appeared that the ten regions could be grouped in three zones: Zone 1 comprising the industrialized countries (North America, Western Europe, Pacific industrialized countries, Eastern Europe including the USSR and South Africa), Zone 2 representing the more advanced developing countries (North Africa and the Middle East, South-East Asia and Latin America) and Zone 3, the less advanced Third World (Africa south of the Sahara but excluding South Africa, South Asia and the CPE Asian countries, including China). This approach could lead towards a tripolar energy world structure [15.2].

(5) Finally, the World Bank in its latest publications [15.1] considers the world groups according to Fig.15.1, i.e. introduces a new subgroup, the high-income oil exporters, and, leaving the CPE developing countries of Europe in the centrally planned economies, determines as balance the 'developing countries' group. Table 15.I lists the countries of each group.

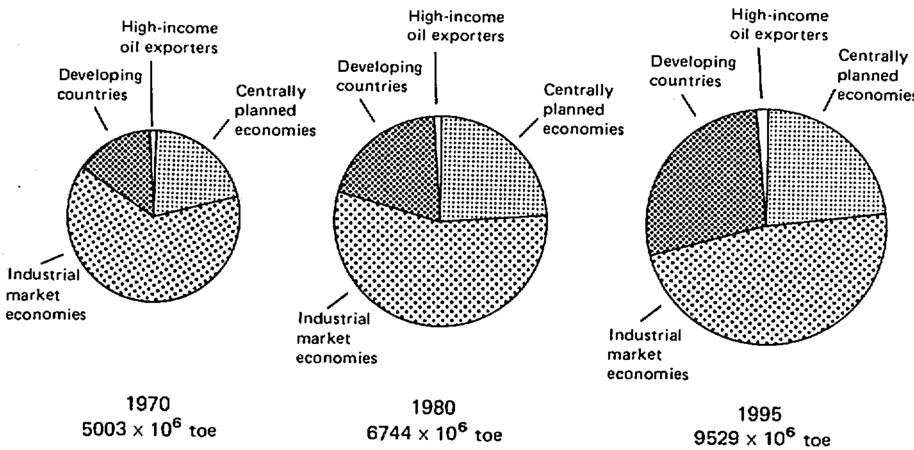


FIG.15.1. Shares of country groups in world commercial primary energy consumption, 1990–1995 [*15.1*].

The difficulty with the different definitions of the developing countries group is, that while each definition is best suited for a certain purpose, it becomes difficult or impossible to use comparable statistical data. Whilst the totals are identical, explicit breakdowns are not.

Here is not the place to discuss the pros and contras of the different classifications. However, the author rather concurs with the recent World Bank approach, since by taking out the two groups – the East European developing countries and the high-income oil exporters – the remaining group becomes somewhat more homogeneous, although still disparate enough, and offers the chance to tackle better its characteristic development problems. Accordingly, this chapter will deal with developing countries taking the World Bank approach and use to this purpose the statistical material and views of Ref. [15.1].

Table 15.II displays the World Bank classification, which divides the developing countries into two basic groups: oil exporters and oil importers. Within each group are three levels in terms of energy resources or options, i.e.: limited, moderate and substantial. The oil exporters are further classified as large or small exporters of low and middle income. The oil importers are classified according to the share of net oil imports in their primary commercial energy consumption in 1980– 0–25%, 26–50%, 51–75%, and 76–100% and are also classified as low or middle-income countries.

The advantage of this classification is that depending on its position in Table 15.I, the energy problems of a country are easier to identify and, once a diagnosis has been reached,possible solutions and options are more readily encountered.

TABLE 15.I. CLASSIFICATION OF COUNTRIES [15.1]

Developing Countries

Low income

Oil importers

- Afghanistan
- Bangladesh
- Benin
- Bhutan
- Burma
- Burundi
- Cape Verde
- Central African Republic
- Chad
- Equatorial Guinea
- Ethiopia
- Fiji
- Ghana
- Guinea
- Guinea-Bissau
- Haiti
- India
- Kampuchea, Democratic
- Lao, PDR
- Madagascar
- Malawi
- Mali
- Mozambique
- Nepal
- Niger
- Pakistan
- Rwanda
- Sao Tome and Principe
- Sierra Leone
- Somalia
- Sri Lanka
- Sudan
- Tanzania
- Togo
- Uganda
- Upper Volta
- Viet Nam
- Zaire

Oil exporters

- China

Middle income

Oil importers

- Argentina
- Barbados
- Bolivia
- Botswana
- Brazil
- Cameroon
- Chile
- Colombia
- Costa Rica
- Cuba
- Dominican Republic
- El Salvador
- Greece
- Guatemala
- Guyana
- Honduras
- Hong Kong
- Israel
- Ivory Coast
- Jamaica
- Jordan
- Kenya
- Korea, PDR
- Korea, Republic of
- Lebanon
- Lesotho
- Liberia
- Mauritania
- Mongolia
- Morocco
- Nicaragua
- Panama
- Papua New Guinea
- Paraguay
- Philippines
- Portugal
- Senegal
- Singapore
- Thailand
- Turkey
- Uruguay
- Yemen Arab Rep.
- Yemen, PDR
- Yugoslavia
- Zambia
- Zimbabwe

Oil exporters

- Algeria
- Angola
- Congo, PR
- Ecuador
- Egypt
- Gabon
- Indonesia
- Iran
- Iraq
- Malaysia
- Mexico
- Nigeria
- Peru
- Syrian Arab Republic
- Trinidad and Tobago
- Tunisia
- Venezuela

Industrial Market Economies

- Australia
- Austria
- Belgium
- Canada
- Denmark
- Finland
- France
- Germany, Federal Republic of
- Iceland
- Ireland
- Italy
- Japan
- Luxembourg
- Netherlands
- New Zealand
- Norway
- Spain
- Sweden
- Switzerland
- United Kingdom
- United States

High-Income Oil Exporters

- Bahrain
- Brunei
- Kuwait
- Libya
- Oman
- Qatar
- Saudi Arabia
- United Arab Emirates

Centrally Planned Economies

- Albania
- Bulgaria
- Czechoslovakia
- German Democratic Republic
- Hungary
- Poland
- Romania
- USSR

Note: This table is based on the classification used in the *World Development Report 1983*. The table does not show all countries with less than one million population and without production (or prospects of future production) of oil, gas and coal.

TABLE 15.II. COMMERCIAL ENERGY TYPOLOGY OF DEVELOPING ECONOMIES [15.1]

Energy resources or options (relative to country size)	Oil exporters		Oil importers: Net oil imports as a percentage of primary commercial energy consumption in 1980			
	Large	Small or medium	0–25	26–50	51–75	76–100
LIMITED			Middle income Lesotho Namibia		Low income Burundi Kampuchea Lao, PDR Nepal Rwanda	Low income Bhutan Ethiopia Guinea-Bissau Haiti Niger Somalia Sri Lanka Togo Upper Volta Middle income Barbados Cuba Dominican Republic Hong Kong Israel Jamaica Jordan Lebanon Liberia Mauritania Singapore Uruguay Yemen, AR Yemen, PDR

MODERATE	<u>Middle income</u> *Syria, AR*	<u>Low income</u> Zaire <u>Middle income</u> Botswana + Korea, PDR + Vietnam Zambia + Zimbabwe	<u>Low income</u> Ghana ***Pakistan** <u>Middle income</u> ***+ Brazil** *Chile Guatemala Ivory Coast Mongolia	<u>Low income</u> ***Bangladesh** Central Afr. Rep. Chad Equatorial Guinea Malawi Mozambique **Uganda** <u>Middle income</u> Costa Rica El Salvador Honduras **+ Korea, Rep. of** **Paraguay** **Portugal** **+ Turkey**	<u>Low income</u> **Benin** Guinea Madagascar Mali Sierra Leone **Sudan** **Tanzania** <u>Middle income</u> **+ Greece** **Kenya** **Morocco** **Nicaragua** **Panama** Papua New Guinea **Philippines** **Senegal** **Thailand**

Notes to Table on next page.

TABLE 15.II (cont.)

Energy resources or options (relative to country size)	Oil exporters		Oil importers			
			Net oil imports as a percentage of primary commercial energy consumption in 1980			
	Large	Small or medium	0–25	26–50	51–75	76–100
SUBSTANTIAL	Low income	Middle income	Low income	Low income	Middle income	
	*+*China*	**Algeria*	Burma	***Afghanistan**	***Bolivia**	
		Angola	***+India**			
	Middle income	Congo, PR		Middle income		
	**Indonesia*	*Ecuador*	Middle income	***+Yugoslavia**		
	**Iran*	**Egypt*	**Argentina*			
	**Iraq*	*Gabon*	Cameroon			
	*+*Mexico*	**Malaysia*	*+*Colombia*			
	**Nigeria*	**Peru*				
	**Venezuela*	**Trinidad and Tobago*				
		Tunisia				

Note to Table 15.II: Not shown are economies with less than one million population and without production (or prospects of future production) of oil, gas, or coal. The economies included in this table are classified according to their energy resource potential (oil, gas, coal, and primary electricity) that could be economically developable during the next decade. Oil exporters are countries whose official earnings from net oil exports exceed 10% of their total export earnings in 1980–81. *Large oil exporters* refers to those countries that produced more than 70 $\times$ 10^6 toe during 1980.

+ Produced two or more $\times$ 10^6 toe of coal in 1980.

* Produced one or more $\times 10^6$ toe of gas in 1980.

Economies shown in *italics* produced more than 5 $\times$ 10^6 toe of oil in 1980.

Economies shown in **bold print** had net energy imports amounting to 30% or more of their merchandise exports in 1980 (information is not available for all countries).

Source: World Bank.

15.2. Future energy evolution in developing countries

The past evolution of energy in developing countries was dealt with as a component of the worldwide presentation in chapter 13. However, before addressing qualitatively the future prospects it might be useful to intercalate a few reflections of a more general character.

15.2.1. Common energy issues in developing countries

In spite of their tremendous diversity, the developing countries as a group have some broad common energy characteristics and consumption patterns susceptible of exerting a strong impact on their future energy development:

(1) Their per head consumption of commercial energy is substantially lower than that of developed countries, in some cases extremely low. While in the industrialized countries the yearly average of the per head commercial primary energy consumption was around 200 GJ/head per year in 1982 (in North America even 325 GJ/head per year) the average of the developing countries hardly reached 24 GJ/head per year, with figures of less than 10 or even less than 3 GJ/head per year in a significant number of countries [13.5]. The ratio of the per head average energy consumption figures of more than 8:1 certainly denotes extremes of over-consumption of energy in the first group of countries against substantial under-consumption in the developing regions, especially in their rural and marginal urban areas.

(2) In the total energy consumption, the share of non-commercial energy resources, all of which are also renewable resources, is high, in general around 50%, reaching sometimes 90% or even more [15.1].

(3) Size, location and structure of energy consumption develop according to the evolution of the basic human settlements: increasing urbanization tendencies, with still a high share of scattered villages.
As displayed in Fig.15.2, the process of urbanization is rapidly progressing in the world. The developing countries, at present less urbanized than the developed ones, are experiencing a constant move to urban areas, leading in the most populated countries to impressive conurbations, with high population density and a rapidly increasing consumption of commercial energy resources. However, the majority of the population still lives in rural areas with a low, decentralized energy consumption, mainly based on non-commercial, new and renewable energy resources. This situation leads in the majority of the developing countries to the well-known rural/urban dichotomy, and its concomitant double structure of the energy economy, both with specific characteristics and different supply solutions.

(4) The aforementioned state of under-consumption of commercial energy is even worse than reflected in the per head average figures, since an enormous

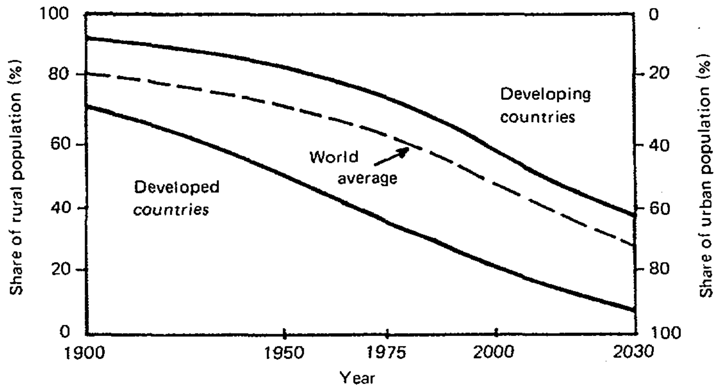


FIG.15.2. The fast progressing urbanization in the world [15.3].

imbalance exists between the energy consumption of high-income groups and the low-income group, which accounts for approximately two-thirds of the population. This imbalance is aggravated in terms of useful energy since the low-income groups consume mainly non-commercial resources in conversion processes of very poor efficiencies. A great contrast appears, therefore in the quantity and quality of energy available and consumed in urban areas and that in rural and marginal urban areas.

(5) The low average per head energy consumption and the substantial under-consumption situation in developing countries denote a considerable potential for increased future demand both for filling the gap of under-consumption as hidden demand and for sustaining the rapid envisaged socio-economic development.

(6) Whilst the great majority of these countries are located in tropical and sub-tropical areas, energy consumption for space heating is limited to a few regions with temperate climate. This alleviates the overall energy balance of the majority of developing countries of an important component, which in the developed countries reaches a share of more than 40% of the primary energy consumption. However, in the long run, a rapidly growing energy consumption for air-conditioning is expected.

(7) Many of the developing countries have serious problems with the depletion of their fuelwood resources, i.e. fighting the effects of the so-called 'second energy crisis', rapid and massive deforestation with all its additional, major environmental damage and social harm.

(8) Most of the developing countries do not have adequate physical and social infrastructure, i.e. transportation, electric power, medical and sanitary services, to cope with their rapid population growth and high rates of economic and energy development.

(9) Most of these countries lack trained energy professionals at all managerial levels, as well as an adequate institutional framework for overall energy development.

(10) With the exception of a few petroleum-exporting countries, the remaining developing countries are net petroleum importers, and the foreign currency payments for petroleum consume a high share of their export revenues.

(11) It might be worth mentioning that, in addition to their foreign expenses for petroleum imports and investment financing difficulties, many of the developing countries have heavy internal burdens because of the substantial subsidies governments give, selling energy to low-income consumers at prices well below the real economic cost.

(12) In spite of the different financial balances, both petroleum net importing and net exporting countries have the same basic interest in energy conservation since any saved or substituted petroleum means reduced import or increased export of petroleum.

(13) In relation to conservation it should be noted that independent of the degree of their development, the existing energy equipment represents (owing to the high rate of development of these countries) a rapidly decreasing share in the total volumes expected ten or twenty years later. This means the additional new components will soon become a progressing majority and determine by their concept, design and operating performances, the technical and economic level of the overall energy system. Therefore, without neglecting existing equipment and its possible improvement, special attention should be given to the new energy investments and the chance of providing them with the highest potential for energy conservation, rather than retrofitting them later at higher cost and less efficiency.

(14) Last but not least, the developing countries, many of them practically starting from scratch, have the chance of searching fro new energy development patterns, avoiding the historical low-efficiency energy evolution in developed countries, and optimizing their own development in the light of the new international and local energy conditions. While in developed countries an existing energy wastage has to be eliminated, the developing countries could prevent it from even appearing.

15.2.2. Energy development prospects

The World Bank projections for future energy evolution in the developing countries are based on the premise that after a slowdown in economic growth to 1.9% per year during 1980–1982, the GDP in developing countries is forecast to grow at an average annual rate of 4.4% during 1982–1985, increasing to a rate of 5.4% during 1985–1990 and 5.5% during 1980–1995. The average rate of 4.9% per year for 1980–1995 compares with 5.1% per year in 1970–1980 and 5.9% per year in 1960–1970.

TABLE 15.III. STRUCTURE OF COMMERCIAL PRIMARY ENERGY CONSUMPTION IN DEVELOPING COUNTRIES, 1970–1995 [15.1]

	10^6 toe			Growth rate (% per year)	
	1970	1980	1995	1970–80	1980–95
Oil	355	626	934	5.8	2.7
Coal	298	494	940	5.2	4.4
Natural gas	47	95	324	7.3	8.5
Primary electricity	56	130	396	8.8	7.7
Total	756	1345	2594	5.9	4.5

Sources: UN J Series and World Bank estimates.

15.2.2.1. Commercial primary energy consumption

As illustrated in Fig.15.1, developing countries account for a small but growing share of the world's commercial energy consumption. During the 1970s, their demand for commercial energy grew at nearly 6% per year and their consumption of oil at much the same rate. After the sharp oil price increase of 1979, and the economic recession that followed, commercial energy consumption in these countries stagnated during 1980 and their demand for oil decreased slightly – by about 5×10^6 toe.

Based on the above assumed premises, in 1980–1985, commercial energy consumption in the developing countries is projected to grow at 4.5% per year – that is, at a lower rate than in the 1970s. The growth in their demand for oil is projected to decrease sharply to about 2.7% per year, or less than half the figure for the 1970s – see Table 15.III.

Despite this slowing down, energy consumption in the developing countries will continue to grow faster than in the rest of the world, partly because their economies are growing faster and partly because increasing industrialization and urbanization will entail a rapid increase in their use of commercial energy. As a result, their share in global energy consumption will increase from a fifth in 1980 to just over a fourth by 1995 – see Fig.15.1. This implies that almost half of the projected increase in global energy consumption over the 1980–1995 period will take place in the developing countries. In petroleum, the developing countries' share of incremental global consumption will be greater than 100%, because oil consumption in the rest of the world is projected to decline in this period. Within

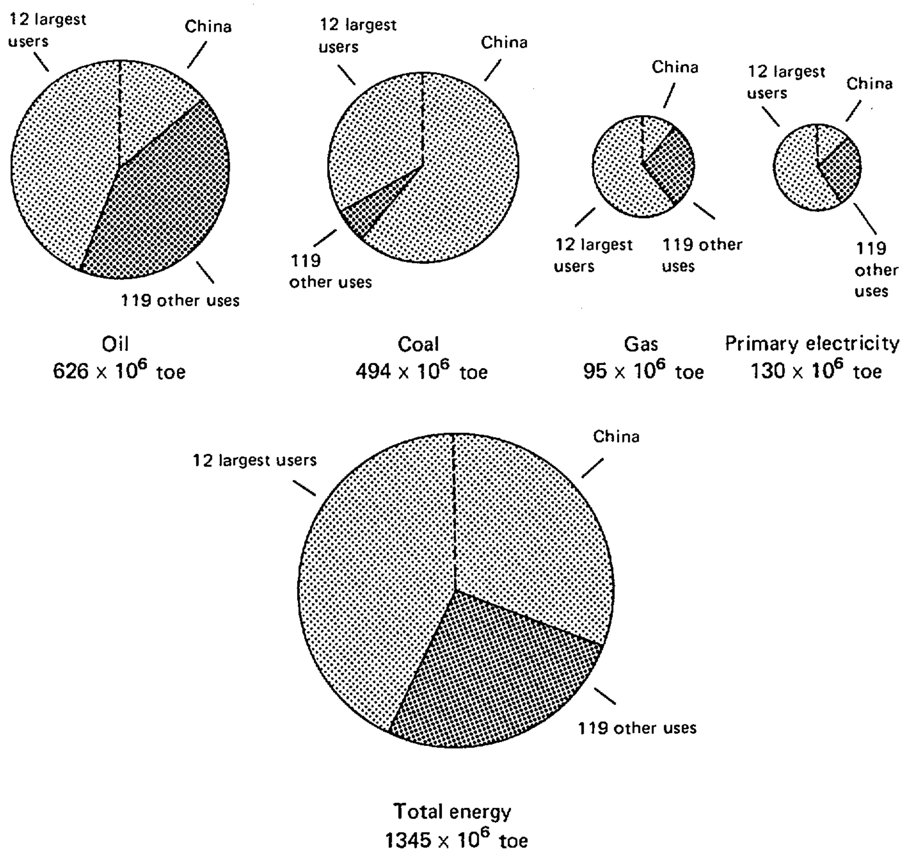


FIG.15.3. Primary commercial energy consumption in developing countries in 1980 [15.1].

the developing countries, the share of petroleum in commercial energy consumption is projected to drop from 47% in 1980 to 36% by 1995. As in the world at large, this will be offset by significant increases in the shares of primary electricity and natural gas.

The general picture is strongly influenced by the energy demand and supply patterns in a few major countries – see Fig.15.3. China alone accounted for about 30% of the commercial energy consumption in developing countries in 1980 and about 60% of the coal used in these countries. Three other countries (Brazil, India, and Mexico) account for a further 20% of the total, and the twelve largest commercial energy users account for over two thirds of all the energy consumed by 131 developing countries. Moreover, the figures in Table 15.III do not reflect the importance of petroleum for most developing countries,

TABLE 15.IV. COMMERCIAL PRIMARY ENERGY PRODUCTION IN DEVELOPING COUNTRIES 1970–1995 [15.1]

	10^6 toe					Growth rate (% per year)		
	1970	1980	1985	1990	1995	1970–80	1980–85	1985–95
Oil importers								
Oil[a]	63	65	105	131	145	0.3	10.1	3.3
Coal	118	192	246	316	384	5.0	5.1	4.6
Natural gas	14	27	46	86	115	6.8	11.2	9.6
Primary electricity[b]	41	98	147	211	306	9.1	8.4	7.6
Total	236	382	544	744	950	4.9	7.3	5.7
All developing countries								
Oil[a]	774	919	1069	1243	1375	1.7	3.1	2.5
Coal	294	502	598	736	886	5.5	3.6	4.0
Natural gas	52	116	185	309	424	8.4	9.8	8.6
Primary electricity[b]	56	130	197	279	396	8.8	8.7	7.2
Total[c]	1176	1667	2049	2567	3081	3.6	4.2	4.2

[a] Includes natural gas liquids and oil production from secondary recovery.

[b] Includes hydro, nuclear, and geothermal electricity.

[c] Excludes alcohol, oil shale, tar sands, and other nonconventional primary energy sources which may add a small amount (up to 10×10^6 toe, or less than 0.5 %) to developing country energy production by 1995 but where the prospects are too uncertain to quantify.

Sources: 1970 and 1980 figures are based on United Nations J Series and the World Bank.

because they are heavily influenced by the coal-based energy consumption patterns of China and India. In developing countries other than China and India, the share of oil in total commercial energy consumption in 1980 was 61% and is projected to fall to 44% by 1995.

15.2.2.2. Commercial primary energy production

Programmes to increase domestic supplies have been stepped up in almost all developing countries. Because of long lead times, the full impact of these programmes has yet to be felt, but most of them have been successful. New reserves have been identified for a variety of energy sources – most notably oil and gas and projects to develop already known reserves of petroleum, coal, and hydro power are under way in many countries. Over the last decade, a number of developing countries switched from being oil importers to exporters of oil, including the Congo, Malaysia, and Peru. Several other countries produced oil for the first time; these include Cameroon, Ghana, Guatemala, Ivory Coast, Thailand, and Zaire.

As Table 15.IV shows, the 3.5% a year increase in developing countries' commercial primary energy production during the 1970s is expected to be surpassed during the next fifteen years, even though their energy consumption will grow more slowly than in the past. Whereas these countries produced about one-fourth of the world's commercial energy in the 1970s, they are expected to supply about one-third by 1995. As such, they will contribute around half the increase in global production of commercial energy in 1980–95 – see Table 15.V.

The growing importance of developing countries, including the currently oil-exporting developing countries, is especially marked in petroleum, where their share of global production is projected to rise from 30% in 1980 to 41% in 1995 – see Fig.15.4. Much of this additional petroleum production will be consumed domestically. However, the developing countries will continue to be net suppliers of petroleum in international trade; their surplus in projected to increase from 293×10^6 toe in 1980 to about 440×10^6 toe by 1995. Natural gas production in developing countries is also expected to outstrip consumption, reflecting the growth of their gas exports to industrialized nations. In coal, however, the growth of coal imports by 15–20 countries will mean that developing countries as a group will become net importers to the extent of about 54×10^6 toe by 1995.

In interpreting the projections, one should also note that the developing countries' production, like their consumption, is concentrated in a few countries. In oil, for example, 18 oil exporters supplied over 90% of total production in 1980. In coal, China and India accounted for 72% of total production in the same year. Thus, the energy production of developing countries as a group will depend mainly on the achievements in these major countries.

Although total commercial energy consumption in the oil-importing developing countries is projected to grow at about 5% a year, their oil consumption will grow at about half that rate. As a result, their net imports of oil are projected to

TABLE 15.V. SHARES OF DEVELOPING COUNTRIES IN WORLD INCREMENTAL PRODUCTION AND CONSUMPTION OF COMMERCIAL PRIMARY ENERGY 1970–95 [15.1]

	1970–80 (%)	1985–95 (%)
Production		
Oil	20.5	158.3
Coal	57.6	38.6
Natural gas	18.8	44.7
Primary electricity	26.1	32.8
Total	29.0	50.8
Consumption		
Oil	35.8	106.9
Coal	56.0	44.8
Natural gas	13.6	33.2
Primary electricity	26.1	32.8
Total	33.8	44.8

Source: World Bank estimates.

drop from 44% of their commercial energy consumption in 1980 to about 28% in 1995. Nevertheless, oil will continue to be a major source of energy for them, supplying about two-fifths of their commercial energy consumption in 1995 – see Table 15.VI. Thus, despite considerable efforts to substitute for oil, the net oil imports of the OIDCs are expected to continue growing, from 295 $\times$ 10^6 toe in 1980 to an estimated 386 $\times$ 10^6 toe in 1995.

15.2.2.3. Renewable, non-commercial energy resources

Nearly all developing countries face a major challenge in developing renewable non-commercial sources of energy. Not only must they confront the crisis in the supply of the traditional biomass fuels, the main source of energy for rural households, but they must also exploit the possibilities – many of which have only recently become profitable – for using biomass, solar, and other renewable resources to provide energy in rural areas and to replace petroleum.

As a group, developing countries consume as much biomass energy as they do commercial fuels. In ten of the thirteen countries for which the World Bank

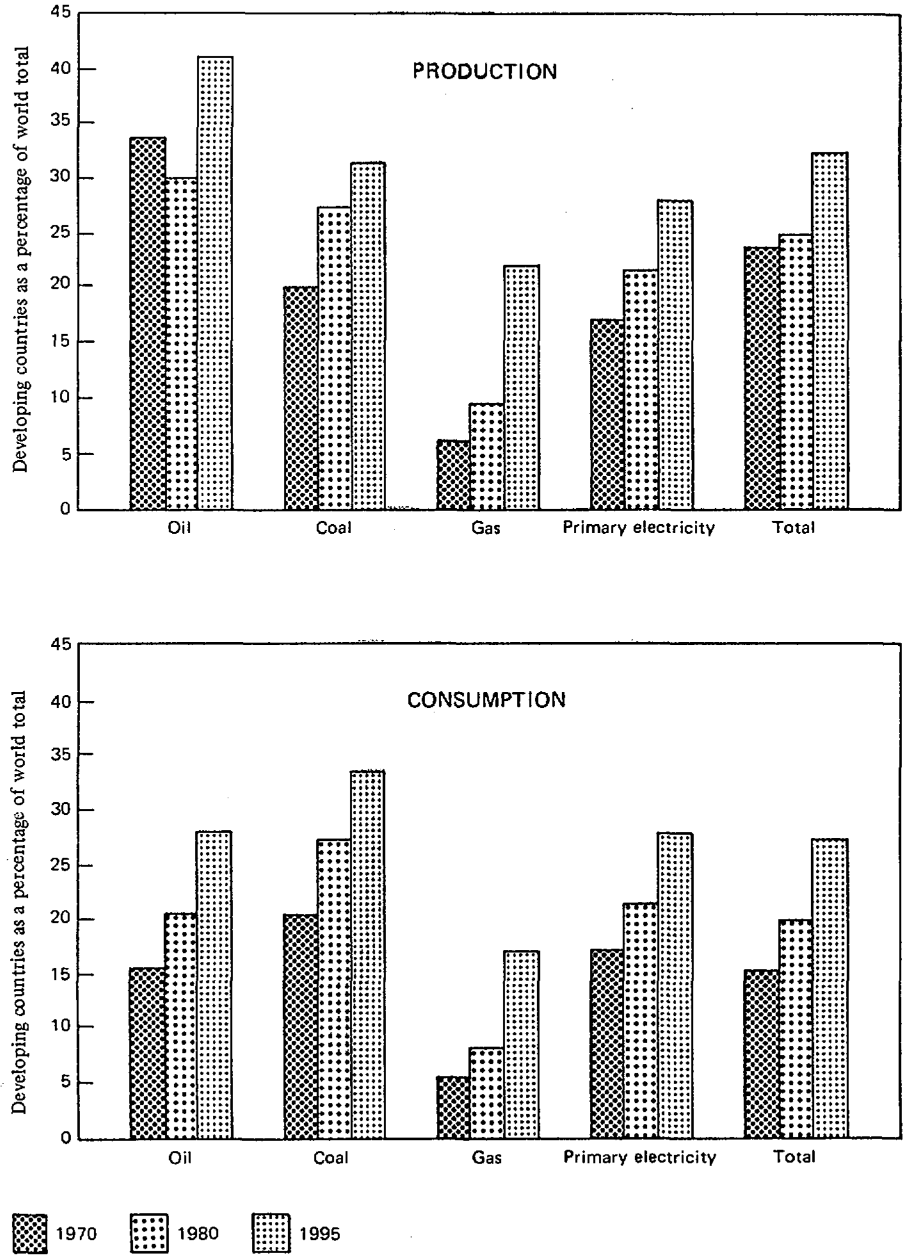


FIG.15.4. Shares of developing countries in world primary commercial energy production and consumption, 1970–1991 [15.1].

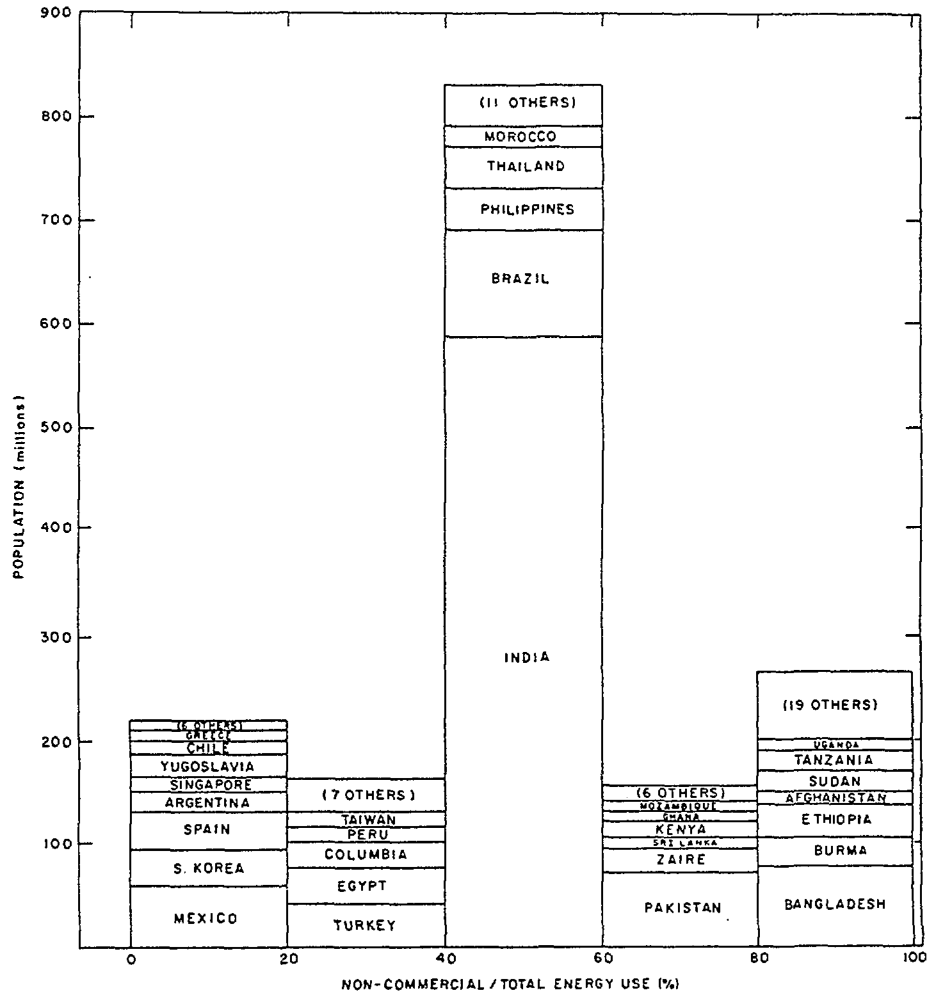
TABLE 15.VI. COMMERCIAL PRIMARY ENERGY PRODUCTION AND CONSUMPTION IN OIL-IMPORTING DEVELOPING COUNTRIES 1970–1995 [15.1]

	10^6 toe			Growth rate (% per year)	
	1970	1980	1995	1970–80	1980–95
Production					
Oil	63	65	145	0.3	5.5
Coal	118	192	384	5.0	4.7
Natural gas	14	27	115	6.8	10.1
Primary electricity	41	98	306	9.1	7.9
Total	236	382	950	4.9	6.3
Consumption					
Oil	223	360	531	4.9	2.6
Coal	121	186	442	4.4	5.9
Natural gas	12	26	120	8.0	10.7
Primary electricity	41	98	306	9.1	7.9
Total	397	670	1399	5.4	5.0
Oil imports	160	295	386	6.3	1.8

Sources: *United Nations J Series and World Bank estimates.*

has completed energy assessments, biomass fuels supply more than half of the total primary energy consumed. In three of these countries, the proportion of energy derived from biomass is 90% or greater and the average for the group exceeds 65%.

Figure 15.5 displays from another source [15.4] the non-commercial energy use as % of total energy use versus population, by country. Current consumption levels have already caused severe problems in many countries. In the group of ten countries mentioned earlier it is estimated that the consumption of fuelwood is greatly outstripping sustainable production, sometimes by a factor of three or four. At present rates of exploitation, accessible forest resources in many countries will be practically obliterated within 20 to 30 years. The situation is a grave one, not only because biomass fuels are an important energy source, but because they are used by the majority of the population who have no real alternative other than a deterioration in living standards.



Sources:

- 1974 (est.) population: UN statistical yearbook 1975.
- Commercial energy use: UN World Energy Supplies 1971–1975 (1977).
- Noncommercial energy use: 400 kgce/rural population.

FIG. 15.5. Non-commercial energy use as % of total energy use, versus population, by country [15.4].

TABLE 15.VII. COMMERCIAL AND NON-COMMERCIAL PRIMARY ENERGY CONSUMPTION IN DEVELOPING COUNTRIES 1970–2020 (10^6 toe)

	1970	1978	1980	1995	2000		2020	
Commercial energy								
WEC-CC		1065			3221	2240	6527	3928
World Bank	756		1345	2594				
Non-commercial energy		619			737	860	682	876

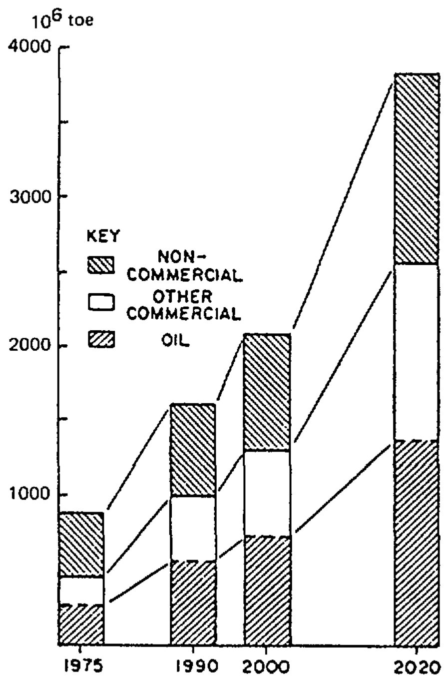


FIG.15.6. Total annual energy consumption projections for all non-OPEC less-developed countries [15.4].

Neither World Bank nor more recent projections on the evolution of non-commercial energy in developing countries have been published, with the exception of the WEC Conservation Commission – see Refs [13.12 and 15.2]. Its estimated total figures for the developing countries (included the high-income oil exporters) are shown in Table 15.VII. In this table the figures of commercial energy consumption have been added, both according to WEC and World Bank estimates. Surprising is the only very slow estimated increase of non-commercial primary energy resources till the year 2020. In contrast, some older projections, with estimates for total consumption of some 2000 $\times$ 10^6 toe in the year 2000 and 3800 $\times$ 10^6 toe in 2020, i.e. rather close to the low WEC scenario figures, expect some 800 $\times$ 10^6 toe non-commercial energy consumption in 2000 and 1300 $\times$ 10^6 toe in the year 2020. Interestingly enough, typical for older projects, the share of oil in the commercial energy consumption is given for all future years as over 50%, very much higher than all other recent estimates, which are around 35–30%.

The demand for commercial energy, shown in Fig.15.6, was estimated using assumed GDP rates and correlations between energy demand, GDP growth and energy prices. Non-commercial energy consumption was based on estimates of current consumption levels, subsistence energy requirements and population growth projections. Although only very approximate, especially for the period after the year 2000, Fig.15.6 offers an interesting overview of the structure of demand, presented in its three main components: petroleum, other commercial and non-commercial energy.

For all the uncertainties included, the trend for these countries appears reasonably characteristic: transportation should still very much rely on petroleum products; progress of urbanization should permit a centralized energy supply mainly based on other commercial energy resources, while decentralized supply of rural areas with non-commercial energy resources, although decreasing in percentage terms, will still grow substantially in absolute terms.

15.3. The rural/urban dichotomy – rural energetization

Figure 15.6 may display the core problem of the energy supply of the developing world.

The energy development of the developing world implies a rapidly increasing energy demand, geographically split between urban areas – even between a few immense conurbations – and scattered villages and farms. It still requires a major petroleum supply and a substantial contribution of non-commercial resources. Although even in some developed countries rural supply of energy is not everywhere completely solved, the rural/urban dichotomy in the developing world remains a dominant challenge, also for the future energy supply.

In the light of the aforementioned considerations, the energy supply of more than 70% of the population of developing countries, which will continue to live in the rural areas – see Fig. 15.2 –, emerges, therefore, as a most urgent problem. A solution, however, can be sought only based on non-commercial primary energy resources.

Therefore, a most important research and development goal to aim at would be a radical new solution for rural energy supply in the sense of an integrated, autonomous 'energetization' of rural human settlements, based only on local renewable energy resources cycled in a circuit which would include the attendant agricultural and forestry activities.

The elements of the local, autonomous rural energy system would be on the primary energy resources side: biomass (fuelwood, agricultural wastes, dung, human waste if psychologically acceptable), direct radiation of solar energy, possibly but not necessarily hydro and wind power. For cooking, the end-use energy supply would consist of: fuelwood, biogas, low-heat-content gas or solar energy; for lighting: biogas, low-heat-content gas or electricity; and for mechanical energy: biogas or low-heat-content gas.

Electricity, if required, could be generated from: fuelwood electric power stations, solar energy or at present best from gas (diesel) motors fuelled with low-heat-content gas or biogas from agricultural wastes or fuelwood. Automobiles and tractors would run on low-heat-content gas, or biogas, or on gas from small built-in charcoal gasifiers, charcoal being a by-product of the low-heat-content gas generation, being (as the gas itself) very pure and with high efficiency in special modern pyrolysis processes.

As described, the necessary elements and techniques exist. The research and development task would be the design of the system in real operating and geographical conditions and defining the climatic and basic physical and economic constraints for its application.

One of the additional advantages of such a solution would be the complete elimination of fuel-oil and kerosene consumption in rural areas and the possibility of partly financing its implementation from the difference between the newly obtainable export price for these products and their former, heavily subsidized internal price.

The above suggestion is not new compared to previous attempts to integrate rural energy supply. However, it calls more for on pyrolysis methods for producing simultaneously from firewood and from wood and agricultural wastes perfectly clean low-heat-content gas for reliable stationary motor operation (i.e. electricity generation) and charcoal able to be easily gasified on moving vehicles or used for cooking purposes.

15.4. Salient problems of energy supply in developing countries

Since 1973, practically all the developing countries have made a major effort to expand their energy production. Most of them quickly recognized that higher international oil prices made it worthwhile to exploit and develop indigenous energy resources that had previously been regarded as uneconomic. Consequently, the formulation and implementation of programmes to increase domestic energy supply became an essential feature of adjustment to the new international energy situation.

In the past, developing countries' commercial energy consumption has grown much faster than production (5.9% versus 3.6% per year respectively in the period 1970–1980). In the 1980–1995 period, however, through a combination of demand management and supply development the gap could be virtually eliminated. Developing countries' production of commercial energy is projected to rise at over 4% per annum during these years. Over 80% of this increment is expected to come from the increased production of fossil fuels – oil, gas and coal – see Table 15.III. Their importance is further enhanced by their tradeability.

Almost all of the increased coal production will be consumed domestically; in the case of both oil and gas, higher production will also enable a higher level of exports. The developing countries' net oil exports to the rest of the world are projected to increase from 293 million tonnes of oil equivalent (toe) in 1980 to about 440 million toe in 1995; the expected increase in gas exports is more striking – from 21 million toe in 1980 to 100 million toe by 1995 [15.1 and 15.5].

The achievement of such a sizeable increase in energy output will require action on several fronts:

(1) First, most developing countries need to formulate clear strategies on how to use the several available means of accelerating the identification, evaluation, development and marketing of indigenous energy resources.
(2) Secondly, they must embark on a focused programme of preinvestment work to minimize the possibility of expensive mistakes in the large and complex investments which will be required.
(3) Thirdly, there is a need to strengthen the management of the energy sector, both in national planning and policy formulation as well as in the capability of individual energy enterprises to implement and operate large and technologically complicated projects.
(4) Finally and most importantly, a massive effort is required to mobilize both domestic and external resources for investment.

From the many problems involved, the following salient problems have been selected for short further comments.

15.4.1. Energy conservation

There is a growing body of evidence which indicates that in developing countries, too, substantial energy and cost savings through better demand manage-

TABLE 15.VIII. POTENTIAL SAVINGS IN COMMERCIAL ENERGY CONSUMPTION BY ENERGY CONSERVATION IN DEVELOPING COUNTRIES IN 1990 (10^6 toe) [15.6]

	Projected consumption	Pricing policies	Taxes and regulations	Retrofit. and techn. improve.	Interfuel subst.	Total reduct.
Electric power[a]	365	5	(.)	30	5	40
Agriculture	85	(.)	(.)	5	(.)	5
Households	330	15	5	5	25	50
Transport	420	5	5	35	10	55
Industry	485	10	10	60	15	95
Other	30	5	(.)	(.)	(.)	5
Total	1715	(40)	(20)	(135)	55	250

[a] Includes energy consumed in generation, station use, losses in transmission and distribution.
(.) Less than 0.05 of the unit shown.
Source: World Bank staff estimates.

ment and higher conversion and transport efficiencies, as well as through adequate petroleum substitution, are both feasible and cost-effective.

Table 15.VIII presents the potential savings in commercial energy consumption by energy conservation in 1990 in developing countries, amounting to 14.6% of the projected energy consumption.

The estimates are based on judgements derived from country, sectorial and project analysis in the respective countries. It is believed that the savings are achievable without affecting the GDP growth rates projected for these countries. If the potential savings are achieved, the growth of energy consumption in the developing countries (projected at 6.2% per year between 1980 and 1990) would be reduced to about 4.5% per year.

For the oil-importing developing countries, the achievement of only half of the full potential savings would reduce oil imports in 1990 by US \$22 $\times 10^6$ (in 1980 dollars).

15.4.2. Increasing domestic petroleum production

The petroleum of the developing countries is needed both for their development and to contribute to the world economic growth. Accordingly, it is considered that the petroleum exploration effort is currently wrongly distributed since the essential part of the petroleum to be discovered, i.e. 60%, is with the developing and the high-income oil exporters [15.7], while 70% of the investment in petroleum exploration outside the socialist countries has been in the OECD areas, where the chance of an oil strike is only 15%, and especially in the USA and Canada, where the percentage is even lower, 11%. Presently 85% of exploratory drillings are in the USA and less than 10% in developing countries.

Figure 15.7 displays a world map with petroleum reserves and exploration trends in developing countries, the latter being listed by country with an estimate of the level of exploration activity. As far as the actual exploration activity between 1972–1981 in 90 developing countries is concerned, some 49% has been carried out by national oil companies – mainly in Argentina, Brazil and India, which covered almost 60% of the entire exploratory drilling in developing countries –, some 22% by international majors, some 12% by other majors, 8% by foreign national oil companies, 7% by independents and the rest by local private companies. However, in order to meet the increasing production goals mentioned before, a substantially reinforced effort is needed.

