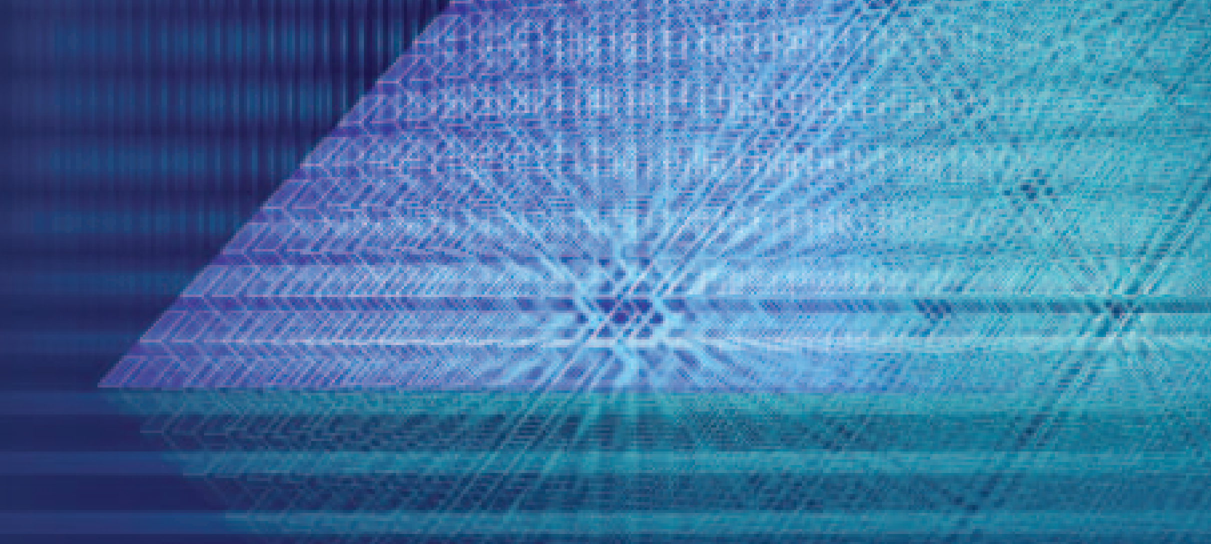

TECHNICAL REPORTS SERIES NO. 410

# Market Potential for Non-electric Applications of Nuclear Energy

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2002

# MARKET POTENTIAL FOR NON-ELECTRIC APPLICATIONS OF NUCLEAR ENERGY

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BANGLADESH
BELARUS
BELGIUM
BENIN
BOLIVIA
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BULGARIA
BURKINA FASO
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHILE
CHINA
COLOMBIA
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ESTONIA
ETHIOPIA
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GUATEMALA
HAITI
HOLY SEE
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
LATVIA
LEBANON
LIBERIA
LIBYAN ARAB JAMAHIRIYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITIUS
MEXICO
MONACO
MONGOLIA
MOROCCO
MYANMAR
NAMIBIA
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
PAKISTAN
PANAMA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
SAUDI ARABIA
SENEGAL
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
TUNISIA
TURKEY
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VENEZUELA
VIET NAM
YEMEN
YUGOSLAVIA, FEDERAL REPUBLIC OF
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

Printed by the IAEA in Austria
December 2002
STI/DOC/010/410

TECHNICAL REPORTS SERIES No. 410

# MARKET POTENTIAL FOR NON-ELECTRIC APPLICATIONS OF NUCLEAR ENERGY

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2002

**IAEA Library Cataloguing in Publication Data**

Market potential for non-electric applications of nuclear energy. — Vienna :
International Atomic Energy Agency, 2002.
p. ; 24 cm. — (Technical reports series, ISSN 0074–1914 ; no. 410)
STI/DOC/010/410
ISBN 92–0–115402–X
Includes bibliographical references.

1. Nuclear energy — Industrial applications. I. International Atomic Energy Agency. II. Series: Technical reports series (International Atomic Energy Agency) ; 410.

IAEAL 02–00305

# FOREWORD

Nuclear energy is known to have a much wider potential than being used solely for the generation of electricity. Ideas and technical solutions for non-electric nuclear applications have been developed, although, for various reasons, they have not yet reached the same industrial maturity as for the generation of electricity.

The IAEA has always followed the progress of nuclear technologies for non-electric energy services, which is manifested by numerous technical documents on cogeneration, heat production, desalination and ship propulsion. However, recent developments have led to the need to focus attention, since:

— There is increased interest in non-electric applications facilitated by the recent development of advanced reactor concepts;
— The current trend to a market oriented restructuring in the energy sector requires an accurate estimation of the costs and benefits of nuclear applications in comparison with the non-nuclear suppliers of similar services;
— Globally, since the use of nuclear energy is at a crossroads, with its prospects ranging between negligible and highly accelerated growth, it is important to identify the potential of the non-electric part of nuclear applications.

The IAEA has therefore prepared this report, which concentrates on the market potential and economics of the nuclear option in district heating, the supply of process heat, water desalination, ship propulsion and outer space applications. In addition, there is an overview of innovative but promising areas of its use, such as fuel synthesis (including hydrogen production), oil extraction and some others.

The report is intended primarily for senior experts in governmental organizations, research institutes, industries and utilities who have influence over decisions related to the support of research and development for non-electric applications of nuclear energy.

The report was prepared in 1999–2001 by two sections of the Department of Nuclear Energy: the Planning and Economic Studies Section and the Nuclear Power Technology Development Section. The IAEA wishes to express its gratitude to all the experts who participated in the drafting and review of the report. The responsible IAEA officer was S. Kononov of the Planning and Economic Studies Section.

## *EDITORIAL NOTE*

# CONTENTS

# 1. INTRODUCTION

## 1.1. OBJECTIVE AND SCOPE

The objective of this report is to assess the market potential for the non-electric applications of nuclear energy in the near (before 2020) and long (2020–2050) terms. The main non-electric applications are defined here as district heating, desalination (of sea, brackish and waste water), industrial heat supply, ship propulsion and the energy supply for spacecraft. This report is principally devoted to these applications, although a less detailed assessment of some innovative applications (e.g. hydrogen production and coal gasification) is also provided.

While the technical details of these applications are covered briefly, emphasis is placed on the economic and other factors that may promote or hinder the penetration of the nuclear option into the market for non-electric energy services.

The report is intentionally targeted towards expected demands. It is for this reason that its sections are structured by demand categories and not according to possible reactor types. At the same time, the orientation on the demand side can result in overlaps at the supply side, because the same nuclear reactor can often serve more than one type of demand. Such cases are noted as appropriate.

Each section characterizes a specific non-electric application in terms of its market size, its prospects for nuclear technologies and the economic competitiveness of the technologies.

## 1.2. MOTIVATION FOR NUCLEAR ENERGY

There are many factors that favour a possible revival of nuclear power production in the future: the development of innovative reactor concepts and fuel cycles with enhanced safety features, which are expected to improve public acceptance, the production of less expensive energy as compared with the non-nuclear options, the need for the prudent use of fossil fuel energy sources and the increasing requirements for curtailing the production of greenhouse gases (GHGs), toxic gases, particulates and acid rain, all of which are associated with the combustion of fossil fuels.

It is thus expected that this revival would also lead to an increased role for nuclear energy for non-electric energy applications, which currently are almost entirely dominated by fossil fuel energy sources. In addition, the use of nuclear energy for non-electric applications has the following advantages:

— The advances in technologies for non-electric nuclear applications and the wide spectrum of temperatures provided by nuclear reactors, from some 200°C to

1000°C, which covers practically the whole range required for non-electric energy applications;
- The extremely high energy content of nuclear fuel, which makes it more attractive in applications in which small amounts of fuel are desirable (e.g. long duration space missions).