In recognition of the developing countries' needs, the World Bank has increased its involvement in the petroleum sector, where its presence helps overcome the constraints impeding the acceleration of exporation and development activity. The World Bank has helped countries in formulating a sound strategy which takes account of the need to offer IOCs a contractual and operating environment that is attractive, stable, and consistent with the country's interest. This has involved the financing of data acquisition and technical assistance designed to accelerate the competitive offering of new acreage to the international petroleum industry on reasonable terms. The preliminary results of such exploration promotion projects have been encouraging. The World Bank has also been ready to support the allocation of public resources to petroleum development when it is convinced that this is an appropriate feature of the country's optimal sectoral and national development strategy, as is the case when the priorities of the international petroleum industry do not match the priorities of the country. For further reading on the subject, Refs [15.8–12] could be particularly helpful.

While the focus here has been on exploration, issues that arise further along in the development process should not be overlooked. In most developing countries oil is still largely produced through primary depletion of the reservoirs, which at best recovers only 5–25% of oil in place. Methods to maintain reservoir pressure such as water/gas injection or assisted recovery (gas lift, pumping), are being used but not to the extent proven feasible in industrialized countries, where pressure maintenance is now applied routinely from the outset of production.

15.4.3. Increasing domestic natural gas production

Natural gas occurs in about 50 developing countries, including 30 which import oil. Many deposits, found in the process of exploring for oil, have not been

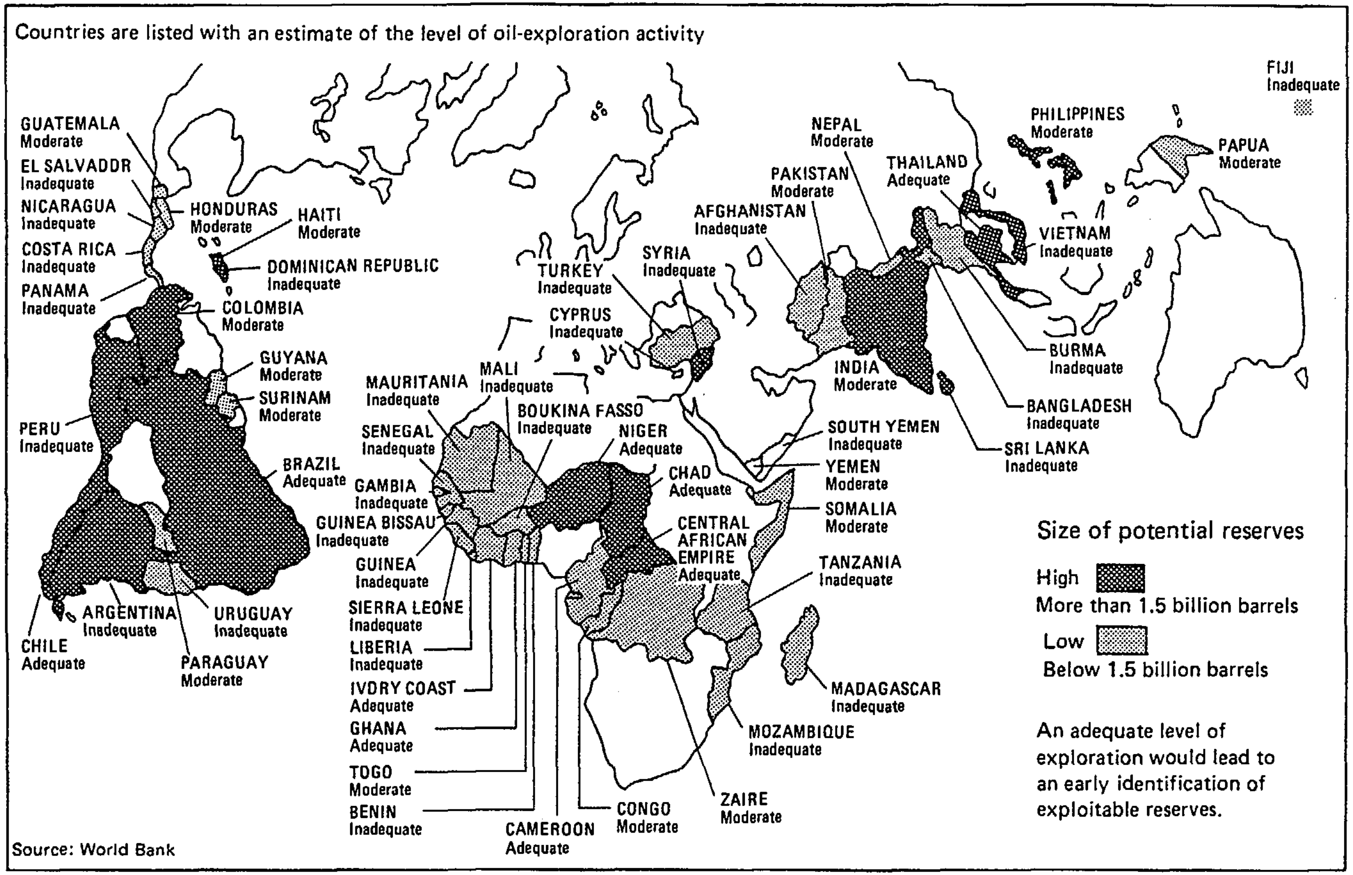


FIG.15.7. Petroleum reserves and exploration trends in less-developed countries.

fully evaluated for lack of infrastructure and incentives. The costs of gas development are often lower, and the potential domestic demand higher and more diverse, than is widely believed. In a large number of developing countries, better utilization of natural gas resources can greatly reduce dependence on oil imports or allow larger oil exports.

Over 70% of the gas produced in LDCs is expected to be consumed domestically. In some case (for example Bangladesh, Pakistan and Tunisia) gas is expected to supply half the addition to commercial energy consumption over the next decade.

A World Bank study recently estimated the average cost of supplying an incremental volume of natural gas over the long run in ten countries[15]. These countries exemplify a variety of reserve and production characteristics and in all cases, the cost of gas at the distribution gate ranged from above US \$2–12 per barrel of oil equivalent, far below the cost of imported petroleum products.

The World Bank has also reviewed the economics of natural gas use in the developing countries. Preliminary results from studies on the value or 'netback' [16] of gas in a variety of uses in the power, industrial, fertilizer and petrochemicals, and residential sectors, indicate that gas is an economically attractive fuel in most uses. The results of these studies show that the ranking of different uses is a highly country-specific and complex procedure. In planning gas utilization strategy, the netback values of gas in different uses, as well as the net present value and quantities of gas used for different projects, should be considered.

Several developing countries such as Argentina, Brazil, Egypt, India, Nigeria, and Thailand with a combination of large reserves, low production costs, and a large number of high-value uses, are on the threshold of major programmes of gas development. In others, such as Bolivia, Cameroon, Chile, Ivory Coast, Morocco, Tunisia, Tanzania, Turkey, and Zaire, gas is beginning to be used and could well become a major energy resource. A few countries, such as Algeria, Mexico, Pakistan and Venezuela already use gas to meet a significant share of their energy requirements. However, in many cases they lack a strong institution to develop an overall natural gas strategy and integrate the activities of the various agencies involved.

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[15] Estimated by dividing all discounted capital and operating costs exclusive of profits, taxes, and royalties by the discounted gas volumes. A real discount rate of 10% per annum was used.

[16] The 'netback', or the average value for gas in a particular gas-using project, represents the price paid for gas by the project that would cause the project to just break even. It is defined as the present value of the net benefits of the project, excluding the cost of gas used, divided by the present value of gas consumed in the project. Both the net benefits and gas volumes are discounted to take account of their differing time streams.

15.4.4. *Increasing domestic coal production*

Coal accounts for about a third of developing country fossil fuel production and is the principal commercial energy source for China and India. Coal remains up to 30–40% cheaper than oil as a fuel for electricity generation and many industrial uses. However, this advantage is dwindling and, in some developing countries, it has disappeared, because of substantial inefficiencies in the management and co-ordination of programmes involving coal and because of delays caused by government procedures and interventions [15.5].

The bulk of total coal investment in developing countries has had to be financed by government budget allocations or domestic subsidized loans because during the 1970s coal prices were set to cover costs (except in China and Yugoslavia), yielding virtually no funds for further investment. Delays in the allocation of public funds have repeatedly slowed down programmes. Major changes are urgently needed in the pricing policy of developing countries, to limit cross-sectoral subsidization and allow coal companies to generate a good part of the local funds required for expansion.

For many developing countries imported coal is a potentially attractive option. However, few developing countries are studying the options for importing coal or have begun to make the necessary investments in infrastructure to facilitate such imports (port handling, storage, internal transportation, etc.).

15.4.5. *Crude oil refining*

The slower growth of oil consumption has resulted in a global excess of primary distillation capacity in petroleum refineries. In the developing countries themselves, crude oil distillation capacity is estimated at about 1×10^9 t/a, which should accommodate the projected growth in their oil consumption up to 1995.

However, there is an acute need to rehabilitate and improve the energy efficiency of oil refineries and to invest in new secondary processing facilities to convert surplus fuel oil into middle distillates (such as diesel oil, kerosene and jet fuel).

Most of the refineries in developing countries are over 15 years old and were designed to minimize capital costs at the expense of higher energy consumption. The increased cost of energy over the past decade makes it worth considering several changes to increase energy efficiency.

Because of the growing demand for diesel fuel (for transport vehicles and agricultural equipment), even though fuel oil is being replaced increasingly by natural gas and coal, developing countries' refineries will find it impossible to match the composition of their output of petroleum products with the changing composition of demand, which is projected in Table 15.IX.

TABLE 15.IX. STRUCTURE OF PETROLEUM DERIVATIVES DEMAND IN DEVELOPING COUNTRIES, 1970–1995 [15.1]

	(%)			Rates of growth (% per year)	
	1970	1980	1995	1970–80	1980–95
Gasoline	15	14	18	5.5	4.26
Middle distillates	30	34	47	7.4	4.66
Fuel oil	38	35	21	5.2	–0.84
Others[a]	17	17	14	6.1	2.74
Total	100	100	100	6.1	2.75

[a] Liquefied petroleum gas, bitumen, asphalts, lubricants, and solvents.
Source: World Bank estimates.

The share of middle distillates is expected to continue to increase, reaching nearly half of petroleum demand in 1995, while that of fuel oil will decline to about 21% in 1995.

Most of the refineries in developing countries are austere in design. Out of 245 refineries operating in developing countries, only about 60 have advanced conversion facilities such as hydro-crackers or fluid catalytic crackers. In developing countries, total secondary conversion capacity amounts to 13% of crude oil distillation capacity compared with 21% in industrialized countries.

The inadequacy of secondary conversion facilities to process fuel oil into distillate products has compelled many developing countries to process more expensive lighter crude oil, often spiked with refined products, as well as to engage in sometimes unprofitable balancing trade in refined products. Taking into account facilities that exist, or are under construction, and assuming that secondary conversion facilities are fully used, it is estimated that by 1995 the production of middle distillates could not exceed 30% of refined products while fuel oil would amount to about 39%.

The relative scarcity of middle distillates and easy availability of fuel oil is expected to be a global phenomenon during the next decade and not one affecting only developing countries. A substantial share of the investment in conversion facilities needed to correct this product imbalance will have to be undertaken in developing countries. The economic returns from such investments depend on specific circumstances. However, it appears that if the current inadequacies and inefficiencies of refineries in developing countries were corrected, the economic cost of petroleum products for many developing countries could be reduced considerably.

15.4.6. Increasing utilization of domestic new and renewable energy resources

The subject has been extensively dealt with in chapters 3, 4 and 6 [15.13]. It is only mentioned at this point to underline once again its overwhelming importance for the rural energy supply of the developing countries, for the rural 'energetization'.

Guidance and advice on new and renewable energy resources can be sought from the focal point for information on new and renewable sources of energy, established at the United Nations, New York, DIESA, in relation to the implementation of the Nairobi programme of action in this sector.

15.5. Electrical energy and nuclear share in developing countries

Historically, electricity use in the developing countries has grown at about 9% a year, although in some of the more rapidly industrializing countries (Brazil, Indonesia, Republic of Korea, and Thailand, for example), growth rates have been much higher. Over the past two years, the general slowing down of economic activity has reduced the growth of electricity demand in some developing countries, notably Brazil, but more commonly (in China, India, Indonesia, Pakistan, Sri Lanka, and Turkey, for example), the growth of electricity consumption is constrained by supply and there is a long waiting list for service. In such countries, the future rate of growth of electricity consumption will be determined as much by the schedule of commissioning new plants as by growth in the underlying demand for electricity.

The growth of demand for electricity comes not only from new connections, but also from existing consumers. Though utilities can use changes in price and other techniques of load management to limit demand to a certain extent, in practice, it is impossible to limit consumers to a given amount of electricity. If capacity is inadequate, the quality of service deteriorates rapidly, with severe consequences for the equipment both supplying and using electricity. This means that once a power system is in operation, planning its expansion to meet less than the level of demand will inevitably lead to a reduction in its efficiency.

15.5.1. Future evolution of electricity demand in developing countries

The demand for electricity in the developing countries is projected to grow at about 6.2% per year in 1980–85, rising to 7% per year in 1985–95 as economic activity picks up. Though lower than in the past, this forecast, nonetheless, implies that electricity consumption will double during the 1980s and will continue to increase its share of total energy consumption. Even after this increase, the untapped market for electricity in the developing countries will be enormous: nearly 75% of the households in developing countries will still not have access to

TABLE 15.X. ELECTRICITY SUPPLY IN DEVELOPING COUNTRIES 1980–1995 [15.1]

	TW·h			Growth rate (% per year)	
	1980	1985	1995	1980–95	1985–95
Primary electricity					
Hydro power	500	682	1 289	6.4	6.6
Nuclear	18	95	262	39.5	10.7
Geothermal	3	10	34	27.2	13.0
Subtotal	521	787	1 585	8.6	7.3
Conventional thermal electricity					
Oil	342	293	257	−3.1	−1.3
Gas	64	121	321	13.6	10.2
Coal	393	578	1 346	8.0	8.8
Subtotal	799	992	1 924	4.4	6.8
Total	1 320	1 779	3 509	6.2	7.0

Source: World Bank estimates.

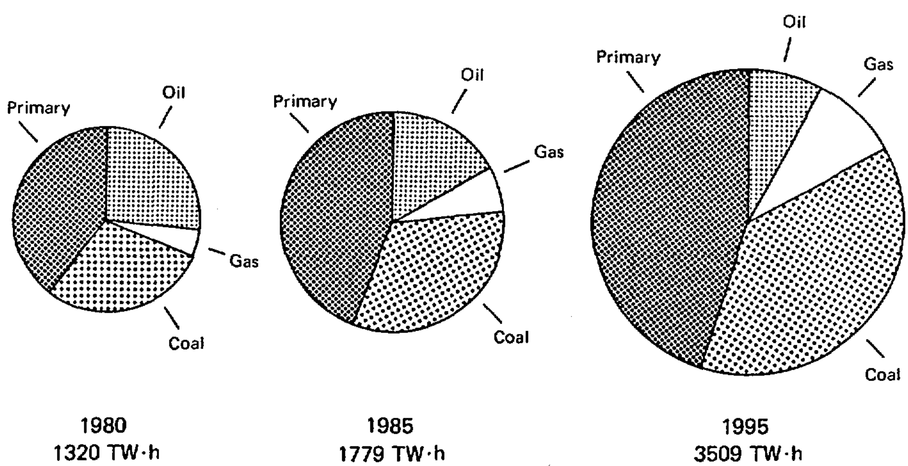

FIG.15.8. Electricity generation mix in developing countries 1980–1995 [15.1].

electricity; the industrial sector, the main user of electricity, will still account for less than 20% of GNP.

In countries which have appropriate energy sources, an important objective of the next fifteen years will be to modify the pattern of electricity generation, using the power system as an instrument to reduce dependence on imported oil. The large scope for this is evidenced by the major share of electricity in the energy sector: in 1980, electric power supplied 24% of the commercial energy consumption of developing countries and 30% of that of the oil-importing developing countries.

Table 15.X displays the evolution of electricity supply in developing countries between 1980–1995, the structure of generating plants and the % yearly growth rate. Figure 15.8 illustrates the electricity generation mix.

As far as the electricity generation structure is concerned, as shown in Table 15.X and Fig.15.8, between 1980 and 1995 oil-based electricity generation is projected to decline by about 25% in absolute terms, and from 26% to 7% of total generation. This dramatic decline is caused mostly by greater reliance on coal, which overtakes hydro as the largest power source, and to a lesser extent, on gas and nuclear energy. The projections do not provide for any conversion of existing oil-fired units to coal, since recent studies shows that this is generally more expensive than accelerating the construction of non-oil-fired units.

The economics of coal-based generation depends not only on plant size – the per kW cost for a 30 MW unit is twice that for a 300 MW unit – but also on the opportunity cost of coal. Large mine-mouth coal-based plants using coal at $40 per tonne would produce electricity at about 4 cents per kW·h, as against 7 cents per kW·h from oil-based plants; the same units using imported coal at $80 a tonne generate electricity at about 5.5 cents per kW·h. Smaller coal units are competitive with oil-fired diesel units only under the best pithead conditions. About thirty developing countries are expected to use coal for electricity by 1995, with this source supplying over a third of total electricity requirements in about a dozen of those countries, including some new coal users. Lignite must be used at mine-mouth and on a large scale to be economic, yet in spite of this and other technical difficulties, it is making an economical and important contribution in Romania, Thailand, Turkey and Yugoslavia.

The role of gas-based generation depends greatly on country characteristics. In countries that produce gas, gas turbines are nearly always economic for peaking duty even though they do not replace much oil. The proportion of power generated from gas will largely depend upon the quantities of gas available and on whether the opportunity cost of the gas used makes it competitive with other sources for base-load generation.

Hydro-electricity generation is projected to increase by more than 150% during 1980–95. Even after this increase, less than 15% of the harnessable hydro potential of the developing countries (about 7 600 TW·h per year) will have been developed. The cost of hydro-electricity is quite site-specific. Though

TABLE 15.XI. NUCLEAR POWER PLANTS IN DEVELOPING COUNTRIES (AS OF 31 DECEMBER 1982) [15.15]

Capacity	Operating		Under construction	
	No. of units	Capacity MW(e)	No. of units	Capacity MW(e)
Developing countries (excluding CPE-Europe)				
Argentina	1	335	2	1 291
Brazil	1	626	2	2 490
Cuba	–	–	1	408
India	4	809	6	1 320
Korea, Rep. of	2	1 193	7	6 227
Mexico	–	–	2	1 308
Pakistan	1	125	–	–
Philippines	–	–	1	620
Taiwan	4	3 110	2	1 814
Yugoslavia	1	632	–	–
Total excluding CPE-Europe	14	6 830	23	15 478
'Developing countries' in CPE-Europe				
Bulgaria	4	1 632	1	1 000
Czechoslovakia	2	762	6	2 520
Hungary	1	408	3	1 224
Poland	–	–	1	440
Romania	–	–	2	1 320
Total in CPE-Europe	7	2 802	13	6 504
Total	21	9 632	36	21 982

Source: IAEA Power Reactor Information System (PRIS).

$1500 per kW is currently typical for many countries, unit costs for hydro projects in preparation range from $900 per kW in Colombia to over $5000 per kW in Upper Volta. In general, real hydro costs are rising because the most attractive sites have been developed first. Where coal or oil is available at international prices, hydro power's economic limit is roughly $2000 to $3000 per kW; but proposed schemes must be studied individually. In some landlocked countries, such as Nepal or Upper Volta, schemes with significantly higher unit costs can be economically justified.

While geothermal electricity generation has been sufficiently discussed in chapters 3 and 4, nuclear power alternatives for developing countries deserve some additional comments, given in subsection 15.5.2.

15.5.2. Nuclear power generation in developing countries

The technical and economic conditions of operation of nuclear power stations in developing countries are basically the same as in the – usually much larger – electrical systems of developed countries. The essential difference resides in the prerequisites for the introduction of this new form of energy in developing countries, which are discussed in detail in chapter 18, and which are mainly aspects of adequate infrastructure, institutional framework, safety, training and management.

As far as the technical conditions are concerned, the two basic conditions are: for stable system operation the frequency change resulting from sudden tripping of a large unit should not exceed 2% of the rated frequency; secondly, a minimum standby generating capacity – hot or spinning – must exist, able to come into service immediately if some unit, even the largest, fails. These conditions impose a maximum limit on the size of the largest unit in the network which, by rule of thumb, determines the power system planner to limit the maximal unit to a maximum 10% of the total generating capacity installed in the electric system [15.14].

The status of nuclear power in the developing countries at the end of 1982 is shown in Table 15.XI. It can be seen that there are ten developing countries outside CPE-Europe and 5 within CPE-Europe which have ongoing nuclear power programmes. While this is practically half of the world total of 31 countries that have ongoing nuclear power programmes, the total operating nuclear capacity in the developing countries is only 5.5% of the world total, and the capacity of the nuclear units under construction corresponds to only about 11% of the world total capacity under construction. The percentages excluding CPE-Europe countries, i.e. in developing countries according to the World Bank classification, are only 4% and 8% respectively.

The developing countries with ongoing nuclear power programmes, as with all countries, have different characteristics. From the point of view of their nuclear programmes, however, some common features can be found. One group comprises developing countries (Argentina, Brazil, India, Republic of Korea and Taiwan)

TABLE 15.XII. IAEA ESTIMATES OF TOTAL INSTALLED ELECTRIC CAPACITY AND ELECTRICITY GENERATION AND SHARE OF NUCLEAR POWER IN DEVELOPING COUNTRIES [13.5]

	Installed capacity (GW(e))		Electricity generation (TW·h)		Installed capacity (GW(e))		(%)		Electricity generation (TW·h)		(%)	
1983	398		1590		8.2		2.1		36.5		2.3	
1990	664	717	2560	2779	20	21	3	3	93	102	4	4
2000	1080	1360	4280	5400	42	82	4	6	270	490	6	9

which have major nuclear programmes with at least one unit in operation and several under construction. There have been some delays and reappraisals of the programmes, but in each case nuclear power development is moving ahead firmly, with substantial national efforts.

Another group is constituted of countries (Bulgaria, Czechoslovakia, Hungary, Cuba and Poland) showing a similar approach in their nuclear power programmes. Each of these countries has a programme based on supply and co-operation with the USSR, and is making steady progress. Bulgaria, Czechoslovakia and Hungary each have nuclear plants in operation and under construction. Cuba and Poland have recently started construction of their first units.

Finally, each country in the third group (Mexico, Pakistan, the Philippines, Yugoslavia and Romania) has only one nuclear power plant (two units each in Mexico and Romania) either in operation (Pakistan and Yugoslavia) or under construction. They do have intentions to proceed with nuclear power programmes, but for various reasons none of these countries have started constructing their second project yet.

In addition to the above-mentioned countries with ongoing nuclear power programmes, there are several other developing countries in different preparatory stages (planning, feasibility studies, acquisition process) who are considering, intend or have decided to go nuclear, but which have not yet launched their first nuclear power project. Among these countries, those which seem to be closest to going nuclear are the People's Republic of China, Egypt and Libya.

As a whole, the contribution of nuclear power to fulfil the needs of the developing countries has been modest to date and would, according to current forecasts, continue so in spite of the rapidly growing energy requirements.

The latest IAEA estimates of the development to the year 2000 are shown in Table 15.XII. The share of nuclear in the total installed electric capacity increases from 2.1% in 1982 to 4–6% in the year 2000 – depending on low and high limits. The share in the electricity generation is 2.3% to 6–9%, i.e. higher, due to base-load operation of nuclear power plants.

In absolute figures, the installed nuclear capacity in developing countries would extend from 8200 MW(e) in 1983 to 42 000–82 000 MW(e) in the year 2000.

Adding, for statistical comparisons, the installed nuclear capacity in the 'developing' countries in CPE-Europe, i.e. 2800 MW(e) in 1983 and 24 000–33 000 MW(e) in 2000, the total installed nuclear capacity increases to 11 000 MW(e) in 1983 and 66 000–115 000 MW(e) in the year 2000 [13.5].

By the year 2000, the number of developing countries with nuclear power plants in operation or under construction is forecast to be 23 countries compared to 15 at the end of 1982 [15.16]. Reference [15.17] brings in this context a brief overview of the major efforts of the IAEA during the last two decades to assist developing member states in improving their capability for nuclear power programme planning embedded in the general supply development.

15.6. Investment requirements, financing, institutional and managerial aspects

The investment requirements for achieving the projected level of energy output in developing countries have been estimated by the World Bank as averaging annually about US $130 $\times 10^9$ (in 1982 dollars) over the next decade; that would be a doubling of the share of energy investments in GDP from about 2–3% of GDP during the late 1970s to an average of about 4% of GDP over the next decade. Almost half of this investment, or just over US $60 $\times 10^9$ per year, would be for the development of fossil fuels. Table 12.II displays the structure and Table 12.III the foreign exchange requirements of the total estimated investment amount of US $1426 $\times 10^9$.

While it is clear that such investments have priority and are an essential feature of the overall adjustment process for many developing countries, they nevertheless, constitute a major financing problem. Oil-importing countries, in particular, not only have to find the resources for energy investments; they also have to finance imports of oil until these investments begin to pay off. While some of the increase in energy investments can be financed by reallocating resources from other sectors, the overall requirements are unlikely to be met without a substantial increase in energy financing from all possible sources, including both debt and equity, commercial and official. In parallel, a major effort is required within the developing countries to raise the level of resource generation within the energy sector through appropriate pricing and other measures. While investment financing alternatives have been discussed in chapter 12, chapter 16 covers the planning and institutional aspects.

A last word for the imperative call for improved and competent management: energy is an input or an output in almost all productive activity and, consequently, the linkages between energy and the rest of the economy are strong and intimate.

Not only do energy investments compete with those in other sectors for scarce investible resources, but decisions on them cannot be taken without careful consideration of their interrelationships with policies and trends in the rest of the economy. These relationships have many dimensions, at international, national, local, governmental and enterprise level. It is not possible to elaborate further upon this here. However, this simple mention is equivalent to an insistent invitation to reflection and implementation of a continuously improving institutional and managerial network [15.18–20].

Part IV

ENERGY PLANNING

Chapter 16

OPTIMIZATION OF ENERGY SUPPLY AND UTILIZATION

The increasing role of electricity

This chapter aims to integrate the technical and economic aspects dealt with previously and describe the necessary approach for designing an optimal energy supply to the managed demand optimized according to chapter 2. This means determining the technical and economic optimal primary energy mix and the appropriate energy conversion and transport chains to the end-use energy stage.

The energy system offers an ideal framework for investigating the possibilities for the implementation of the best energy development strategy. It permits the location of losses and waste and the evaluation of their order or magnitude as well as identifying any increase in efficiency. As auxiliary tools, energy flow charts and global and partial energy balance sheets, which permit detailed analysis to any depth desired, could prove particularly helpful.

Accordingly, there are several characteristic sequences in the necessary investigations, each of them described in a separate subsection. A first overview is of efficiencies, losses and waste of energy in the energy system, analysis of the various energy chains depending on the available primary energy resources, desirable and rational first substitution options and evaluation of the possibly increasing role of electricity as probably a major vector of future development.

While emphasis apparently seems to lie on the technical alternatives, these are permanently accompanied by their economic estimates, optimization alternatives having constantly to be evaluated according to the criteria described in chapters 10 and 11. Proceeding in this manner the prerequisites for the planning phase are finally completed.

16.1. Efficiency, losses and waste of energy in an energy system

The general analysis of a complex, hypothetical energy system of the type displayed in Fig. 1.1, which could represent a country, a major region or even the entire world, might offer a suitable reference background against which concrete cases could be plotted and possible improvements compared.

For the first global information, Figs 16.1 and 16.2 present the main quantitative structure of an overall energy system of a country with reasonably efficient energy husbandry. Figure 16.1 shows that from the primary energy consumed and taken as 100%, only 30% serves as useful energy – the proportion 22% heat, 7% mechanical energy and 1% radiant energy are real average shares; the balance of 70% represents the consolidated losses and waste in all stages of the system: production, conversion and transport and the final consuming stage [16.1].

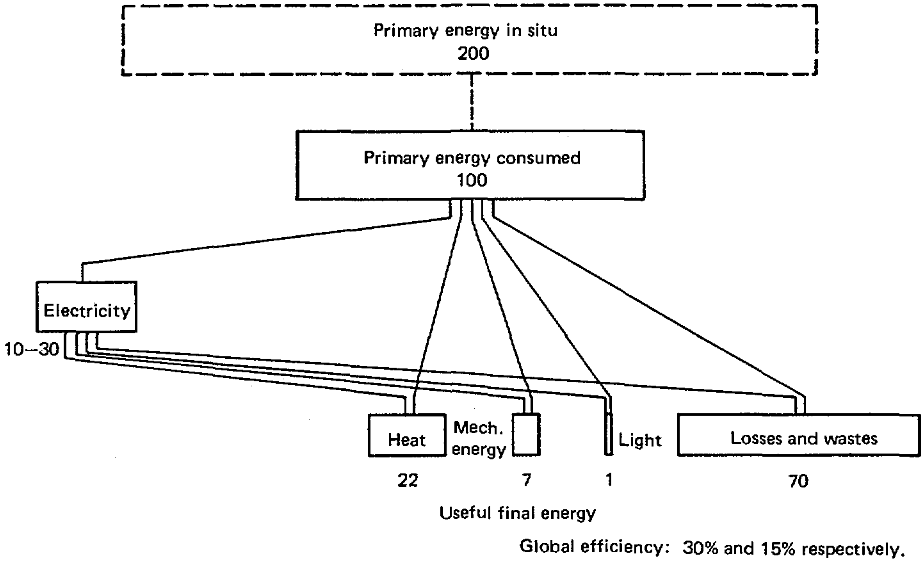

FIG.16.1. Efficiencies, losses and useful energy in an energy system [16.1].

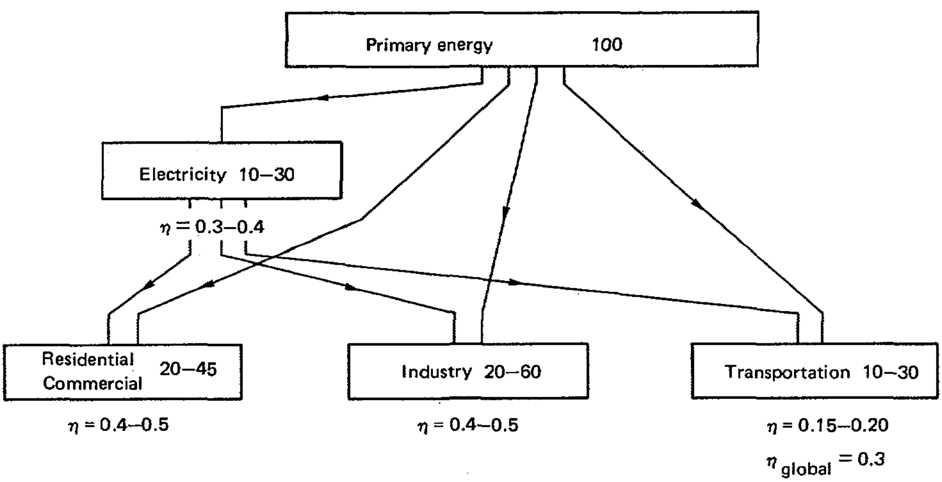

FIG.16.2. Share of energy-consuming sectors and average efficiencies in an energy system [16.1].

With a global recovery factor of only 50% of the in situ primary energy, the real efficiency of the energy system drops to 15%, a rather poor performance figure when related to the world energy scarcity. Figure 16.2 shows for the same energy system the shares of the final energy consuming sectors: residential, commercial, industrial and transportation, and the involved average efficiencies. Notable are the low efficiencies in the transportation sector, the sector with almost exclusive consumption of petroleum derivatives. The share of primary energy consumed for electricity generation varies between 10% and 30%.

Detailed analysis of actual and possible future figures of energy conversion and transport efficiencies have been included in this book when debating the relevant main issues; for example, in chapter 2, regarding the conversion of end-use energy forms into useful energy, in chapter 7, regarding the energy transport processes and in chapter 5, in relation to biomass conversion. Table 8.V gives an overview of present and long-term efficiency figures encompassing the whole energy system, from the primary energy stage to the final consumption stage, in the latter even specified by the main end-use sectors. Interestingly enough, the extraction efficiencies are included, which bring the overall efficiency of the energy system to only 15% currently, with a possibility of 20% or 30% in the future, i.e. in line with the previous comments and the general presentation of Figs 16.1 and 16.2.

To round up the subject, Table 16.I presents the missing typical processing and conversion efficiencies of preparation or conversion of primary energy resources into intermediate energy forms in the ECE area [8.17].

16.2. Analysis of various energy chains

To meet a given need for final useful energy, as Fig. 1.1 shows, there are usually several alternative solutions possible depending on the input primary energy resource and the selected conversion and transport chain. However, under real conditions, the number of feasible alternatives is much more limited owing to available primary energy resources and/or intermediate energy forms or other local conditions. Nevertheless, usually a few alternatives might compete in the final comparison, the choice depending on the optimization criteria applied.

For such final evaluation, the input of primary energy is a decisive factor to be determined by the integrated effect of all partial efficiencies involved in the respective energy chain and resulting in a final overall process efficiency.

While advising more careful analysis for each practical case, for general evaluation the figures indicated so far in the present work for actual and future efficiency ranges offer a reliable reference basis.

However, no consolidated presentation of the total efficiency of different chains has been shown so far. Preference was given to illustrating characteristic portions of chains and leaving open combinations to reach total efficiency figures, depending on the options selected. The total efficiency will always

TABLE 16.I. TYPICAL PROCESSING AND CONVERSION EFFICIENCIES IN THE ECE AREA [8.17]

Process	Efficiencies (%)		
	Currently obtained	Practically possible by early 1990s	Maximum possible by early 1990s
Coal preparation	90	90	92
Coal conversion into coke and coke oven gas; patent fuel; brown coal briquettes; brown coal coke	90	90	92
Coal conversion into synthetic liquid and gases	60–70	60–70	65–75
Refining of oil	88–94	90	94
Refining of oil shale	85	97	99
Processing of natural gas	96–97	97	97
Conversion of primary energy into electricity:			
– at conventional fossil plants	30–35	38	50–60
– at nuclear plants (nuclear reactor excluded)	32	36	45–50
Conversion of primary forms of energy into electricity and heat	70–80	70–80	70–80
Enrichment of uranium ore	60	70–80	70–80
Weighted average, ECE region	78	70	76

result from the following main components: efficiency of conversion of the primary energy resource into an intermediate energy form (including any preparation taking place), efficiency of conversion of the intermediate energy form into end-use energy and efficiency of conversion of the latter into useful energy, taking into account all transport efficiencies which apply. Another approach is to take the efficiency of consumption and efficiency of end-use energy supply (including transport efficiencies). If the energy chain is traced back to in situ primary energy, then the efficiency of extraction, i.e. the recovery factor, has to be introduced.

Table 16.II illustrates an important end-use energy supply alternative, i.e. space heating. This example has been chosen since it refers to a key energy consumption sector which represents a share of up to 40–42% of the total final

TABLE 16.II. APPROXIMATE SPACE HEATING EFFICIENCIES FOR COAL, PETROLEUM, NATURAL GAS, ELECTRICITY AND DISTRICT HEATING SUPPLY IN THE ECE REGION [8.17]

Direct/indirect use	Coal[a]			Oil			Natural gas		
	Early 1970s	Early 1990s		Early 1970s	Early 1990s		Early 1970s	Early 1990s	
		Practically possible	Maximum possible		Practically possible	Maximum possible		Practically possible	Maximum possible
(a) *Direct use*									
Extraction	70	72	75	35	45	60	70	80	87
Upgrading and conversion	90	90	92	90	90	94	97	97	97
Transport	99	99	99	99	99	99	98	99	99
Utilization for heating	45	54[b]	59[b]	63	76[b]	82[c]	75	80[d]	83[d]
System's efficiency	28	35	40	20	31	46	50	61	69
(b) *If converted into electricity*									
Extraction	70	72	75	35	45	60	70	80	87
Upgrading and conversion	33	38	55	33	38	55	33	38	55
Transport	92	92	92	92	92	92	92	92	92
Utilization for heating	95	95	95	95	95	95	95	95	95
System's efficiency	20	24	36	10	15	29	20	27	42
(c) *If converted into electricity and steam, in combined power plants*									
Extraction	70	72	75	35	45	60	70	80	87
Upgrading and conversion	75	75	75	75	75	75	75	75	75
Transport	92	92	92	92	92	92	92	92	92
Utilization for heating	95	95	95	95	95	95	95	95	95
System's efficiency	46	47	49	23	30	39	46	52	57

[a] Underground, long-wall mining.
[b] Corresponding to an average potential increase of 20%.
[c] Corresponding to an average potential increase of 30%.
[d] Secretariat estimate.

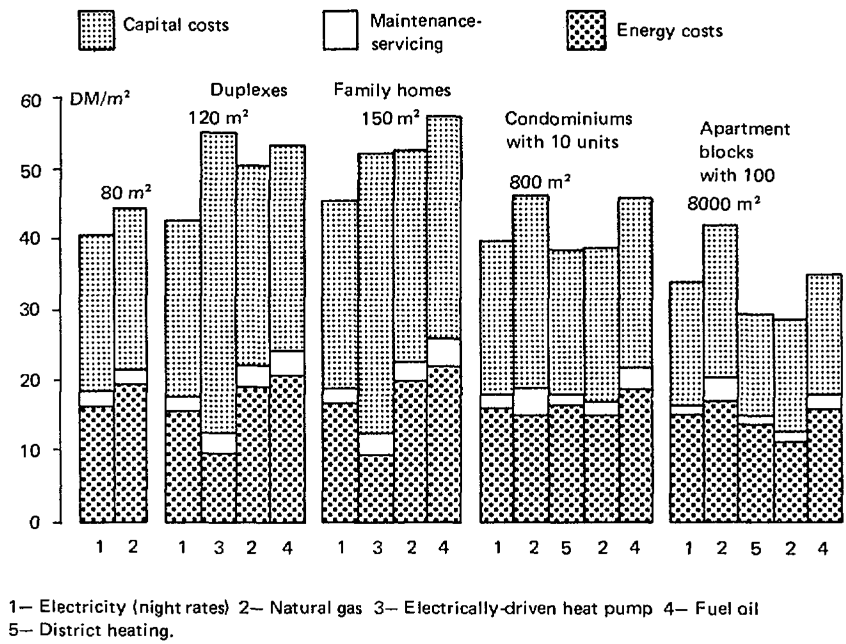

FIG.16.3. Comparison of space-heating costs for different types of dwellings and end-use energy supply [16.2].

energy consumption in the temperate and cold developed countries and which can be covered from a series of alternative primary energy resources over various energy chains.

Comparatively presented are approximate partial and total efficiencies of space-heating energy chains, taking coal, petroleum and natural gas primary energy resources for either direct supply or via an intermediate energy form, i.e. electricity and co-generated heat. The figures refer to the status in early 1970 and to possible or maximal progress in the early 1990s. They all refer to the ECE region, with maximal heat requirements for space heating, but also endowed with the most advanced technology and investment potential [8.17].

The table is self-explanatory when its basic assumption is recalled: the energy chains are supposed to begin from the in situ deposit of primary energy. With the lowest recovery factor of all three primary energy resources — currently 35% — the oil chain starts in the comparison with a heavy handicap and results in by far the poorest efficiency values of all chains. The co-generated heat supply shows again the advantages of combining energy processes.

However, the integrated view, from the national economy standpoint, contrasts strongly with the private consumer's view on the subject, the latter limiting his judgement to the last link of the energy chain, i.e. the efficiency of the burning process in his premises or the electricity or heat delivered to his home heating system.

The analysis of energy chains constitutes, therefore, an extremely useful tool in the optimization of energy supply, both from the point of view of the private consumer as well as of the national economy.

It is of interest at this point to go a step further and follow up an efficiency analysis integrated into a total annual cost analysis, carried out with actual (February 1982) capital and energy costs in the Federal Republic of Germany [16.2]. Figure 16.3 shows for example a comparison made from the point of view of private consumers, regarding the total annual costs for space heating referred to one m^2 of habitable surface for various heating systems and energy carriers and some typical dwellings [16.2]. The energy carriers envisaged were: fuel oil, natural gas, district heating, electricity (at reduced night heating rates) and electrically driven heat pumps.

The total costs, expressed in DM/m^2 (1 DM = 0.35 US$), are also indicated separately for their three main components: energy, maintenance and supervision and costs of capital. The highest costs appear for fuel oil and electrical heat pumps for all types of dwellings, while for the other energy carriers, the levels are different depending on the type of dwelling.

16.3. Rational energy substitution

The substitution or switch of energy forms constitutes an old challenge in the energy field, enacted and amplified by a continuous offer of more convenient and less expensive energy forms and the technical progress of equipment able to use them with even better efficiencies.

In recent decades, in the stage of primary energy resources, coal was replaced more and more by hydrocarbons; in the area of intermediate forms of energy, liquid and gaseous petroleum derivatives are joining electricity in a favourable but also competitive expansion. The overall energy systems developed correspondingly with a heavy reliance on hydrocarbons and centralized electricity supply.

With the described evolution of petroleum availability and its high pricing the interest in substitution reversed; it is now petroleum which has become the most enviable substitution target.

Decisions on energy substitution used to be just based on rather simple direct comparisons, with little awareness of, or afterthoughts on, the additional impact on other sectors. The advantages and low price of petroleum overrode all other considerations.

It is, therefore, fortunate that in recent years, when substitution for petroleum became such an imperative, the concept and techniques of the overall energy system have offered such an admirable tool to investigate and evaluate the potential for petroleum substitution throughout the whole energy system.

Technically, petroleum can be substituted for at any stage of the energy system. Practically, it is a question of efficiency, availability of the substituting energy forms, possible scale of substitution, management, and, last but not least, economic costs and effects.

In the final consuming stage, the main difficulties reside in replacing petroleum derivatives in the transportation sector and in developing countries in addition for lighting (kerosene) and partly cooking. The main alternatives are natural gas, synfuels, gasohol and electricity, but only gradually and in the long term.

In the intermediate stage, replacing petroleum products in the electricity generation of developed countries is a process getting rapidly under way; however, the substitution in developing countries, especially in rural areas, is more difficult, although water power and biomass – direct or gasified – offer acceptable alternatives.

In general, for primary energy on a large scale, the alternatives are coal, water, nuclear power and biomass.

In conclusion, the potential for petroleum substitution is considerable, on different scales and over different periods and with long-term prospects for implementation in the transportation sector.

However, careful short-, medium- and long-term studies are necessary to consolidate a policy both for the displacement of petroleum from existing uses and meeting the prospective increase in demand as far as possible by other means. There are sectors or uses in which the switch away from petroleum can be relatively easily achieved – non-specific sectors – and specific sectors, mainly transportation, where no short- or medium-term substitution appears possible.

In this respect, the valuable report of the Oil Substitution Task Force of the WEC Conservation Commission might be mentioned [16.3]. Its basic objectives were to identify and assess the technology, economic and other factors affecting petroleum substitution by other energy resources, to quantify the most likely amount of substitution which will take place in the different significant country groups and study the sensitivity of petroleum substitution to changes in price and availability of crude oil. The time scale was until the year 2000 and beyond; many considerations extended until 2020.

As an overview, the worldwide progress of petroleum substitution is reflected in decreasing world petroleum consumption, although this evolution also includes real savings and negative effects of the preceding years of economic recession.

The real and estimated share of petroleum products in % of the overall energy consumption in the IEA area declines from 52% in 1973 to 50% in 1979 and towards 39% in 1990. In the countries with centrally planned economies the petroleum share in 1980 was around 25% while in developing countries it amounted to 64%.

Whereas developed countries (with a few exceptions among petroleum exporters) will tend to reduce in the future – by substitution and saving – their dependence on petroleum or even on hydrocarbons in general, the developing countries are likely, in spite of saving and substitution efforts, to increase their petroleum consumption and imports, because of their higher expected growth rates.

A spectacular example of reduction of its reliance on (imported) petroleum is offered by the French energy strategy and illustrated by the figures presented in Table 16.III [16.4]. The impressive reduction of petroleum consumption resulted one-third from savings and two-thirds from substitution, mostly by nuclear energy and partly by coal.

As further examples: the share of petroleum products in the national energy consumption declined in the Federal Republic of Germany from 55.4% in 1972 to 50.7% in 1979 and 43.8% in 1981. In Spain this share is expected to decline from 68.0% in 1980 to 45.2% in 1990 and 33.8% in the year 2000, due to energy saving, petroleum substitution, especially for electricity generation and in industry and the extension of other domestic primary energy production [16.5].

16.4. Partial and global optimization of energy supply and utilization

Undoubtedly, the ideal way to design and implement optimal energy supply and utilization is in connection either with an existing energy system and its extension or with a new system in countries where energy development is starting practically from the grass roots.