## 1.3. MARKET SIZE

Two different types of market size are distinguished for most applications:

- In the low estimate the market size is estimated using conservative assumptions for the potential nuclear penetration into the market; for example, for district heating the low estimate is determined on the basis of the amount of heat that is currently supplied by centralized heat sources[1]. The low estimate therefore corresponds to the situation in which only existing heat distribution networks are used, while heat that is currently provided by decentralized energy sources is excluded.
- In the high estimate, in contrast, the possibility of a full penetration of nuclear energy into the respective markets is assumed. For the case of district heating all the heat required (for space heating, water heating and cooking) would be supplied by centralized sources, regardless of the mode of supply (centralized or non-centralized) that exists today. This would require the development of new networks or the existing ones to be considerably modified.

Table 1 summarizes the two estimates for the applications considered in Sections 1.3.1 to 1.3.6.

### 1.3.1. District heating

Table 1 shows that there is indeed a very large market for district heating, irrespective of the estimate used. The global estimate is between 340 GW(th)

---

[1] 'Centralized' means that the produced heat is sold for utilization to a third party; the heat thus defined corresponds to the definitions used by the International Energy Agency (IEA). Although this definition is not perfect (some heat sources that are technically centralized may not be covered), it is used throughout this report because of the vast amount of IEA energy statistics that can be utilized.

TABLE 1. MARKET SIZE AND NEAR TERM PROSPECTS FOR NON-ELECTRIC APPLICATIONS OF NUCLEAR ENERGY

| Application | Present status of nuclear applications | Low estimate of the global market | High estimate of the global market | Nearest prospects of nuclear applications |
|---|---|---|---|---|
| *Traditional applications* | | | | |
| District heating | Available: has been used in several countries, mostly as cogeneration | ~340 GW(th) | 7600 GW(th) | China: a promising NHR-200 concept is being developed based on the experience with NHR-5. The Russian Federation: a nuclear heating plant (NHP), the AST-500 (in Voronezh), is being considered; an AST-500 feasibility study (in Seversk) has been accomplished; floating stations with KLT-40 reactors are being designed. |
| Desalination | Available: has been used in two countries (Japan and Kazakhstan[a]) in the cogeneration mode | Not estimated: the market is potentially very large and high growth is likely in the future; quantitative estimates are not possible at present because of the uncertain role of desalination in general | | Egypt: a feasibility study of a nuclear desalination plant at El-Dabaa is being conducted. Europe and Canada: a consortium of seven European and Canadian organizations has recently launched the EURODESAL project in southern Europe, which is based on the use of innovative reactors for desalination. India: a hybrid desalination facility to be connected to existing pressurized heavy water reactor (PHWR) units in Kalpakkam is being constructed. Republic of Korea: the cogeneration approach for desalination on the basis of an advanced reactor concept (SMART) is being developed. Morocco: the use of a dedicated heating reactor of a Chinese design (NHR-10) for deslination has been considered. The Russian Federation: feasibility studies of a floating nuclear power desalination plant with KLT-40 reactors are under way. |

TABLE 1. (cont.)

| Application | Present status of nuclear applications | Low estimate of the global market | High estimate of the global market | Nearest prospects of nuclear applications |
|---|---|---|---|---|
| Process heat | Available: has been used in three countries (Canada, Germany and Switzerland) as cogeneration | ~240 GW(th) | 2900 GW(th) | China: an HTR-10 reactor reached criticality in 2000. France, Japan, the Russian Federation and the USA: a promising GT-MHR project with a modular system is being developed (which would be suitable for most non-electric applications). Japan: a 30 MW(th) high temperature engineering test reactor is under development and has reached first criticality at the Japan Atomic Energy Research Institute (JAERI). South Africa: the development of a modular nuclear reactor of 268 MW(th), applicable to the supply of non-electric energy, is being pursued. |
| Ship propulsion | Available: has been used in four countries (Germany, Japan the Russian Federation and the USA); at present, only the Russian Federation uses nuclear propulsion: nuclear powered icebreakers and a carrier | ~40 million GT | ~400 million GT | Japan: concepts of innovative marine reactors are being developed based on the experience with the first Japanese nuclear power ship, the *Mutsu,* which was decommissioned in 1992. The Russian Federation: the use of nuclear powered icebreakers and a carrier continues, as well as the research and development of new designs. |
| Space applications | Under development: has been used in two countries (the former Soviet Union and the USA); no active applications at present (the emphasis is on research) | Not estimated: the key driver — interest in space exploration — was not quantified | | The search for technically feasible and economically affordable applications of a nuclear reactor as a spacecraft energy source continues, in particular in the USA and the Russian Federation. |