It is not intended to sum up at this point all previous considerations in this respect nor to enter into detail which has purposely been left out of this limited framework. Rather, it is felt that before engaging in the practical planning phase, an ultimate reflection on some basic optimization aspects may be both helpful and motivating. These are of a rather technical character, but well linked to economic reality. No answers are offered but multilateral and multidisciplinary study and insight are suggested.

The approach is again in the full context of the global energy system, but the accent is somewhat different. To that purpose, Figs 16.4 and 16.5 display two new presentations of the global energy system, in addition to the ones previously worked with.

Figure 16.4 is interesting for its display of the solar-related background of the different primary energy resources and their grouping according to their energy 'density'. It distinguishes in this respect:

(1) Dense energies, which need to be deconcentrated to serve useful purposes, i.e. uranium, thorium, petroleum, natural gas, coal, lignite.
(2) Intermediate dense energies, which need to be concentrated for use, i.e. wood and peat, biomass (plants and animals) and tidal, geothermal and hydro energy.

TABLE 16.III. THE PRIMARY ENERGY BALANCE OF FRANCE (STRATEGY S6) [16.4]

		1973	1978	1980	1985	1990	1995	2000
Primary energy consumption (10^6 toe)		177.7	187.3	191.7	187.7	203.2	219.9	237.6
Electricity	(10^6 toe)	13	22.5	28.9	55.5	71.8	83.3	98.6
	%	7.3%	12%	15%	29.6%	35.3%	37.9%	41.4%
Fuels	(10^6 toe)	162.7	162	159.7	128.1	125.2	128.3	128.5
	%	92.7%	88%	85%	68.2%	61.6%	58.3%	54.1%
Coal	(10^6 toe)	30.5	32.4	34.4	22.7	19.3	25.2	31.2
	%	17.2%	17.3%	18%	12.1%	9.5%	11.5%	13.1%
Natural gas	(10^6 toe)	15	20.8	23.6	23.8	29.6	29.3	28.0
	%	8.4%	11.1%	12.3%	12.7%	14.6%	13.3%	11.8%
Petroleum	(10^6 toe)	117.2	108.8	101.7	81.5	76.3	73.7	69.3
	%	66%	58.1%	53%	43.4%	37.5%	33.5%	29.2%
Renewable energy	(10^6 toe)	2	2.8	3.2	4.1	6.2	8.3	10.6
resources	%	1.1%	1.5%	1.7%	2.2%	3.1%	3.8%	4.5%
Domestic energy production	(10^6 toe)	44.1	49.3	58.1	78.7	95.1	107.8	124.3
Degree of energy independence, in %		24.8%	26.3%	30.3%	41.9%	46.8%	49%	52.3%

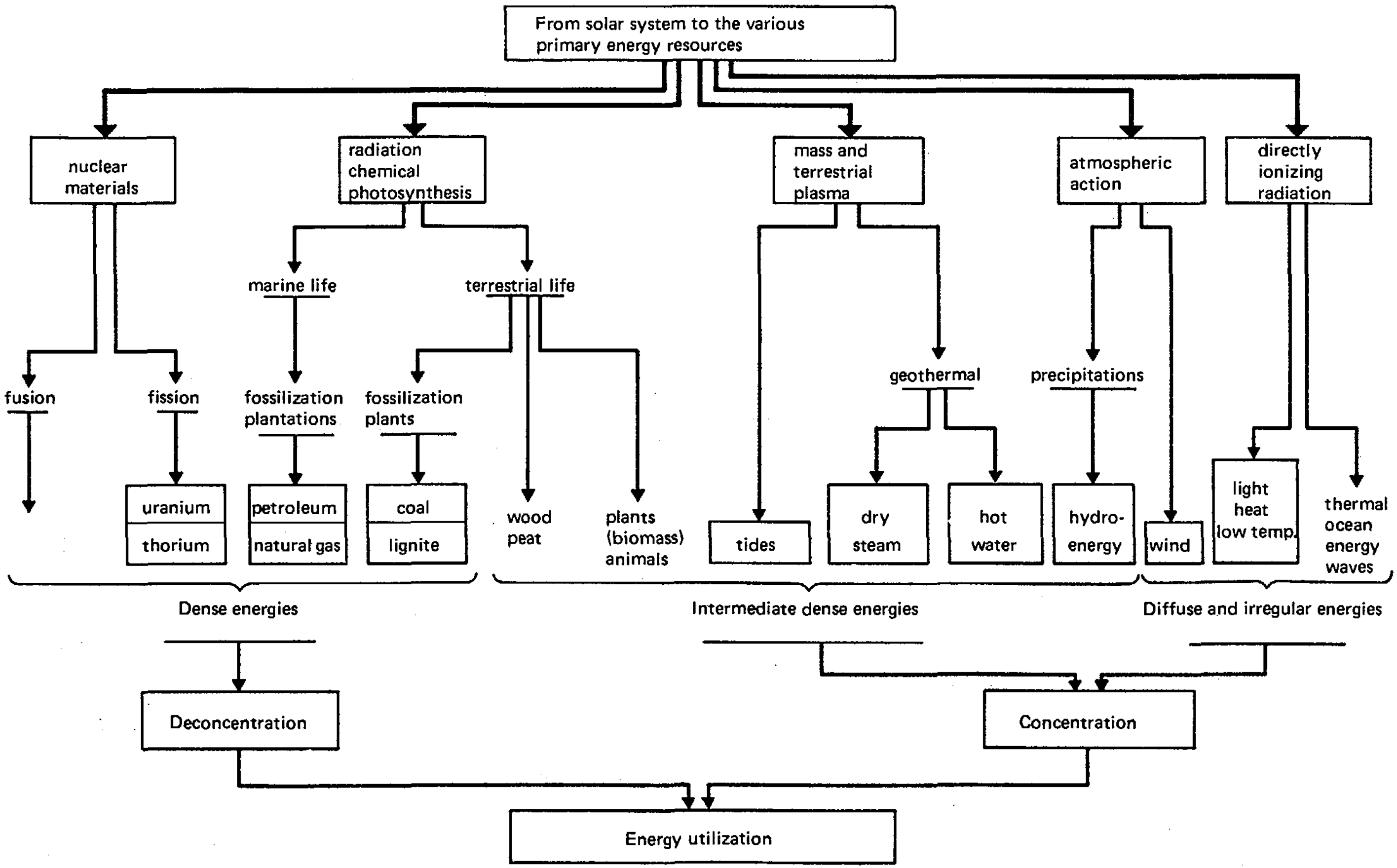

FIG.16.4. Energy resources: from solar to the various primary energy resources [16.6].

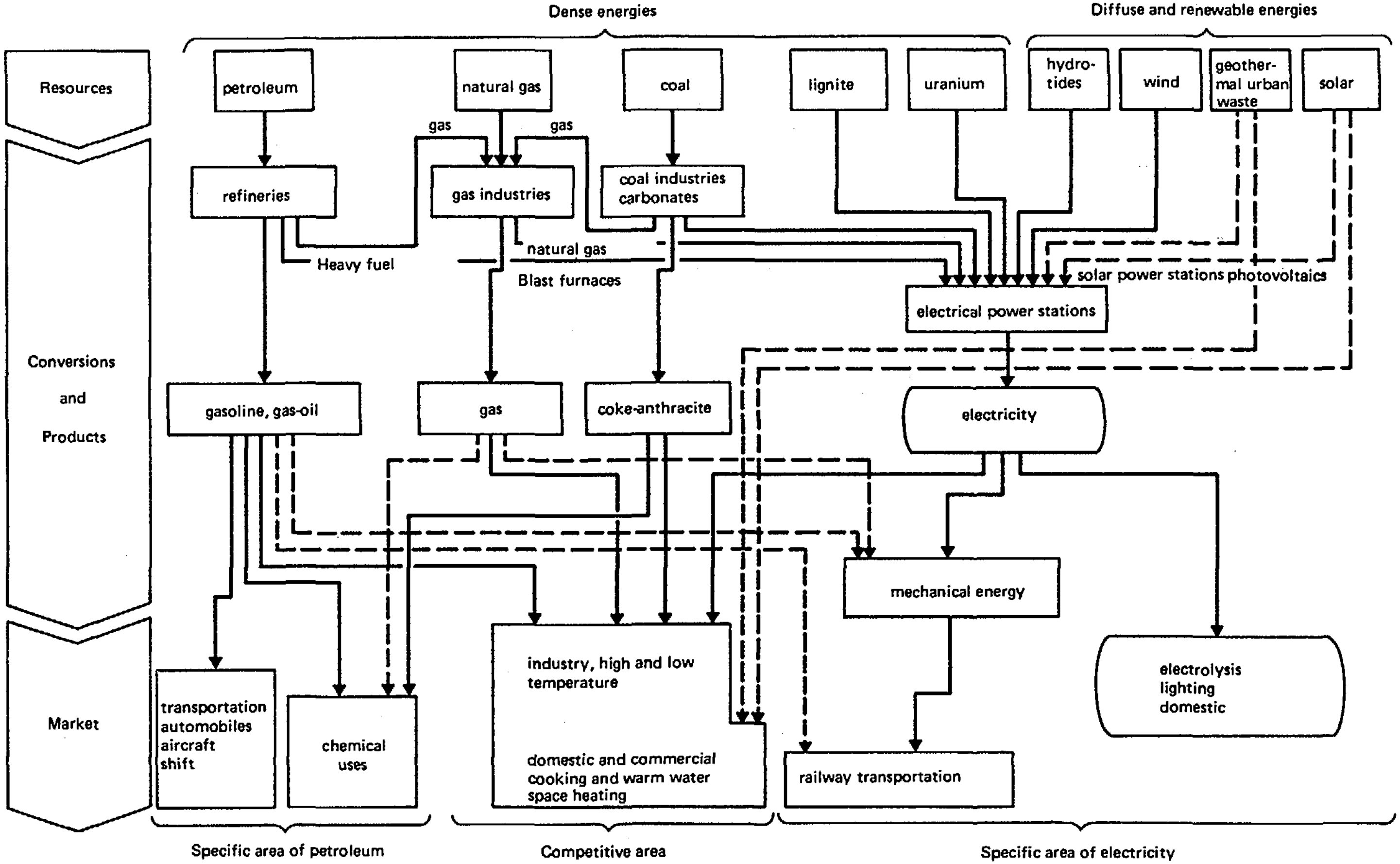

FIG.16.5. From primary energy resources to energy markets – simplified scheme [16.6].

TABLE 16.IV. THE SYSTEM'S EFFECT OF INCREASED EFFICIENCY ON RESOURCE DEPLETION (IN UNITS OF USEFUL ENERGY, FOR EXAMPLE toe) [8.17]

Demand by stage of energy flow	Early 1970s	Early 1990s Practically possible	Early 1990s Maximum possible
Ultimate use	1.00	0.80	0.70
Input into end-use appliances	2.38	1.57	1.27
Input into transport, distribution and storage	2.42	1.64	1.30
Input into upgrading and conversion	3.10	2.34	1.71
Deposit which has to be worked to enable ultimate use	6.73	3.97	2.41
Percentage savings	0.00	41.00	64.00

(3) Diffuse and irregular energies, such as wind, direct solar radiation, heat of low temperature, wave and ocean thermal energy, which need even stronger concentration.

Figure 16.5 displays in the usual manner the structure of the energy system, with the input, however, grouped into dense, diffuse and renewable primary resources. The final uses are grouped according to a categorization to be further discussed, i.e. in areas specific for petroleum or for electricity supply and in a middle area open for competition between these two energy carriers, and also for other supply chains.

Figure 16.4 visualizes the heavy, consistent character of 'dense' primary, but non-renewable, energy resources, in contrast to the intermediate dense, diffuse and irregular other resources, the latter two of renewable character. In this configuration the short formulation: 'energy from income – not capital', which made headlines some years ago [16.7], without being contradicted, needs to consider the factor time, as recent experience has demonstrated. Thought must be given to timing and technological progress.

In contrast, a similar short economic formulation might be: 'energy saving, once implemented, is money in the bank, since it is an alternative with zero fuel costs'. In addition, the saved fuel represents an immediate, dense energy resource, In this respect, hardly a better example and incentive than Table 16.IV could be offered, since it demonstrates with specific figures how immensely high the

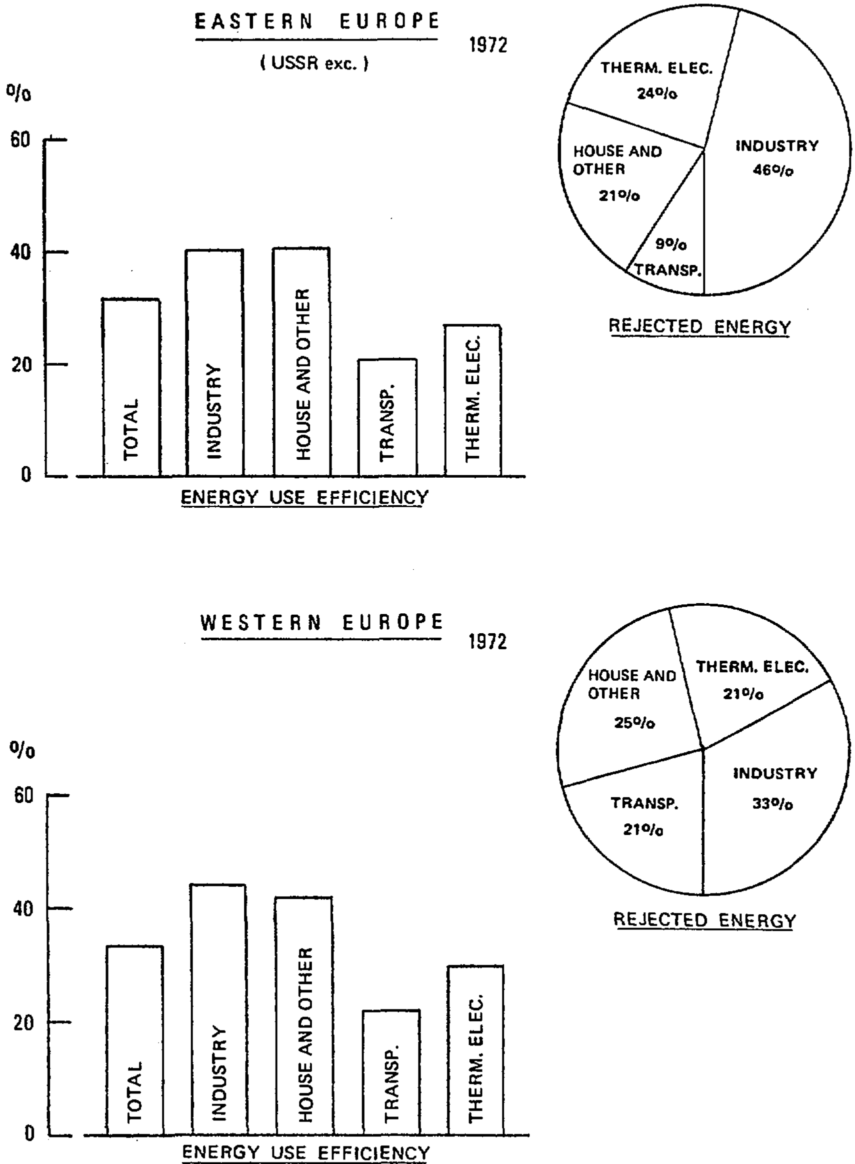

FIG.16.6 Energy use efficiencies and rejected energy, Eastern and Western Europe, 1972 [8.17].

TABLE 16.V. SHARE OF ELECTRICITY (%) IN THE WORLD ENERGY BALANCE [16.4, 10 and 11]

Year	World	Developed market economies	Planned economies Europe and USSR	Planned economies East Asia	Developing countries	France
1928	6.0					5.5
1950	12.5	13.4	10.0	3.8	11.0	12.5
1960	17.5	20.7	14.8	5.0	14.6	18.7
1970	22.5	25.8	21.0	6.9	19.1	20.9
1974	25.2	28.5	22.9	8.1	20.7	24.9[a]
1980	25.3	28.5	23.9		15.3	
1982	26.3	30.2			17.7	
1985	28–29	33			19	29.6
1990	31–32	36–37			23	35.3
2000	35–37	39–40			29–31	39.8

[a] The data 1928–1974 originate from Ref. [16.10], for later years from Ref. [16.11], and for France from Ref. [16.4].

expenditure of primary energy resources is for a unit of useful energy and the snowball effect of possible savings in the 1990s by improving the efficiencies in all energy chains: 41% being practical and 64% the maximum possible.

However, all ad hoc and emergency conservation measures taken in the last decade under unexpectedly developing pressure should be gradually integrated and managed from the point of view of optimal energy system development.

In chapter 8 the energy saving technology of combined processes, i.e. co-generation of heat and electricity, ISER recovery, etc., was amply described and recommended. However, the basic principle of its efficiency, i.e. the sequential utilization of the exergy potential of the energy resource, from higher towards lower exergy levels, was not sufficiently emphasized, as an example generally worth emulating. A favourable geographical location of the energy consumers and production facilities has a similar positive effect, and is often the prerequisite for permitting combined processes. Large industrial platforms concentrating various industries with sequential material and energy links at short distances could represent, from the energy point of view, ideal time-and-space-integrated conditions [16.8].

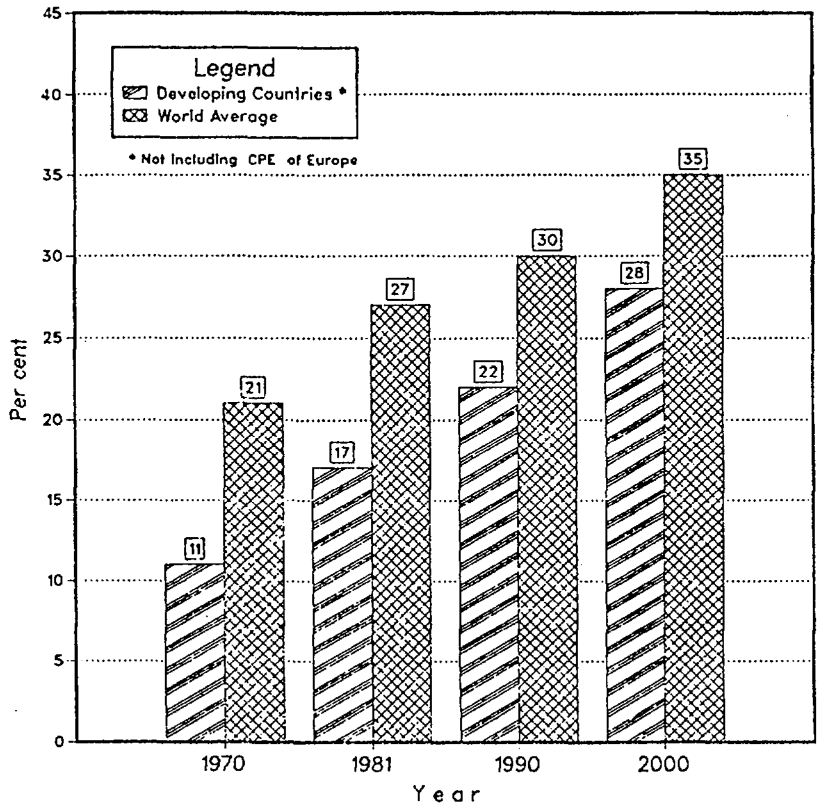

FIG.16.7. Share of total energy consumption used for electricity generation [4.3].

A low level of energy utilization, which it is imperative to increase, is characteristic also for very large spaces. Figure 16.6 illustrates for example the combined average efficiency of energy use in Eastern and Western Europe in total and in sectors in 1972. The structure of the rejected energy reflects indirectly the very different shares of the final energy-consuming sectors in the two regions.

16.5. Increasing role of electricity

Historically, the share of electrical energy in the global energy balance of the world and its main regions has increased continuously. Table 16.V presents the % figure between 1928 and 2000. The rather high figures for the developing countries have only a limited significance, since they relate solely to commercial energy consumption: including non-commercial energy consumption, they would

TABLE 16.VI. SHARE OF ELECTRICITY (%) IN THE NATIONAL ENERGY BALANCE IN SOME DEVELOPED COUNTRIES IN 1973 [16.10]

Norway	69.5	Switzerland	35.5	United Kingdom	29.4
Iceland	49.4	Japan	35.0	Fed. Rep. Germany	27.2
New Zealand	46.4	Canada	31.5	Australia	26.3
Sweden	42.7	Spain	30.9	USA	25.4
Finland	36.8	Austria	29.8	USSR	23.4

TABLE 16.VII. SHARE OF ELECTRICITY (%) IN THE NATIONAL BALANCE IN SOME DEVELOPING COUNTRIES

	1950	1976
Brazil	17.2	32.5
India	6.6	22.5
Republic of Korea	12.7	22.1
Egypt	6.2	20.8
Mexico	10.0	19.7
Algeria	12.9	12.2
China	3.6	7.8

TABLE 16.VIII. SHARE OF ELECTRICITY IN SOME FINAL CONSUMPTION SECTORS IN 1974–1975 [16.10]

Industry (without iron and steel)		Iron and steel industry		Residential and commercial	1960	1975
Norway	74.0	Norway	75	Norway	66.0	73.7
Canada	48.4	Sweden	41.1	USA	25.1	46.2
Sweden	46.8	Italy	28.9	Sweden	25.7	37.6
Japan	46.3	USA	26.3	United Kingdom	21.1	42.3
Fed. Rep. Germany	43.5	United Kingdom	20	France	16.5	29.8
France	36.2	France	18.3	Fed. Rep. Germany	15.7	37.6
USA	35.5	Netherlands	13			

result in lower figures. The differences between the trend 1928–1974 and after 1980 could be partly due to the different reference sources. However, the strongly increasing general trend remains obvious.

Figure 16.7 confirms in another presentation – the centrally planned developed countries of Europe are not included in the figures for developing countries – the same trend for the period 1970–2000 [4.3].

Although as a whole continuously progressing, the share of electricity in the national energy balances varies very much between the different countries. The level reached in 1973 in some countries is given in Tables 16.VI and 16.VII.

Entering into more details, Table 16.VIII shows the share of electrical energy in some typical final consumption sectors.

With the past rate of growth extrapolated and recently readjusted, the share of electricity in the world energy balance could reach around 35–37% by the year 2000. For France 30% is forecast for 1985 and some 40% in the year 2000 – see Table 16.V.

The share of electrical energy in the total energy balance increased in the past, due to the special qualities of this remarkable energy carrier. As emphasized in chapter 6, electricity is not an energy resource, it is an intermediate form of energy, an energy carrier – a vector – of exceptional versatility. It is the least specialized, the most open to innovation and the least endangered energy form in changing situations, since ever-increasing shares of electricity in the overall primary energy balances are rightly credited with important reductions of primary energy consumption rates per unit of GDP. The related bibliography is abundant. Two examples may quantify the effect:

- in the USA a study of 350 categories of goods and services arranged in 20 groupings shows that an 8% increase in electricity's share of total energy use saves 18% of primary energy per dollar of producer cost [16.12];
- in the Federal Republic of Germany, industry has reduced its specific fuel consumption (per 1000 DM, i.e. around US $370 net production) between 1960 and 1981 by 50%. The specific electricity consumption increased in the same interval by 14% [16.13].

A more subtle effect of the increasing share of electricity in the end-use energy supply is displayed in Fig. 16.7 [16.14].

The energy utilization ratio E is defined as the ratio between useful energy and end-use energy, while the energy utilization ratio P is the ratio between useful energy and primary energy. For the utilization ratio E in the FRG typical figures are: industry 55%, the residential and commercial sector 45% and transportation 17%. These figures demonstrate in the left-side diagram of Fig. 16.8, that the higher the electricity share in the end-use energy supply, the higher the energy utilization ratio. The same effect is seen in the right-side diagram where the utilization ratio P is introduced, i.e. the conversion efficiency of electricity from primary energy is taken into account. One may be tempted to link the 3 points

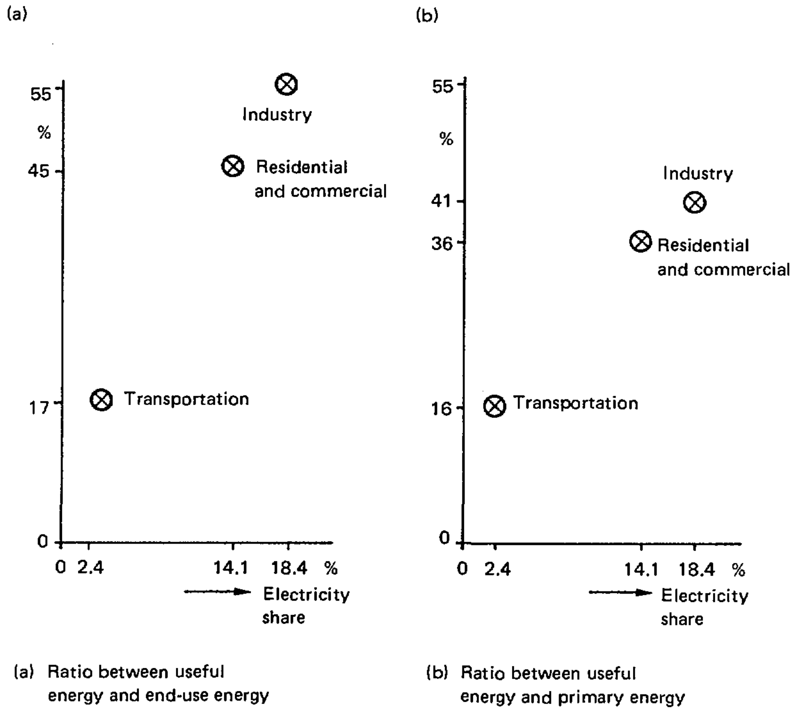

FIG.16.8. Energy utilization ratio and electricity share in end-use energy in the Federal Republic of Germany [16.14].

in both diagrams by a straight line and try to find a mathematical relation. This would definitely be wrong, since the figures are valid only as discrete, singular points for the conditions of the specific end sector. However, the positive conclusion of the effect of stronger electrification on end-use energy supply is once more convincingly demonstrated [16.14].

In the previous chapters of this volume it became evident that as far as petroleum and petroleum products are concerned:

- the available production would not notably increase, either in the medium or in the long term
- demand for them will certainly continue to grow. First, due to the increasing demand of developing countries, secondly because of the specific areas – see Fig. 16.5 – where substitution is not possible or only in the long term, i.e. transportation (automobiles, aircraft, ships) and some chemical needs and feedstock.

Under these circumstances, in order to maintain a stable balance on the petroleum world market, action is needed in the following basic directions:

- intensifying exploration efforts to extend or at least to maintain petroleum world production at its maximal reasonable level
- reducing to a technical and economic reasonable minimum the consumption of petroleum products in the non-specific consumption areas by substantial conservation measures, i.e. by direct saving and substitution
- starting a gradually increasing production of liquid (and gaseous) synfuels, to complement the natural petroleum products in their specific end-use areas.

Possible petroleum substitution in the primary energy stage of the energy system will not be insisted upon here, i.e. for production of intermediate energy forms, since these aspects have been exhaustively dealt with. However, it is worth recalling that electricity is largely adaptable.

As far as the utilization phase is concerned, petroleum substitution is possible by coal, natural gas, renewable energy resources and electricity. Since natural gas itself appears in the long run to have limited reserves, the principal energy forms on the longer-term horizon remain coal, renewable energy forms and electricity; however, except for heat from direct solar energy and biomass, the renewable forms would enter action via electricity. Coal in the final consumption stage would have to compete with electricity, the decision being between direct supply or via coal-generated electricity.

Once established that electricity can extensively substitute for petroleum products in the competitive consumption area, the problem arises, how could electricity compete with synfuels, which would be perfectly suitable for direct substitution without any change of installations and which would derive from coal, as electricity partly would also.

Here appears a core problem of long-term energy development optimization which, commented on in chapter 8, requires however a deeper analysis, because of its considerable dimension and the long lead time involved. The main aspects to be considered are the following:

- both electricity and synfuels are necessary to cover the energy demand for their specific areas of utilization – see Fig. 16.5.
- for the competitive area of uses synfuels would not require changes in the consuming installations and equipment. Electrification would impose basic changes in the utilization areas but would also offer additional advantages, which are discussed later.
- synfuels can be produced from coal and biomass as can electricity; electricity has, however, a substantially larger primary energy base since, in addition, it could be generated from all other renewable resources and also from nuclear energy.

- both electricity and synfuels, as carriers of intermediate energy forms, require considerable initial investments and a costly transport and distribution infrastructure.
- synfuels, relying exclusively on coal – with the exception of a slowly developing biomass contribution – as input energy resource, might be temporarily hampered by the slower development potential of coal mining, coal being needed for other purposes, too. Increasing demand for coal as feedstock for chemical and other industries might also be a limiting factor with increasing weight in the future.
- the extension of electrical energy can call upon established technologies, while synfuels are still in a research and development phase.

Of course, only a thorough and realistic comparison of the alternative solutions can offer the base for a decision. Such a decision could come down not exclusively in favour of one or the other alternative, but possibly propose an optimal mix, since both energy carriers are needed for certain specific uses. In addition, as referred to in chapter 8, in the very long term, new aspects may intervene, if and when hydrogen can be conveniently produced from water and if nuclear fusion energy were commercially available.

However, substitution of petroleum products by electricity will encounter a series of difficulties in the areas of utilization because it necessitates basic changes to existing equipment, and in the case of industrial consumers a profound change in the manufacturing process.

The difficulties are more of psychological character than real. For example, conventionally, the utilization of electricity for heating purposes is considered undesirable, since electrical heat originates from thermal power plants of rather low efficiencies. This judgement ignores that if appropriate heating processes are selected, i.e. those best adapted to the purpose, electricity could offer better, sometimes considerably better, efficiency than direct fuel firing [16.15].

Such better efficiencies could more than compensate for the primary energy losses in electricity production – if the power station is of the normal thermal steam-condensing type and burns fossil fuels. The combustion of the fuel takes place at higher efficiencies in the power plant and secondly the heat in an industrial process, for example, is provided electrically much closer to the real need and with better regulation. The same applies for electrical space heating of adequately insulated houses with individual regulation in each room [16.16].

The psychological barrier to be overcome is – as repeatedly insisted on previously – to understand that a joule of heat is not equal to a joule of electricity. They are therefore not comparable. Usually, electricity replaces 2–3 joule heat, sometimes more. It should be remembered that the UNIPEDE and WEC equivalence of 1 joule of electricity for 2.6 joule of fuel has been recommended under the currently prevailing technical conditions.

Of course, where electricity originates from hydro power, nuclear or co-generation plants, the above ratio does not apply.

In the light of the above general considerations, the development in two countries – France and the USA – which have paid very much attention to the subject may be summarized as follows:

France was probably the country with the quickest practical reaction to the first petroleum price increase in 1973. By savings and substitution of petroleum by nuclear energy and coal, the share of petroleum in its overall energy balance declined from 66% in 1973 to 53% in 1980 and is forecast to decrease further to 44% in 1985 and as low as 31% in the year 2000 – see Table 16.III. These results are the effect of an energy policy that aims to reduce – both for economic and strategic reasons – the country's share of imported petroleum in its global energy balance and further direct French energy development towards an 'electrification of energy' [16.10]. With France having few coal reserves, the French energy development will clearly be based on nuclear energy. It is no wonder that under these circumstances France is leading by far in nuclear development including breeder reactors, because of their economy in uranium utilization.

In the United States of America, particularly rich in coal and oil shale resources and a tremendous consumer of petroleum products, the synfuels alternative could have evolved differently. However, it appears – since no firm policy or strategy exists – that without neglecting the promotion of synfuels, in the distant future synthetic together with natural liquid hydrocarbons will be used primarily for transport fuels and feedstocks, i.e. their specific areas of use. On the other hand, having become a more efficient and electrified society, the country would increasingly rely on domestic supplies of coal and uranium [16.9]. The fraction of total primary energy converted to electricity in the USA has risen steadily for the last 30 years, up to 33% in 1980. It could possibly reach 42% in the year 2000.

Chapter 17

ENERGY PLANNING

As part of the introduction to chapter 1, which recommends using the energy system as the framework for any energy-related investigation or management issue, energy planning was emphasized as the natural optimal measure for energy development. Subsequently, the necessity of an energy master plan (EMP) was agreed upon, its goals and content briefly outlined and the major steps in its elaboration highlighted.

The objective of this chapter is to provide a more detailed description of the planning process, focus on its main issues and phases and elaborate critically on the methodology and the modern planning techniques practically involved.

Energy planning in developing countries will have priority, since this is of particular interest.

As in other chapters, whenever feasible the presentation will rely for the planning aspects on IAEA published material, both for the sake of consistency and to enable easy access for further reading[15].

17.1. Introduction to overall energy planning

A systematic approach to energy planning includes a number of phases, such as:

(1) Definition of the goals and objectives of the EMP
(2) Selection of the approach to be taken
(3) Identification of the information needed for the planning process
(4) Selection of the analysis process
(5) Analysis
(6) Presentation of the results to decision-makers
(7) Preparation of the EMP.

All of these phases constitute part of a dynamic planning process and may be carried out several times before proceeding to the next phase. Each may be revised as information from succeeding phases becomes available.

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[15] *In this case it is chapter 2 of the IAEA guidebook, authored by Dr. R. Cirillo from* the Argonne National Laboratory, USA, who repeatedly lectured on the subject in the IAEA yearly course for which this book serves as guideline and reference base [17.1].

17.1.1. Goals and objectives of the EMP

The EMP can have several different goals and objectives depending on the needs and situation of the country. There are three basic goals that can be identified:

- To prepare the capital investment programme that will lead to the construction of energy facilities
- To develop appropriate government policies relating to the control of the energy system, and
- To provide signals to energy industries and equipment suppliers as to the directions that will be taken in the future.

The preparation of the capital investment programme is probably the most significant goal of the EMP, as it represents the most substantial commitment of financial and human resources. This goal is most critical in countries where the government owns and operates large segments of the energy industry. In these cases, the energy plan becomes the investment programme for the government.

The second goal of the EMP is to develop government policy regarding the energy sector. This is a goal for countries both with and without private ownership of energy industries. The policies contained in the energy plan include laws, regulations, tax incentives, subsidies, and other government actions affecting the energy system. Energy pricing is one of the most significant policies that is included in the EMP. Under ideal conditions, the set of policies is consistent and reflects a definitive policy direction.

The third goal of the EMP is to give information, or signals, to the energy industries and to equipment suppliers as to future directions. This is an important aspect of the plan as energy projects often require long lead times and advance preparation.

The objectives of the EMP are not as easy to categorize as the basic goals. The following are offered as examples:

- To develop the least-cost energy supply system
- To develop a diversified energy supply system with less dependence on imported oil
- To maximize the use of indigenous energy supplies
- To maximize the use of renewable resources
- To provide energy for optimum industrial development
- To reduce non-commercial fuel use and resulting deforestation.

17.1.2. Approaches to energy planning

The second phase of the energy planning process is to determine the approach to be taken to meet the goals and objectives of the EMP. The choice of approach

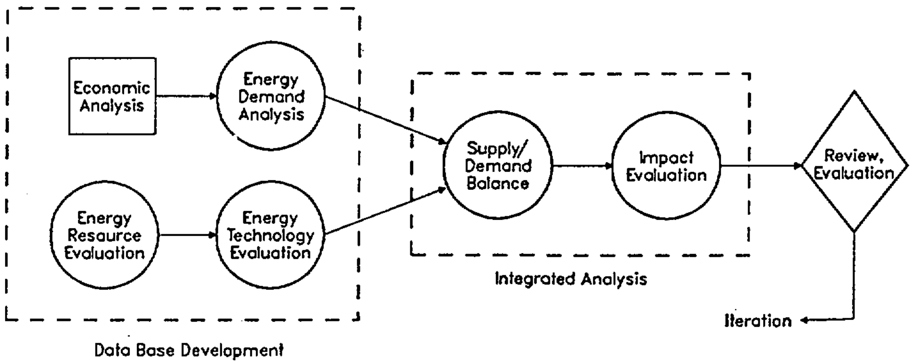


FIG.17.1. Typical sequence of tasks in energy planning [*17.1*].

must deal with four basic decisions: the scope of the plan, the scale of the plan, the time horizon, and the level of detail.

The scope of the EMP is the entire energy system; the entire electric system is the scope of a national electricity master plan. The scale of the EMP determines the spatial disaggregation necessary; the time horizons have been discussed in chapter 1. The level of detail in an EMP is most closely related to the time requirements for decisions.

17.1.3. Information needed from the EMP

One of the purposes of an EMP is to provide information to decision-makers. On this basis there are two distinct types of information involved in energy planning: detailed technical information and decision-making information.

Detailed technical information is required by energy planners (including engineers, geologists, economists, etc.) to conduct analyses and to evaluate the technical and economic viability of alternatives.

A distinctly different set of information is required by senior decision-makers, who are generally not as technically oriented as the energy planners. They may ask the following questions:

- What are the energy requirements for the country's economic development?
- What energy suppliers are available to meet the demand?
- What resources (money, labour, materials, etc.) are required to build and operate the required energy system?
- What alternatives are available and what are the impacts of the alternatives?

17.1.4. The analysis process

The fourth and fifth phases of energy planning, the choice of the analysis process and the conduct of the analysis, are heavily dependent on the situation and needs of individual countries. Attempts have been made to outline a specific analytical procedure that would apply to all developing countries, but they failed because of the wide diversity of these countries.

However, despite the range of possible analytical approaches, energy planning studies all have some common elements which can be viewed as tasks that must be undertaken to complete an energy analysis. Figure 17.1 gives a typical sequence of the tasks that should be included in such an energy analysis.

17.1.5. Presentation of results

One of the most neglected, and perhaps one of the most important, aspects of the energy planning process is the presentation of the results of the analysis to decision-makers. Whatever the form, there are several aspects of the decision-making process that planners must consider when presenting the results of their analyses. First, the decision-maker is generally not as technically trained or experienced as the analyst. The presentation of information that is beyond the technical comprehension of the decision-maker is of little value in assisting in the choice of a course of action.

Second, a decision on the energy system is based on a multitude of factors, not all of which the analyst can include in the energy planning study. Political considerations, public pressure, international relations and other items often influence an energy decision as much as, if not more than, any analytical results. The energy planner must recognize this and be prepared to accept the fact that the recommendations that logically result from a study may not always be the ones to be chosen. In these circumstances, the astute energy planner should be in a position to provide decision-makers with an evaluation of what the effects of an alternative choice will be. Should a course of action be chosen on the basis of some non-analytical factor, the good energy planner can tell the decision-maker some of the impacts (e.g., costs, labour requirements, energy availability, etc.) of that choice.

Finally, because of the complex nature of energy issues and the divergent opinions on analytical methods and data, energy planners are often accused of developing any result that they desire. Therefore, planners must take pains to conduct their analyses without biasing the results to any particular point of view (e.g. preferring one particular technology over another). It is the role of the decision-maker, not the analyst, to include non-technical factors in the decision process. The analyst must provide the best technical information possible to assist in this process.

17.1.6. Preparation of the EMP

With all of the steps of the energy planning process completed, reviewed, iterated, and re-evaluated, the culmination of the activity is the preparation of the EMP. Recall that the plan is a statement of the choices made and is itself subject to periodic review and revision.

No one format can serve as the basis for all EMPs. The basic elements that the EMP should contain are:

- A statement of the goals and objectives of the plan
- A statement of the current energy situation in the country
- A discussion of possible growth alternatives for the country and the energy demand implications of these alternatives
- A review of possible courses of action that were considered and analysed as part of the energy planning process
- A statement of the choices made in terms of projects to be built, policies to be implemented, and additional studies to be undertaken
- A statement of the steps to be taken to implement the plan.

17.2. Energy planning procedures

Figure 1.1 showed a typical structure for an energy planning analysis. There are alternative approaches which will be further presented.

17.2.1. Economic analysis

Figure 17.1 showed that economic analysis is the first step in the energy analysis; it is the basis for comprehensive energy planning. It is the pattern of economic development that determines the need for energy. Likewise, the price and availability of energy can shape economic growth. However, the nature of economic growth in developing countries is the subject of countless theoretical arguments and divergent opinions. There are, nevertheless, a number of economic analysis issues that must be considered by energy planners.

(1) Energy and GDP. The relationship between energy consumption and the gross national or domestic product (GNP-GDP) has been mentioned in a number of contexts. However, the GDP variable appears not to be the most appropriate indicator for measuring a process of economic development, particularly when that process is conceived in human and comprehensive terms and not just from a purely materialistic standpoint.

It also appears that:

- GDP overlooks any socio-economic activity that is not reflected on the monetary market, although in developing countries such activity is fundamental

– GDP increases with any type of economic activity, regardless of whether that activity enhances or diminishes the populations's well-being
– the average value of this variable reveals nothing about the social and geographical distribution of the income which is its counterpart.

For the above reasons, GDP should be used in concrete energy planning only in the most extreme circumstances where no other measure is available.

(2) Energy and the macroeconomy. There are numerous methods available to analyse the growth of the macroeconomy for use in energy planning. Among the most frequently used techniques are trend extrapolation, input/output analysis and econometric analysis. All of these procedures are designed to develop projections of how the country's economy will grow in the future. These projections are expressed in terms of value added or output of each sector of the economy. It is important to recognize that the projections are stated either in financial units (e.g. dollars of value added) or in physical quantities (e.g. tonnes of steel produced). They are not expressed in energy units. The conversion of these economic projections to energy demand projections is a separate step in the analytical process.

Independent of which economic analysis technique is used, the most frequently used procedure is to develop a set of economic growth scenarios reflecting different possible paths that the economy may take in future. This is one method of dealing with the uncertainty inherent in forecasting the economic future, particularly over the long periods (20–30 years) used in energy planning. The scenarios chosen should represent a reasonable range of probable developments and should establish the bounds within which the economy can be expected to grow. In this way the planner can determine the range of possible requirements that may be made on the energy system.

Because of the strong interrelationship between energy and overall economic growth, this type of economic projection analysis must make some assumptions about the price and availability of energy. This presents a dilemma to planners in that the energy planner cannot provide a good estimate of energy costs until he knows the size of the demand that economic growth will place on the energy system. Likewise, the economic planner cannot provide a good estimate of growth without knowledge of energy costs. To break into this interdependent loop for analysis purposes, the usual procedure is to start with a rough assumption of energy costs. This is used in an initial economic analysis to project the pattern and extent of growth. These economic projects are then used to analyse the demands placed on the energy system and to reestimate the cost of energy. If necessary, the economic projections are then revised and the energy analysis redone with the new projections. This type of iterative procedure is used throughout the energy planning process.

(3) Sectoral economic analysis. In addition to macroeconomic analysis, other studies are done to evaluate growth potential in certain portions of a country's activities. These sectoral analyses are an important component of the economic analyses required for energy planning. The sectors which are usually studied include industry, agriculture, transportation, residential, commercial, and rural communities. All are important energy users and should be included in energy studies.

Analyses done of the growth potential in each of these sectors is often carried out by separate planning groups located in separate government organizations. These analyses often focus only on the unique aspects of each sector and do not represent an integrated analysis of development. In theory, all of these sectoral analyses should use common assumptions and should be co-ordinated with the macroeconomic analysis previously described. In practice, achieving this level of co-ordination and consistency is very difficult. The energy planner may be presented with a macroeconomic analysis and a set of sectoral analyses that are inconsistent and based on different fundamental assumptions. Often the energy planning process provides the impetus to bring these various studies together and to arrive at a consensus as to the assumptions that will be used for analysis of future growth.

Industrial sector studies are especially important to energy planners, as industry is usually the biggest energy and electricity consumer. However, industrial sector studies are rarely done on the long-term (20–30 years) planning horizon used for energy planning. The result is that the macroeconomic analysis is most frequently used to provide long-term insight into industrial growth, while the industrial studies are used to identify changes in industrial processes and technologies.

The agriculture sector generally is not a large energy consumer since much of its energy requirement (i.e. fertilizer, food processing, etc.) is treated as part of the industrial sector. Nevertheless, in developing countries agricultural trends toward mechanization and needs for irrigation water pumping represent a significant demand on the energy system. For this reason, sectoral studies in agriculture are a significant part of the energy-planning process.

The transportation sector is usually one of the most well developed with respect to planning because transportation infrastructure development requires long lead times and extensive planning. Since transportation energy requirements are a function of passenger and freight activity, the macroeconomic analysis described previously provides only limited insight into possible energy requirements of the transportation system. In general, a transportation analysis uses a macroeconomic analysis as its primary input (much in the same way as an energy analysis does) and then proceeds to estimate passenger and freight travel demand. An energy analysis of the transportation system needs to use this same approach.

The residential and commercial sectors use energy in similar ways but the demands involve different parameters. Commercial activity is closely related to general business activity and so can be analysed using macro-economic approaches. Residential growth depends on population growth, household formation, residential construction, and personal income. These parameters are usually analysed using other procedures than used in macro-economic studies and so must be treated separately in an energy analysis.

Rural communities are an important component of energy studies since they represent a large component of the population in developing countries and they are a significant consumer of energy. Rural communities are a microcosm of an entire national economy in that they represent all sectors of economic activity (industrial, agricultural, residential, commercial, transportation) in one small geographical area. A complicating factor in the analysis of rural communities is that much of the energy is provided by non-commercial sources (firewood, agricultural waste, animal dung, etc.) and is difficult to analyse using traditional market economy techniques. Data on rural community energy consumption patterns are virtually non-existent in many developing countries. Nevertheless, these communities represent a significant potential (suppressed) demand for commercially supplied energy and must be included in an energy analysis.

17.2.2. Developing energy demand projections

Projecting future energy demand is one of the basic issues in the elaboration of an EMP. For better understanding of its features, a brief historical review of the past procedures of demand forecasting might be helpful.

17.2.2.1. Past procedures

Virtually every demand forecast study in the past began by emphasizing the close relationship between total consumption of primary energy resources – almost always referred exclusively to commercial energy resources – and economic development represented by GDP [17.3].

Since both economic and energy variables developed significantly, it was agreed that there was a close and rigid relationship between them which was represented by the classic exponential model of constant product elasticity. Gradually, it was recognized that such elasticity was not constant and during the 1950s and 1960s an attempt was made to explain variations in elasticity by linking them to different stages in the developing process. Later analysis showed that this assumption was only partly correct.

In a parallel approach in France [17.4] time was added in an exponential relation as an explanatory variable and instead of the absolute values of energy and GDP, the increasing values of both variables were considered. The new approach helped to interpret the relationship between energy demand and economic development more accurately since, through the time variable, it tacitly acknowledged the influence of factors other than the level of economic activity.

A further advance was made when a model was developed in Argentina at the beginning of the 1970s [17.3] which related variations in the product elasticity of energy consumption directly to the GDP growth rate and indirectly to other aspects of the economic system under analysis, such as: variations in the production structure, the level of technological development and variations in the energy supply structure.

In spite of the progress made, Suarez [17.3] rightly criticizes these approaches since they are too global and establish relationships between variables which were not really representative of the phenomena of interest – energy demand and economic development – because energy as normally measured far from represents the real energy requirements of a given socio-economic system since:

- by excluding non-commercial energy sources, it overlooks an important sector of the energy system, particularly in developing countries
- by referring to gross primary energy products rather than useful energy actually obtained, it overlooks the influence which production, processing and consumption systems and their respective outputs have on consumption
- by considering only the demand expressed on the monetary market, it overlooks the requirements of sectors which are not part of that market.

Furthermore, the aggregate nature of variables only makes it possible to determine total energy demand and does not provide much information about the energy's final use.

Last but not least, past approaches did not take into account the impact of prices on demand. While this approach was more or less acceptable in times of price stability, it has clearly ceased to be valid in the changing situations which have characterized the years since the mid-1970s.

However, notwithstanding this criticism, the past stage of planning, of which the above demand forecast methods constituted the reference base, presented in the developing countries where it existed the advantage of forcing the planners to obtain and process far more complete and systematic economic and energy data and to build up gradually a core of specialists in energy planning techniques.

17.2.2.2. New approaches

In the light of the above, a new approach has been proposed for energy planning in developing countries and particularly for forecasting energy demand. This approach or methodology takes particular account of:

- the socio-economic characteristics of developing countries (especially the rural/urban dichotomy)
- the availability of socio-economic and energy data in those countries
- all the energy sources used by the system, be they commercial or non-commercial
- the contribution of new and renewable energy resources towards meeting energy needs
- countries' specific ecological and climatic conditions
- the relationship between socio-cultural factors and problems of energy supply and demand
- energy needs, and not just demand, expressed in terms of useful energy rather than net or gross energy
- effects of demand management.

From another standpoint, it could be underlined that this approach determines total energy demand not by global methods such as those criticized before but by an analysis broken down by:

- geographical areas, with a distinction being made between rural and urban areas
- energy consuming sectors or activities; households, rural production, industry, transportation, services
- population income levels, with at least three different income levels being identified (low, middle, and high)
- types of energy use: cooking, water-heating, heating, food conservation, process heat, locomotion, etc.

In other words, the basic energy requirements for each use at each income level, in each sector and in each area are determined and then added together to determine total sectoral and global requirements.

This type of methodology calls for more information on the energy system under consideration, particularly with regard to:

- biogeographical and climatic characteristics of that system
- the nature and size of the present and future population
- total income and distribution of population by income level
- structure of the goods and services sector
- physical indicators of past and future trends in each sector (agricultural, mining and industrial production; levels of service activity, etc.)
- surveys of the population's basic energy needs
- nature of the technology and appliances available for producing, processing, transporting and consuming energy.

17.2.2.3. Practical procedure

There is a practical, partly improved procedure, which forecasts directly end-use energy demand by relating the current fuel and electricity consumption (end-use energy as billed for by a supplier) to the economic activity and applying the economic growth rates to the energy use. Since this is a simple procedure and requires only the minimum amount of data it is frequently used. While acceptable for short-term planning, using this procedure is not the recommended way to proceed for long-term analysis as it does not allow the planner to account for developments such as fuel-switching, technology improvements, and market influences on energy demand.

Long-term and in general more improved demand forecasts should be based, as underlined, on the demand for useful energy. In chapter 2, where features and issues of useful demand were discussed, a list of typical useful energy demand categories for each of the end consuming sectors is included – Table 2.II. The process of making practical energy demand projections is illustrated in Fig.17.2.

The first step is to assemble data on current energy consumption (i.e. fuel and electricity), unless this has already been done in a previous diagnosis study on the existing energy status – see chapter 1. This information should be disaggregated by each of the demand sectors (e.g. industry, agriculture, transport, etc.) and may be disaggregated by subsector if desired. This is fuel use data and can be measured using customer bills, fuel distributor records, etc. An important

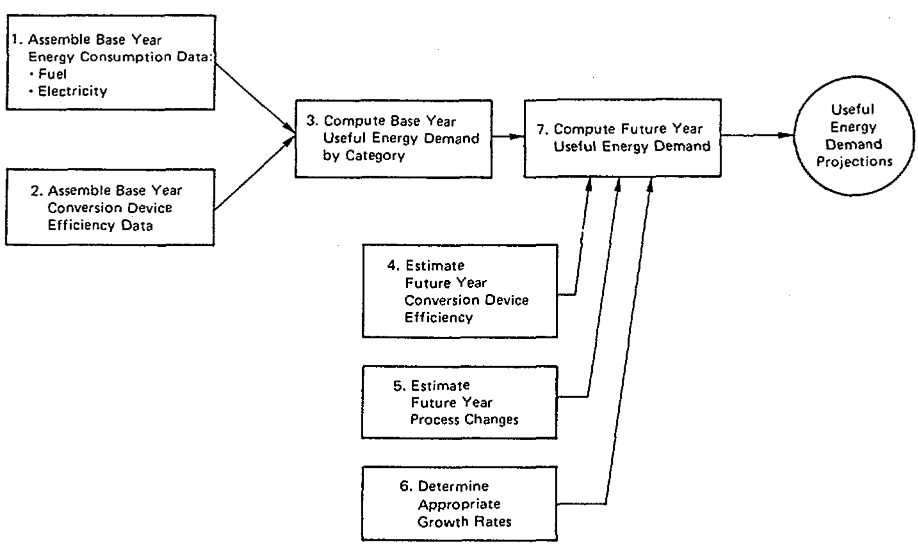


FIG.17.2. Typical energy demand forecasting procedure [17.2].

aspect of this data assembly is determining the quantities of this energy that are used for different purposes. For example, in considering industrial use of fuel oil, the information required includes the total quantity used and the portions used by boilers (indirect heat), furnaces (direct heat), and other systems. This level of detail often can be obtained only by surveys and on-site visits as it is rarely available as part of routine record-keeping.

The second step of the process is to assemble data on base year conversion device efficiencies. Information generally used in planning studies has been occasionally given in previous chapters. A more accurate way of determining this is to conduct spot surveys of actual equipment in place in the country. This is a fairly effort-intensive activity and involves making measurements of equipment performance. A carefully designed sampling programme, including the recording of surrogate data, is required to avoid a great deal of measuring.

The third step of the demand projection process is to estimate the base year energy demand. The general equation is:

$$\text{Base year useful energy demand} = \frac{\text{Base year fuel consumption}}{\text{Base year conversion fuel efficiency}}$$

The base year useful energy demand should be computed in as disaggregated a manner as the data permit.

The fourth step of the process is to estimate the improvements in conversion device efficiency over the planning period. For example, it may be estimated that current oil-fired boilers are operating at 70% efficiency and that new boilers with better heat recovery systems could function at 80% efficiency. The sources of information about these improvements are the energy conservation technology studies conducted in the USA, Europe, Japan and several developing countries. Equipment manufacturers are another source of information.

The fifth step is to determine where process changes in future years will result in a different useful energy demand per unit of output. An example would be the shift from the wet process to the dry process in cement manufacture. Another example is mode shifts in the transportation sector. These changes will alter the useful energy requirements above and beyond any changes resulting from equipment efficiency improvements.

The sixth step is to determine which growth rates from the macroeconomic and sectoral economic analyses are appropriate to each demand category. For example, growth in direct heat requirements in the cement industry may be tied to the growth in value added in this industry as projected by the macroeconomic analysis. Growth in residential space heating demand may be tied to household formation or to housing construction. All of the basic economic parameters for this analysis should be derived from the macroeconomic and sectoral studies.

The final step in the demand analysis is to apply the information to make a projection. The basic equation is:

$$\text{Base year useful energy demand} \times \text{Change resulting from process changes} \times \text{Economic growth parameter} = \text{Future useful energy demand}$$

The projections of useful energy demand from the above equation are the basis for the subsequent analysis of supply and demand balance. Separate projections should be prepared for each of the economic scenarios studied in the macroeconomic analyses.

When the appropriate mix of fuels used to satisfy the useful energy demand is determined, it is converted back to fuel and electricity consumption requirements using the future year efficiency:

$$\text{Future energy consumption} = \frac{\text{Future useful energy demand}}{\text{Future year conversion device efficiency}}$$

Tying the useful energy demand forecasts to economic activity parameters is a more reasonable way to project energy requirements than just making fuel use projections. As repeatedly underlined, useful energy is more closely correlated to economic activity than is fuel use because the parameters of conversion device efficiency and fuel choice are accounted for separately. This method is the one of choice whenever data and resources permit.

17.2.3. Resource evaluation

Referring back to Fig. 17.1 shows that there is another set of activities in the database development that is distinct from the demand analysis. The first activity in this set is the resource evaluation and it focuses on the determination of the energy resources available to a country.

Chapters 3 and 4 presented all the basic information regarding resources, reserves and production potential of non-renewable and renewable primary energy resources worldwide. This constitutes an excellent general background of information, which a national energy planner must be well aware of. However, for a national EMP, specific information on the country's resources is needed. This could be either available from an energy diagnosis study or has to be compiled.

17.2.3.1. Planning information on national primary energy resources

The basic set of information on domestic primary energy resources needed includes the following:

- Total reserves – the total quantity of an energy supply that is available for extraction and use.
- Rate of additions to reserves – the rate at which an exploration programme can be expected to increase the size of the reserves; this is a speculative estimate but is important for long-range planning, especially where extensive exploration activities are under way.
- Possible production rates – the maximum rates at which a particular reserve can be exploited; this accounts for physical and practical limitations to how quickly the energy material can be extracted.
- Extraction costs – the cost of extracting a unit of energy material; these costs need to be separated into their various components (labour, material, taxes, etc.).
- Constraints on production – any physical (e.g. environmental) or practical (e.g. public policy) constraints on the exploitation of the reserves.

One method of assembling this information into an analytically usable form is to develop a long-run resource supply curve. The curve relates the production cost (per unit of output) of a single resource (e.g. crude oil) to the total amount of the resource that is known to be available for production in the future.

The resource supply curves are used in energy planning studies to determine the economic competitiveness of each depletable resource relative to other depletable resources, imported fuels, and renewable resources. The analysis determines how much of the resource it would be economically competitive to produce in each period, given the resource supply curves that characterize the production cost of the resource.

The production cost for a depletable resource, sometimes termed the lifting cost, generally does not reflect the true value or opportunity cost of the resource to the owner and so is not by itself useful in an energy planning study. The opportunity cost of producing a unit of the resource in the current year includes the production cost and a component to account for the fact that production of the resource now eliminates the possibility of producing the resource at some later time when it may have a greater value. This component, termed the 'economic rent', is equal to the difference between the price and the production cost of a unit of the resource. Whether the resource is privately owned or is under the control of the government it is necessary to include the intertemporal economic rent in the price of the resource as part of the analysis.

17.2.3.2. International energy supplies

In addition to information about domestic energy supplies, the energy planner must have some information about possibilities for imported energy supplies. Imports can be in the form of primary, unprocessed energy (e.g. crude oil, coal, etc.) or in the form of processed fuel that is ready to use (e.g. petroleum products, nuclear fuel rods, etc.). Table 2.3 of Ref. [17.2] shows some of the ways in which projections of import prices of fuels can be developed.

Crude oil is the most significant imported energy form and the prices of other energy supplies are often related to it. Given the uncertainty in the crude oil markets, the most frequently used approach is to develop a set of scenarios of the future oil price. The energy planning analysis is then carried out for each scenario to determine the sensitivity of the results to changes in the import price. Growth rates in crude oil prices of 0–5% per year (in constant currency) have been used for energy planning studies. The choice is based on the best estimate of the analyst.

Petroleum product import prices are usually tied to crude oil prices. The lighter products (such as gasoline) are often taken to be 30–50% higher than crude oil prices while the residual products may be priced at or below crude oil prices.

The growth in coal prices is highly speculative and will depend on whether steam coal becomes a major international energy commodity. One method of developing an upper limit to steam coal prices is to assume that potential purchasers will not pay any more to generate electricity using coal than to generate electricity using residual fuel oil. This ties the coal price to the residual fuel oil price. Metallurgical coal must be priced separately from steam coal because of its specialized uses. It is significantly more costly.

Natural gas, either in the form of gas or LNG, is generally more expensive than oil because it is a premium fuel. Nevertheless, its price is often related to crude oil prices. There have been some attempts to tie the gas price to the energy content equivalent of oil.

Nuclear fuel, usually traded in the form of reactor fuel rods, is not as sensitive to oil prices as other energy forms and so is priced independently. The major factor determining the price is the amount of enrichment of the nuclear material. Growth in nuclear fuel prices has generally been considered to be slower than crude oil prices.

Whatever method is chosen to project international energy prices, the safest procedure for the energy analyst to use is to construct several alternative price scenarios and try each of them. This will help determine if the resulting energy supply system is very sensitive or insensitive to the import fuel price.

17.2.4. Energy supply technologies

There is one final piece needed to complete the database development as shown in Fig. 17.1; that is the energy technology evaluation. There are a large number of energy technologies available, each with its own characteristics and applications. It is necessary to assemble information about each of the technologies that is considered a potential candidate for some role in the energy supply

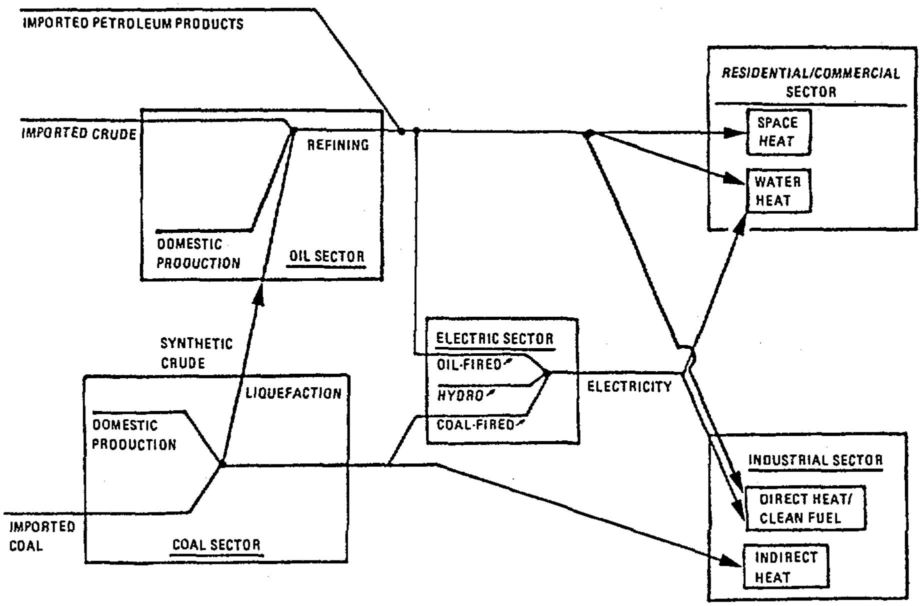


FIG.17.3. Simplified energy supply/demand structure [17.2].

system. This information must be assembled in a consistent fashion so as to permit later a comparison of the alternatives to be made.

For convenience, the technology evaluation can be divided into three basic categories: fossil fuel technologies, renewable resource technologies, and electric system technologies. This distinction is based on the usual separation of engineering expertise. The information required relates to engineering performance data, economic data and acillary data accounting for other parameters besides engineering and cost.

Engineering performance data is the information that describes the type and quantity of energy that can be delivered by the supply technology and the efficiency with which it delivers this energy. This information is used to determine the size and extent of the energy supply system needed to meet demand. Estimates of the performance of technologies not yet in place in the country must be included in order to evaluate their potential for application.

The economic data is used to estimate the costs of the various technologies. Cost is one of the most significant factors in the choice of energy supply systems. There are numerous ways that cost analyses are done, the most frequently used being a discounted present value analysis.

Ancillary data are included to account for other parameters of an energy supply technology, besides engineering performance and cost, that may be significant in arriving at a decision on whether or not to implement the technology. Such are for example: air and water pollution, noise, labour requirements for construction and operation, barriers to implementation (social acceptance, policy issues), etc.

Chapters 3 to 9 include comprehensive descriptions of the status and perspective of fossil fuel, nuclear, renewable energy resources technologies and electricity generation and supply, whilst chapters 10 and 11 cover economic data, including cost and cost-calculating methodologies, in order to provide the energy planner with the background knowledge necessary to approach his concrete tasks in these areas. Therefore, and to avoid repetition, no other comments are made on these subjects.

17.2.5. Integrated energy analysis

Figure 17.1 showed that after the completion of database development, integrated analysis is performed to structure the data in a consistent format for the evaluation of alternatives. The two major components of the integrated analysis are the supply/demand balance and the impact evaluation. Some of the integrated analysis steps can be carried out while the database development is still under way; others must have a completed database before they are initiated.

17.2.5.1. Developing a supply/demand network

The first step of the integrated analysis is to develop a supply/demand network that traces the flow of energy from primary resource through to its end-use. Figure 17.3 shows a typical network. It is a greatly simplified version for illustrative purposes only. The same type of structure can be displayed as an energy balance in tabular as well as graphic form. A number of standardized displays have been developed by the United Nations, the Latin American Organization for Energy Development (OLADE), and others. It is important to note that the details of the structure are constrained by a number of factors including:

- the types of questions that need to be answered in the energy planning process
- the availability of information and data, and
- the analytical tools that will be used in the process.

To develop the structure on the demand side, the energy-using sectors must be broken down into elements with common characteristics. These sectors must be further disaggregated into subsectors to provide more detail for planning. The subsectors must then be disaggregated by end-use device classifications to provide the most detailed perspective of the energy use pattern. On the supply side, all of the possible pathways from primary resources through to end-users must be identified. Potential new steps in a fuel cycle as well as existing steps must be identified. It should be noted that the process of creating these classifications for the purpose of national energy planning must necessarily vary from country to country to reflect different energy use patterns, energy consuming devices, and energy supply systems.

17.2.5.2. Developing a base year energy balance

With the network formulated, the next step is to develop a base year energy balance. This step involves filling in the network structure with the quantity of energy flowing along each of the links. Account must be taken of efficiencies and losses at each step in the network so that there is a mathematically consistent balance from one end to the other.

The base year balance is the foundation upon which the projections for future energy system growth will be built. It must, therefore, be developed in a fashion consistent with the structure used for economic growth projections. The data for the base year balance should be compiled as part of the database development tasks. One of the key efforts that will be required is to resolve the inconsistencies in data that inevitably appear. For example, data on petroleum derivatives production obtained from refinery operators will not match data on sales to consumers. Differences result from unaccounted-for losses, different accounting procedures, errors in data tabulation, and other factors. The effort required to resolve these differences should not be underestimated.

The selection of the base year to be used is an important consideration. The base year should be as close to the current year as possible to reflect more accurately the existing energy situation. A number of issues may preclude the choice of a very recent year, the most significant of which is the availability of data.

Another issue affecting the choice is the representativeness of the base year data. Although it is difficult, if not impossible, to find a year that is 'normal' in all aspects of a country's energy situation, an effort should be made to avoid the choice of a base year that is clearly anomalous in terms of energy conditions. Examples of such situations would be a year of unusually severe weather resulting in droughts (and decreased hydro-electric output), a year of economic turmoil with major disruptions to economic and energy-consuming activities, a year with major natural catastrophes (e.g. floods, earthquakes, etc.), and other such conditions.

Although the principal function of the base year energy balance is to display the flow of energy, another important piece of information that must be displayed on the base year network is the price of the various energy commodities. On each link of the network, prices must be displayed that reflect the cost of energy at that stage in the network. This will allow for an economic comparison of energy alternatives in the base year and will provide the starting point for the analysis of future possibilities. The specification of the prices should be broken down

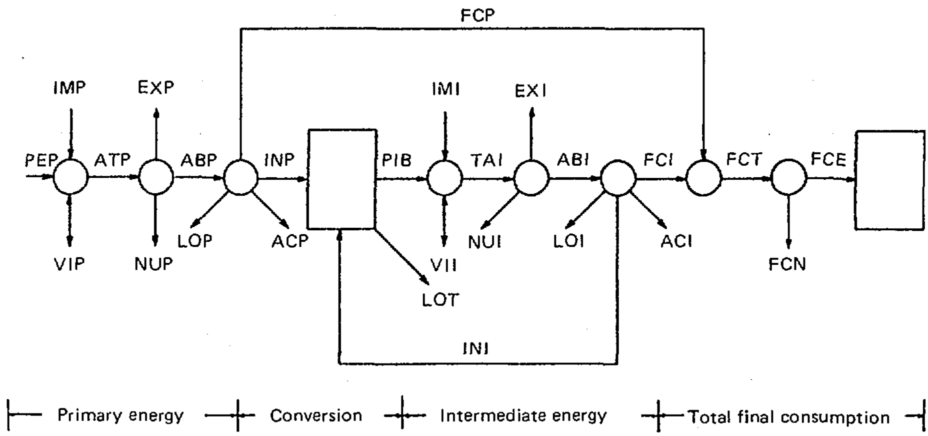


FIG.17.4. Basic structure of an energy balance [17.5].

into the various components: production cost, taxes, royalties, subsidies, etc. This will allow the planner to investigate the effects of alternative pricing policies.

17.2.5.3. Constructing projected energy balances

The development of energy balances for future years is one of the key portions of energy planning analyses. These projected balances will define the size and configuration of the energy supply system in the future. There are a wide variety of analytical approaches to constructing these balances and there are a number of methodologies and models available to assist the planner. The choice of the appropriate analytical approach and the selection of the proper model(s) to use should be the subject of an intensive review on the part of the planner.

The two fundamental approaches to projected future energy balances are the prospective approach and the normative approach. The prospective approach relies on the analysis of past trends and behaviour and on an estimate of how energy users and suppliers will respond to different conditions. This information is then used to predict what the demand for energy will be in the future and how it will be supplied. In contrast, the normative approach postulates a scenario about future conditions and attempts to design an energy supply system that will meet certain objectives (e.g. least cost, lowest foreign exchange requirements, etc.). The difference between the two methods is that the prospective approach attempts to predict developments. Since it relies on the extension of historical behaviour into the future it is most useful for short- and medium-term analyses.

TABLE 17.I. INTEGRATED ENERGY BALANCE OF PERU IN 10^3 toe [17.5]

				ENERGIA PRIMARIA					
				1	2	3	4	5	6
				Carbón mineral	Leña	Otros comb. veg. y animales	Petróleo crudo	Gas natural libre	Gas asociado
SECTOR ENERGETICO	Oferta	1.	Producción	43	3072	594	8791		1329
		2.	Importación	36					
		3.	Variación de inventarios				(116)		
		4.	OFERTA TOTAL	79	3072	594	8675		1329
		5.	Exportación				(1129)		
		6.	No aprovechada						(336)
		7.	OFERTA INTERNA BRUTA	79	3072	594	7546		993
	Centros de transformaci.	8.	TOTAL TRANSFORMACION	(32)	(30)	(48)	(7714)		(967)
		8.1.	Coquerías, altos hornos	(32)					
		8.2.	Carboneras		(30)				
		8.3.	Biomasa						
		8.4.	Refinerías				(7714)		
		8.5.	Plantas de gas						(967)
		8.6.	Centrales eléc. serv. público			(48)			
		8.7.	Centrales eléctricas autoprod.						
		9.	Consumo propio sector energét.						
		10.	Pérdidas (trans., dist., almac.)						
		11.	AJUSTES	(14)			168		(26)
CONSUMO FINAL		12.	CONSUMO FINAL TOTAL	34	2768	546			
		12.1.	Consumo final no energético			165			
		12.2.	Consumo final energético	34	2768	381			
		12.2.1.	Residencial y comercial		2385	251			
		12.2.2.	Público						
		12.2.3.	Transporte						
		12.2.4.	Agropecuario y agroindustria			130			
		12.2.5.	Pesquería						
		12.2.6.	Minero metalúrgico	14					
		12.2.7.	Industrial	20	383				
		12.2.8.	Consumo no identificado						

Observaciones: PRODUCCION DE ENERGIA SECUNDARIA BRUTA

BALANCE ENERGETICO CONSOLIDADO AÑO: 1983

ENERGIA SECUNDARIA

7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Hidroenergía	Geoenergía	Combustible fisionable	Total energía primaria	Coque	Carbón vegetal	Gas licuado	Gasolina y nafta	Keroseno y turbo comb.	Diesel y Gasoil	Combustibles pesados	Otros comb. energéticos	Productos no energéticos	Gas	Electricidad	Total energía secundaria	TOTAL
945			14774													14774
			36	26		17	42	37	172			17			311	347
			(116)				(16)	18	28	47		8			85	(81)
945			14694	26		17	26	55	200	47		25			396	15090
			(1129)				(72)		(43)	(1761)		(3)			(1879)	(3008)
			(336)													(336)
945			13229	26		17	(46)	55	157	(1714)		22			(1483)	11746
(945)			(9736)	(31)	121	112	1328	1163	1146	3139		57	1019	908	8970	(766)
			(32)	(31)									27		4	(28)
			(30)		121										121	(91)
			(7714)			111	1322	1163	1348	3442		51	81		7518	(196)
			(967)			1	6					6	954		967	
(945)			(993)						(202)	(303)			(43)	908	360	(633)
							5	(50)	(86)	(76)			(741)	(5)	(963)	(963)
														(23)	(23)	(23)
			(128)	24		(6)	(16)	(20)	24	(262)		(7)	(193)		(456)	(584)
			3348	19	121	124	1262	1146	1240	1086		73	85	880	6036	9384
			165									73			73	238
			3183	19	121	124	1262	1146	1240	1086			85	880	5963	9146
			2636		121	112		755					53	343	1384	4020
							48	76	194	62					380	380
							1183	281	646	149					2259	2259
			130				5	2	25	85				35	152	282
							1		34	54				24	113	113
			14	19		2	17	19	229	217				185	688	703
			403			10	8	13	113	519			32	293	987	1390
				21	121	112	1328	1163	1348	3442		222	1062	908	9127	2377

The normative approach takes the viewpoint that the future is so uncertain that the only way to deal with it is to determine a range of possible scenarios that are likely to occur and then to evaluate what type of energy supply system might be necessary to meet the needs. This approach has found widespread use in medium- and long-range analyses where historical trends are not as influential in determining future patterns.

17.2.5.3.1. Energy balance set-up methodology

In chapter 1 the basic concept and utility of energy balances were discussed and the value of exergy balances and the controversial issues of units and equivalence factors for energy balances addressed.

Notwithstanding all these aspects, the energy planner has in practice to proceed with his planning. To complement the basic presentation of the simplified supply/demand structure of the energy flows of an energy system in Fig.17.3, Fig.17.4 displays the practical set-up of an energy balance based on an OLADE methodology developed in Latin America while Table 17.I presents the energy balance of Peru in 1983, elaborated mainly from an adapted United Nations procedure.

The direction of energy flows is indicated by arrows; the nodes constitute points of balance for entering and outgoing energy flows, while the blocks represent conversion centres and consuming sectors.

In order to maintain the overview, nodes and blocks are marked in Fig.17.4 by initials only. Their denomination and basic relationship are as follows:

Primary Energy Stage: $\mathrm{ATP} = \mathrm{PEP} + \mathrm{IMP} \pm \mathrm{VIP}$

$\mathrm{ABP} = \mathrm{ATP} - \mathrm{EXP} - \mathrm{NUP}$

where:
- ATP = total available primary energy
- PEP = production of primary energy
- IMP = imported primary energy
- VIP = variations of inventories of primary energy
- ABP = available gross primary energy
- NUP = not-used primary energy
- EXP = exported primary energy

In addition, the checking relation: $\mathrm{ABP} = \mathrm{INP} + \mathrm{FCP} + \mathrm{ACP} + \mathrm{LOP}$

where:
- INP = input of primary energy (for conversion purposes)
- FCP = final direct consumption of primary energy
- ACP = auxiliary consumption of primary energy
- LOP = losses of primary energy

Conversion Stage: PIB = INP + INI − LOT

where: PIB = gross production of intermediate energy
INP = primary energy input
INI = intermediate energy input
LOT = conversion losses

The above relation represents the balance in the conversion cubes, where the incoming energy (primary and intermediate) is converted into one or several intermediate energy forms with the conversion losses LOT.

Intermediate Energy Forms: TAI = PIB + IMI ± VII and
ABI = TAI − EXI − NUI

where: TAI = total available intermediate energy
PIB = gross production of intermediate energy
IMI = import of intermediate energy
VII = variations of inventories of intermediate energy
ABI = available gross intermediate energy
EXI = exported intermediate energy
NUI = not used intermediate energy

With the checking relation: FCI = ABI − INI − LOI − ACI

where: FCI = end-use consumption of intermediate energy
INI = input of intermediate energy
LOI = losses of intermediate energy
ACI = auxiliary consumption of intermediate energy

End-use consumption: FTC = FCP + FCI

where FCT = total end-use energy consumption.

In this node, the end-use energy consumption (FCT) is covered by the part of primary energy (FCT) which is directly supplied to the consumption stage and the intermediate energy forms (PCT).

The last relation is: FCT = FCE + FCN

where: FCE = end-use energy consumption
FCN = final consumption for non-energy usages.

The final block in Fig. 17.4 usually includes the main consuming sectors: residential, commercial and public, industrial and agricultural, transportation and non-identified consumption.

It is hoped that in the future the final consumption stage might be detailed to reflect the consumption of useful energy and not only the supply of end-use

TABLE 17.II(a). PROFORMA-I: THE ENERGY BALANCE FORMAT (TOTAL) [17.7]

Country: Year:

	Solid fuels	Oil	Gas	Nuclear power	Hydro and geothermal	Non-commercial	Energy	Total
Indigenous production								
Imports (+)								
Exports (–)								
Marine bunkers (=)								
Stock change (+/–)								
Total energy requirements								
Transformation and energy sector								
– electricity generation								
– gas manufacture								
– oil refineries								
– other transformation								
– own uses and losses								
Total final consumption								

i. Household sector
ii. Industry sector
iii. Transportation sector
– road
– rail
– air
– navigation
iv. Agriculture sector
v. Other sectors
– commercial
– public service
Non-energy use
Total

TABLE 17.II(b). PROFORMA-IA: THE ENERGY BALANCE FORMAT (PETROLEUM PRODUCTS) [17.7]

	Crude	Nat. gas	LPG	Motor spirit	Avgas	Automatic transmission fluid	Kerosene	Fuel oil	Residue	Others
Indigenous production										
Imports (+)										
Exports (–)										
Marine bunkers (=)										
Stock change (+/–)										
Total energy requirements										
Transformation and energy sector										
– electricity generation										
– gas manufacture										
– oil refineries										
– other transformation										
– own uses and losses										
Total final consumption										

i. Household sector
ii. Industry sector
iii. Transportation sector
– road
– rail
– air
– navigation
iv. Agriculture sector
v. Other sectors
– commercial
– public service
Non-energy use
Total

TABLE 17.II(c). PROFORMA-IB: THE ENERGY BALANCE FORMAT (NON-COMMERCIAL ENERGY) [17.7]

Source	Fuel wood	Fuel crops[a]		Agricultural residues		Char-coal	Alcohol	Bio-gas	Solar			
		Sugar cane	Other	Crop	Livestock				Thermal	Light	Wind	Total
Primary production												
Stock change												
Primary supply												
<u>Transformation</u>												
Charcoal production												
Distillation												
Fermentation												
Gas production												
Electricity generation												
Final energy used												
<u>Industry</u>												
Drying												
Heating and cooling												

Mechanical
Power
Lighting
Other use
Transport
Household
Cooking
Lighting
Other use
Agriculture
Others (specify)
Residue

[a] Corresponding to the fuel use portion of the total crop harvested.

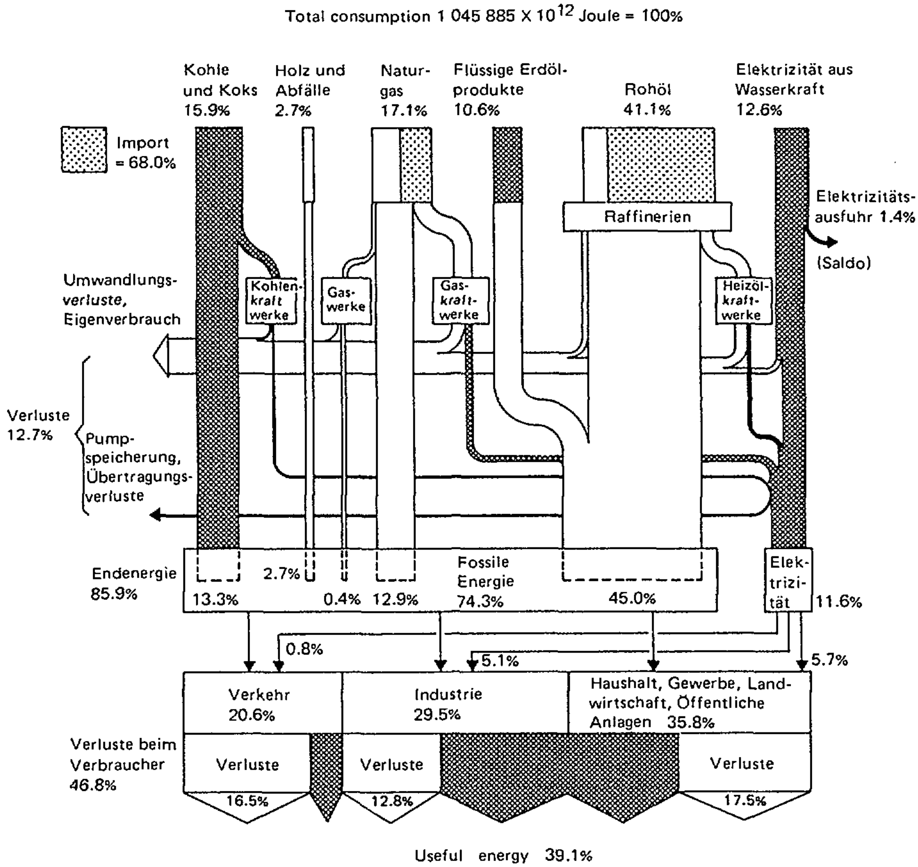


FIG.17.5. Austrian energy balance – 1980 [*17.8*].

energy to the main consuming sectors. It is only then that the energy balance would offer the complete image and account of energy utilization in an energy system.

Further detailed information on energy balance methodologies can be found in the following papers: Ref. [17.6] gives in addition to an in-depth description of the set-up of a national energy balance a practical example of the energy balance in Nicaragua in 1980. Reference [17.7] describes, also in the light of the discussions of the IEA workshop in 1979 in Paris [17.17], two energy balance formats which have received widespread attention in recent years: the tabular accounting framework adopted by the United Nations Statistical Organization (UNSO) and by the IEA and the reference system (RES) developed by the Brookhaven National Laboratory. Although the UN Statistical Organization format appears the best suited – and Ref. [17.14] used that format – it is felt [17.7] that this presentation could be improved with a total energy balance presented in a statement I in which petroleum products are aggregated and given in one column and the non-commercial energy in another column. This should be accompanied by two substatements of which one could give the details of oil products (i.e. the details from which the column of oil products is compiled for statement I), the other substatement giving the details of the non-commercial energy consumption. Accordingly Table 17.II(a) shows the proposed format for statement I, Table 17.II(b) the format for the petroleum products and Table 17.II(c) the format for the non-commercial energy, so important but still so deficiently exploited for developing countries.

17.2.5.3.2. Examples of overall balances

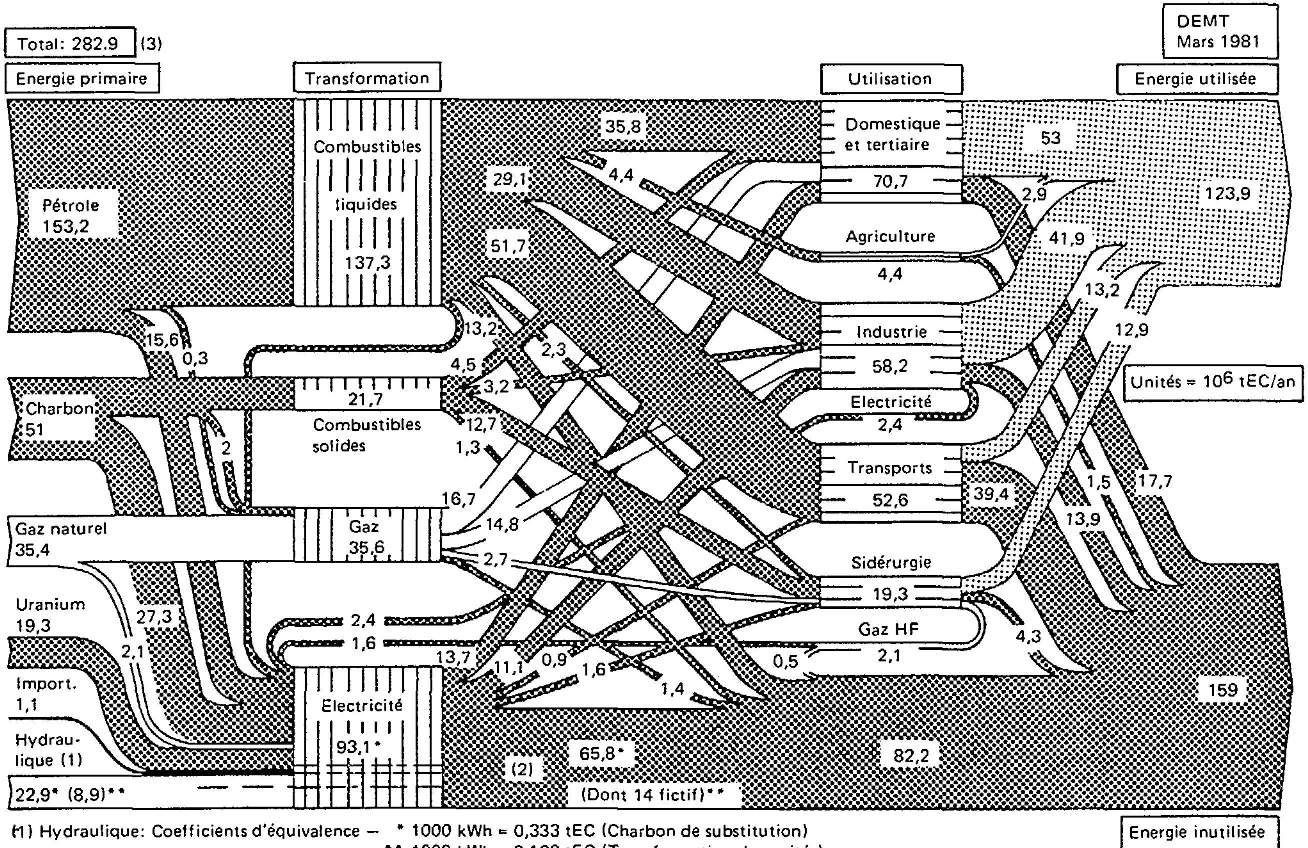
Both the examples of overall energy balances were selected to illustrate the diversity of the presentation as well as the different order of magnitude of the energy consumption involved. In addition, to underline the lack of uniformity, the balances have been given expressed in their original units for energy.

(1) Austria. Figure 17.5 presents the Austrian energy balance in the form of an energy flowchart for 1980, quantified in 10^{12} joule and structured in %. The key figures are: 85.9% of primary energy appear as end-use energy, only 39.1% are finally converted into useful energy.
(2) France. Figure 17.6 displays the energy flow chart in France in 1980, expressed in 10^6 tce; the overall energy efficiency is 43.8%.
(3) Federal Republic of Germany. Figure 17.7 presents the energy flow diagram for the year 1981, in PJ [17.10].
(4) India. The first national energy balance was drawn up in 1965; further efforts followed in 1974 and 1979. Since reliable data are not available for non-commercial energy consumption, which even now accounts for a high proportion of the total energy consumption, preparing a national energy balance is extremely difficult. Official balances are available for commercial energy consumption [17.11, 12].

    However, based on data on non-commercial energy consumption in the household sector compiled through surveys and micro-studies, Table 17.III displays a prospective energy balance for India in 2000. The balance has two alternative projections: the so-called reference level and the optimal level.

    The reference level projection has been based on past trends and assumes that no vigorous measures would be taken to manage or restrict the energy demand. The optimal level projection makes these assumptions too and, in addition, supposes that the non-commercial energy resources will continue to contribute a substantial portion to energy supply [17.13].

[16] Since easily understandable, the energy balance texts have not all been translated and the original figures have been kept.



(1) Hydraulique: Coefficients d'équivalence — * 1000 kWh = 0,333 tEC (Charbon de substitution)
** 1000 kWh = 0,129 tEC (Transformation des unités)

(2) 4,9 = Autoconsommation des producteurs (séparation isotopique, combustible nucléaire)

(3) + Bois = 4,8

FIG. 17.6. Energy flow chart of France – 1980 (10^6 tce) [17.9].

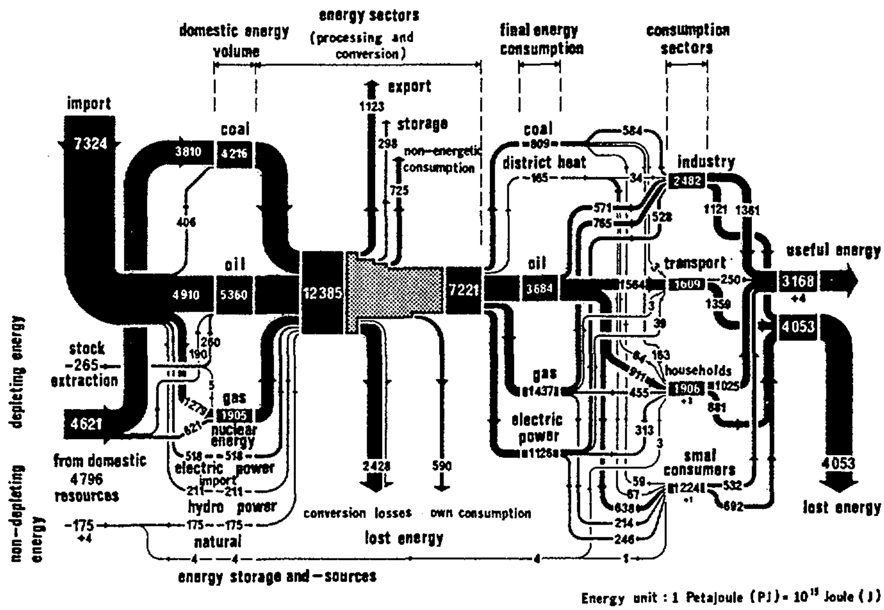


FIG.17.7. Energy balance of the Federal Republic of Germany – 1981 (PJ) [17.10].