TABLE 1. (cont.)

| Application | Present status of nuclear applications | Low estimate of the global market | High estimate of the global market | Nearest prospects of nuclear applications |
|---|---|---|---|---|
| *Innovative applications* | | | | |
| Hydrogen production | Ongoing and available research and development, including testing under nuclear conditions | Not estimated for all innovative applications; generally, the market is expected to be large | | Operation of the HTTR reactor (Japan); continued research and development; European Union design studies |
| Coal gasification | Tested under nuclear conditions | | | Continued research and development |
| Other fuel synthesis | Not yet tested; research and development available | | | Continued research and development |
| Oil extraction | Tested under nuclear conditions | | | Possible promising nuclear applications for tar sands in Canada (Alberta province) |
| Use of nuclear submarines for fossil fuel transportation | Not yet tested; research and development available | | | Continued research and development |

[a] The Aktan NPP in Kazakhstan was shut down in 1998.

(the low estimate) and 7600 GW(th) (the high estimate)[2]. Regional estimates for North America, Europe and the countries of the former Soviet Union are of the order of hundreds (for the low estimate) and thousands (for the high estimate) of reactors per region. The countries of North America, Europe, the former Soviet Union and Asia have a larger potential, especially for the high estimate, because of their climatic conditions and, in certain countries, their historical preference for centralized heating. At the same time, the low estimate for Latin America, the Middle East, Africa, Asia and some other regions is virtually zero, reflecting their current dearth of centralized heat supply systems.

### 1.3.2. Water desalination

It is estimated that freshwater availability may become a key development constraint for many developing countries. An attractive solution for alleviating future water shortages is water desalination. However, desalination brings with it a demand for energy. Future desalination strategies based solely on the use of fossil fuels would thus be undesirable for the reasons given in Section 1.2.

In the past, global desalination capacities have almost doubled each decade. However, it is difficult to estimate accurately the market potential for nuclear desalination in terms of the number of reactors that will be required, as the share of desalination for the supply of fresh water is still very small. Developing hypotheses for the long term share of desalination for the global supply of fresh water is beyond the scope of this report. Low and high market estimates have therefore not been made for desalination.

An approximation of the market potential can be obtained by considering a 600 MW(e) nuclear reactor operating in the cogeneration mode and producing about 500 000 $m^3$ of water per day. For such water production about 20% of the electrical capacity of the plant will be used. The total existing world desalination capacity (~26 $Mm^3/d$) could therefore be powered by ~50 such reactors.

### 1.3.3. Industrial process heat applications

The main process heat consuming industries are the petroleum and coal processing, chemical, paper, primary metal and food processing industries.

Similarly for district heating, high and low estimates for the market potential (Table 1) were prepared for the supply of process heat. They indicate smaller numbers

---

[2] A large proportion of district heating customers would require energy sources with net capacities of the order of 100 MW(th). Assuming such a capacity, the low estimate would correspond to about 3400 reactors and the high estimate to about 76 000 reactors.

for the global total than for district heating: between 240 GW(th) (for the low estimate) and 2900 GW(th) (for the high estimate). The regional estimates for the countries of North America, Europe, the former Soviet Union and Asia are the highest, owing to the size of their heat consuming industries.

### 1.3.4. Ship propulsion

About 25% of global energy is used for transportation. However, the available nuclear technologies can only be directly applied to a small fraction of this market; that is, international and national maritime navigation.