(5) Indonesia. Figure 17.8 presents a line diagram showing the prospective energy balance of Indonesia in 1990.

(6) Jamaica. Table 17.IV presents the energy balance of Jamaica in 1980 as an example of the energy balances published by the United Nations [17.14].

(7) Mexico. Figure 17.9 displays the energy flowchart for Mexico in the year 1978, this time expressed in 10^{12} kcal [17.15].

(8) USA. Figure 17.10 presents the energy flow diagram for the USA in 1983 [17.16]. The sectoral end-use energy consumption had the following structure: residential and commercial 36%, industrial 37% and transportation 27%. The total end-use energy consumption in 1983 was 0.5% below the 1982 figure and 10.6% below the peak level in 1979. Typically, the units for energy are Quads (10^{15} Btu). The total end-use energy consumption of 70.45×10^{15} Btu is equivalent to 1777×10^6 toe.

(9) IEA Table 17.V presents the IEA energy balance for 1980 in a simplified format [14.4].

(10) Further examples of energy balances of developing countries are included in the proceedings volume of the IEA workshop on energy data held in Paris in 1978 [17.17].

TABLE 17. III. PROSPECTIVE ENERGY BALANCE OF INDIA [17.13] (10^{15}joule)

Energy consumption	Reference level	Optimal level
Primary energy		
Coal	12 212	10 147
Oil	4 172	3 110
Nuclear	297	351
Hydro	2 046	1 958
Total commercial energy	18 727	15 566
Non-commercial energy	3 495	4 166
Total primary energy	22 222	19 732
Secondary energy		
Coal	7 762	6 787
Oil	3 732	2 782
Electricity	1 676	1 426
Total commercial energy	13 170	10 995
Non-commercial energy	3 495	4 166
Total final consumption	16 665	15 161
Of which		
In transport	1 952	1 495
In agriculture	416	321
In industry	8 600	7 428
In household	4 808	5 165
In others	188	188
As feed stocks	701	564
For energy conversion	5 557	4 571

17.2.5.4. Selecting and evaluating alternatives

Whatever analytical methodology is employed to construct future energy balances, the usefulness of the approach to planning efforts is apparent when alternative conditions are evaluated. This is where the planner can gain insight into the potential effects of different strategies and policies on the development of the energy sector. It is easy to develop a list of possible alternatives that the planner would like to consider. Table 17.VI shows some of the typical alternatives that might be evaluated using the integrated analysis methodology.

Text continued on p. 689.

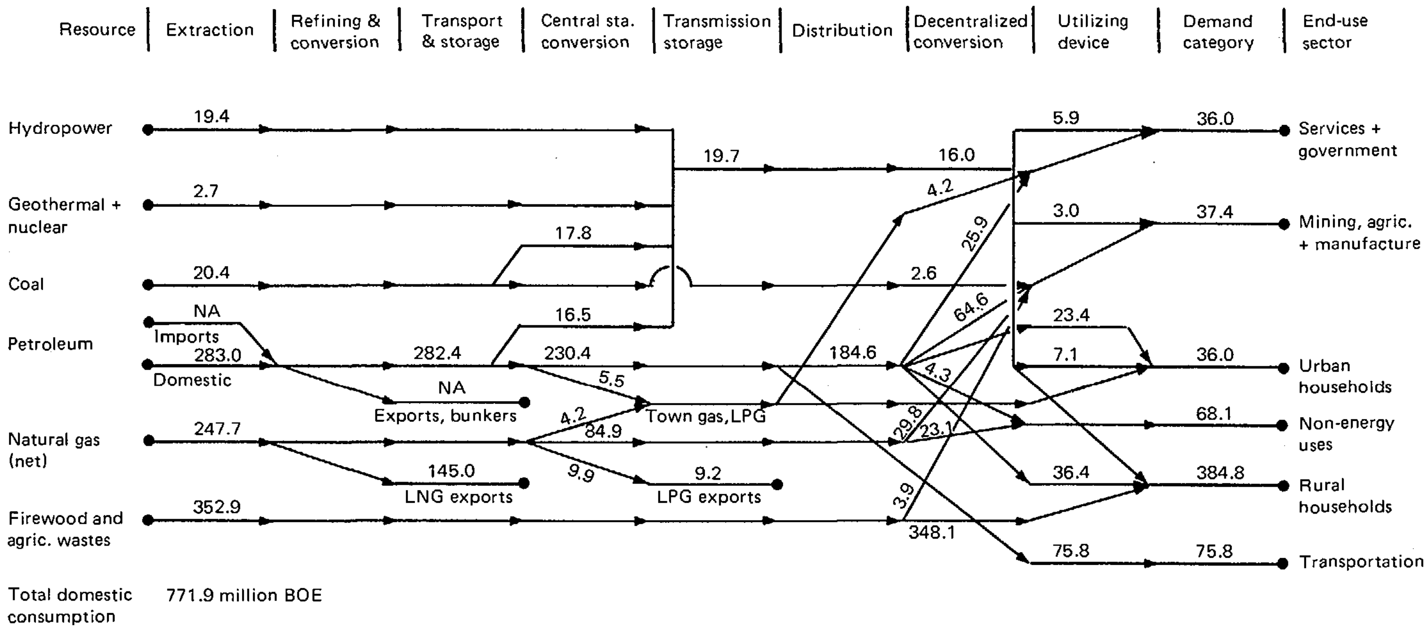


FIG.17.8. Prospective energy balance of Indonesia in the year 1990, in 10^6 boe [17.7].

TABLE 17.IV. ENERGY BALANCE OF JAMAICA IN 1980 (in Tj) [17.14]

Commodities / Transactions	Hard coal Brown coal Lignite	Briquettes and cokes	Other solid energy	Crude petroleum and NGL	Light petroleum products	Heavy petroleum products	Other petroleum products	LGP and other petroleum gases
Production of primary energy	–		6 065					
Imports	0	26	–	39 801	3 381	73 244	1 096	501
Exports	–	–	0	–	–1 798	–41	–716	0
Marine/ aviation bunkers	–				–864	–622	–	
Stock change	0	0	–	1 278	0	340	–	–
Total energy requirements	0	26	6 065	41 079	719	72 920	379	501
Energy converted	–	–	–	–41 079	13 478	3 446	838	1 589
Briquetting plants	–	–	–					
Coke ovens & coke plants	–	–						–
Gasworks	–	–		–	–	–		–
Blast furnaces		–						
Petroleum refineries				–41 079	13 478	24 266	838	1 589
NGL processing plants				–	–	–	–	–
Electric power plants	–	–	–	–	–	–20 820		–
Heating plants								
Other conversion industries	–	–	–			–		–
Net transfers				–	–	–	–	–
Consumption by energy sector	–	–	–	–	–	– 1 458	–	–770
Losses in transport & distribution	–	–	–		–	–	–	–
Consumption for non-energy uses	–	–	–			–	–1 217	–
Statistical differences	0	0	0	0	0	5 353	0	182

TABLE 17.IV (cont.)

Commodities / Transactions	Hard coal Brown coal Lignite	Briquettes and cokes	Other solid energy	Crude petroleum and NGL	Light petroleum products	Heavy petroleum products	Other petroleum products	LPG and other petroleum gases
Final consumption	0	26	6 065	–	14 198	90 261	–	1 503
By industry & construction	0	26	5 938	–	–	67 825	–	–
Iron & steel industry	–	26	–		–	–	–	–
Chemical industry	–	–	–	–	–	–		–
Other industry & construction	0	–	5 938		–	67 825	–	–
By transport industry	–	–	–		10 569	5 305		–
Road			–		9 012	4 887		–
Rail	–	–			–	498		
Air					1 557			
Inland & coastal waterways	–	–			–	–		
By households & other cons.	–	–	127		3 629	7 051		1 503
Households	–	–	127		–	5 436		–
Agriculture			–		–	1 615		–
Other consumers	–	–			3 629	–		1 503

Table is continued on next page.

TABLE 17.IV (cont.)

Natural gas	Derived gases	Nucl., hydro and geothermal electricity	Nuclear electricity	Hydro and geothermal electricity	Electricity	Steam and hot water	Total energy	
		Conventional fuel equiv.	Physical energy input				Conventional fuel equivalent	Physical energy input
–		1443	–	433		–	7 508	6 498
–	–				–		118 049	118 049
–	–				–		–2 556	–2 556
							–1 486	–1 486
–	–						1 618	1 618
–	–	1 443	–	433	–	–	123 134	122 123
–	–	–1 443	–	–433	8 093	–	–15 078	–14 068
							–	–
–	–						–	–
–	–						–	–
	–						–	–
							–908	–908
–							–	–
–	–	–1 443	–	–433	8 093		–14 170	–13 160
						–	–	–
–	–						–	–
–	–					–	–	–
–	–				–180	–	–2 408	–2 408
–	–				–397	–	–397	–397
–	–						–1 217	–1 217
–	–				0	–	5 536	5 536

TABLE 17.IV (cont.)

Natural gas	Derived gases	Nucl., hydro and geothermal electricity	Nuclear electricity	Hydro and geothermal electricity	Electricity	Steam and hot water	Total energy	
		Conventional fuel equiv.	Physical energy input				Conventional fuel equivalent	Physical energy input
–	–				7 516	–	109 569	109 569
–	–				5 919	–	79 708	79 708
–	–				–	–	26	26
–	–				–	–	–	–
–	–				5 919	–	79 682	79 682
–	–				–	–	15 954	15 954
					–		13 899	13 899
					–		498	498
							1 557	1 557
							–	–
–	–				1 597	–	13 907	13 907
–	–				1 146	–	6 710	6 710
–	–				–		1 615	1 615
–	–				451	–	5 582	5 582

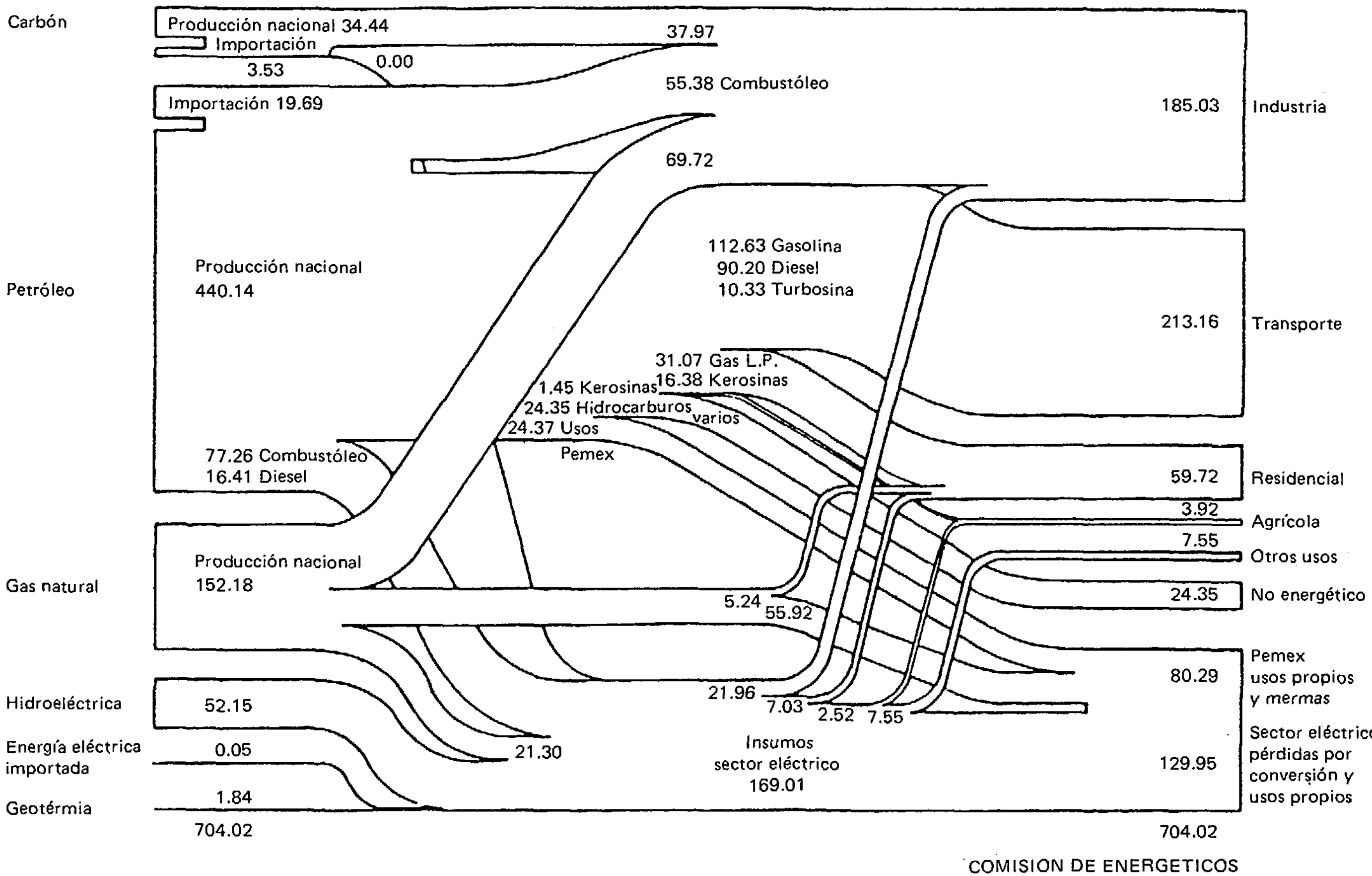
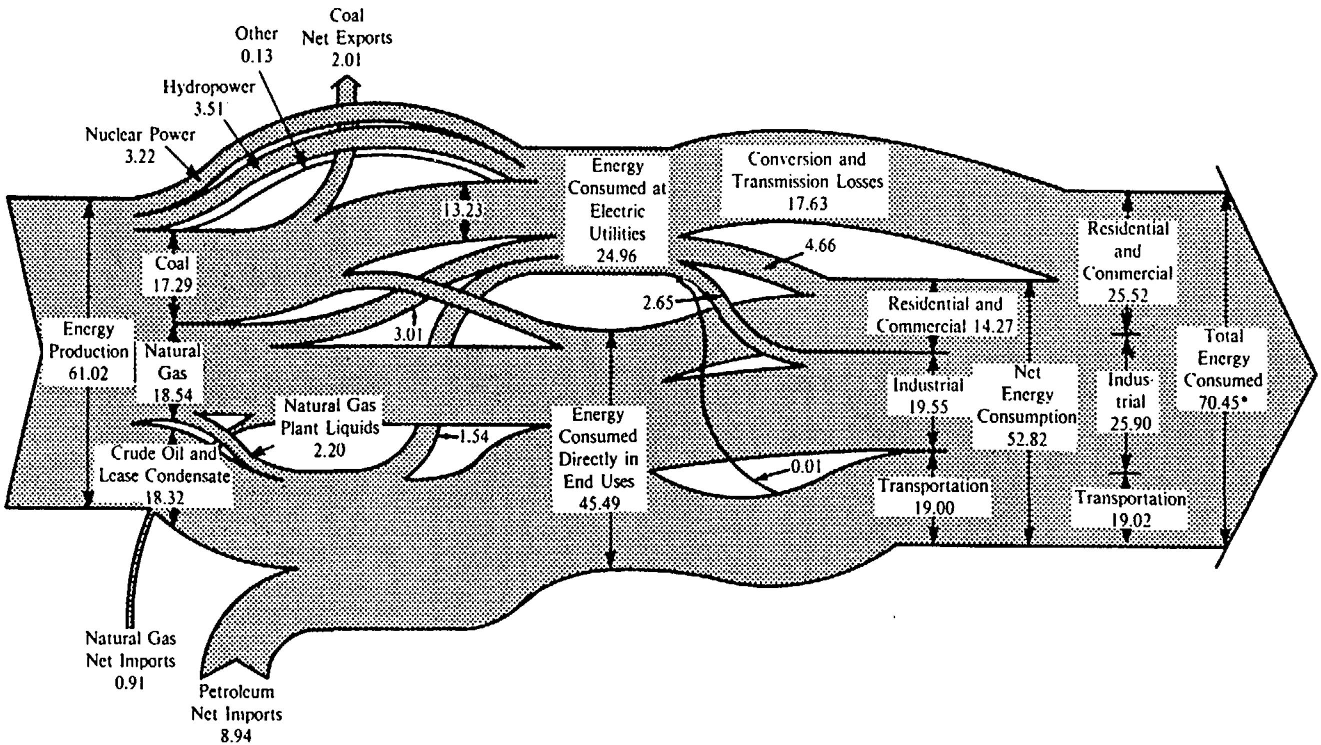


FIG.17.9. Energy flow chart in Mexico in 1978 [17.15].

(Quadrillion Btu)



*Total Energy Consumption with conversion and transmission losses allocated to end-use sectors in proportion to the sectors' use of electricity.
Sum of components does not equal total due to independent rounding; the use of preliminary conversion factors; and the exclusion of changes in stocks, miscellaneous supply and disposition, and unaccounted for quantities.

FIG.17.10. Energy flow diagram in the USA in 1983 [17.16].

TABLE 17.V. IEA ENERGY BALANCE IN 1980 (10^6 toe) [14.4]

	Solid fuels	Oil	Gas	Nuclear	Hydro/ geothermal/ solar/wind	Electricity	Heat	Total
Domestic production	780.6	710.6	687.1	131.3	233.4	–	–	2543.0
Imports	121.2	1270.7	118.4	–	–	8.3	–	1518.6
Exports	–114.4	–220.7	–92.1	–	–	–8.4	–	–435.6
Marine bunkers	–	–69.8	–	–	–	–	–	–69.8
Stock changes	–22.5	–25.1	3.6	–	–	–	–	–44.0
TPE requirements	764.9	1665.8	717.0	131.3	233.4	–1	–	3512.3
Electricity	–512.5	–184.8	–130.7	–131.3	–233.4	427.6	8.2	–757.0
Manufactured gas	–1.6	–6.6	5.5	–	–	–	–	–2.7
Petroleum refinery	–.3	–87.9	–20.1	–	–	–5.7	–	–113.9
Energy sec. and losses	–39.2	38.0	–57.0	–	–	–58.1	–0.5	–116.8
TFC	211.3	1424.6	514.7	–	–	363.7	7.6	2521.9
Industry[a]	173.4	383.7	231.9	–	–	160.9	1.5	951.4
Transport	0.5	714.7	2.0	–	–	4.5	–	721.7
Others[b]	37.4	326.2	280.8	–	–	196.4	6.1	848.8

[a] Including non-energy use.

[b] Residential, commercial, agricultural and government use.

It is also possible to combine the various alternatives into sets. For example, one case might be based on a high growth rate, moderate rate of oil price increase, aggressive conservation efforts, and a requirement for a diversified energy supply system. The planner can then construct the energy balance for this set of conditions and evaluate the impacts of this balance.

The number of possible alternatives to be considered can become very large through the combination of the various conditions. It is important for the planner to be selective in the number of alternatives considered. Certain configurations will lead to little or no change and do not provide any useful information upon which to base a decision. Other configurations are known, a priori, to be infeasible and should be discarded. With a systematic methodology that can produce energy balances accurately and rapidly there is often the temptation to evaluate every possible combination of conditions. The planning effort can then deteriorate into a numerical exercise in which a large volume of data is generated but not evaluated in any detail. The planner must exercise careful control over this process.

17.2.5.5. Evaluating the impact of an energy balance

Once an energy balance has been constructed, the impacts or implications of that balance must be determined. It is the evaluation of these impacts that provides the basis for developing information for decision-makers. Section 17.1.3 provided some general guidance as to what information needed to be generated by the planning process. Table 17.VII provides some more detailed specification of how the impacts evaluated as part of the analytical process match the decision-making requirements. Additional impacts can be included to address issues of particular concern to the country.

Some of the impacts require a fairly detailed computational procedure. For example, the computation of the costs of the construction of new energy facilities requires the estimation of total capital costs, interest during construction, escalation factors, contingencies, and a time distribution of cash flow. For completeness, the calculation should be expressed in constant currency, current value currency, and also discounted to present value. There are a number of analytical tools available to the planner to help compute some of the impact parameters. The tools are generally straightforward computational algorithms but they should be evaluated for their compatibility with the rest of the analytical methodologies being used.

17.2.5.6. Choosing between alternatives

The final step of the integrated analysis is to choose from the various alternatives and to select from the impacts evaluated the information that will be presented to decision-makers for review. In section 17.1.5 emphasis was placed on the need for the analyst to prepare the results in a form suitable for

TABLE 17.VI. TYPICAL ALTERNATIVES FOR EVALUATION [17.2]

Energy issue	Specific alternatives
Economic growth	Rate of growth Structure of economic growth
International energy prices	Price of crude oil Price of petroleum products Price of coal Price of gas Price of nuclear fuel
Domestic energy price policy	Subsidies Taxes Price controls
Conservation programme	Business-as-usual conservation efforts Moderate conservation programme Aggressive conservation programme
Renewable resource programme	No special emphasis Incentive programmes
Supply system configuration	Least-cost system Restrictions on certain imports Requirement for diversification Emphasis on indigenous supplies Choice of specific technologies

use by decision-makers. Such preparation involves the collection of all the information generated as part of the integrated analysis and the assembly of this information into a format suitable for review and evaluation by a decision-maker.

It can be expected that the decision-making process may lead to the need for additional analyses and changes to the original set of assumptions. If the analytical methodology is properly set up, such iterations should be able to be carried out with a minimum of impact and extra effort.

17.2.6. Remark

The preceding material represents an overview of the energy planning process and an identification of the tasks necessary to conduct an energy analysis. The actual implementation of an energy planning programme will require the adjustment and adaptation of the steps previously discussed to the needs of the individual country. The most important consideration to keep in mind is the orientation of the energy planning process toward decision-making. With this perspective in mind, appropriate choices of methodologies, procedures,

TABLE 17.VII. TYPICAL IMPACTS TO BE EVALUATED [17.2]

Decision-making information	Specific impacts to be evaluated
Energy requirements	Total quantity of energy required Quantities of each type of energy (fuel, electricity) required
Energy supplies	Sources of energy available Imports required Indigenous resources used
Supply system configuration	Number and type of energy facilities required (e.g., power plants, refineries, pipelines, etc.) Dates new facilities must be operational to meet demand
Costs	Capital investment required in energy facilities Operating costs of new and existing equipment Delivered costs of fuel and electricity
Financial data	Foreign exchange required for energy system Financial analysis of energy projects Revenue generated from energy system
Economic effects	Energy sector contribution to GDP Energy sector requirements as a portion of GDP
Labour	Personnel required for construction of energy facilities Personnel required for operation and maintenance of energy system Skilled labour requirements
Environmental effects	Air pollution Water pollution Solid waste Noise Hazardous waste
Materials	Material requirements for the energy sector Imported material requirements

organizational structures, and other aspects of the energy planning process can be made.

In addition to Ref. [17.2] other substantial informative material prepared by the Center for International Energy Development in the Argonne National Laboratory exists, for example the view-graphs displayed in the 1982 and 1983 IAEA courses in Jakarta and Ljubljana [17.18–24]. References [17.25–27] reflect French experience on the subject.

17.3. Electric system planning

In the framework of overall energy planning, i.e. of the energy master plan (EMP), similar detailed master plans can be elaborated for different energy resources and carriers. The electricity master plan (ElMP) is one of the most important, and in many countries was the first to appear, the ElMP often preceding the EMP.

Since an IAEA guidebook on electric system expansion planning [17.1] was recently published, in the present framework the subject will be only outlined as a part of overall energy planning, and this in strong reliance on the easily accessible guidebook.

17.3.1. Relationship to overall energy planning

Electric system planning is linked to overall energy planning primarily through the demand forecast, which should account for anticipated economic activity, population growth, and other driving forces for changes in electricity demand over time. The benefits of linking the two planning activities include avoidance of effort duplication (such as making independent sectoral economic projections), consistency of assumptions for important independent variables, and an understanding of the basis for the forecasts. This is not to say that electric system planners should accept without question assumptions made by others. Sensitivity analyses of important parameters are often the most useful result of electric system planning studies.

Additional connections with overall energy planning could include financial analysis and resource use. If financial constraints exist, such as limited availability of capital for construction of new projects, then the importance of co-ordination not only with the overall energy activity but also planning of other capital-consuming activities is more evident.

Regarding the use of the relationship between aggregate economic activity and overall energy or electrical demand for planning, it is interesting to point out that the statistical correlations are quite different for the two energy categories.

For several decades prior to 1973, electrical energy demand grew more rapidly than the demand for overall energy. While the growth in energy demand slowed considerably after 1973, electrical energy demand was only slightly deflected

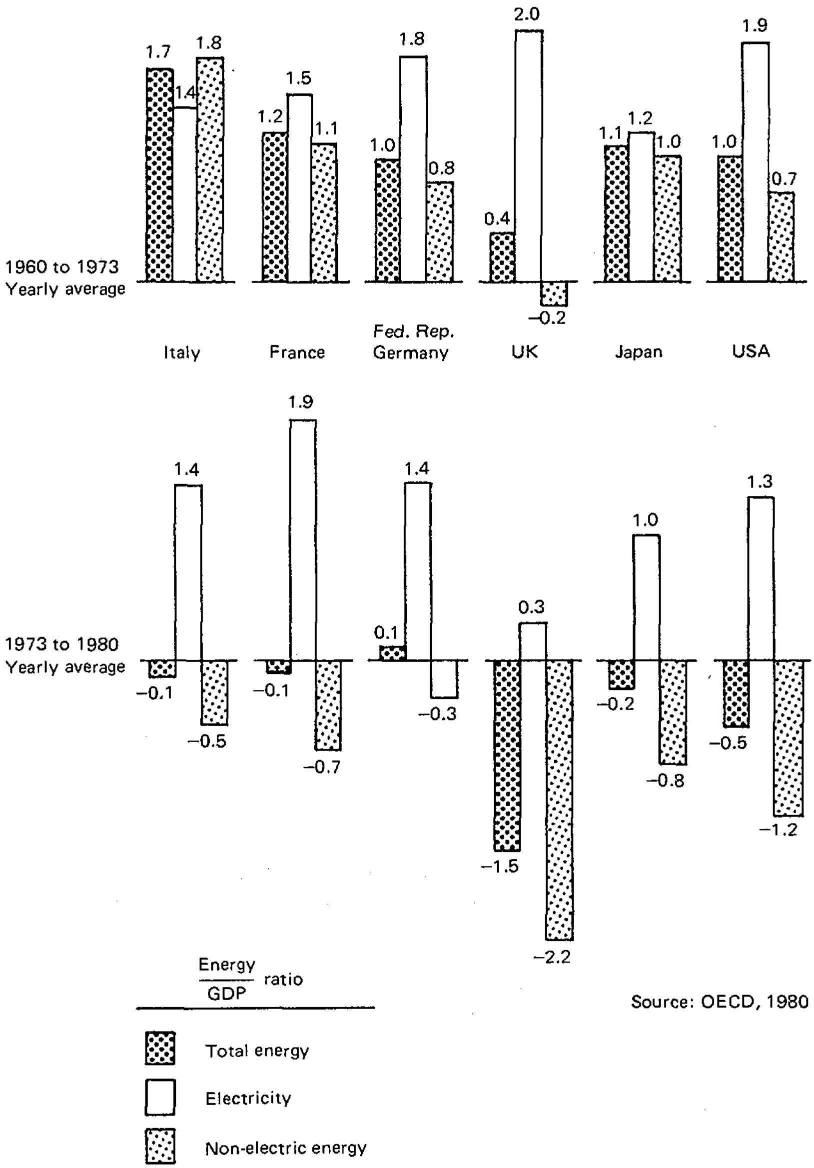


FIG.17.11. Electric and non-electric energy growth rate relative to GDP growth rate [17.2].

from its historical growth path. Figure 17.11 shows this quite well by comparing the per head growth rates of total energy, electrical energy, and non-electrical energy relative to the growth of GDP in six developed nations. The growth in non-electrical energy relative to GDP took a sharp drop after 1973, while average growth of electrical energy relative to GDP was generally quite similar from 1960 to 1980.

17.3.2. Objectives and time horizons of an ElMP

The primary objective of a public utility company is adequately to meet the demand for electrical power at the minimum cost. The definition of 'adequate' has been commented on at length in chapters 6, 11 and others. Of course, the utility must conform to existing constraints, such as financial limits, domestic resource availability, and governmental policies. Thus, 'minimum cost' usually means minimum cost subject to a set of financial, resource, technical, environmental, and political constraints, and these constraints define in turn whether the minimum refers to minimum costs for the utility, the economy, or a combination of both – see chapters 10, 11 and others.

The careful planning and co-ordination of investments in the generation and transmission system as a whole is an important step toward a satisfactory overall performance of a power system.

Accordingly, the following four basic questions have to be answered in the course of the planning process:

(1) What capacities (power stations and electric lines) to install to ensure an appropriate level of reliability?
(2) How to pick the best combination of the different technologies at hand now and later on?
(3) Where to locate the new equipment and construct the electric lines?
(4) When is the proper time to incorporate them into the system?

Briefly stated, major decisions in expansion planning of the generating and transmission system must address alternative generating unit sizes, types of capacity, electric lines implementation, timing of additions, and locations.

Electric system planning encompasses a broad collection of activities spanning several time horizons. Electric system planning may be divided into categories of analysis such as demand, generation, transmission and distribution. Each category of analysis may be carried out for a short time frame (e.g. less than 5 years), for a medium time frame (e.g. 5–10 years), or for a long time frame (e.g. more than 10 years). This does not imply that electric system planning can simply be divided into a dozen independent activities; instead, it is conceptually convenient to think of these categories because, in general, different problems are faced and different analytical techniques are used depending on the time frame and the category of electric system planning. For example, studies of the generating system over the next year or two generally involve limited options for changing the generating system, such as deferring retirement of a unit. In contrast, studies of the evolution of the generating system over the next 25 years typically involve substantial changes in composition for the system. Therefore, different types of models and levels of data detail are needed for the two types of studies.

17.3.3. ElMP planning procedures

Experience has shown that for long-term electricity planning a step-by-step approach is the most convenient procedure.

According to this procedure, the planning exercise may be split into two phases: the economic optimization phase and the detailed analysis phase.

(1) Phase 1: The planner concentrates on the search for the most economical expansion plan; that is, the programme of capacity additions, and transmission system development that leads to an optimum value for the economic criteria selected for the comparison of alternative plans, while providing a satisfactory level of system reliability and continuity of supply, and obeying other quantifiable constraints.

Any quantifiable constraints must be explicitly taken into account in finding this optimum. Due consideration to remaining potential constraints may be given in this phase by applying certain broad ground rules based on past experience in the operation of the power system or arising from qualitative considerations about the future conditions that will surround the system. It is obvious that it is not practical simultaneously to compare different alternatives for generation system expansion and the required development of the transmission system. This has led a number of system planners to make a split between generation and transmission planning, which consists of:

- determining the generation system expansion as a one-node exercise excluding network considerations and assuming that demand and generating facilities are concentrated at the same point; and
- deducing the corresponding optimal power plant siting and network expansion, with iterations being carried out between these two steps as necessary.

Such an approach is generally justified if:

- the network is adequately interconnected
- the lead time for a power line is less than the lead time for a plant
- the total investment costs for the transmission system are much smaller than those for the generation system.

This is the approach followed by most models, such as WASP — see subsection 17.4.3.5. As a first approximation, the transmission system is neglected, considering that all generation expansion plans will lead to a similar development of the transmission network and only major differences in transmission requirements (e.g. long transmission lines to connect a power station to the grid, introduction of a higher grid voltage) are accounted for in the comparison of alternative system expansion plans. The best expansion policy for the generation system found by this method is then subject to analysis of the transmission network configuration. These studies evaluate load flows, transmission line requirements, voltage levels, system stability, etc., in order to determine the expansion required in the transmission system. Obviously, this expansion should also be determined trying to minimize its costs. The results of the transmission expansion studies may also have a feedback effect on the assumptions made for determining the optimum schedule of plant additions.

(2) Phase 2: Once the economic optimal solution for system expansion has been found, the planner must analyse the results and determine whether the economic optimum expansion plan is also a feasible programme from the standpoint of the system characteristics and the economic and financial situation of the region or country involved. From this analysis, the planner will check in more detail all potential constraints which were not explicitly taken into account in the previous phase. For example, the proposed system must be examined in order to guarantee frequency stability in the event of loss of the largest plant or unit when operating at full power. Fuel requirements imposed by the proposed plan have to be compared to the country's policy for energy use. Total manpower requirements of the plan should be determined and compared with the available resources of the country; needs for training and corresponding costs have to be evaluated. Also, a financial analysis of the proposed plan should be carried out in order to assess viability of implementation and its impact on the overall economic development of the country. Certain solutions must be checked for relevant infrastructure needs, e.g. coal transportation and new harbours, and environmental constraints. It is recommended to submit to these checks not only the economically optimal solution but also some other near-optimal solutions, since the ranking between these solutions may be altered as a result of the analysis. Hence, adequate comparison between competing alternatives needs due consideration not only of all direct and indirect costs produced by each plan but also of its direct and indirect benefits. In some extreme cases, it may be also necessary to repeat Phase 1 in order to calculate new optimal solutions until the solution so found also satisfies all checks of Phase 2.

To conclude, it seems important to emphasize once more the need for a thorough integration for electric system planning efforts into an overall energy planning exercise. Often the electric system planning is done separately from other planning efforts. The only point of contact is through the use of a load forecast that may be tied to the economic growth plan. Simultaneously, the overall planning studies often overlook the work done by the electric system planner and so develop electricity analyses with little or no consideration of the efforts already expended. It is vitally important that this lack of interaction be avoided. From an analytical standpoint there is no reason why detailed electric system planning and overall energy system planning cannot be conducted in a consistent and mutually beneficial fashion. The organizational requirements for implementing this are often the only obstacles. References [17.28, 29] also refer to the necessity of integrating electricity planning into the EMP and add some comments on modelling.

17.3.4. Nuclear energy

In the ElMP nuclear energy is treated as one of the primary energy sources considered for electricity generation. Should preliminary examinations conclude that it represents a viable alternative, then opportunity, timing and further conditions for its integration in the ElMP need to be studied according to the detailed procedures described in chapter 18, dealing with the launching conditions and implementation of a nuclear power programme.

17.4. Models helping energy planning

17.4.1. General considerations

The utilization of models in energy planning has been favoured by the increasing importance of planning and of the volume of work involved in this activity on the one hand and by the progress in systems analysis approaches and computer techniques on the other. An obvious explanation is that in simple systems, the human mind can probably hold six to ten variables and massage them rather thoroughly. But when one faces multiple sets of very uncertain factors, the human mind cannot make the total integration. That is what a model does. It does not make the decision: it shows the possible consequences of making the decision. And it may sometimes highlight details the decision-maker had not thought were very important [17.30].

Basically, models are used in energy planning for forecasting, optimization and complex analyses, i.e. testing and assessment of the effects of various measures and policies on the energy system itself or on the physical, social and economic environment.

Any model consists of a group of mathematical relations linking to each other a given set of variables, and allowing for the calculation of the value of one variable from the basis of one or several others. Some of these variables are considered to be 'exogenous' to the model in so far as no mathematical relation allows for their calculation, but are, however, used in the calculation of other variables, the latter being considered 'endogenous'.

However, behind this formal mathematical aspect, a model is a conceptual representation of interfacing facts of the real world, originating from physical and human action [17.31]. Its elaboration requires both a fair knowledge of the area under examination and of the simulation techniques best suited to the problems involved.

According to the nature of the intervening factors, the models can be divided into descriptive and normative models, in both cases of simulation character. The former contain mainly physical variables and parameters of the examined system, the latter rather subjective behavioural factors such as preferences of the consumers, standards of living, human reaction to technological changes or proposals, etc.

The majority of the energy-oriented models belong to the descriptive type, with two main tasks: optimization and operational reliability. The normative type refer to two basic functions: impact (social, environmental, ecological, etc.) and market behaviour (future orientations of the energy consumer, reactions to new products and processes, etc.).

Descriptive models are used for the evaluation of energy demand and supply, analysing their optimization from the point of view of maximum economic benefit, optimal economic or operational behaviour or of both of them. The operational reliability can be analysed from the point of view of best structure and sequence, minimum of failures, risk of these or any other intervening causes.

Normative energy models analyse in which measure construction of hydroelectric plants, opening of new open-cast coal mines, technology changes, changed manpower requirements and individual and public behavioural preferences, may alter economic, social and educational existing development conditions. In addition, they may tackle market-related aspects such as structures of energy consumption, preferences, level of saturation or suppressed demand [17.31].

As far as the mathematical techniques of energy models are concerned, they range, depending on the complexity of the model, from classical operations research methods such as linear programming to the building of complex normative scenarios for analysis and development of energy systems. For a better understanding the following main mathematical techniques used in energy modelling may be enumerated: correlation (an objective energy function is related in a given form to a given variable, for example energy consumption to income, price, etc.), linear programming (for optimizing a linear cost function under linear constraints), dynamic programming (for example for an investment choice in an electricity utility), simulation, input/output analysis (relationship between energy consumption and the money value of the output of different sectors of the industry), scenarios (description of different states through the aggregation of elementary events).

As far as practical applications in energy planning are concerned, they relate to the following two phases:

(1) Projection of energy demand, and
(2) Optimization of the supply/demand energy system.

Independently of which category a model belongs to, there are a few, dramatically simple conditions which should not be overlooked when selecting or using a model. They can be briefly summarized as follows [17.32]:

- A model is nothing more than a tool, a set of calculations.
- Its usefulness depends on three critical factors: theoretical soundness, data and skill of the interpreter.
- The skill of the interpreter is probably the most significant item in the use of an energy model; accordingly engineer, economist, operation researcher and computer scientist skills are to be provided.
- Models should not be used as 'black boxes'.
- No one model can provide all the necessary information; a set of analytical tools is necessary.
- In general a model can only answer the question for which it was originally designed.
- Sound judgement might help to escape the unpleasant dilemma that is well expressed in the famous phrase 'all which is simple is wrong, everything which is complicated is useless' [17.33].

17.4.2. Models for energy demand forecasting

17.4.2.1. Increased accent on energy demand

Interest in elaborating models for energy forecasting increased, when after the first so-called energy crisis of 1973–1974, energy planning previously oriented to promote energy consumption became aware of the importance to start planning from consumer needs and proceed from this base to the optimization of energy supply [17.34, 35].

There was a gradual recognition that supply strategies would not solve all the problems and that energy demand management policies should be implemented to accelerate the move away from oil. Energy demand growth was no longer considered as deterministic but rather as flexible, especially in the long term, and could be influenced by energy policy tools; this idea being supported by the fact that the historical relationship between energy consumption and GDP had largely altered, in most countries, after the oil crisis. Thus energy demand management became an important component in energy planning. This change in attitude towards energy demand was accompanied by a questioning of the traditional econometric methods used until then to study energy demand, and by the development of new methods, often called 'end-use methods', which will be referred to in this book as 'technico-economic methods'.

Accordingly, the traditional econometric methods were no longer considered suitable for the evaluation of energy demand in the long term and interest concentrated on the other two categories of models: technico-economic and models of general equilibrium.

The models of general equilibrium were essentially used in the past for macroeconomic projections, considering energy in monetary terms and in an aggregate way. After 1973, models of general equilibrium were developed combining a macroeconomic and a technical approach where energy, as regards the supply and the demand, is considered in a disaggregate way.

However, the technico-economic (phenomenological) models became the most popular models for energy demand forecasting. Among them there are two categories:

(1) The 'accounting models' in which the progression of most variables is exogenous and defined within the framework of a scenario, the main function of the model being to perform rapidly a whole series of multiplications and additions (thus, they are accounting tools rather than real models). In these models changes in the social and economic structures, in the technology (and in particular energy savings), and in the energy mix are exogenous and specified in the scenario, which thus plays a key role. Users of these models must therefore have very accurate knowledge of the social, economic and technical problems linked to energy. The MEDEE S model that will be described below belongs to this category (as well as MEDEE 2).

(2) The 'systemic models', in which the progression of most social and economic factors and the technological options are endogenous to the model and simulated on the basis of relationships aimed at sticking as closely as possible to real phenomena, such as behavioural relationships and possible econometric relationships. These models thus require previous analysis to be made of the mechanisms by which energy demand develops, and of its determinants; this analysis is then formalized into the model. MEDEE 3 is an example of this type of model.

Technico-economic methods have a number of advantages which to a great extent explain their popularity. First, they provide simple, transparent answers to a number of questions concerning the long-term development of energy matters: the impact of contrasting energy policies, especially with regard to energy savings and the development of substitutes for hydrocarbons, the effect of the style of development on energy demand, etc. Secondly, these methods allow a better analysis of the supply of final energy by investigating the balance of supply and demand at a more detailed level (taking account of temperatures, or of the spatial dimension, for instance). Finally, with these methods the major demand determinants are made explicit, particularly the variables of action to control the long-term development in energy demand.

The use of these methods also raises some problems: they require a large quantity of data and information and they rely heavily on scenarios which must be designed carefully to avoid inconsistencies, especially in the interface between macroeconomic development and technological changes. The consistency problem may be solved in part by using complementary economic models and structured scenario methods. With regard to the information required, this aspect should on no account be an argument against using technico-economic methods or an excuse for using aggregate methods; rather, they should be the starting-point for data research [17.36].

17.4.2.2. The MEDEE models

The MEDEE (Model for Energy Demand Evaluation) models, i.e. MEDEE 2, MEDEE 3 and MEDEE S, are phenomenological (techno-economic) long-term energy demand simulation models, designed by B. Chateau and B. Lapillonne at IEJE (Institut économique et juridique de l'énergie) in Grenoble, France, between 1974 and 1982 [17.37].

The MEDEE 1, a mathematical model which has never been computerized has only been used for the first MEDEE study on France. The MEDEE 2 model was developed from 1976 to 1978 by B. Lapillonne at IIASA (International Institute for Applied Systems Analysis in Laxenburg, Austria), within the framework of the energy programme aimed to outline world energy prospects. MEDEE 2 was also used to explore future energy demand in the USA and a version adapted to developing countries was developed for the IAEA under the name of MAED.

The MEDEE 3 version was developed at the IEJE from 1977 to 1981 and was used for the forecast of end-use energy demand in France [17.38] and for the energy demand of the European Economic Community up to the year 2000.

MEDEE S, the new version for developing countries, has already been used in Argentina, Brazil, Colombia, Costa Rica, Ecuador and Nicaragua.

MEDEE 2 and 3 differ in: first, their level of disaggregation, MEDEE 2 being more aggregate (the trip purposes, the age structure of housing, the various service sectors as well as the energy-intensive industries are not accounted for in a detailed way). Secondly, in MEDEE 2, the development of new energy forms and technologies (e.g. solar, heat pump, electricity) as replacements for fossil fuels is normative and defined within the framework of the scenario while in MEDEE 3 this development is simulated on the basis of the energy prices, the energy policy, and the decision-maker's behaviour. Thirdly, there is associated with MEDEE 3 a systematic procedure for the scenario design aiming at improving the coherence of the scenario. Finally, MEDEE 3 simulates the whole evolution of the socio-economic system (e.g. evolution of people's mobility, industrial activities) and calculates the energy demand for each module. MEDEE 2

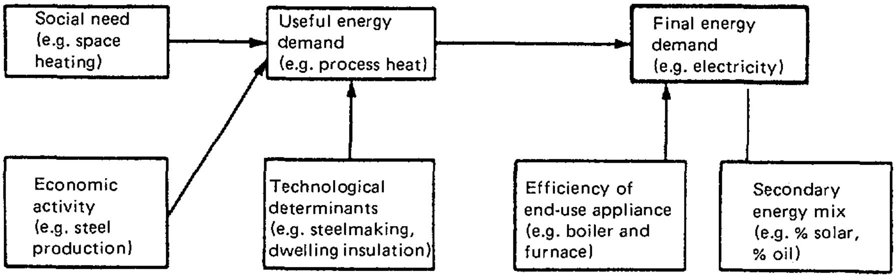


FIG.17.12. General scheme for energy demand analysis in MEDEE 3 [*17.40*].

is more an accounting framework than a real simulation model, which translates or quantifies a given scenario in terms of useful and final energy demand.

17.4.2.2.1. The MEDEE approach

The MEDEE approach is based on two fundamental ideas:

(1) No fatalism or determinism exists either in the evolution of the economy or in the relationships between economic growth and energy demand growth over a long period of time; this means that it is necessary to substitute – in contrast to the traditional purpose of the forecast, which is to predict the future – a new attitude towards the future which consists of exploring the reasonably possible futures and the conditions allowing these futures to occur.
(2) The complexity of the relationships between economic growth and energy demand growth cannot be hidden in aggregated formalized relations for long-term approaches (as econometric models do); a very detailed analysis of the mechanisms of formation and evolution of energy demand is required before trying to formalize in any model the evolution of this demand.

The approach itself refers to two methodological tools:

– system analysis applied to the analysis of the socio-economic system energy demand
– a scenario method for the description of the possible evolutions of this system.

The system analysis of the energy demand was organized and performed from the fundamental scheme which explains the energy demand formation, presented in Fig.17.12.

According to this scheme, three major steps are carried out in the system analysis:

(1) Disaggregation of the energy demand in a set of 'modules' in which the energy demand can be analysed in an aggregated and homogeneous way:

- homogeneous regarding the social need or the economic activity from which energy demand derives
- homogeneous regarding the economic function and the behaviour of the end-users of energy
- homogeneous regarding the physical and technological context.

(2) Analysis of the mechanisms of evolution of energy demand within each module, i.e. identification of the factors (or determinants) which explain the evolution of the three groups of variables determining the energy demand (needs or activities, technological context, equipment) and identification of the relationships linking these factors.

(3) Construction of a simulation model by formalization of the relationships identified for each module and by linkage of the modules together on the base of the structure identified in the first step.

In the following, the final step – the simulation model MEDEE 3 – and the scenario design method used to this purpose are briefly described.

17.4.2.2.2. MEDEE 3 – short description

MEDEE 3, as a simulation model of energy demand long-term evolution, simulates on a 20–30 year basis the evolution of the main energy demand determinants (technical, economic, social and political) that have been identified through the analysis of the energy demand evolution mechanisms and calculates for each five years the energy demand on the basis of the determinants' values [17.41].

MEDEE 3 could be regarded both as an engineering and economic model since some of the relations formalized are technical relations and some of them are econometric relations. It is not an econometric model in the traditional sense, since it does not directly relate the energy demand to any economic aggregate.

MEDEE 3 has the following characteristics:

- it is a very disaggregated model, requiring a rather large number of technical, social and economic input data
- it has a hierarchical structure which means that it is made up of ordered sub-models and that all the equations are recurrent
- it is fed with scenario assumptions which are made in a consistent and plausible way through an elaborated scenario design model

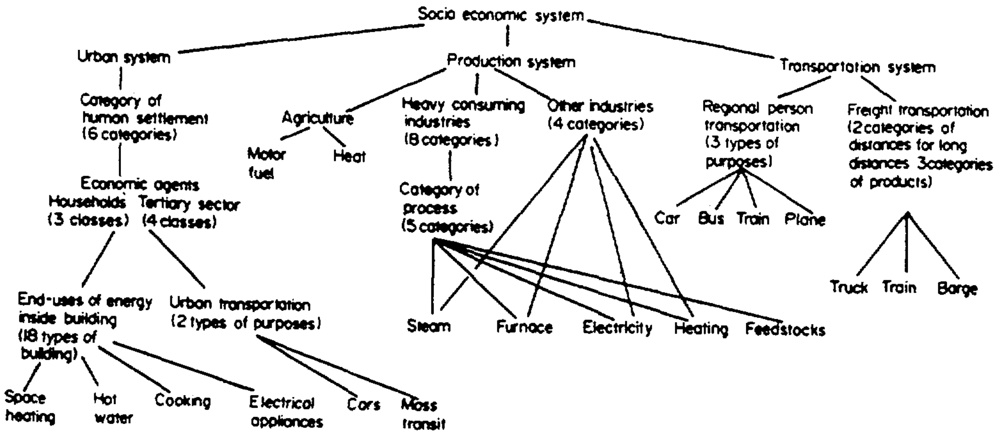


FIG.17.13. Disaggregation of the socio-economic system in MEDEE 3 [17.40].

– its outputs are useful and/or end-use energy demand by category of users and by category of end-users.

The level of disaggregation and the structure of this model are shown in Fig.17.13.

The equations of MEDEE 3 are of four types:

– mathematical equations to calculate energy demand for a given year
– mathematical equations to simulate the evolution of the technical and economic determinants of energy demand, from the year t to the year t + 1
– mathematical equations to control that no disturbances, inconsistencies or errors appear during the simulation
– tabular functions allowing the association of quantitative values to qualitative indicators used in the scenario description.

Three types of variables (determinants) are linked through these equations:

– endogenous quantitative variables, for which the value is calculated every five years by the model
– exogenous quantitative variables, either constant or defined for each year of calculation, but independent of the evolution of the socio-economic system under consideration
– the scenario's qualitative and quantitative variables which describe the evolution of the main technical, political, social and economic features of the socio-economic system under consideration.

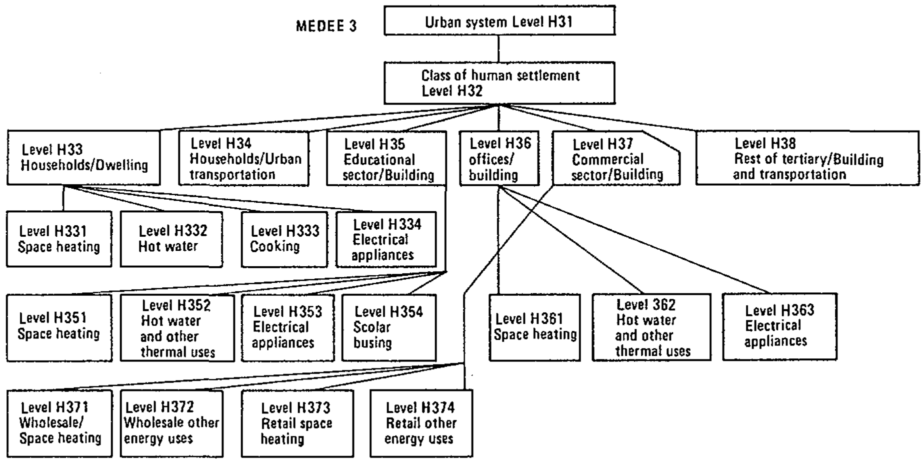


FIG.17.14(a). Hierarchical organization of the urban system of MEDEE 3 [17.41].

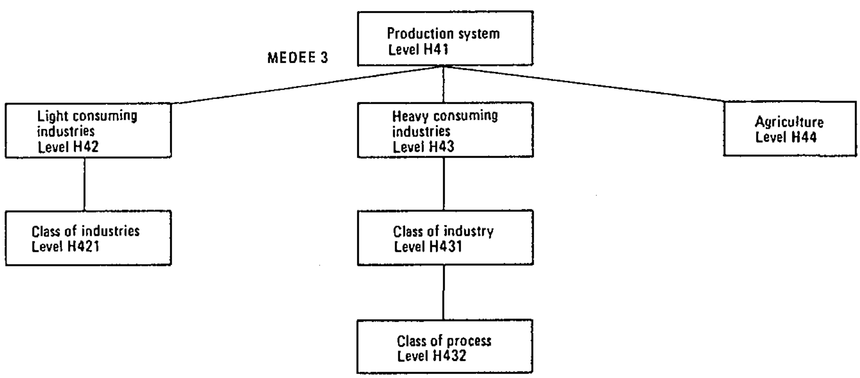


FIG.17.14(b). Structure of the MEDEE 3 submodel related to the production system [17.41].

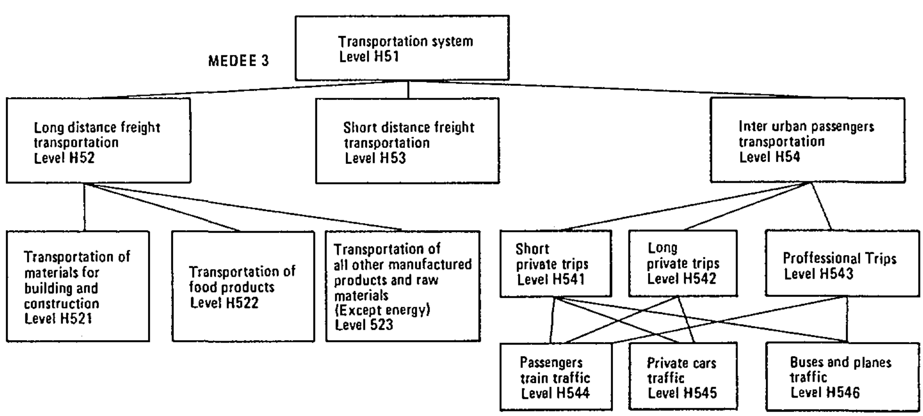


FIG.17.14(c). Structure of the transportation system submodel of MEDEE 3 [17.41].

MEDEE 3 has mathematical submodels related to the urban production and transportation system. They are reproduced in Figs 17.14(a), (b) and (c) [17.41]. Without entering into more detail, a few examples will illustrate the significance of the 'levels'. For example:

(1) The urban system – Fig.17.14(a)

Level H31: simulation of the evolution of the structure of the human settlement, and calculation of some indicators characterizing the evolution of the urban system as a whole (ten equations).

Level H331: calculation of the useful and final energy demand for space heating by class of dwellings and by type of heating system; simulation of the choices among the various heating systems in the new dwellings, which choices depend on the behaviour of the various decision-makers (household, public and private developers), on the prices of the various energy products and on the costs of the various systems (54 equations).

Level H332: simulation of the needs for useful energy for warm-water calculations of the resulting energy demand by category of households and dwellings (eight equations).

Level H333: calculation of the end-use energy demand for cooking (five equations).

The database of the submodel related to the urban system gathers the following elements:

- 65 endogenous variables for which it is necessary to give the initial values (201 values)
- 40 exogenous variables for which the values are given either once for all or for all years of calculation, independently of the scenarios (104 values)
- 38 scenario variables (68 values given) for each year of calculation and 67 values independent of time, for which the values are given in the tabular functions.

(2) The production system – Fig.17.14(b)

Three classes of light consuming industries have been taken into consideration: food and textile, mechanical goods and equipment, and the rest of the light consuming industries.

Eight different heavy consuming industries have also been distinguished: iron and steel, aluminium, cement, paper and pulp, glass, ammonia, ethylene and chlorine.

Each heavy consuming industry is divided into two to six subclasses, depending on the main usual or new production processes within the industry.

For each group of light industries or for each class of process within the heavy consuming industries, the useful and/or final energy demand is calculated for the main end-uses of energy: steam, furnace, electrical appliances, electrolysis, and mechanical uses, space heating and feedstocks. Examples of parts of the sub-model:

Level H41: calculation of the values of macroeconomic variables characterizing the production system: value added, employment and productivity of industry, building and construction, agriculture (16 equations).

Level H421: simulation of the evolution of the useful energy needs for steam, furnaces, mechanical uses and space heating in each class of light consuming industries, depending on the value-added of this class, calculation of the resulting final energy demand for all of these uses, taking into account the penetration of electricity in furnaces (13 equations).

Level H432: simulation of the evolution of the specific energy consumption for steam, furnace, electrical appliances and mechanical uses, space heating and feedstocks, by unit of production, for each process; calculations of the resulting energy demand, related to each use within each process (15 equations).

The database of this submodel, as far as France is concerned, is made up of the following elements:

- 25 endogenous variables for which it is necessary to give the initial value (218 values)
- 3 exogenous variables (6 values), independent of the scenario
- 25 scenario variables (161 values), independent of time, and 119 values given for all years of calculation.

(3) The transportation system – Fig.17.14(c)

Three different means of transportation have been taken into account for long-distance freight transportation: trains, trucks and barges.

Two kinds of trains have also been distinguished for passengers: traditional trains and high-speed trains.

No distinction was made among private cars.

Examples of parts of the sub-model:

Level H51: simulation of the evolution of the infrastructures of transportation: mileage of railways, roads, motorways and canals (17 equations).

Level H542: simulation of the evolution of the number of private long trips by class of households, calculation of the model split of these trips and simulation of the resulting traffic for each means of transportation (25 equations).

Level H543: simulation of the evolution of the number of professional trips; simulation of the resulting traffic for each means of transportation (11 equations).

The database of this sub-model is made up of the following elements:

- 42 endogenous variables for which it is necessary to give the initial values (51 values)
- 12 exogenous variables, independent of the scenario (31 values)
- 18 scenario variables (15 values independent of time and 12 values that must be given for each year of calculation).

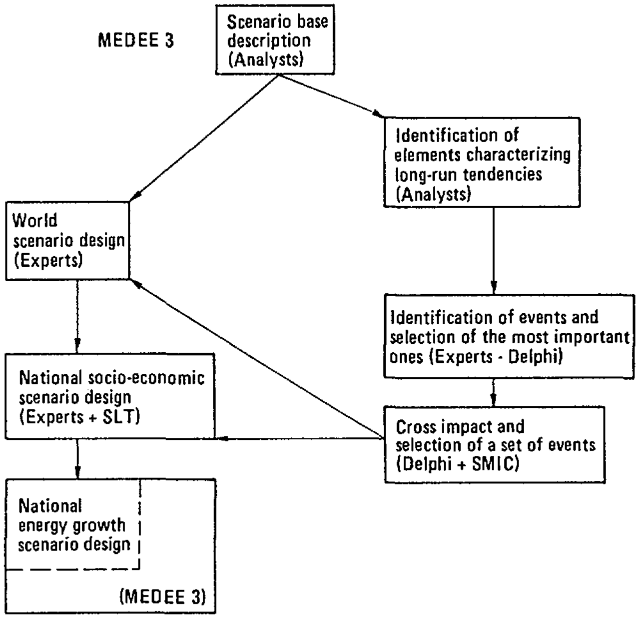


FIG.17.15. General procedure of scenario design in the MEDEE 3 approach [17.41].

(4) The scenario

As indicated previously, MEDEE 3 is fed with "scenario assumptions which are made in a consistent and plausible way". This has two meanings: MEDEE 3 translates, in energy demand terms, the evolution of the socio-economic system described through the scenario assumptions; and the quality and the pertinence of the projections of the long-term energy demand depend on the consistency and the plausibility of the scenario assumptions.

The scenario method is a synthetic approach which, on the one side, simulates, step by step and in a plausible and consistent way, a series of events leading a system to a future situation, and which, on the other side, presents an overall picture of this situation. It is based upon 'synchronic' and 'diachronic' analysis: the first simulates the state of the system at a given time and is oriented by the necessity of a consistent description, while the second deals with the sequence of events and must focus on the causality and the interrelationships which link them together.

The method of designing a scenario consists of three major elements:

– a dynamic base, which describes the initial situation of the system under consideration, its laws and its evolution tendencies, even those which are only germinal

– a path, which describes the overall evolution of the system in relation to the evolution of its components and of their interferences
– a final picture, which is the result of this evolution and which makes a pair with the base, with the same dynamic character.

The method used to design the scenario in the framework of the MEDEE approach is directly derived from this procedure. It is graphically displayed in Fig.17.15 [17.41].

(5) Conclusion

MEDEE does not predict the long-term energy demand, but relates the evolution of the energy demand to the evolution of the society; the quality of the long-term energy demand projections is directly dependent on the quality of the description of the development of the society.

Therefore:

– MEDEE can be used to prospect the energy future within a time horizon and a set of events which allow the investigator to describe consistently and plausibly the evolution of the society, i.e. if it can reasonably be assumed that in the period of time under consideration and within the general framework described by the chosen set of events, no major disruption appears, neither in the world environment, nor in the national system.

If this is the case, then MEDEE can be used in a satisfactory way as an energy planning tool, since:

– it translates, into final energy demand terms, the social, economic and technological policies of the public authorities, and then allows exploration of the alternative energy supply policies which could meet this demand
– it reveals the potential contradictions or inconsistencies which could result from these policies within the time period, and then facilitates making the appropriate decisions in the energy field
– it permits study of the impacts on the energy demand evolution of such perturbations as an oil price increase, technological innovation, etc.

17.4.2.2.3. The MEDEE S model – brief presentation

Inspired by the MEDEE approach, the MEDEE S model was developed to evaluate energy demand in developing countries. It is a technico-economic accounting-type model whose logic is akin to that of MEDEE 2. Nevertheless MEDEE S was conceived in a very different way from MEDEE 2 – it was completely rewritten – drawing on the experience gained from the MEDEE 2 and MEDEE 3 models and using an analysis of energy demand determinants from various developing countries. The following presentation heavily relies on the authors of the model descriptions [17.36].

Four main objectives governed the creation of this model:

(1) First of all to have a sufficiently general representation of energy consumption which would be relevant whatever the features and development level of the country examined and the information available. Thus the breakdown level, i.e. the type of sectors, end-uses or energy sources examined may be easily adapted for each country: in the same way, certain calculations can be made using various alternative methods (e.g. several alternative relationships for a single variable).
(2) To restrict the number of scenario variables in order to simplify the description of scenarios and to limit any risks of inconsistency.
(3) To adapt the modelling to the information available (or likely to be available); this has led to the adoption of a very different modelling from one sector or end-use to another (this creates a certain dissymmetry in the model) and to the selection of indicators normally found in national and international statistics as well as in energy surveys, as the energy demand determinants (that is as explanatory variables).
(4) To have, as far as computing is concerned, a language sufficiently standardized so that the model can be transferred to the largest possible number of computers at the least cost (greater 'portability' of the computing model).

The model is thus a very simple tool which can be redesigned for each particular situation. For each sector it has a basic module used in all situations and supplementary modules which may be added to these basic modules to provide more detailed modelling on a particular sector or end-use. In a way these supplementary modules throw more light on (or expand) important sectors or end-uses.

Before describing the MEDEE S, the main characteristics of the accounting model will be recalled, emphasizing the originality of MEDEE S in comparison with other models of this type.

Although they are simple as far as mathematical formulation is concerned – and perhaps because of this – these models have several advantages which explain and largely justify their development:

(1) They give a transparent outline for understanding energy demand by clearly showing the driving variables of this demand and therefore showing on which variables energy policies can act to control the development of energy demand.
(2) They can be used to establish energy consumption 'balance sheets' by end-uses, these evaluations being made by successive iterations, juggling with the values of the different parameters until the balance sheet consumption by sector is returned.
(3) These models mean that the implications of certain changes or socio-economic scenarios on the evolution of energy demand can be openly

and rapidly quantified (no hidden mechanisms or 'black boxes'): they therefore appear as tools which transcribe scenarios or socio-economic and technical changes into energy terms.

(4) Information requirements can be identified and therefore a framework for the collection of data necessary for actual and future energy consumption evaluation easily established.

In comparison with other accounting models the originality of MEDEE S stems from the following aspects: the method of understanding useful energy, the choice of scenario variables, the breakdown method and finally the existence of consistency controls and tests. The most important aspect by far is that concerning useful energy.

In MEDEE S the approach in terms of useful energy is not systematic and is only used for substitutable uses. To understand this, one must recall the two major reasons which led to the introduction of useful energy into accounting models: i.e. to measure the impact of the energy substitutions of energy sources with different efficiencies on consumption levels, and to take into account improvements in efficiencies. Efficiency gains can be taken into account directly at final energy level for non-substitutable uses and therefore it seems superfluous to resort to useful energy.

The approach in terms of useful energy amounts to the fact that a useful energy consumption level can be defined for each use, independently of the techniques used, and that the substitution of one energy for another means a variation in consumption levels only according to the differences in efficiency. But in many cases this approach seems to be far from reality as energy or technique substitutions bring about behavioural changes.

It is a problem which certainly exists in developing countries where the substitution of electric lighting for traditional lighting methods is taking place and probably also when cooking fuels are changed. In both these situations, the difference in consumption before and after substitution cannot be explained simply by examining the efficiencies. A socio-cultural dimension must be added to the technical one. In order to take this phenomenon into account a new coefficient (substitution coefficient) has been introduced. This coefficient encompasses the differences in efficiencies and measures the real variation in consumption when substitutions are made. It can be measured in surveys. If the behavioural effect is negligible this coefficient will represent an efficiency (absolute or relative according to the situation).

Another peculiarity of MEDEE S is that it has a limited number of scenario variables in view of its breakdown level. The energy consumption breakdown method is not theoretical or fixed but may be easily adapted according to whatever aspects are to be emphasized in the exploration of the future development of energy consumption and according to the information available.

Finally, as emphasized, the multiplication of scenario variables, and therefore of assumptions, increases the risk of inconsistency. To compensate for this risk, numerous consistency tests and controls have been introduced into the model in order to assist users and enable them to judge the consistency of certain developments or results in comparison with the initial assumption.

The MEDEE S model is made up of a certain number of basic modules which cover the main energy consumer sectors. Despite the relevance of other kinds of breakdown for analysing energy demand determinants in developing countries (modern sector/traditional sector, urban system/rural system, etc.), the sectors type approach seemed the only feasible one at the modelling level since most social, economic and energy statistics favour such a breakdown.

The model considers five sectors or basic modules: industry, households, agriculture, transport and services. Although presented separately they are not of course independent.

(1) Agriculture (and fishing). The main uses of energy to be considered in this sector are mechanical energy for irrigation (wind energy, diesel engines, animal energy, solar pumps . . .) and traction (e.g. fuel for tractors, animal energy), propulsion energy for fishing boats (fuel, wind energy . . .) and perhaps, in certain countries, the energy used for the conservation and drying of agricultural products (wood, fuel, solar energy . . .). Because of the comparatively small share of this sector in total commercial energy consumption (generally less than 5%) a fairly rough breakdown should be sufficient.

Four types of energy uses are examined: tractors, for working the land and transporting agricultural products; boats for fishing; irrigation techniques and water pumping; and thermal uses. Each use is characterized by the type of equipment used and its unitary energy consumption: for example irrigation considers gravitation, diesel pumps, electric pumps.

The supplementary module shows agricultural production in physical terms and can be combined with one or other of the basic variants.

(2) Industry. The breakdown of industry should be operated on the basis of the following principles:

- The main energy-intensive industrial consumers (e.g. steel production, construction materials, ammonia, nitrogenous fertilizers) should be identified and looked at in detail. The other industrial sectors should be grouped into a few major categories, which make it possible to characterize accurately the nature of industrial development (e.g. agricultural and food industries, capital goods industries).
- A breakdown according to major uses should be introduced: specific uses of electricity (electrolysis, electronics, small engines), other mechanical uses, and thermal uses according to the different temperature

levels (low, medium and high temperature) in order to analyse more accurately the possibilities of energy substitutions and development of new energy and techniques (solar energy, heat pumps, co-generation . . .).

The industrial submodel is made up of a basic module and two supplementary modules, 'iron and steel production' and 'energy-intensive products'. The basic module encompasses all the industrial sectors except for production already taken into account in the supplementary modules. The number of types and sectors examined can be chosen. Nevertheless three sectors at least must be examined in the majority of countries because their relative size characterizes the type of industrial specialization: intermediary goods (metals, construction materials); industrial and household equipment (e.g. cars, machines); consumer goods (textiles, food).

In the basic module the projection of energy consumption by energy type is deduced from the development of value added for each sector, then from the development of 'energy content' by main uses ('fuel', 'specific electricity' and 'thermal uses') and finally from the role played by each energy in competitive (substitutable) uses (thermal uses). Energy content may vary within the model due to a structure effect, related to the sector but independent of the end-uses and due to a technical effect, related to the end-use but independent of the sector.

To project the penetration of different energies for competitive thermal uses, two alternative approaches may be used in the basic module: one favours an analysis of penetration possibilities according to the type of thermal uses (temperature level) and does not differentiate between sectors; the other examines thermal uses as a whole (independent of the temperature level) but differentiates between sectors.

(3) Households. Most of the energy at present used by households in developing countries is for cooking. The rest of the energy used is for lighting, and in certain temperate or continental zones, for heating. Distinctions in this sector should also be made between the other energy uses which are likely to become more widespread if average incomes rise (domestic hot water, electrical household appliances, air-conditioning).

Different social groups should be distinguished in order to take into account the social heterogeneity, i.e. differences in life styles. This breakdown into social groups also makes it possible to integrate the effect of changes in social structure on energy demand.

In large countries with substantial regional disparities which result in different degrees of access to commercial and non-commercial forms of energy (electrification or not in certain zones, difficulty of access to the distribution network of petroleum products, biomass availability), or with differences in climate, a breakdown based on major regions is necessary. Thus the disaggregation should be made in several ways: end-uses, social groups (including urban/rural distinction), regions, etc.

The 'household' submodel examines two main end-uses: cooking and lighting. In addition supplementary modules representing four other uses may be added: 'heating', 'water heating', 'cooking' and 'electrical appliances'. The adaptation of the model to a specific country will consist in selecting the most appropriate combination of modules. If only the basic module is considered, the end-use 'cooking' will have to include other uses of fuels (heating for instance) and the end-use 'lighting' all the uses of electricity.

The population can be divided into a certain number of categories. To the usual breakdown between urban and rural households, especially useful in accounting for the substitutions of commercial energy for non-commercial energy, a double breakdown into 'areas' (region for rural households for instance, type of cities for urban household, for instance) and 'social classes' may be added. These classes may differ for urban and rural households. They can be based on income, living standards (type of dwelling, size), or professional activity for urban households. As to rural households, the classification used should take into account the conditions of access to biomass (agricultural wastes, wood) and rely on the activity (agricultural or not), the possession or not of land, the level of monetarization, etc.

(4) Transportation. The distinction traditionally used in the industrialized countries between the transportation of goods and people remains relevant although some of these activities are covered by vehicles which may be used for both. For the transport of people, an approach based on the mode of transport, purpose and household category, makes it possible to characterize trends in individual mobility, in substitution between modes (foot, bicycle, car, etc.) and in the mode/mobility relationship (access to such and such a mode of transport generating new trips). A distinction between urban trips and trips between towns or from town to country, whenever feasible, is necessary in that it is then possible to deal with homogeneous areas of substitution between modes of transport.

For the transport of goods, the distinction should also be made between the modes of transport and, whenever possible, distinguishing short-distance trips, which are often made by vehicles having a high petrol consumption rate. Long-distance trips can be examined on the basis of major axes, in order to take into account existing infrastructures and the possibilities of substitution between modes of transport.

The 'transport' submodel is made up of a basic module in which three types of transportation are distinguished: domestic passenger transport, domestic transport of goods and international air and sea transport. A supplementary module enables a more detailed analysis of urban transport to be made.

The scenario enables the specification of the following developments in the transport sector:

- The development of household car ownership, of public transport supply, and therefore, of substitutions between modes, on the one hand, and the development of goods traffic by modes on the other, as a consequence of economic development and transport policy.
- The development of vehicle stocks by type of fuel used and their unitary consumption, dependent on energy policy.

(5) Tertiary sector. This sector is never easy to define as it groups together a multitude of often heterogeneous activities. However, it is possible to distinguish between two major uses (specific electricity and air conditioning). In countries where tertiary activities account for a substantial share of overall energy consumption, a breakdown of major types of activity could be operated (offices, hotels, commercial establishments, artisan premises, etc.). Concerning commercial establishments and artisan premises, an urban/rural distinction could be made, if it is necessary to take into account the conditions of access to energy resources (e.g. electrification or not, in the zones under consideration). For those countries where air-conditioning may become important an approach based on climatic zones should be considered.

The tertiary sector submodel is made up of one basic module and two supplementary modules, 'heating' and 'air conditioning', which, as their names imply, enable the identification of determinants for heating and air-conditioning and their terms of development.

In the basic module, energy demand is related to employment and subdivided into two end-uses: specific electricity uses (current uses of electricity) and thermal uses (all current uses of fuels). Two variants permit the introduction of either a breakdown in terms of activities whose number is variable (e.g. businesses/hotels), modern sector/traditional sector or a breakdown of all activities by area, following the example of the 'household' submodel. In the first case, the distribution of energies for thermal uses may be defined by sector and in the second case by areas.

MEDEE S, a type of accounting model, should not be the final objective of energy demand evaluation and forecasting, but slowly, as the data become satisfactory and the major issues have been identified through alternative scenarios, the model should be enriched so as to integrate endogenous procedures which simulate the behaviour of households and industry with respect to their technical and energy choices. Then one comes up with a systemic model of the MEDEE 3 type, which implies a careful analysis of the behaviour of economic actors and, more generally, of the dynamics of changes in energy demand determinants [17.36].

17.4.2.3. The MAED model

The MAED model (Model of Analysis of the Energy Demand) is a simulation model designed to evaluate medium- and long-term demand for energy in a country or in a region.

MAED was developed by the IAEA working in collaboration with IEJE, Grenoble and IIASA, and is very similar to the simplified MEDEE 2 model (1978) which was adapted by B. Lapillonne to suit the needs of IIASA. However, further work was necessary to facilitate its application with the more limited database which is typical of developing countries [17.43]. This was done at the beginning of 1980 and completed during 1981. MAED is now used by the Agency to develop coherent projections of future energy and electricity needs. It was first applied in Algeria.

17.4.2.3.1. The MAED 1 version

The MAED model, outlined in Fig.17.16, provides a flexible simulation framework for exploring the influence of social, economic, technological and policy changes on the long-term evolution of energy demand.

In order to analyse the energy demand of a given country, the economy is subdivided into the major economic sectors (household, transport, industry, services), and the energy needs of each sector are subdivided into various elementary needs of useful and final energy (needs for space heating, cooking, furnaces, inter-city transport, and so forth).

The useful and final energy requirements are described by two types of parameters: one linked to the technical considerations (such as the efficiency of different appliances) and the other linked to life-style considerations (e.g. average distance travelled by car during a year, size of dwelling, etc.).

Special emphasis is given to the forecast of electricity demand, not only in terms of total annual requirements as for other forms of energy but also in terms of the hour-by-hour distribution of power demand during the year.

The MAED approach involves the following steps:

(1) A systematic analysis of the social, economic and technological system in order to identify the major factors determining the long-term energy demand evolution.
(2) Disaggregation of the total energy demand into numerous end-use categories. The selection of the categories to be considered depends upon the objectives of the analyst and on the availability of data.
(3) Organization of all determinants into a multi-level structure, from the macro to the micro level, showing how the 'macrodeterminants' affect each end-use category.

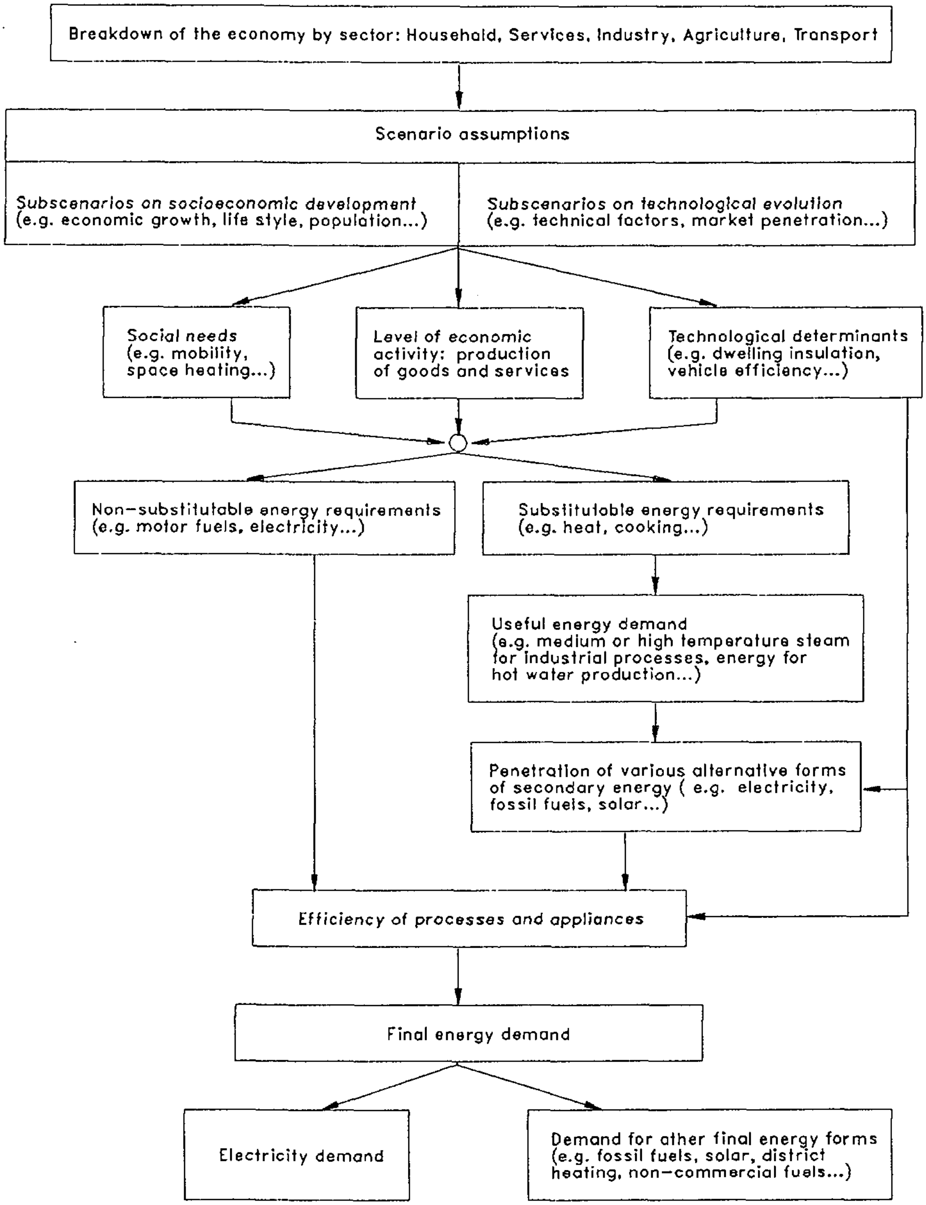


FIG.17.16. Scheme used in MAED to project useful and final energy demand [*17.44*].

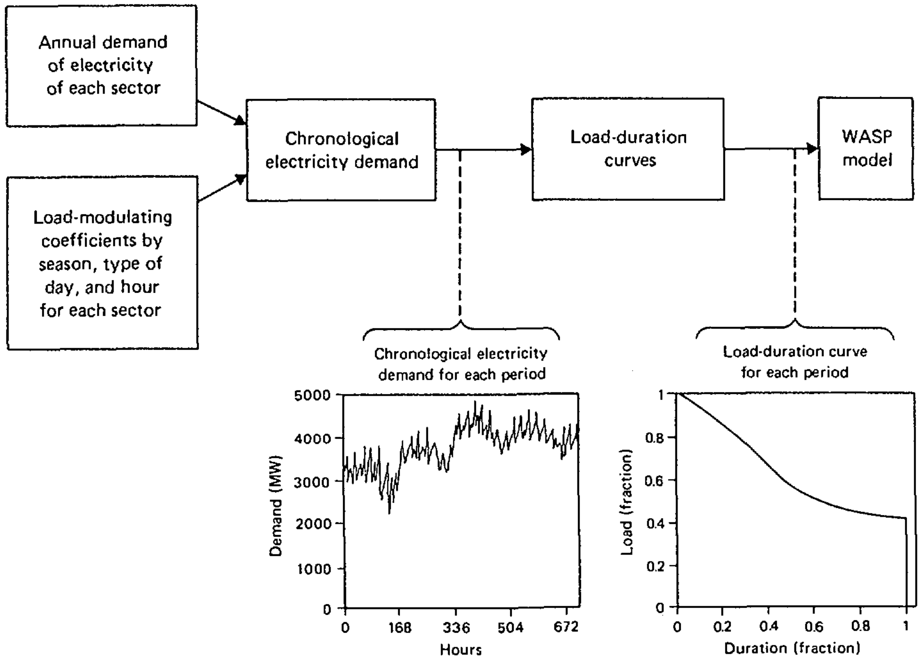


FIG.17.17. MAED estimates of load-duration curves for input into the WASP model [17.43].

(4) Construction of a simulation model by simplifying the system structure and grouping the determinants into exogenous determinants and scenario elements.

The exogenous determinants encompass those factors for which the evolution is difficult to model (e.g. population growth, number of persons per household), but for which long-term evolution can be adjusted suitably from past trends or from other studies such as demographic studies. The determinants chosen as scenario elements are those for which the evolution cannot be extrapolated from past trends because of possible structural changes in the energy demand growth pattern. Policy factors are an example.

The annual electricity demand of each sector as determined in module 1 can be further processed:

– by module 2 ('hourly electric power demand') into the hourly power demand imposed on the grid
– by module 3 ('load duration curve') which ranks the hourly demands imposed on the grid in decreasing order of magnitude and provides the annual electric load duration curve – see Fig.17.17.

- module 4 ('load modulating coefficients') is an auxiliary module which may be used to analyse the past evolution of the coefficients describing the variation of the hourly electric loads, based on load curve information determined from statistical data.

The MAED model was applied for the first time in a study carried out in co-operation between the Société Nationale d'Electricité et du Gaz d'Algerie, SONELGAZ (Algerian National Society of Electricity and Gas) and the IAEA. This application was very successful, but during the study some weak points of the model and the necessity to modify the model were discovered. That led to the improved version of MAED 2.

17.4.2.3.2. The MAED 2 model

In the improved version of MAED 2 a series of modifications were introduced, i.e.:

(1) The computer code of MAED 1 has one unified block for energy demand calculations, so it is not easy to insert any changes. Therefore, it was considered necessary in the new version to design a code consisting of several submodules or subroutines, each corresponding to a different sector or subsector of the economy. This is the first distinctive feature of the new version.
(2) Further, the MAED 1 version has a rigidly defined set of determinants for every sector. There is no possibility in the model to choose one or another set of these determinants, or factors, which serve as the driving forces for the model. The new version offers the possibility of choosing one or another set of determinants and, correspondingly, to calculate the energy demand depending on the availability of input information.

MAED 2 provides two options for every sector and subsector. If all the necessary initial information is available, the energy demand calculation can be conducted by using parameters in physical terms, for example, for the steel industry tonnes of steel produced, for the household sector the number of dwellings, for transportation tonnes·km transported, etc.

In the case of lack of information or when the expected energy demand for a given sector is small and there is no reason for detailed calculation, the economic parameters in monetary units (such as GDP, value added, average income) can be used as determinants for energy demand calculations. Therefore, the second distinctive feature of the new version is the possibility to choose one out of two methods described for every sector and subsector of economic activity.

The third distinctive feature of the new version consists of the possibility to distinguish, in most sectors, specific industries or even specific processes.

For instance, the energy-intensive industries subsector could consist of up to nine different industries or processes, such as chemical industry, non-ferrous industries, steel production by electrical furnace, steel production with fossil fuels, etc.

All modifications which have been introduced relate to module 1 of the model, where energy demand determination is considered. Modules 2 and 3 for the load curve and the load duration curve remained unchanged.

The structure of the new modified version MAED 2 is shown in Fig.17.18. Accordingly the model consists of eight blocks. The first block is similar to the subroutine MACRO and is used for the same purpose – to define in quantitative terms the evolution of the growth of each economic sector.

The seven other blocks correspond to the seven sectors of the economy considered: manufacturing, mining, agriculture, construction, transportation, services and household.

Each block or economic sector includes at least two sub-blocks. If the detailed estimation of energy demand is required and if proper information is available, the sub-blocks located on the scheme on the right-hand side could be used. These sub-blocks consider the sector with further breakdowns; both monetary and physical units could be used to specify the value of the determinants.

In another case one can use the sub-blocks shown on the left-hand side. These sub-blocks consider the sector as a whole and GDP or the part of it contributed by the sector serve as a driving force.

A slightly different structure can be observed for two sectors, transportation and household. The whole sector of transportation is broken down from the beginning into the following four parts: urban passenger, intercity passenger, international and freight transportation. To determine the energy demand by freight transportation it is also possible to do so either in terms of economic activity in monetary units or in terms of the tonnes·km of goods transported.

Taking into account the importance of the household sector for most developing countries, it was decided to have three options in the model for this sector: the sector as a whole by average income, the sector as a whole by the number of people living under a certain level of energy consumption, and a very detailed consideration, with three types of settlements and with the breakdown into subsectors with different process categories considered.

The computer code is designed in such a way that every sub-block or every rectangle in the scheme corresponds to the separate subroutine in the code. There is a main controlling program which governs all calculations and chooses one or another subroutine by means of indicators which should be introduced by the user.

How the inside structure of the economy sectors is considered in the model is presented in Fig.17.19. For example, within the household sector there are three types of settlements which could be treated separately – large cities,

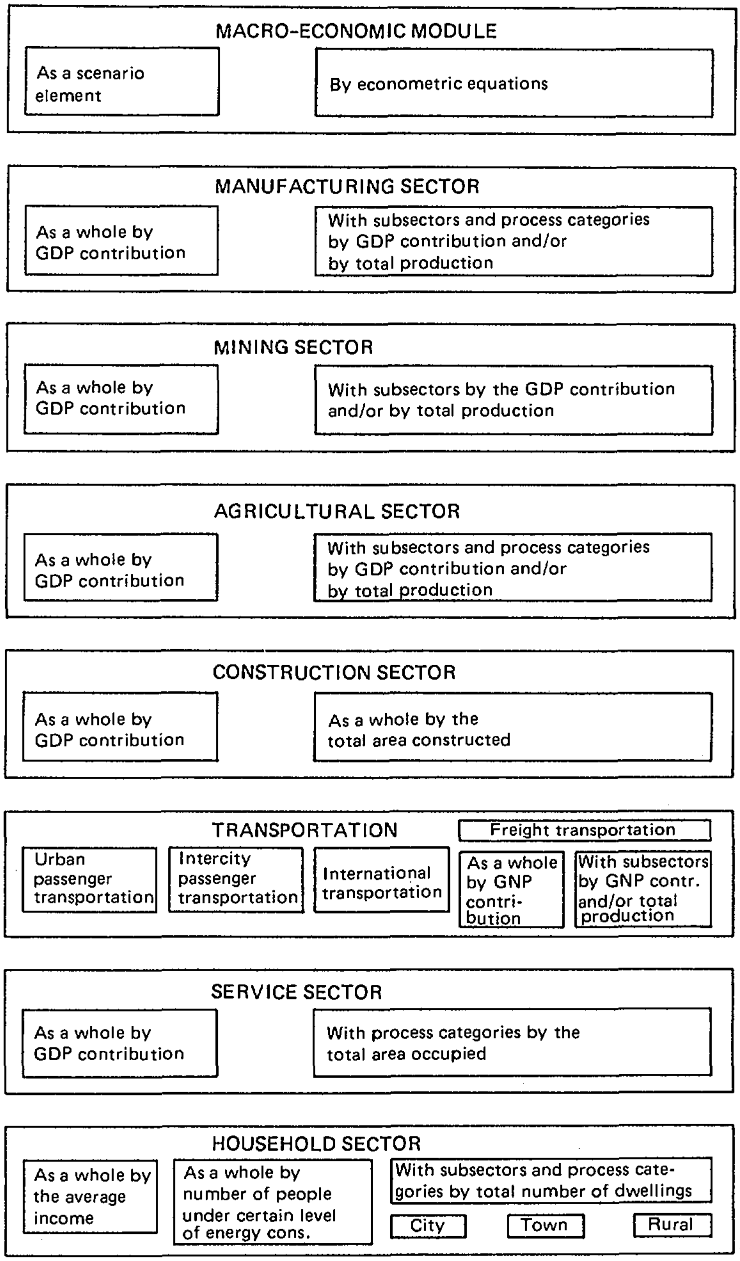


FIG.17.18. MAED 2 – model structure [17.45].

MANUFACTURING SECTOR

ENERGY-INTENSIVE INDUSTRIES (UP TO 9 INDUSTRIES OR PROCESSES)

FOR EXAMPLE:
1 - STEEL, FOSSIL FUEL FURNACE
2 - STEEL, ELECTRICAL FURNACE
3 - NON-FERRO MATERIALS
4 - CEMENT AND BUILDING MATERIALS
5 - CHEMISTRY
6 - GLASS
7 - PAPER AND PULP
8 -
9 -

CONSUMER GOOD INDUSTRIES (UP TO 4 INDUSTRIES OR PROCESSES)

FOR EXAMPLE:
10 - FOOD
11 - TEXTILE
12 -
13 -

OTHER INDUSTRIES

14 -

MINING SECTOR

(UP TO 2 PROCESSES)

FOR EXAMPLE:
15 - DRILLING
16 - MINING

AGRICULTURAL SECTOR

(UP TO 5 SUBSECTORS OR PROCESSES)

FOR EXAMPLE:
17 - GRAIN
18 - MEAT
19 - OTHER ANIMAL PRODUCTS
20 - MILK AND DAIRY PRODUCTS
21 - OTHER AGRICULTURAL PRODUCTS

CONSTRUCTION SECTOR

(3 AREAS ARE CONSIDERED)

HOUSEHOLD
SERVICE
INDUSTRY

TRANSPORT SECTOR

(4 MODES ARE CONSIDERED)

URBAN PASSENGER TRANSPORTATION
INTERCITY PASSENGER TRANSPORTATION
FREIGHT TRANSPORTATION
INTERNATIONAL AND OTHER TRANSPORTATION

HOUSEHOLD SECTOR

(3 TYPES OF SETTLEMENTS ARE CONSIDERED)

CITIES
TOWNS
RURAL AREAS

SERVICE SECTOR

FIG.17.19. MAED 2 – economy sectors considered [17.45].

towns or large villages and rural areas. Further details on MEDEE S can be found in Refs [17.48–50].