In terms of the quantity of transported goods and fleet capacity, two services have occupied the largest share of the market over the past decade: the transportation of oil and oil derivatives and the bulk transportation of goods such as grain, coal and iron ore. Nuclear powered ship propulsion could be used for such services in addition to the present use of nuclear powered propulsion systems in icebreakers and the one cargo ship used off the north of the Russian Federation.

The estimation of the market potential shows (see Table 1) that the market size is between 2400 ships of 15 000 gross tonnes (GT) (for the low estimate) and 4000 ships of 100 000 GT (for the high estimate). Thus the market is potentially very large; other considerations in addition to market size, however, will determine the penetration of nuclear energy into this sector.

### 1.3.5. Space applications

Qualitatively, the most suitable application for nuclear reactors is that for missions requiring high power levels and/or long operating times. More specifically, lifetimes of the order of 7 to 10 years and power levels in the range of 10 to 200 kW(e) outline the area in which nuclear energy is the most appropriate energy source. For low level and short missions, non-nuclear energy sources are available and considered preferable.

### 1.3.6. Innovative applications

Several innovative applications have been considered:

- Fuel synthesis, including hydrogen production and coal gasification;
- Oil extraction;
- The use of nuclear submarines for fossil fuel transportation.

With the exception of nuclear submarines, the potential market is extremely large, which favours the extensive application of nuclear technologies. The use of nuclear energy will be determined, on one hand, by the development of the market concerned (e.g. the introduction of hydrogen) and, on the other, by the ability of nuclear technologies to withstand the economic competition of alternative energy options.

## 1.4. POTENTIAL NUCLEAR SOLUTIONS FOR NON-ELECTRIC ENERGY SUPPLY

A broad range of nuclear reactors is currently available for the supply of non-electric energy. Future generation reactor concepts incorporating enhanced safety features and meeting stricter economic criteria are under investigation in many countries.

Nuclear reactors are capable of providing heat with a wide range of temperatures, covering the requirements of nearly all the non-electric applications discussed above. No technical impediments to coupling nuclear reactors to various applications have so far been observed, although a number of safety related studies of coupled systems may still be necessary.

There are two ways in which nuclear reactors can be used for a given application:

- The cogeneration mode, in which heat is retrieved as steam from the various expansion stages of a turbine or from a condenser; in general, the portion of the steam retrieved is small compared with that used for electricity production.
- The dedicated heat only mode, in which heat is supplied directly (through a heat exchanger) from the reactor to the customer.

The cogeneration mode has several practical advantages: an increased plant thermal efficiency, the possibility of varying the heat supply according to demand and an easier implementation, as almost all nuclear reactors for electricity production can be adapted. Thus the first nuclear non-electric applications are likely to be of the cogeneration type. This has been confirmed by experience with nuclear district heating and desalination.

### 1.4.1. District heating

Nuclear district heating is in use in several countries and is technically a mature industry. Its future expansion will be determined by a combination of several factors, such as the size and growth of the demand for space and water heating, competition between heat and non-heat energy carriers for space and water heating, and competition between nuclear and non-nuclear heating. The availability of a heat distribution network is an important factor for nuclear district heating.

### 1.4.2. Water desalination

Low temperature heat and/or electricity is required for desalination, and hence all existing designs of nuclear reactors could be used. Relevant experience with nuclear desalination is already available. The use of nuclear heat requires a close location of the nuclear plant to the desalination plant, while the use of electricity generated by nuclear energy for reverse osmosis (RO) does not differ from any other use of electricity in that the energy source may be located far from the customer, with electricity being provided through the electricity grid. It should be noted, however, that electricity taken directly from the plant is cheaper than that from the electricity grid and that a distant location would not allow the use of warm water from a condenser for the RO feed.

### 1.4.3. Process heat supply

For process heat supply there is a wide range of required heat parameters that determine the applicability of different reactor concepts. One particular concept, the high temperature gas cooled reactor (HTGR), covers almost the whole temperature range and is therefore considered to be a leading candidate for the supply of nuclear process heat. The development and demonstration of an HTGR with a relatively small capacity would provide a strong impetus for process heat applications.