17.4.2.4. Draft of a more simple energy model

After describing in so much detail the efficient but complex MEDEE and MAED models, an interesting proposal might be mentioned for a more simple energy forecast model, which might prove acceptable in initial planning phases, especially in developing countries. Its principal merits, besides its simplicity, consist in including the non-commercial energy resources, separating a rural and an urban GDP, and singling out electricity as a variable for its special important role in developing countries and its high investment requirements. The proposal was formulated by A. Ferrari [17.46] and inspired by the J. Parikh model elaborated at IIASA.

17.4.2.5. More specialized models

In contrast to the national or regional category of models presented, there are a great series of more specialized models, forecasting for example end-use energy demand of the residential sector, transportation sector, etc.

17.4.3. Optimization models for energy system development

The history of the attempts to elaborate optimization models for energy system development is not very old, since the system approach to energy is itself rather new. As described in chapter 1, it took a long time to extend the system concept, already so popular in the electricity sector, to the overall energy complex, and this evolution is still not completed. Under these circumstances, it is particularly pleasant to discover that the conceptual gap in the current electricity-energy approach is much less encountered in the modelling discipline.

An impressive number of energy and electricity optimization models are available or in different phases of elaboration or research. References [17.33 and 17.51] give an excellent overview, in an adequate classification, according to areas covered – national and international, number of fuels treated and linkage between energy and general economy. However, and this is a personal opinion of the writer, despite the sophisticated energy models available and partly applied, we still lack one which is simple, transparent and extendable, and able easily to accommodate the requirements of the majority of developing countries with low GNP and energy consumption, although such a model is urgently needed.

As interesting bibliographical documentation from IAEA course papers on the subject [17.52–58] are here referred to.

Once energy demand is determined or at least 'prospected' it is necessary to check if its level is compatible with the constraints of the existing energy system and the rest of the national economy, and to find the best options for meeting it by adequate supply. Such operations, however, require more complicated techniques, in the form of tools, which can model the different reciprocating influences.

There are two groups of models developed for this purpose:

– supply/demand balance models
– import analysis models.

From the large number of such models in use, a few are briefly commented on, the selection criterion being their presentation in previous IAEA courses.

17.4.3.1. The optimization model EFOM

The model EFOM (Energy Flow Optimization Model) was designed at the IEJE by D. Finon [17.53] to serve for French national planning and was later adapted to the needs of the European Economic Community (EEC) [17.59]. The first version, an Energy model for France [17.60] was very competently reviewed by Y. Mainguy in [17.61], which represents also a good summary description.

The energy supply system considered in EFOM consists of all operations permitting cover of a certain energy demand at the consumption stage, i.e. primary energy extraction, production, import, conversion, storage, transport and distribution.

The model determines a coherent optimized energy supply system to meet the energy demand, the optimum being defined by the lowest present-value costs. Interestingly, this optimization is sought under constraints, i.e. under the influence on the energy system of factors other than costs. The study for France was carried out in 1975 for the period 1975–2020. The final results were: the primary energy balances for characteristic years, the intermediate detail energy balances, the necessary equipment and investments and subsystem balances [17.59].

17.4.3.2. The MARKAL model

The MARKAL model (MARKAL: an acronym for market allocation) is a multi-period linear programming model which has been developed and applied by 15 OECD countries for the purpose of energy technology research and development planning [17.62]. Triggered by the IEA interest to optimize the energy research, development and demonstration (RD&D) programme – over US $\$7 \times 10^9$ were spent in 1980 by IEA governments – in order to ensure adequate energy supply in the coming decades, especially by reducing dependency on imported oil, the MARKAL model can also serve for other purposes, such as:

- the representation of energy technologies and the description of the system interactions between technologies and energy carriers depending on costs, technical parameters and socio-economic constraints
- the analysis of substitution and conservation effects
- the quantitative analysis of the future role of energy technologies in the energy system
- the determination of cost-, supply- or environmental optimal supply systems or optimal systems related to a combination of these overall aspects.

As a dynamic multi-period model the energy system is not represented at a single point of time but in its development over successive interdependent planning intervals which constitute the planning period. The number and length of the planning intervals are user-defined.

For every model application the objective functions are specified in correspondence with the overall goals of a country's energy policy. If desired, trade-off analysis can be pursued.

In the context of MARKAL's use in different projects, for example, the following objective functions were defined:

- minimization of total energy system costs
- minimization of oil imports
- minimization of the amount of foreign exchange for energy imports
- maximization of renewable energy use
- maximization of domestic energy resource.

Figure 17.20 shows the representation of the energy system in the MARKAL model.

MARKAL is written in a flexible general code which allows for the representation of very different energy systems. If the model features available in the current version are adjudged to be insufficient for an appropriate description of the system analysed, the model is enlarged by new model features. Thus, the current structure of the model is a product of an initial systematic approach enriched by the experience gained in a number of projects in industrialized as well as in developing countries.

The basic input data are structured in a series of classes and tables which contain quantitative information about energy carriers and technologies. For each technology and energy carrier one table is used to describe their technical, economic, and time parameters.

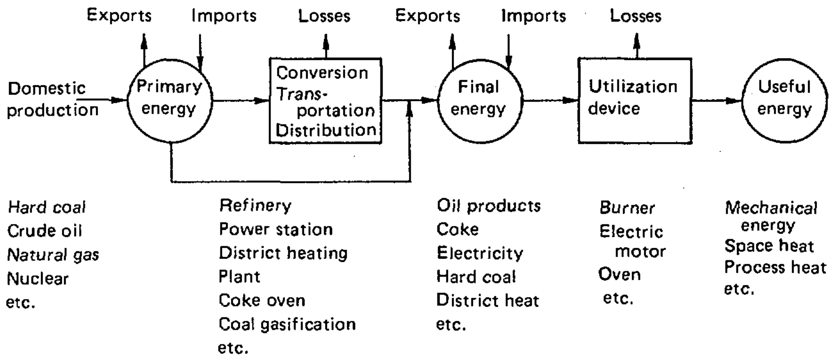


FIG.17.20. Structure of the energy system representation in the MARKAL model [17.63].

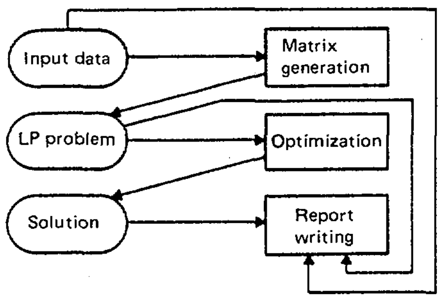


FIG.17.21. Processing step in MARKAL use [17.63].

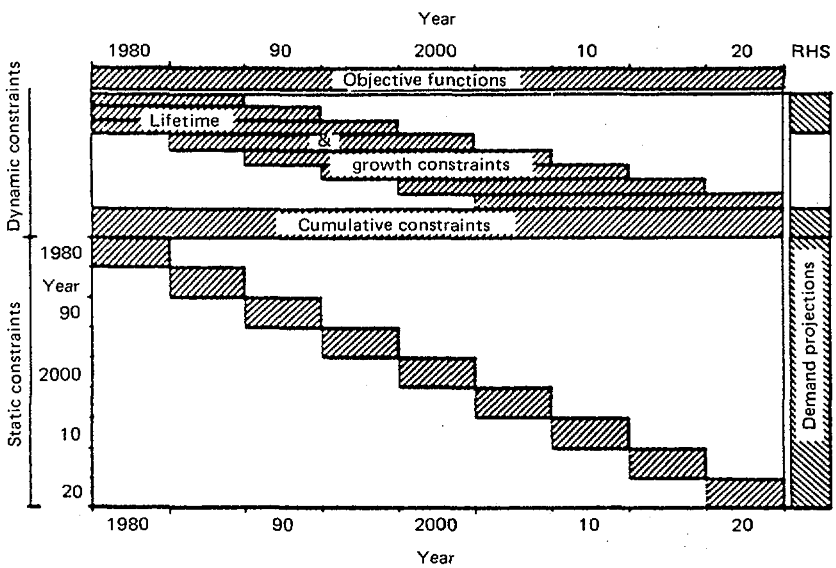


FIG.17.22. Structure of the multi-period matrix of the MARKAL model [17.63].

The equations/constraints of the model are categorized in four types:

- balances for energy carriers
- constraints for capacity expansion and operation of technologies
- special equations for the modelling of electricity generation and load management
- non-binding accounting constraints which do not place limitations on the operation of the system.

The generation of equations as a matrix uses the programming language OMNI, which has been developed specially for the generation of matrices in *linear programming.*

The class and table structure is a feature of the OMNI language. Classes structure energy carriers and technologies according to relevant energy-economic properties and/or report requirements. For example, all electricity-generating technologies form a class and so does a subset of them such as base-load power plants. If the user specifies a heavy-oil power plant as a member in the class of electricity-generating technologies, automatically the model creates a number of equations referring to the operational characteristics of the plant and introduces its electricity production in one of the electricity balance equations. The latter type of equation ensures that the total electricity production in the system is sufficient to meet the demand.

After the matrix generation the optimization of the linear programming problem is executed. A report program compiles the desired information from the solution, which is the output from the optimization step. The sequence of processing steps for MARKAL is graphically shown in Fig.17.21.

The generation of equations leads to a matrix structure as shown in Fig.17.22.

The static constraints which constitute the block diagonal structure in the lower part of Fig.17.22 can be further subdivided into

- balance constraints
- technical constraints and
- constraints reflecting other political, technical and economic conditions.

Constraints for the electricity sector in general correspond to the aforementioned constraints. But electricity is treated in a special manner to allow for load management. For this purpose, the year is divided into three seasons — winter, intermediate (spring and autumn) and summer — and two diurnal divisions — day and night.

To approximate/model the load curve, up to six time divisions can be defined, i.e. winter-day, winter-night; summer-day, summer-night; intermediate-day, intermediate-night.

Which of these six time divisions are actually used and how they are defined is based on the analysis of medium-to-long-term load forecasts.

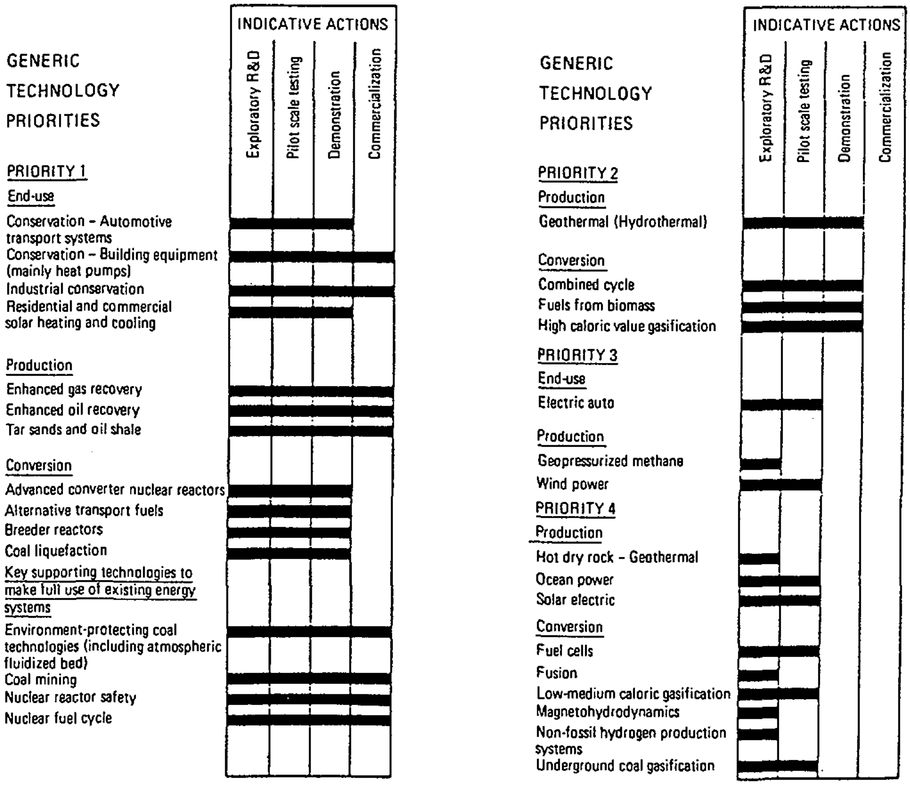


FIG.17.23. IEA energy RD&D group strategy [17.62].

The defined electricity balance constraints are automatically generated. Their function is to ensure that the electricity demand in each time division is met. The electricity demand results from the operation of electricity-consuming processes and demand (end-use) technologies, and the electricity input to the mining of primary fuels. If the demand is given in terms of useful energy demand, which is usually required, the total electricity demand is endogenously determined because the choice of electricity-consuming technologies is subject to the optimization.

Peaking constraints ensure that sufficient capacity is available to meet the peak demand, including a reserve factor to allow for plant outage. The peaking equations are written for both the summer and winter day divisions.

The base-load constraint ensures that base-load power plants, like nuclear and large coal-fired plants, maximally produce an exogenously defined proportion of the sum of total electricity night production within the system and electricity imports. They are constrained to operate at the same power level day and night.

Constraints reflecting other political, technical and economic conditions which have to be taken into account can be formulated and added to the aforementioned constraints, which are automatically generated by the specification of class members and provision of data for these class members in the corresponding tables.

The function of MARKAL is to represent the energy system of a country, or one of its regions, as a linear programming model, which is a set of linear constraints, with variables and parameters defined by the user as input data. The chosen objective function is then minimized taking into account the constraints and the resulting energy flows, technological options and costs are available for further analysis. The energy demand is exogenous in terms of useful energy. The energy demand in terms of final energy is determined endogenously by the optimization.

The model results are presented in report-tables which can be modified according to the information desired by the user.

Important output figures from the model are:

- amount of domestically produced, exported and imported energy
- capacity expansion of technologies over time
- production of energy carriers in conversion processes
- supply of useful energy by end-use technologies
- shadow prices of energy carriers, etc.

The main input data for the tables of the model are:

- energy demand in terms of useful energy
- technology data, including energy inputs and outputs, thermal efficiency, economic lifetime, availability, environmental emissions, investment cost, fixed and variable operation and maintenance costs, transport and distribution costs and losses
- prices for energy imports
- costs of domestic primary energy production
- constraints on energy imports, domestic production, technology capacity expansion and use, etc.

Since its first IEA group application in 1976, the MARKAL model has undergone many improvements and adaptations. A general version was developed for each of the 15 IEA countries participating in the project, providing a flexibility in modelling the respective national energy systems. The model was further used for the study of local energy systems, i.e. geographically more narrowly defined systems, in Sweden and Canada. Since 1980, the model has been applied and further developed for the analysis of national energy systems in Brazil and Guangdong province in the People's Republic of China. Projects under way which will use the MARKAL model are for Indonesia and OLADE.

The MARKAL model is not proprietary in the sense that it is purchasable. A model transfer, i.e. transfer of the software and all kind of documentation, is carried out without any monetary changes. However, experience has shown that a meaningful use of the MARKAL model requires a lot of experience and training with the model. Guided by that insight a purely technical model transfer will not be effected. Instead, in the Federal Republic of Germany, the KFA Jülich provides a training programme embracing relevant issues in energy planning for developing countries, modelling of energy systems with MARKAL, and running and analysing the model.

Although not directly related to energy planning, it is interesting to conclude with a presentation of MARKAL's ability to examine complex problems, in the form of the final results of the IEA energy RD&D group strategy study – see Fig. 17.23 [17.62].

17.4.3.3. The Argonne energy model – AEM

The Argonne energy model is an analysis tool used for projecting energy supply/demand balances [17.32]. It is a generalized equilibrium model, derived from the SRI/GULF model, in use in the USA and other countries and available in several versions.

The model is based on the matching of energy supply and demand on the basis of price. It uses a network formulation to trace energy flows – see Fig. 17.24.

AEM has a number of generic process models that can be linked to form a desired network: conversion, resource, allocation, transportation and electric power. The conversion process simulates energy processing facilities, the resource process simulates the production of a depletable resource, the allocation process simulates market competition.

The model uses an iterative solution technique summarized as follows:

- start at the bottom of network, assuming the quantities to be used
- work up, computing prices at each step
- with prices of delivered fuel at top, compute demand for different fuels
- work back down determining quantity of resources required
- repeat up and down iteration until there is no change.

The process as shown in Fig. 17.25 is equivalent to finding the intersection of the supply and demand curves for the entire energy system.

The model also handles other features, for example: technology availability, learning curves, equipment ageing, behavioural lag, relaxation algorithms.

The initial model solution, computed for specified future years, reflects an equilibrium condition, unconstrained, of least cost within the allocation parameters and balanced for the entire energy system. This solution allows evaluating

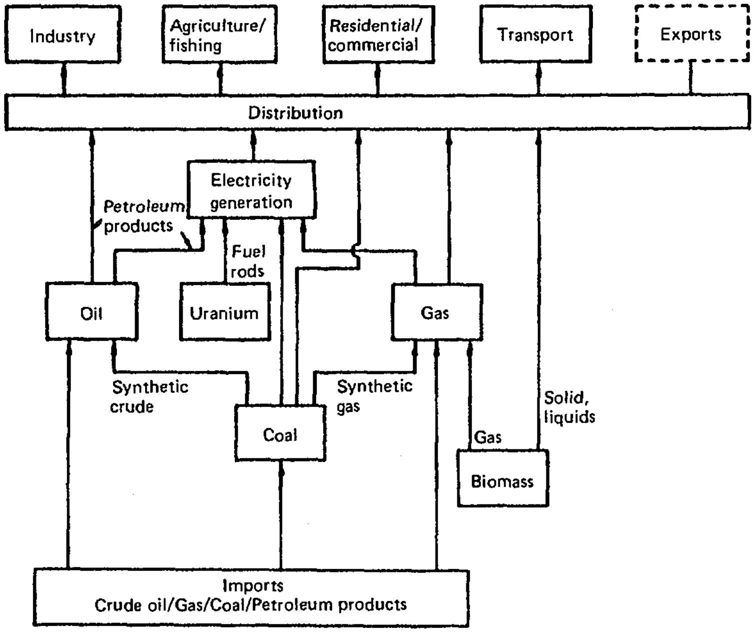


FIG.17.24. Network formulation of the AEM model [17.32].

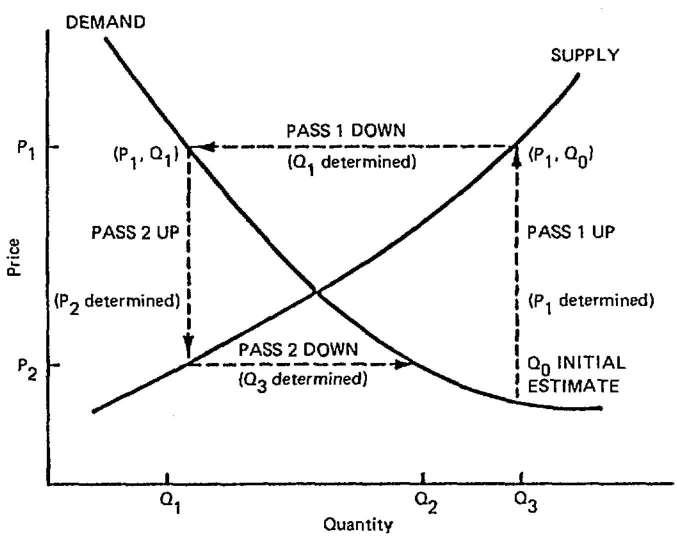


FIG.17.25. Iterative steps of the AEM model [17.32].

what the optimal energy supply system is in the absence of government constraints, how the demand for different fuels would grow in the absence of controls and what the market clearing prices of various energy forms would be.

Subsequent model runs allow the planner to test the impact of various energy policies and strategies, such as: price controls, quantity constraints, subsidies, technology emphasis, conservation, growth scenarios, etc.

The AEM model has some substantial advantages: it can be designed to suit special purposes, to display the latest situation, it can deal with non-linear behaviour and provides the ability to address many alternatives. It has, however, also some drawbacks: it is complex, data-intensive, difficult to apply to small systems and not especially user-friendly.

The Argonne National Laboratory is currently developing a new energy planning model, which will be easier to use, will reflect developing country conditions more accurately, will continue to use the equilibrium concept and will permit evaluation of specific capacity additions [17.32].

Once a system-wide supply/demand balance runs (by the AEM model or a manual balance), other models can take over and analyse more specific tasks, for example: ESPM for developing facility build schedules, costs and labour requirements or WASP to analyse the electric sector in more detail.

The Energy Supply Planning Model (ESPM)

The ESPM (Energy Supply Planning Model) provides a systematic means of calculating, for any candidate energy development strategy, the total direct resources (capital, labour, materials, equipment, land, water, and energy) required to build and operate the energy-related supply facilities needed for the strategy. The model is used to analyse the feasibility and impacts of proposed strategies by addressing such questions as:

(1) What energy and transportation facilities need to be constructed to implement a given national energy development strategy?
(2) When do these facilities need to be on line?
(3) When do they need to be committed, based on the lead time for building the facilities?
(4) What are the financing requirements for the strategy?
(5) What are the import requirements for the strategy and what impact will the strategy have on the balance of payments?
(6) What are the requirements of a specific energy industry? For example, what will be the labour requirements of the coal industry in a given future year? What will the land and water requirements be?
(7) What resources are required to operate the facilities?

The ESPM was developed by Bechtel for the US National Science Foundation from 1973 to 1975. The model's original primary application was identification of the potential bottlenecks to rapid development of US domestic energy resources. Since then the model database has been extensively revised and expanded. The computer programs have also been extensively revised to enhance user accessibility and provide additional features. The model has been modified to address specifically issues of importance to energy planning for developing countries and has been adapted for use in studies for Egypt, Indonesia, Peru, Portugal and the Republic of Korea. Computer programs have been developed to assist in the adaptation process.

The ESPM has the following distinctive characteristics:

- The basic database consists of detailed engineering design made for over 100 categories of capital, labour, materials and equipment resources required both to construct and operate energy-related facilities.
- The model is conceptually simple. The model user directly specifies the energy development strategy to be evaluated; no feedback loops or optimizing procedures are employed.
- The model is flexible, allowing for user specifications at various levels of detail and for different time periods.
- The model provides estimates of capital and other resource requirements for the construction and operation of the entire energy supply system, including facilities needed to extract, import, process, convert, transport, distribute and export energy. There are currently 76 energy production and conversion facilities in the model's database.
- The model captures the dynamics of energy transition strategies by calculating annual schedules for required facilities and resources, taking into account construction lead times, facility lifetimes, and retirements of existing facilities.
- Because encouragement of the use of indigenous resources (energy, labour and industry) is a primary element of resource development strategy for most countries (thereby reducing balance of payment burdens), the model provides detailed information on the foreign exchange implications of alternative energy development strategies.
- The model allows consistent comparison of the financial impacts of alternative strategies through computation of present values for all financial results.
- The detailed energy supply system representation of the model allows calculation of the gross energy efficiency of the total system and of any component (e.g. the electric power sector) of the system.

Although dimensionally quite large, the model is structurally straightforward and, therefore, easy to understand. It proceeds from user-specified assumptions through a series of submodels to produce an annual schedule of facilities that are required to be brought on stream and the related resource requirements. Essential input to the model is the proposed energy development strategy, usually specified by energy/fuel type, at five to ten year intervals.

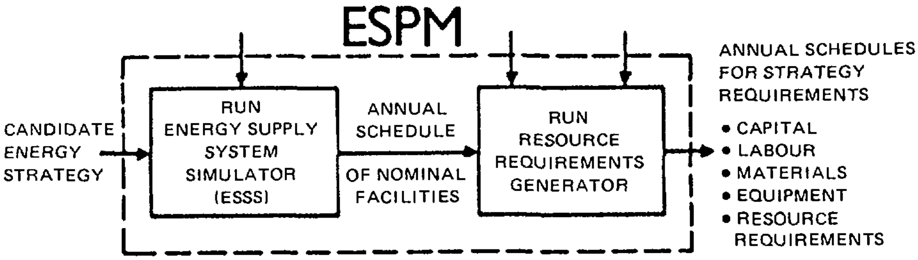


FIG.17.26. ESPM methodology, inputs and outputs [17.32].

Input may be detailed in areas of particular interest (e.g. synthetics from coal), or more general. User access to policy and other variables is deliberately emphasized, so that model results represent information derived from user decisions rather than from any decision-making capability endogenous to the model. Thus, the user may specify assumptions at various levels of detail, making the model suitable for use by energy policy-makers and analysts, and in conjunction with other energy models. To allow for flexibility in specifying inputs, a set of reference (or default) specifications exist in the model.

The results of the model may be used to analyse the economic and other related impacts of energy strategies. By virtue of the extent of detail in its results, the ESPM can help identify labour, materials, and equipment categories for which shortages may occur unless remedial actions are taken. These results can be used to investigate their impacts on specific sectors of the economy in order to determine manufacturing capacity and labour force expansion needs. Figure 17.26 illustrates how the ESPM can be used as an energy planning tool.

17.4.3.4. The SRI/DFI energy model

The SRI/DFI energy model was designed by Stanford University and Decision Focus Inc. in California as a model of generalized equilibrium. In addition to being used in many places in the USA and elsewhere, such a model is in operation, together with an AEM and the complementary models ESPM and WASP, in the computing centre of the University of Buenos Aires, Argentina [17.64].

The model permits analysis, included in an unique network, of energy conversion, allocation and transport processes and optimization of the supply/demand balance in relation to various major criteria, similar basically to other models of this type [17.65].

17.4.3.5. The WASP models

The WASP (Wien Automatic System Planning) model is a system of computer programs using dynamic programming techniques for economic optimization in electric system expansion planning (ESEP). It may be taken as an example of a supply model, limited, however, to electrical energy [17.43].

The WASP model was developed for the IAEA by the US Tennessee Valley Authority (TVA) and was first used during the 'Market Survey for Nuclear Power in Developing Countries' (1972–1973). With further assistance from the TVA and the US Oak Ridge National Laboratory, it was upgraded in 1976 to the WASP II version which has been widely used by the Agency and member states.

A joint effort of the United Nations Economic Commission for Latin America (ECLA) and the IAEA developed the WASP III version, which was completed in 1980. This latest version of the WASP model was designed to meet the need of the ECLA to study the interconnection of the electrical grids of six Central American countries where large potential hydro-electric resources exist; it fulfilled the 1979 recommendations of an IAEA advisory group on electrical system expansion planning.

The WASP model is structured in a flexible, modular system which can deal with the following interconnected parameters in an evaluation: load forecast characteristics (electric energy forecast, power generation system development); power plant operating and fuel costs; power plant capital costs; power plant technical parameters; power supply reliability criteria; and power generation system operation practices.

The electric energy forecast is obtained through use of MAED as described previously. In addition to the total annual demand for electricity, MAED provides WASP with some essential details about the estimated time distribution of the demand, that is, a load duration curve, as indicated in Fig. 17.17.

The WASP model is composed of six principal programs. One of these programs can be used to describe the seasonal characteristics of the electrical loads for each year of study. With a second program, it is possible to describe the existing power system and all plants which have been scheduled for commissioning and decommissioning. A third program is available to describe the alternative plants which could be used to expand the power system (plant candidates). With a fourth program one can generate alternative expansion configurations. A configuration is a set of power plants which meets the electrical capacity requirements of the utility or member state. A fifth program determines whether system operation with a particular configuration has been simulated. If not, the program simulates that new configuration. Using a probabilistic simulation model, expected energy generation by each plant and the corresponding operation cost can then be calculated. The reliability of the generating system and the probable amount of unsatisfied demand are also estimated. A sixth program can be selected in order to calculate the lowest cost expansion schedule for adding new units to the system over the period of interest, using the data files created by the other modules together with economic inputs and reliability criteria. The objective function of this dynamic programming optimization is the present-worth discounted value of operating costs (including fuel) plus

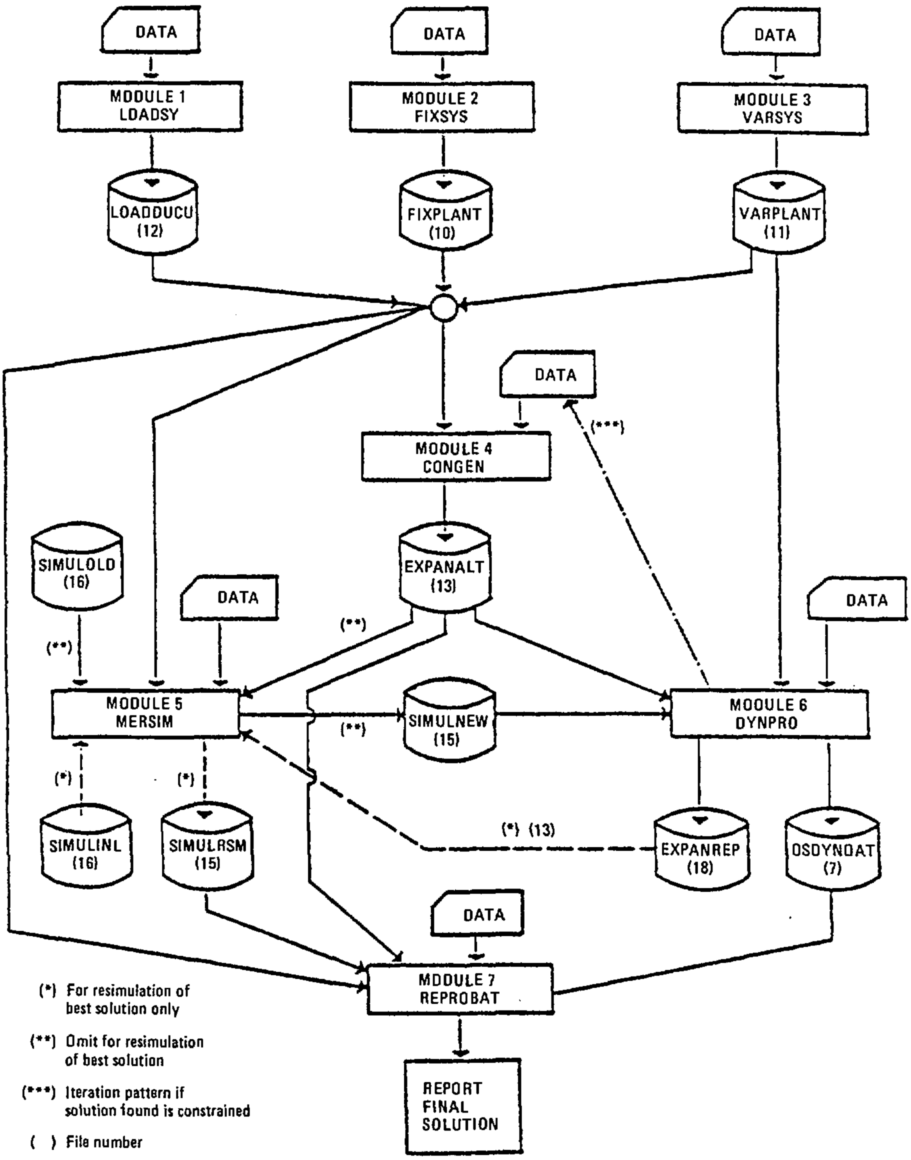


FIG. 17.27. Simplified flow chart of the WASP III computer code [17.68].

capital investment costs, plus a penalty cost for energy not supplied, minus a salvage value credit for plant economic life remaining at the planning horizon.

By mid-1982, the Agency had transferred the WASP package to 45 requesting countries and to five international organizations interested in planning for electrical system expansions. To date, the 45 countries report having used WASP in about 60 ESEP studies, with plans for an additional 30 or more studies.

To develop expertise in the member states to enable them to do their own projections and supply planning, the IAEA conducts two courses which train specialists from developing Member States in the techniques for energy demand analysis and electric system expansion planning.

Since the WASP models are much better known [17.66, 67] and a detailed description is also included in the Handbook [17.1], no further details will follow, except as an example the simplified flowchart of the WASP III version, presented in Fig.17.27 [17.68].

17.4.4. Final remarks on energy modelling

During the last decade an ever increasing number of energy models have been built, developed and implemented in various ways. An enormous potential for providing important insights into many complex economic and environmental interactions that affect the energy sector have become readily available. However, in the energy modelling field, greater attention is still given to building and extending models than to analysing and understanding them. This situation breaks the chain of model development and application and prevents model users and decision-makers from taking full advantage of the new tools with such tremendous disaggregating (analytical) and aggregating (synthetic) computer power.

Once this weakened linkage was identified, efforts for progress were initiated in different circles and countries, for example, the creation of the Energy Modeling Forum (EMF), administrated by the Stanford University Institute for energy studies [17.69]. Its main task is to improve the practical use of energy models for planning and analysis of energy policy issues. EMF operates through a series of working groups of energy model developers and users who make comparative tests of a variety of energy models.

While such approaches would undoubtedly improve the general quality level in the area, it seems that practical success very much depends on good communication between modeller, planner and decision-maker. In fact, a model is only a tool intended to improve understanding and assist decision-making; it cannot replace deep and comprehensive analysis, but can make it easier and more extensive. Accordingly, all participants involved in the process must understand its basic mechanisms, the applied methodology and the premises and have a fair idea of the validity of data.

In this respect, D. Finon, himself an early model builder and a lecturer at the IAEA course in 1980 [17.53], recently published a challenging paper regarding the use and abuse of energy models [17.70], which in addition to its main subject contains a series of practical recommendations for users, also in developing countries.

And a final remark: the key to the successful application of models to energy system development is the skill of the modellers and the quality of the analysts.

17.5. Energy planning and energy policy

17.5.1. General considerations

The interface between energy policy (and strategy) and energy planning has been commented on in the general framework of chapter 1. Energy policies and strategies have been dealt with in chapter 14 for developed and chapter 15 for developing countries. Even world energy strategies have been touched upon in chapter 13. However, although always implicitly present and herewith taken into account, nowhere, except in this chapter, has energy policy been directly related to energy planning.

In such a situation an example might best highlight the relationship:

In November 1983 an IEA workshop was held in Paris on methods of formulating energy policy. Reference [17.71] presents a random selection of titles from some of the papers presented. There is hardly one which does not refer to energy planning, actually presents planning methodologies and results, and hails planning as the base for formulating energy policy. In fact, all that is not new, however. What is partly new and interesting is how in the conditions of market economies both planning and energy policy can be implemented successfully.

Lecturers in the IAEA course traditionally comment and participants join in on this subject, so that many interesting views are presented in the round table discussion related to these aspects. However, a short presentation on energy planning in the USA, showing how complicated energy policy framing is and how dispersed the decision-making, may constitute a challenging example for further reflection and debate.

17.5.2. Energy planning in the USA

According to T. Wolsko, a lecturer at IAEA courses, energy planning in the USA can be summarized as follows:

Since the USA is essentially a free market economy, energy planning is carried out at several levels of government and industry to provide direction for energy policies or technology/resource development programmes. The economic elements of these different energy planning activities are dependent upon who is doing the planning. For example, the federal government is primarily concerned with the national economy, whereas a private corporation is primarily concerned with the profits that can be made through the proper development, sale or utilization of energy resources and/or technology.

Described below are four levels at which energy planning is performed in the USA. The description includes structure of organizations at each level, their planning objectives, and the outcome of activities planning.

17.5.2.1. Energy planning by the federal government

There are two principal organizations in the federal administration (US Department of Energy and US Department of the Interior) which perform energy planning at the national level and one organization that performs energy plan analysis in support of the US Congress (Congressional Office of Technology Assessment). Each of these organizations supplies information about the utilization of energy resources and the development of advanced energy technologies that is used by the administration and Congress in formulating national energy policy in the form of regulations or the allocation of federal resources.

(1) US Department of Energy

The Department of Energy (DOE) was created in 1977 by the Department of Energy Organization Act. This new department brought together for the first time many facets of energy planning and research into one department. The importance of this new organization for unified energy planning activity was identified in the National Energy Plan presented by President Carter in April 1977. The new DOE developed a 30-year energy plan that describes the expected energy demand in all consuming sectors and the different supply systems that are expected to meet this demand. Detailed energy supply/demand models and data bases were used by the DOE to develop these plans (forecasts). The Energy Information Agency (part of the DOE) maintains these models and databases and publishes energy planning information.

The goal of these national energy plans is to describe an energy supply/demand strategy that supports a healthy US economy. Focus for these plans, which are revised yearly, is determined on the basis of what the federal administration perceives as important energy policies necessary to aid the US economy. For example, conservation incentives to reduce energy demand growth, increased production of electricity from coal and nuclear to replace expensive oil and minimize foreign dependence, etc. These plans, therefore, describe a path of resource utilization, energy technology research and development, and incentives and disincentives for increased use of energy resources or technology which represent the current policies of the administration. Energy research programmes of the DOE are formulated to meet the energy supply goals that are described in the National Energy Plan. A comprehensive research plan was assembled and widely distributed in 1976.

(2) US Department of the Interior (DOI)

The DOI has responsibility for the development of energy resources to meet the energy demands as identified in the National Energy Plan. Its control over energy resources (coal, oil, gas and uranium) is exercised through the leasing of federal lands to private companies. Its activity in energy planning is limited to determining the number of leases for energy resource development that are necessary to allow private development adequate opportunity to meet resource demands. Since a significant part of the US energy resources are located on federal lands, this activity is significant in meeting the national energy planning goals.

(3) Congressional Office of Technology Assessment

Since the US Congress plays a significant role in implementing energy plans and policies it has resources to evaluate the effects of any plan or policies proposed by the administration or by other members of Congress. The plan analysis can range from the development of a national energy supply/demand balance or to assessing the impacts of an advanced energy technology in terms of economic, social, technical or political issues. An example of its output is the Analysis of the Proposed National Energy Plan of President Carter in 1977.

17.5.2.2. Energy planning by state level government

Since most electricity and gas in the USA is supplied by publicly regulated monopolies (utilities), state governments have public utility commissions that analyse and evaluate the appropriateness of energy technology expansion plans and energy costs for utilities in their respective states. Their objective is to ensure that plans submitted to them by electric or gas suppliers represent the best economic, environmental and social choices for the people of the state. Energy technology investments made by utilities are large and are long-term so that the public utility commissions (PUCs) must carefully evaluate these plans to ensure the health of the state economy. Energy cost, reliability, assurance of adequate supplies and safety are the primary focus of their plan evaluations. Since utilities usually supply one plan, the PUCs will typically develop alternative plans and compare them to the utility-submitted plan.

17.5.2.3. Energy planning by utility/industrial groups

Each of the major energy sources (electricity, oil, gas, coal, nuclear) has organizations that evaluate the markets for its technologies and/or resources. Most of these organizations publish annual reports that present a picture of energy demand and supply over some planning horizon (10, 20, 30 years). In some cases these plans represent composites of plans developed by individual utilities and in other cases represent their own perspectives on energy.

(1) Electricity

Each electric utility assembles its own energy plans and in developing these plans may include purchasing or selling electricity to another utility. to co-ordinate this sharing of electricity-generating facilities the USA and Canada are broken down into nine planning regions. Each of the regions develops an annual electric supply and demand plan with a ten-year planning horizon. These plans are assembled by the North American Electric Reliability Council (NERC) and a summary report is published annually. The objective of this planning activity is to ensure the reliability of supply and is not directly concerned with economic, environmental or social issues.

Another organization involved in electricity planning is the Electric Power Research Institute (EPRI). This organization is supported by member electric utilities to perform research on technologies of interest to electricity producers. However, to evaluate the future viability of advanced technologies EPRI develops forecasts of energy demand and supply. In addition, EPRI develops planning methods, models and data to be used by the utility industry (e.g. demand forecast models, fuel price projections, electric system expansion models). Documentation of these planning tools is extensive and available to the public (free to many foreign governments).

(2) Other industrial planning groups

Since the USA is primarily a free market economy, private corporations must perform energy supply/demand planning to support their decisions regarding expansion plans, technology choice, resource development, technology research, etc. The objective of these plans is to permit corporate decisions that will develop and sell products (resources, technology or energy) at a price that will provide an acceptable return on investment to the owners. The focus of these energy studies is on demand (quantity, quality and price) and competitive producers (domestic and foreign) of the same products or markets. Included in their plans are the government regulations that could affect the markets for their products. The American Gas Association is one such organization that performs and reports such planning analyses.

17.5.3. Energy and electricity master plans in various developed and developing countries

While the industrialized and the CPE countries possess in one form or another both EMPs and ElMPs, only a few of the developing countries have reached this

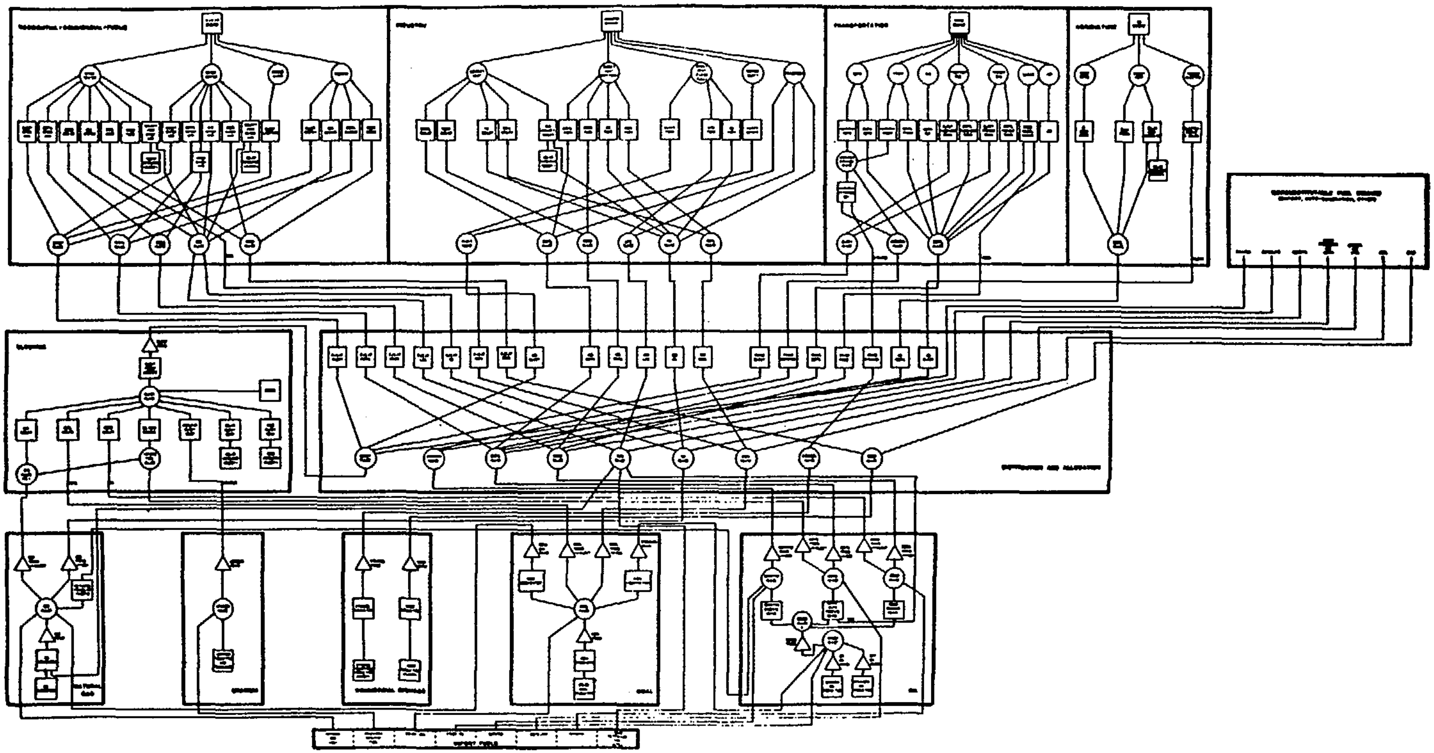


FIG.17.28. Integrated supply/demand network of Argentina energy assessment [17.73].

stage. However, among the latter, some have produced remarkable basic studies and plans, of which some are listed as follows:

(1) Algeria. The Energy and Nuclear Power Planning (ENPP) study carried out in co-operation with the IAEA. The study, also presented in the IAEA course in 1983 in Ljubljana [17.72], is included as an example in the Guidebook on Electric System Expansion Planning [17.1].

(2) Argentina. During 1980 and 1981, the USA, in co-operation with the Government of Argentina, conducted a comprehensive assessment of Argentina's energy resources, needs, and uses and developed several alternative strategies for meeting projected energy requirements. This assessment was a collaborative effort by a team of US and Argentine experts in energy resources and technologies, development economics, and energy systems planning and analysis. The US Department of Energy managed the USA component of the assessment with primary technical management by Argonne National Laboratory, while the Secretariat of Planning managed the Argentine component. In this endeavour extensive use has been made of modern planning and modelling techniques [17.73, 74]. Figure 17.28 illustrates for example the integrated supply/demand network used for the representation of the energy flow.