### 1.4.4. Ship propulsion

Nuclear powered ship propulsion has already been used for merchant shipping in several countries. However, so far it has appeared non-economic and the use of nuclear powered ship propulsion has been discontinued, with the exception of nuclear icebreakers and a bulk carrier operating off the north of the Russian Federation. Although the market for large tankers and cargo ships is huge, the future of nuclear powered ships will depend on their ability to offer competitive services in this highly competitive market. The need to observe safety and licensing requirements in receiving ports is an additional obstacle for the application of nuclear powered ship propulsion.

### 1.4.5. Supply of spacecraft energy

The application of nuclear reactors for the supply of spacecraft energy has been tested: dozens of nuclear powered missions have been launched in the past. With the exception of the SNAP-10A mission in 1965, which was launched by the United States of America, all missions have been Soviet or Russian. However, at present there is a need to develop a concept that meets the current safety requirements and possesses features that are superior to the non-nuclear options. Achieving this goal is more likely for medium and long duration space missions, where, in terms of power level, load weight and mission duration, there is no energy carrier that is comparable with nuclear energy. No such design is currently flight ready, but the prospects are likely to improve as a result of ongoing research.

### 1.4.6. Innovative applications

For many significant energy consuming activities direct applications of nuclear power are either a long term possibility or improbable. However, an indirect approach could circumvent the difficulties of a direct application, either by bringing forward nuclear applications or allowing them in those areas in which they could not otherwise be foreseeably applied. In this context, nuclear applications such as fuel synthesis (including hydrogen production), coal gasification, oil extraction and the use of nuclear submarines for fossil fuel transportation from deep-sea locations may represent a significant market potential. They are at present at varying degrees of industrial maturity.

Hydrogen may be applied to all types of transportation. Thus, for example, while aircraft powered directly by reactors are implausible, aircraft fuelled with liquefied hydrogen produced by nuclear power have substantial advantages. Ships and trains could also be powered by liquefied hydrogen, the latter often with better economics than with a direct electrification of the track. Finally, the future widespread use of gaseous hydrogen for fuel road vehicles is already widely acknowledged.

## 1.5. ECONOMIC COMPETITIVENESS

As a general rule, the economics of non-electric nuclear applications will follow the same trends as those for nuclear power production for generating electricity. This is particularly true for the cogeneration mode, since for many applications the amount of heat required is a small fraction in comparison with that used for producing electricity. The main factors that would improve the competitiveness of nuclear options include lower specific overnight costs, shorter construction times, lower discount rates, the incorporation of environmental externalities in the price of energy and the expectation of increasing fossil fuel prices. Recent IAEA studies on the economics of nuclear desalination and heat supply quantitatively support these conclusions.

For dedicated heat only reactors the competitiveness of non-electric applications will be strongly influenced by the demonstration that the proposed nuclear reactors can be sited near population centres. The relatively high costs of the transportation of heat (or desalted water) from the reactor over large distances could otherwise become prohibitive. Detailed site specific analyses are therefore essential for determining the best energy option.

Currently, nuclear powered cargo ships do not appear attractive economically, as petroleum derivatives are relatively cheap and maritime transportation is a highly competitive market. However, nuclear powered ships are likely to be the best solution in the situation in which there is a need for transportation to remote areas, especially those hindered by ice. This is confirmed by a long and successful use of nuclear icebreakers off the Russian Federation.

For space applications, the longer the mission duration, the more economic the nuclear options would be, because of the high energy density of nuclear fuels.

## 1.6. PROSPECTS

As specific nuclear applications currently represent only a small share of their total markets, the near term (2000–2020) and long term (2020–2050) prospects for nuclear penetration are assessed only qualitatively.

### 1.6.1. Near term

Near term prospects are assessed on the basis of ongoing projects in the final stages of design or under construction (see Table 1). On this basis, the prospects for nuclear district heating depend on the successful completion and operation of several reactors, for example the NHR-200 in China and the AST-500 in the Russian Federation.

For nuclear desalination some ongoing and prospective projects are the 220 MW(e) heavy water reactor (HWR) in India coupled to a multistage flash distillation (MSF) and RO desalination plant, the Chinese 10 MW(th) NHR-10, a heat only pressurized water reactor (PWR) for Morocco (work on this project is at present suspended), the 100 MW(e) PWR (SMART) in the Republic of Korea, the KLT-40 barge-mounted concept with RO preheating, the 15 MW(e) and 90 MW(e) integral PWRs Nika and the 55 MW(th) heat only pool reactor Ruta (in the Russian Federation). A consortium of seven European and Canadian industrial and research and development organizations has recently launched the EURODESAL project for desalination in southern Europe, which is based on the use of innovative reactors.

For process heat supply, the operation of the High Temperature Engineering Test Reactor (HTTR) (in Japan), implementation of the pebble bed modular reactor (PBMR) project (in South Africa), operation of the HTR-10 (in China) and operation of gas turbine modular helium reactors (GT-MHRs) (in France, Japan, the Russian Federation and the USA) are the nearest prospects.

With the exception of icebreakers in the Russian Federation, there are no ongoing projects for nuclear powered ship propulsion. The three tested nuclear cargo ships have all been decommissioned, mainly for economic reasons. Moreover, widespread public concern about nuclear energy has limited the number of harbours open to nuclear powered merchant ships.

The near term prospects for the use of nuclear reactors in space missions are low, but future space missions are increasingly likely to use nuclear power. No standard nuclear design is currently flight ready, but there is ongoing and active research, in particular in the USA and the Russian Federation.

### 1.6.2. Long term

For the long term, use has been made of an arbitrary scale ranging from 0 to 2 for five critical areas: market structure, demand pressure, technical basis, economic competitiveness and public acceptance. Qualitative estimates of the long term prospects for nuclear penetration for the non-electric energy supply market are shown in Table 2. The main results are as follows.

Owing to the availability of heat distribution networks, nuclear district heating appears most promising for the countries of central and eastern Europe and the countries of the former Soviet Union. The chances of nuclear penetration into this market in North America and western Europe are rated as medium. For these regions the market structure is less favourable because of the lack of adequate heat distribution networks, but there is a technical basis for creating competitive nuclear options. The same is true for China and some other countries in the region of centrally planned Asia.

For nuclear desalination the prospects depend upon the combination of two factors: the lack of fresh water and the ability to use nuclear energy. When these conditions are present, the prospects are medium to high, as shown for South Asian countries such as India and Pakistan as well as in the region of centrally planned Asia. It should be noted that the region of centrally planned Asia and South Asian countries may represent more than 50% of the world's population in 2020. Ultimately, the choice of the nuclear option will be determined by economic considerations.

The situation in the Middle East and North Africa region is of particular interest. Similarly to Africa and South Asia, the region experiences a lack of water and a high demand pressure, which is why countries in the region have been looking into the possibility of using nuclear power for desalination. However, as the technical basis for the introduction of nuclear power has not yet been created and the economic competitiveness of nuclear desalination is not definite, the overall ranking of the long term prospects for nuclear energy is still low. With the introduction of nuclear power

TABLE 2. LONG TERM PROSPECTS FOR NON-ELECTRIC APPLICATIONS OF NUCLEAR ENERGY BY WORLD REGION

| Application | North America | Latin America and the Caribbean | Sub-Saharan Africa | Middle East and North Africa | Western Europe | Central and eastern Europe | FSU[a] | Centrally planned Asia and China | South Asia | Other Pacific Asia | Pacific OECD | World average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Traditional applications* | | | | | | | | | | | | |
| District heating | M | L | — | — | M | M | M | M | M | L | L | M |
| Desalination | L | — | L | L[b] | L | L | L | M | H | L | L | L |
| Process heat | M | L | — | — | L | M | M | H | M | M | L | M |
| Ship propulsion | M | — | — | — | — | L | M | L | M | — | M | — |
| Space applications | Not estimated | | | | | | | | | | | |
| *Innovative applications* | | | | | | | | | | | | |
| Hydrogen production | Not estimated | | | | | | | | | | | |
| Coal gasification | Not estimated | | | | | | | | | | | |
| Other fuel synthesis | Not estimated | | | | | | | | | | | |
| Oil extraction | Not estimated | | | | | | | | | | | |