(3) Colombia. Paper 4.6.2 presented at the IAEA course in Madrid in 1981 analyses in its first part the primary energy resources base and the energy production and consumption between 1930 and 1979 of the country, the energy balances and structural changes. In the second part are presented figures on the energy demand till 2000, which serve as a starting point for a comprehensive EMP now in progress [17.75]. An ElMP was completed a few years ago.

(4) Ecuador. Reference [17.76] presents the first investigations within the framework of an EMP now in execution by the National Energy Institute (INE) with the technical assistance of EEC experts. In essence, forecasting energy balances and input/output tables for Ecuador covering the period 1980–2000 have been prepared, using a partly new approach. The work is continuing with energy demand projections with the model MEDEE S.

(5) Jamaica. A first version of an EMP is presented [17.77], drafted almost completely by national experts. It was later repeatedly updated and kept abreast with the newest energy developments.

(6) Republic of Korea. In the framework of the US co-operative programme mentioned for Argentina, a country energy assessment has been carried out also in the Republic of Korea, a country slowing down its development after years with very high growth rates. The petroleum share in the energy balance was 54%; industry with 44% is the largest user, but the residential/commercial sector comes very close with 38%, because of the great weight

of space heating, the Republic of Korea being geographically located in contrast to the majority of developing countries, in a temperate climate zone, with substantial space heating requirements [7.78]. The Republic, being one of the developing countries which embarked early and determinedly on nuclear energy, had by the time of the assessment 9% of electricity generated by nuclear power stations.

(7) Portugal. Similar to Argentina and the Republic of Korea, a co-operative assessment has been completed for Portugal, a European country attempting to recover from recent declines. The country possesses, with the exception of some coal and hydro power, only uranium as a primary energy resource. It therefore relies heavily on petroleum, which represented 75% of the total primary energy consumption [17.78].

(8) Spain. In contrast to the above-mentioned national studies, a recent provincial energy planning study was presented in the IAEA course in Ljubljana in 1983 by the Spanish lecturer Dr. A. Alonso. It was the so-called White Book on Energy in Catalonia [17.79], which presents in Vol. 1 a thorough analysis of the primary energy resources of the province, the evolution of energy demand and consumption between 1965 and 1980 and an energy balance for the latter year. Volume 2 contains the energy demand projections to the year 2000, supply alternatives including strong energy conservation measures, all proposals being co-ordinated with the national EMP. As requested by the Parliament of Catalonia, when the study was decided upon, the latter includes detailed specifications regarding all measures necessary to implement the recommended provincial EMP.

Given the importance of energy development plans, the World Bank requests these for any further financing action in a developing country, even if such plans are of a very preliminary character.

Since many developing countries have not yet embarked on the necessary energy planning activities, a joint UNDP/World Bank programme for energy sector assessments was established in 1980, with a view to help these countries make the first planning steps in the right direction. Up to November 1983, 35 developing countries had received expert missions and 21 reports were completed; further reconnaissance missions were scheduled for 1984, to reach the final number of 50 planned assessments. In addition, a follow-up programme of assistance for energy management improvement is under way.

Every annual IAEA course on energy planning includes sessions where participants in addition to lecturers' presentations are given the chance to present the energy plans of their countries and to listen to constructive critical comments on the part of their colleagues or lecturers.

17.5.4. Institutional framework and manpower for national energy planning

Once the imperative of co-ordinated energy planning has been accepted and the energy master plan established as the convenient conceptual framework, the institutional framework and the planning mechanisms should obey the same hierarchical principle.

Ideally, a single energy ministry or authority should control all energy-producing, transporting and distributing organizations and determine, in close co-operation with the other economic sectors, energy policy. Accordingly, energy planning would be with the energy authority. Such an institutional framework exists in a number of countries and practical experience has confirmed its viability and effectiveness.

On the other extreme, in many countries energy planning, where it exists, is carried out ad hoc, scattered in many organizations and at best on a subsector basis. Typically electricity and petroleum subsector planning have been carried out independently of each other as well as of other energy subsectors, and unless there is improved understanding concerning the need for integrated planning, or unless political-economic pressure intervenes, the inertia of separate acting will be difficult to overcome.

In countries where energy planning activities exist, the problem is how to merge and subordinate them best hierarchically and create the necessary operational links to their homologues in the other economic sectors. In countries starting energy planning from grass roots a cautious start should be envisaged. In such countries, particularly in small ones, where skilled manpower resources and office space are limited, locating a fledgling energy planning group within an established subsector institution may be the only realistic short-term alternative [17.80]. In such a case, the electricity authority, since professionally more planning-minded, could be the best choice. Anyhow, this is rarely a desirable long-term solution, especially if it strengthens the bias and dominance of the subsector agency or becomes a heavy burden on it. Implanting an energy planning cell within an existing national economic planning body may also be possible, and this would facilitate co-ordination between energy and the other sectors. However, this is likely to result in less dilution of energy-related responsibilities and may reduce the effectiveness of energy policy, especially if economic planning itself is perceived mainly as a paper exercise that is rarely implemented.

A stepwise approach in reorganizing the energy sector may often be more desirable. For example, an energy council or board which brings together representatives of all energy suppliers and major users might be constituted initially to co-ordinate national energy planning. This body could have a secretariat which would form the nucleus of the network for data collection and analysis, to begin implementing the planning.

Once the advantages of co-ordinating the energy plan become evident, a central energy authority (CEA) or ministry of energy (MOE) might be set up which would have full control over the energy sector [17.81]. The CEA concept is modelled on the lines of a central bank, because the pervasive role of energy makes it the physical counterpart of money. Therefore, the CEA should be an autonomous body with maximum authority. The alternative approach of a MOE would be more conventional.

Whichever institution is established, two general points should be emphasized. First, because of the importance of energy, the CEA or MOE should have direct access to the head of state and be able to invoke his authority, to bring other ministries or institutions into line. Secondly, the CEA or MOE should be primarily concerned with energy planning and policy-making, including in particular the gathering and analysis of energy data, and review of major decisions relating to pricing, investment and energy usage. Execution of energy policy, day-to-day operations, preparation of subsector investment or pricing programmes, routine paper work and so on should be left to the line agencies in the various subsectors themselves, for example, electricity authority, forestry department, and so on. Involvement of the CEA or MOE in these functions would soon transform it into a huge bureaucracy and drastically reduce its effectiveness. While a CEA could be set up independently with specific safeguards against this danger, an MOE is more likely to become bureaucratized, especially in countries where many existing ministries are still influenced by administrative procedures with roots stretching back to old inertial bureaucracies. Therefore, it would be worth while to set up a separate group or institute for planning and policy within the MOE, which would act as a driving force.

Those carrying out the EMP should be drawn from as many other government departments and institutions as possible, to represent a wide variety of viewpoints and skills. This would help develop a balanced approach and also maintain links with other sectors and institutions without which the EMP could become an abstract theoretical exercise. In particular, the commercial energy subsectors should not be allowed to dominate the traditional fuels subsector.

The balanced development of energy planning skills both at the management and technical level is important. The underlying theme should be self-reliance in energy planning, because the final responsibility for the EMP should rest on local staff and policy-makers. Although in many cases it may be necessary to rely on foreign experts or consultants to initiate the process and play an advisory role, the training of local counterparts and the goal of eventual transition to completely national staffing should have a high priority. At the same time, because both technical and economic knowledge in the energy area tend to change rapidly, energy planners should have good, up-to-date library and documentation facilities, as well as ready access to international conferences, training courses – such as IAEA courses and others [17.82] – and meetings. Finally, if salary levels are inadequate, it will be rather difficult to recruit and retain personnel with energy-related skills [17.80].

Chapter 18

LAUNCHING CONDITIONS AND IMPLEMENTATION OF A NUCLEAR POWER PROGRAMME

Introduction of nuclear power in a country is a long, complicated but also a challenging process, with three distinct phases: a conceptual preparatory phase embracing all basic technical-economic investigations needed for the justification of this very important step, a national infrastructure-preparing phase creating the conditions for the launching of a nuclear programme and finally the implementation phase-comprising all project-oriented activities leading to the successful commissioning and reliable operation of the first and next nuclear power plants.

Once this chapter has been reached, it may be assumed that sufficient background and information has been accumulated by the reader and tools and skills acquired, so that the first conceptual preparatory phase for a nuclear programme could be successfully tackled and its justification convincingly submitted. To enable this has been the goal of this book and should be that of any introductory course based on its guidance.

However, it is felt that before closing, a brief outlook should be presented on what the next two phases of action might encompass.

While it is obvious that only very basic information can be focused on, the three available IAEA guidebooks [18.1–3] and the further intensive IAEA activities related to the subject can always provide support when needed.

18.1. Launching conditions for a nuclear power programme

The introduction of nuclear power and of nuclear technology in a country creates specific new requirements of the country's infrastructure and requires national commitments on a long-term basis involving substantial efforts.

It is emphasized that for the successful introduction of nuclear power in any country, the first essential requirement is a clear understanding at the decision-making level of the specific aspects of nuclear power, and a thorough knowledge of the tasks and activities to be performed as well as of the requirements, responsibilities, commitments, problems and constraints involved.

A nuclear power programme requires a very large effort (money, resources, manpower, etc.) on a national level over a long period of time. The country has to commit itself to the fulfilment of the requirements and has to establish clear policies to ensure the continuity of the programme in terms of investment and industrial support. In some countries the Government's nuclear policy and the commitment to its implementation has been promulgated in a constitutional mandate.

Only a solidly based and long-term nuclear power programme containing a series of nuclear power projects can justify the sizeable effort needed to plan and implement the national infrastructure development and the supporting organizational structures and activities. A single nuclear power plant not integrated into a nuclear programme may become an expensive venture. These fundamental points have not always been clearly understood in the past, with delays in nuclear power programmes and projects as a result.

Once the conditions are met, the successful launching of a nuclear programme depends, according to the IAEA, which has long experience in this field, on the creation of the necessary national infrastructure. The main issues involved to this purpose are the following [18.4–6]:

(1) A corresponding infrastructure of the electricity grid
(2) An effective decision-making capability of adequate institutional infrastructure
(3) Qualified manpower
(4) Industrial support
(5) Financing.

Drawing on the IAEA experience, – see the guidebook on the introduction of nuclear power [18.1] and the other above-mentioned references –, the following comments may be made:

18.1.1. Infrastructure of the electricity grid

The interaction of grid characteristics with the design and performance of nuclear power plants was dealt with in subsection 6.4, based partly on the IAEA guidebook with the same title [18.3]. To avoid repetition, it will only be recalled here that the relationship is not only one of reciprocal size, although that is the first condition to be met, but also of structure, reliability and stability of the whole electrical system. Therefore, in many cases, the limited amount of generating capacity and fragmented transmission grids are the most important factors limiting or delaying the possible introduction of nuclear power in a country. However, in long-term planning, the conditions could be met, especially if smaller nuclear reactors become available on the market.

18.1.2. Adequate institutional framework

Apart from the high commitments required for the introduction of a nuclear programme, an adequate institutional and organizational infrastructure is needed for its practical implementation.

Basically, the distribution of tasks, functions and responsibilities between the organizations involved follows patterns similar to those for any other conventional power or industrial programme, but in addition, there will be a regulatory body. The functions of this organization will be the regulation and control of all nuclear facilities, and ensuring that the manufacture, construction and operation of the nuclear plants comply with the safety requirements and the quality standard needed.

There is no optimal organizational framework that is equally applicable to every country and every situation. Different countries have adopted different organizational frameworks and it is difficult to say which approach has given better results, because other factors, in particular the availability or the lack of availability of well-qualified personnel to staff the organizations, seem to be more decisive than the type of approach adopted.

Without doubt, the organizational infrastructure is an important prerequisite for launching a nuclear power programme, but setting up such an infrastructure should not constitute per se a major constraint for any developing country. Staffing the organizations, on the other hand, may constitute a constraint. Even those developing countries that already have substantial nuclear power experience and clearly defined organizational structure are having staffing problems.

18.1.3. Qualified manpower

Competent manpower plays a fundamental role for safety and reliability in a nuclear power programme. There can be no compromise on safety; high safety and quality standards must be established and strictly maintained. The required manpower competence and work attitudes can be acquired only through appropriate education, training and experience.

In a country without a nuclear industry, technology is usually acquired from a more advanced country able and willing to transfer it. However, for technology transfer to be successful, the recipient country must be capable of absorbing the technology, and the key to this is the availability of qualified manpower.

It should be pointed out that in many developing countries the need for scientists and research-oriented personnel, particularly in the nuclear field, is often overestimated, while the need for highly qualified and experienced practically-oriented engineers, technicians and draftsmen is very much underestimated. Manpower development requires long lead times, and this is frequently not taken into account in programme planning.

The development of an adequate national educational and training infrastructure is the only way to develop competent local manpower. Any country for which nuclear power is a viable option would have an electric system of reasonable size and a basic industrial infrastructure, and would thus also have certain technical manpower and education and training infrastructures. This will have to be expanded and adjusted in every case to meet the requirements of the nuclear power programme. It is possible and may be necessary to obtain some highly specialized experts and training from abroad, in particular in the early phases of a nuclear power programme, but this can only be utilized in a very limited way and a national manpower development programme is still essential.

IAEA experience shows that all developing countries with ongoing nuclear power programmes have found it necessary to invest substantial efforts in manpower development. The degree of success they have been able to obtain in the implementation of their nuclear power programmes and in the achievement of their development goals for national participation and technology transfer has largely depended on the efforts expended in manpower development and the availability of competent manpower.

India is an outstanding example of a developing country where large-scale manpower development was assigned first priority already in the earlier stages of starting the nuclear power programme. There is no doubt that without this the country would never have attained the resuls it did in achieving practical self-sufficiency in the design, construction and operation of its nuclear power plants. The IAEA guidebook 'Manpower Development for Nuclear Power' constitutes an excellent reference for further reading on the subject [18.2].

18.1.4. Industrial support

There are no firm rules regarding the industrial support infrastructure requirements of a country starting on a nuclear power programme, but it has to be recognized that the plants have to be built, the equipment and components have to be installed and tested, and the plants have to be operated and maintained within the country. This means a basic requirement of competent construction and erection firms and of operations and maintenance capabilities. The available industrial infrastructure will probably not have all the technology, know-how, level of quality or the expertise necessary for nuclear power, but these can be acquired.

The national engineering, manufacturing, construction and erection capabilities play an essential role in the promotion and development of the nuclear power programme. These industrial infrastructures should be closely associated with the nuclear power programme for which they provide a pool of necessary skills and human resources. The high quality requirements of nuclear technology call for the enforcement of a strong programme for quality assurance and quality control in particular.

All of the developing countries which have started nuclear power programmes have fairly well-developed industrial infrastructures, approaching to varying degrees the levels usually associated with the 'industrialized' countries. They can certainly not be classified as 'least developed' countries.

Experience shows that the higher the level of the industrial infrastructure of a country, the better it has been able to meet the challenge of incorporating nuclear power, of absorbing the technology, and of achieving its national participation goals. In this respect, it should be mentioned that, in addition to the level of the available industrial infrastructure of a country, bilateral technical co-operation in transfer of technology has played a major and possibly decisive role.

Experience also shows that up to now no country with a very low level of industrial infrastructure has successfully incorporated nuclear power. This in itself is not sufficient reason to affirm that such countries cannot or should not go nuclear; however, the results of such a case are yet to be seen.

18.1.5. Financing

The availability of financing on reasonable terms has often been stated to be an overriding problem for nuclear power introduction in developing countries. The investment related to the gross domestic product (GDP) seems to have been a most important factor. According to studies by the World Bank, power expansion investment requirements have remained at about 7–8% of the gross fixed capital formation of developing countries. It is estimated, however, that a shift to higher-capital-cost plants (including nuclear or hydro) would force an increase in this proportion to about 10–12%. This would correspond to about 1–1.5% of GDP for these countries. Thus the financing of a nuclear power programme must be seen as a major national effort, which will require long-term arrangements, in order that the impact on the domestic economy can be made acceptable during the long lead time before the savings from the low fuelling costs for nuclear power begin to provide economic benefits. Also, it must be recognized that a nuclear power programme is only one of several development programmes which will compete for available investment funds.

Among the developing countries with ongoing nuclear power programmes, Mexico is possibly the most outstanding example where financing constraints have seriously affected the country's nuclear power programme. The effect of financing constraints has also been causing substantial delays in the programmes of other countries such as Brazil, Romania and Yugoslavia. In fact, there is hardly a country whose nuclear power programme has not been affected negatively by this problem. Bangladesh and Turkey are examples of developing countries where the effective initiation of their first nuclear power project seems to depend mainly on finding a satisfactory financing arrangement.

18.2. Implementation of a nuclear power programme

18.2.1. Summary of activities in nuclear power projects

An overview of the activities involved in the introduction of a nuclear power programme, i.e. its first nuclear power plant, is provided by Table 18.I, which includes all three phases previously mentioned.

TABLE 18.I. SUMMARY OF ACTIVITIES IN NUCLEAR POWER PROJECTS [18.1]

1. Project planning (pre-project, programme-oriented activities)	National energy supply planning Power system planning Nuclear power programme planning Development of legal and organizational framework International agreements and arrangements National infrastructure survey National participation planning Manpower development planning and implementation Site survey
2. Project implementation (pre-construction project-oriented activities)	Feasibility study Site evaluation Supply market survey Definition of contractual approach Preparation of specifications and invitation of bids Definition of codes and standards Preparation of bids Bid evaluation Technology transfer arrangements Procurement and assurance of fuel and fuel cycle services supply Financing arrangements Negotiation and finalization of contracts Plant conceptual design Preparation of site infrastructure Site and construction authorization (licensing) Public information and public relations
3. Project implementation (management and engineering)	Overall project management Basic design engineering Detailed design engineering Design reviews Preparation and review of equipment and plant specifications Procurement of equipment and materials Establishment of quality assurance policy Quality assurance and quality control programme implementation Supervision of manufacturing, construction and commissioning

TABLE 18.1. (cont.)

	Safety analysis Emergency planning Safeguards physical protection Schedule planning and control Cost control Planning and co-ordination of the training of operations personnel Development, review and implementation of safety and engineering procedures Development of plant operation and maintenance manuals Progress reporting Public information and public relations
4. Project implementation (manufacturing, construction and commissioning)	Equipment and component manufacture Construction and commissioning management Site preparation Erection of buildings and structures Expediting and transport of materials and equipment Plant equipment and systems installation Plant component and systems testing Commissioning and plant acceptance testing Recruitment and training of plant operations personnel Authorization (licensing) of plant operation and of plant operations staff Inspection and auditing
5. Plant operations and supporting activities	Plant operation and maintenance Quality assurance and quality control Training and retraining Radiological protection and environmental surveillance Safeguards and physical protection Fuel and fuel cycle services procurement Fuel management at power plant Waste management and disposal Licensing and regulatory surveillance Public information and public relations

TABLE 18.II. CONTENTS OF THE FEASIBILITY STUDY REPORT (Example) [18.1]

1. INTRODUCTION
   - 1.1. Objectives
   - 1.2. Scope
   - 1.3. Background information
   - 1.4. National energy market analysis
2. ELECTRIC SYSTEM ANALYSIS
   - 2.1. Electric system description
   - 2.2. Demand forecast
   - 2.3. Generation expansion programme
3. CHOICE OF UNIT SIZE
   - 3.1. Electric supply grid analysis
   - 3.2. Unit size definition
   - 3.3. Station size
4. SITE CONSIDERATIONS
   - 4.1. Site survey
   - 4.2. Site evaluation
5. TECHNICAL ASPECTS OF NUCLEAR PLANTS
   - 5.1. Nuclear power supply market survey and choice of reactor types
   - 5.2. Design characteristics
   - 5.3. Construction schedule
   - 5.4. Fuel cycle evaluation
6. NUCLEAR COST ESTIMATES
   - 6.1. Basis of cost estimates
   - 6.2. Capital costs
   - 6.3. Fuel costs
   - 6.4. Operation and maintenance costs
7. GENERATION COSTS
   - 7.1. Annual charges
   - 7.2. Total generating costs
   - 7.3. Cost estimates and comparison of alternative sources
8. FINANCIAL REVIEW
   - 8.1. Financial review of utility/owner
   - 8.2. Financial requirements of nuclear project
   - 8.3. Financial projections for utility/owner
   - 8.4. Survey of financing sources
9. PROJECT DEVELOPMENT
   - 9.1. Project organization
   - 9.2. Project development schedule
   - 9.3. Contractual approach
   - 9.4. Safety criteria
   - 9.5. Legal framework
10. STAFFING AND TRAINING REQUIREMENTS
    - 10.1. Project management
    - 10.2. Construction
    - 10.3. Commissioning
    - 10.4. Operations and maintenance
    - 10.5. Industrial infrastructure
11. NATIONAL PARTICIPATION
    - 11.1. National participation policy and strategy
    - 11.2. Survey of industrial infrastructure
    - 11.3. Participation goals and implementation measures
12. CONCLUSIONS AND RECOMMENDATIONS
    - 12.1. Feasibility of nuclear power project
    - 12.2. Implementation programme

18.2.2. The feasibility study

Phase-3 implementation begins with a feasibility study, which should provide a detailed analysis and information on all pertinent technical, economic, financial, etc. aspects, with specific recommendations to enable the authorities concerned to make appropriate decisions for the implementation of the project. It should also outline the further steps to be taken and identify the areas in which more detailed investigations are still needed.

The scope of the feasibility study will depend on the factors associated with a given situation and project characteristics. The depth of evaluation will also be influenced by the amount of effort that was applied in the nuclear power planning phase and, in this regard, parts of the feasibility study will involve an updating and closer investigation of the work performed in the previous planning study.

It is emphasized that the reliability of the results and of the recommendations will largely depend on the input data and information used in the study and analysis, therefore utmost care should be taken to ensure a high degree of accuracy and reliability of these data and information. It should be noted in particular that information on the reference designs and cost estimates to be used for the study, which may be obtained from the suppliers or provided by consultants, should be reviewed and thoroughly checked and adjusted to the prevailing local conditions.

To perform such an interdisciplinary study, ten to fifteen professionals would be required, assisted part-time by experts (advisers, consultants) in specific subjects. It is essential that the best available resources and experienced people be made available for performing the studies. The local staff should be carefully selected at the highest possible technical level of the various organizations concerned with the areas related to the study.

Some of the personnel involved in the nuclear power planning study would logically expand their work into this activity and would form a team with other professionals who could have gained their experience in non-nuclear projects. The performance of a feasibility study usually requires a year to a year and a half, not including site survey and evaluation, which would be an ongoing activity during the time the feasibility study is being performed.

A sample of contents of a feasibility study report is given in Table 18.II. Feasibility studies have been prepared in various developing countries. In some countries such feasibility studies were prepared by foreign consultant firms, in others consultants were only used in an advisory capacity by local teams and there are a few cases where the feasibility study was a wholly national effort.

While the performance of a feasibility study should always be undertaken by the local authorities, it is often delegated to some well-known and experienced foreign firm of consultants. The main reason for this delegation is that the feasibility study will be of importance in the negotiations for financing the

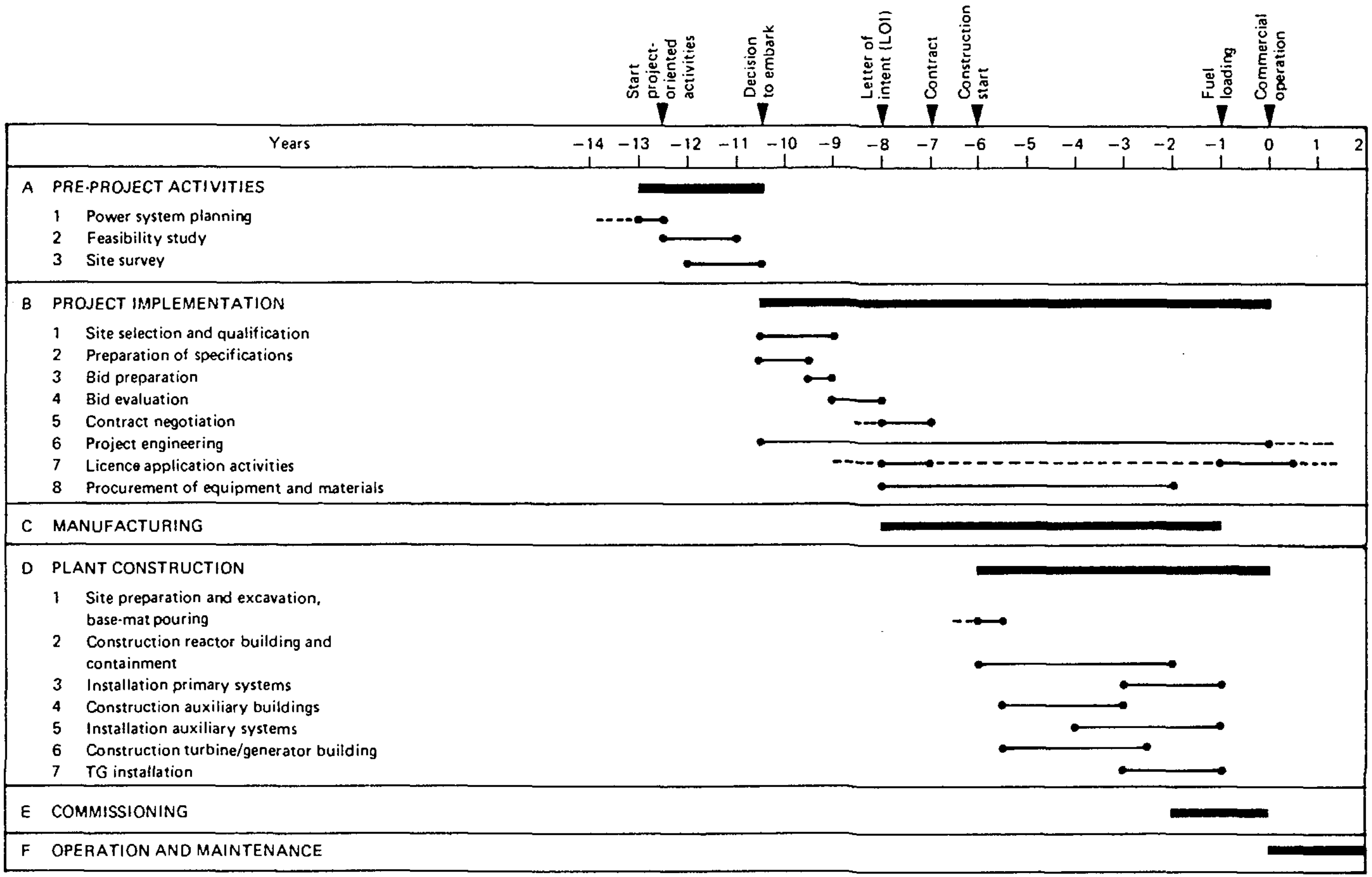


FIG.18.1. Schedule for nuclear power plants [18.1].

project and it is assumed it will carry more weight if performed by reputable and experienced foreign consultants. Should this approach be adopted, it is essential to define with great care the scope of the study and the terms of reference under which it is to be performed before the study is started.

If requested, IAEA assistance could be made available for guidance and help in feasibility studies.

18.2.3. Schedule of nuclear power projects

One of the main aspects of nuclear power development programmes and the implementation of nuclear power projects is the fact that long lead times are involved. This characteristic feature of nuclear power creates difficulties for a country contemplating the introduction of nuclear power, since planning and performance of a series of activities involving substantial efforts has to be started long in advance of the time when the energy needs are to be met. In addition, if the nuclear power programme calls for a series of nuclear power plants over a certain period of time, as would normally be the case, it will be necessary to proceed with the implementation of more than one plant at the same time.

The schedule for performing each of the activities listed in Table 18.I depends on many factors, and is affected largely by the amount of planning and the adequacy and sufficiency of the staffing of the project management organization. It also depends on the approach adopted for dealing with the various tasks. There is no precise rule that would define the time period required for each phase and it may vary over a wide range from case to case depending on the prevailing situation and conditions. Approximate estimates, however, may be obtained from previous experience, which would serve to provide guidelines and might give an indication of the ways and means that could lead to shortening or at least not unduly prolonging the time schedule overall of a given project in a particular situation.

A typical schedule for a nuclear power project is shown in Fig.18.1 as an example. It spans a period of 13 years, encompassing the major project-related activities. However, the periods shown for different activities as well as the starting points are approximate and should be considered only indicative. Supporting activities of the nuclear power programme are not included in this schedule; they begin even before the pre-project activities of the first nuclear plant are started and then continue throughout the programme.

Major factors affecting the project schedule are:

- The time needed for making decisions
- Availability of qualified manpower
- Licensing requirements and procedures
- International institutional arrangements
- Financing arrangements

– Siting studies and the procedures for site selection aud authorization
– Timely completion of engineering
– Project management efficiency
– Quality assurance programme implementation
– Unforeseen manufacturing or construction problems
– Late alterations in the design.

The schedule is the major control tool of project management and is essential for the overall co-ordination of the tasks among the partners involved. There are certain milestones in the master schedule, some of which are indicated in Fig.18.1. The milestones are major events in project development and connecting points of activities. Some of the typical milestones are:

– Decision to start nuclear power planning
– Establishment of national legislative framework
– Establishment of nuclear regulatory organization
– Decision to start the feasibility study
– Feasibility study completion
– Site selected
– Decision to initiate the acquisitation process
– Bids requested
– Bids received
– Letter of intent issued
– Main contract(s) signed
– International institutional and financing arrangements completed
– Construction permit granted
– Site preparation started
– First structural concrete cast
– Containment erection completed
– Installation of components started
– Reactor heavy components installed
– Turbine and generator installed
– Fuel loaded
– First criticality of reactor reached
– Hot functional testing started
– Operating licence granted
– Commercial operation started.

The pre-project and project implementation activities including the periods required for their performance and their schedule are discussed in more detail in Ref.[13.1]. The overall time required to complete the process of planning and acquisition of the power plant up to the start of construction is estimated at about seven years, according to the schedule presented in Fig.18.1 as an example. This schedule includes reasonable time for decision-making.

TABLE 18.III. PERIODS REQUIRED FOR NUCLEAR POWER PROJECT ACTIVITIES [18.1]

Activity	Period (months)
Nuclear power planning study	6–12
Site survey	6–12
Site evaluation	18–24
Feasibility study	12–18
Preparation of bid specifications	6–12
Bid preparation	6–8
Bid evaluation	6–12
Contract negotiation and finalization	9–18
Plant construction including commissioning	72–96

Note: Some activities overlap (see Fig.18.1). The periods given are orders of magnitude and will depend on particular situations and prevailing conditions.

A period of seven years from the start of nuclear power planning to the initiation of construction of the power plant may seem excessively long; however, there are ways to shorten this period. Experience shows that in some cases, even for a first nuclear power project, an overall shorter period of three to four years has been achieved. Nevertheless, experience also shows that there are cases where ten or more years were required. There are also some countries that started planning activities for their first nuclear power project in the 1960s and have still not reached the construction stage. It is, therefore, very difficult to generalize regarding the overall time required for these preparatory activities. A period of five to eight years seems to be a reasonable target for planning purposes, but this should be analysed in detail for each particular case, considering the prevailing conditions.

A summary of the estimated periods required for the performance of each of the major activities leading to project completion is presented in Table 18.III. It should be noted that some activities overlap. Siting studies in particular would start during the nuclear power planning stage and continue throughout the following preparatory stages.

Regarding the possibilities for shortening the time required, these should be evaluated with great care. Obviously, every effort should be made not to prolong the process unduly, but short cuts or a lowering of quality requirements could prove in the long run very expensive indeed, both in terms of money and of overall time. As to nuclear-safety-related aspects in particular, legitimate safety concerns should prevail over the interest in achieving shorter schedules.

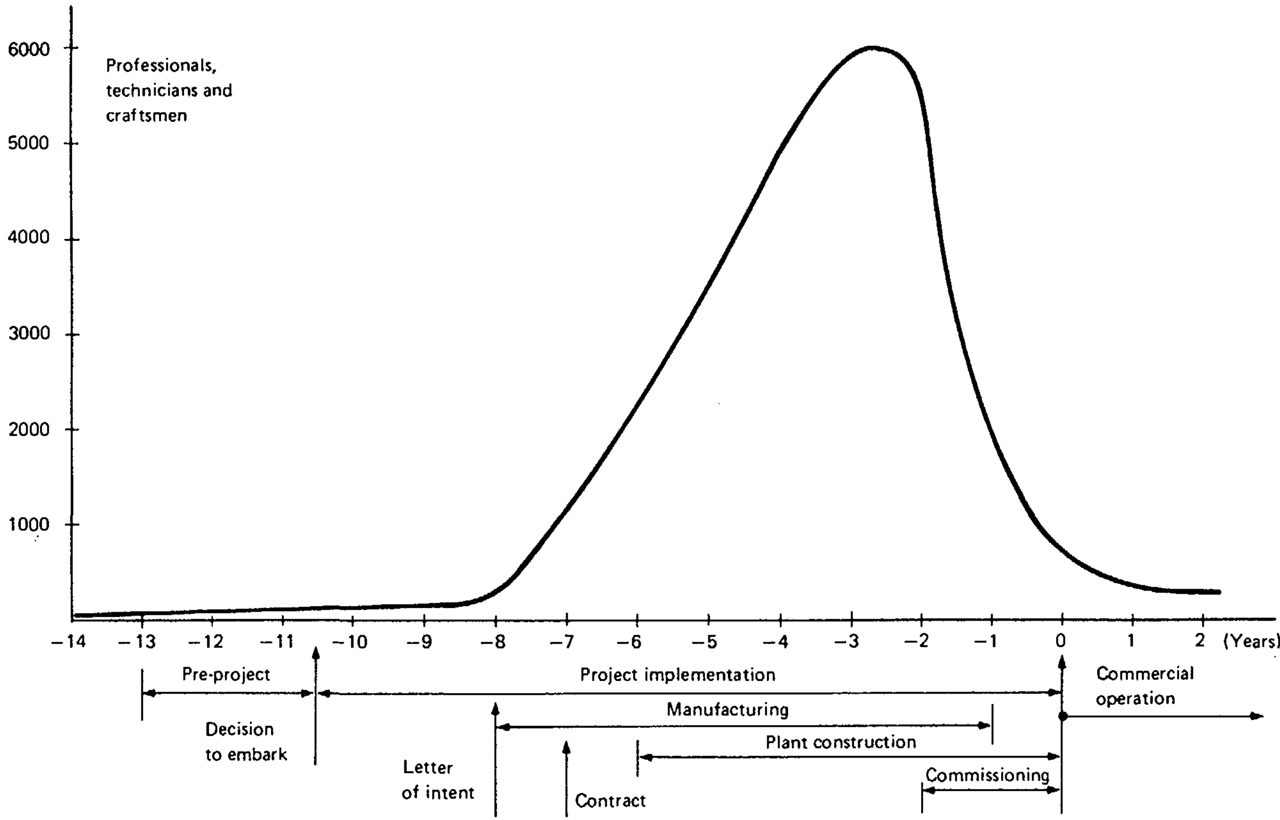


FIG.18.2. The French nuclear programme and the export nuclear power plants [18.11].

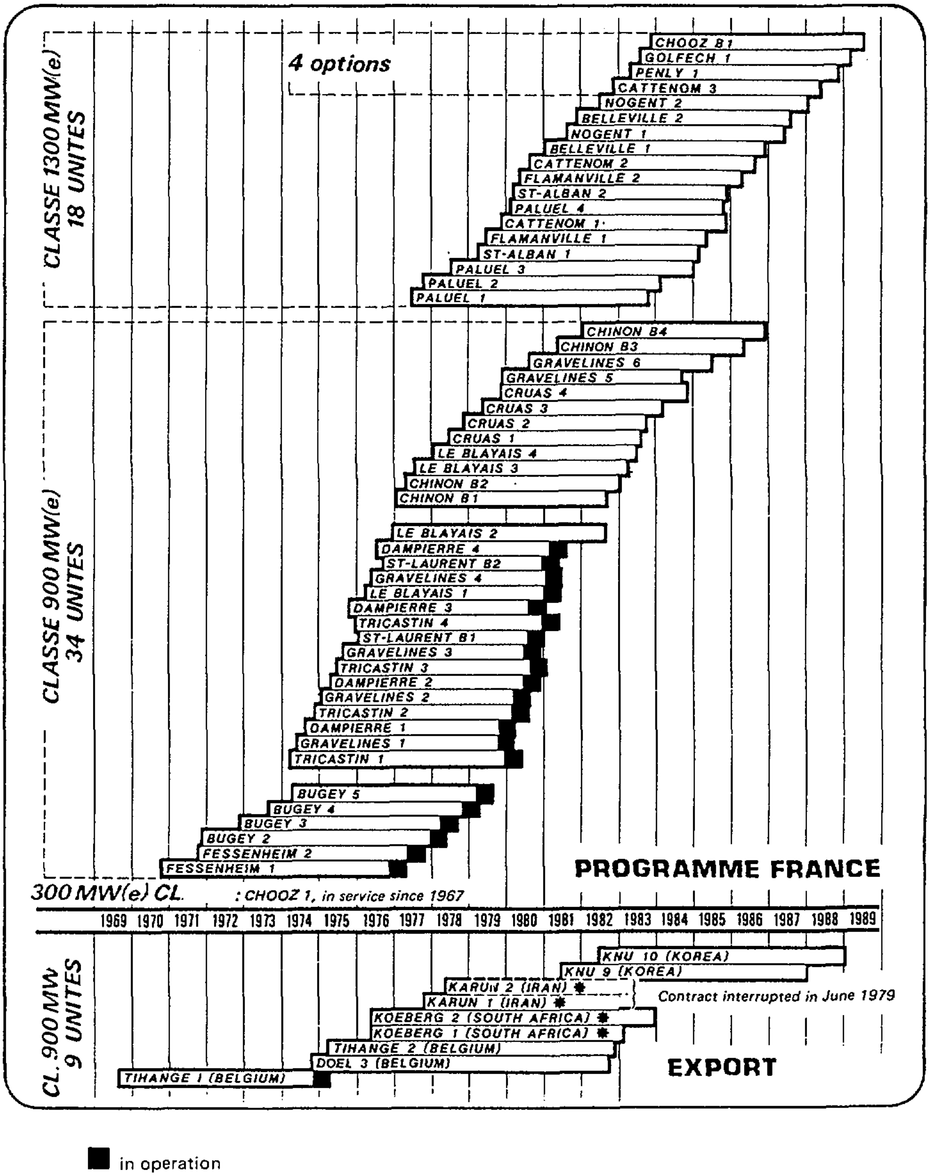


FIG. 18.3. Overall manpower requirements of a nuclear power project [18.1].

A spectacular example of short nuclear power plant implementation schedules, almost of assembly line character, is that of the French nuclear programme presented in Fig.18.2. It consists of a series of 34 units of 900 MW(e) and 18 units of 1300 MW(e) in addition to the first 300 MW(e) unit commissioned in 1967. Another nine units of each 900 MW(e) are export nuclear power plants. Twenty-one units of 900 MW(e) in France and one in Belgium were operating in 1981.

18.2.4. Manpower development requirements

The overall manpower requirements of a nuclear power project (national and foreign in the case of imported plants) are illustrated in Fig.18.3 [18.1].

During the pre-project and early implementation phases, relatively few (50 to 100) but highly qualified professionals are needed. The requirements start to increase strongly when the commitments are made (letter of intent, contract) to install the plant. Manufacturing and construction are the activities that have by far the largest manpower requirements, of the order of 5000 people. Most of these (about 85%) will be technicians and craftsmen. In nuclear power the requirements for unskilled labour are very low (of the order of 10%), although in some countries their proportion might be considerably higher, mainly owing to local labour practices and employment policies. Professionals during the design and construction phase are needed primarily for project management and engineering (250 to 350). Finally, for operation and maintenance, a staff of about 170 to 270 highly trained people are required. In general, it can be estimated that the manpower requirements of a nuclear power project are of the order of 6000 professionals, technicians and craftsmen during its peak period and are relatively small but not less important during the initial phases and during commercial operation of the plant. In addition, manpower is required to perform the supporting activities: nuclear power programme planning and co-ordination, regulatory and licensing activities, fuel cycle activities, research and development, education and training.

To provide the highly qualified and experienced people at the proper time, the essential conditions to be met are:

- An early and full awareness of the need for manpower
- The careful and detailed planning of a manpower development programme
- The effective implementation of this programme
- The application of an appropriate personnel management policy.

A comprehensive manpower development programme must be an integral part of the nuclear power programme and consistent with national participation policies. It should, if possible, be organized, co-ordinated and controlled by one specially created group. It is emphasized that:

- The implementation of a nuclear power programme is not feasible without sufficient national manpower

- Only properly qualified manpower can be considered for meeting the manpower requirements for a nuclear power programme
- Manpower development is a long-term activity and must be programme-oriented rather than project-oriented. As many as ten to fifteen years may be required to establish the independent, national manpower development capability necessary to produce highly qualified manpower for a nuclear power programme
- Although manpower development will require what seems to be a large investment, its cost is very small when compared with the investment associated with the overall nuclear power programme.

In developing countries there is usually a shortage of qualified manpower and consequently a high demand for qualified professionals, technicians and craftsmen. Such a situation would normally lead to higher attrition rates and major difficulties in providing replacements. Therefore, in assessing manpower requirements, care should be taken to include, in addition to those people who actually will be needed to perform the tasks and functions, an adequate number of reserve and replacement personnel. A policy of a reasonable degree of overstaffing, especially in critical areas, is thus advisable.

It should also be emphasized that many high-technology projects, especially nuclear power projects, have been delayed and have encountered other serious problems for lack of qualified technicians. In some countries the attempt to recruit and retain those most able to fill these positions failed. In other cases, capable technicians have tried to become engineers in order to overcome the economic and social problems associated with the technician's status. However, many capable and necessary technicians could not become similarly capable engineers. Thus, measures must be taken to ensure the availability of sufficient numbers of the qualified technicians necessary for a safe and efficient nuclear power programme.

No amount of outside guidance can substitute for an organized, disciplined and comprehensive effort by a national team responsible for evaluating manpower requirements and defining, planning and implementing such a development programme. The programme for each country has its own unique characteristics that must be understood and taken into account. This is only possible when the programme is primarily developed by national planners. General guidance, or outside expertise can and should be used wherever needed, but it must never supplant the country's own effort to define its manpower requirements from a thorough understanding of the nature of each activity and task in its own nuclear power programme and its understanding of the qualitative and quantitative manpower conditions needed to perform these tasks. The planning process itself is an indispensable factor for an effective national manpower development programme.

18.2.5. Initial project start manpower group

To start the development of a nuclear power programme it is necessary to establish a relatively small project group which will have the overall responsibility for carrying out the various studies involved in the pre-project activities. An important aspect in the formation and organization of this project group is that it should not exclusively consist of nuclear specialists but rather of senior and experienced planners and engineers who have been engaged in large projects such as conventional power plants or industrial installations including the general planning of the distribution systems in the country concerned and be supplemented by a few nuclear experts who are familiar with nuclear reactor engineering and nuclear power systems.

The size of this group need not be very large (25 to 40 professionals), but the important point is that they should be carefully selected and be of the highest available quality, competence and experience. It must be recognized that this group represents the main core of the organization of the whole nuclear programme and will have great responsibility in taking major decisions and presenting recommendations involving important and far-reaching commitments and large investments. It will be necessary to provide the staff of this project group with additional training in nuclear power, both through special courses and on-the-job training assignments, probably abroad.

18.3. International co-operation – the role of the IAEA

Facing tasks of the complication and magnitude discussed above, developing countries which enter the process of introducing nuclear power and nuclear technology, need all the co-operative assistance that can possibly be obtained. Industrialized countries exporting nuclear equipment offer on a bilateral basis substantial assistance in significant phases of the commercial implementation process. The bilateral assistance is much more scarce in the initial phases of nuclear programme introduction. Therefore, the IAEA considers one of its most important tasks to be to assist its developing Member States in covering the limitations imposed by infrastructure constraints [18.7, 8].

Accordingly, assistance is provided in the area of planning and decision-making capability, in organizational structures, in electric grid infrastructure requirements, in manpower training, in advice and guiding for industrial support development and even in the financing area, with advice on financial planning and economic studies and up-to-date information on nuclear power costs [18.9].

In addition to meetings, seminars, training courses, fellowships, expert missions, etc., a number of guidebooks [18.10] on the above most important issues have been published, including publications such as the present one.

As far as relevant experience in the introduction of nuclear power in other countries – developed and developing – is concerned, the IAEA International Conference on Nuclear Power Experience held in Vienna in September 1982 generated impressive and topical documentation. The bibliography at the end of this book contains a series of the most interesting papers for further reading [18.1–10].

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