**Abbreviations:** — = negligible, L = low, M = medium, H = high.

[a] Newly Independent States of the former Soviet Union.

[b] As noted, although the countries of the Middle East and North Africa region have been looking into the possibility of using nuclear power for desalination, the overall ranking of the long term prospects for nuclear energy is at present still low because the technial basis for the introduction of nuclear power has not yet been created and the economic competitiveness of nuclear desalination is not definite. This does not exclude, though, that the prospects for nuclear energy for certain countries in the region are higher.

in the region, even for electricity generation only, this estimate will most likely change to medium.

The prospects for nuclear process heating are assessed as low or negligible in Latin America, Africa and the Pacific region, mainly because of the lack of a centralized heat supply. The prospects for western Europe are also low because of the lack of a demand pressure and a reserved public attitude to nuclear energy. In central and eastern Europe the prospects are medium, which reflects the favourable structure of the market (i.e. the existence of heat consuming industries and the availability of heat networks) and a sufficient technological basis. In Asia (both the region of centrally planned Asia and South Asia) the combination of a demand growth, the existence of a technological basis and a favourable market structure lead to medium or high estimates for nuclear penetration.

The prospects for nuclear powered ship propulsion appear relatively high in the regions in which the use of nuclear energy could be combined with large fleet capacities, such as North America, the countries of the former Soviet Union (especially the Russian Federation), South Asia and the Pacific OECD (Japan). Elsewhere, the estimate is low or negligible.

The long term prospects for the space applications of nuclear reactors critically depend on the success of current projects. Because of the large uncertainties, even a qualitative estimate of the prospects for nuclear energy is difficult to make.

## 1.7. STRUCTURE

This report is structured as follows:

- The objectives and structure of the report are given in Section 1.
- Section 2 gives the background and motivations for the use of nuclear energy for non-electric energy services.
- Section 3 describes the methodology used for the evaluation of the market potential.
- Sections 4 to 8 describe the market potential for the most advanced non-electric applications of nuclear energy: district heating, water desalination, the supply of process heat, ship propulsion and energy for spacecraft.
- Section 9 gives the prospects for some innovative applications of nuclear energy, such as oil extraction, coal gasification and hydrogen production.
- Section 10 is the summary of the estimated market potential for the non-electric applications of nuclear energy.
- The conclusions of the report are given in Section 11.

Sections 4 to 8 follow a common structure of describing the:

- Market characterization (the estimate of the market size and its specific features considered important for nuclear applications);
- Potential nuclear solutions (the estimate of the applicability of nuclear technologies to the market);
- Economic competitiveness compared with the non-nuclear options;
- Current and prospective market for nuclear energy in the short and medium terms.

This structure is not based on the types of nuclear reactor, either existing or innovative, that may be required. The report is instead broken into sections in accordance with expected demand categories. This approach reflects the targeting of the demand side, which is a principal feature of the report. At the same time, the orientation on the demand side can result in overlaps at the supply side, because the same nuclear reactor can often serve more than one type of demand. Such cases are noted where appropriate.

Section 9, which is devoted to innovative applications, is shorter and does not follow the uniform structure described above.

# 2. MOTIVATION AND BACKGROUND

## 2.1. BACKGROUND

According to the most recent data (that for 1999) there are approximately 430 nuclear power reactors in the world [1], which produce about 16% of the world's electricity [2]. However, it is well known that nuclear energy has the capability to provide products in addition to electricity. In the 1970s, when the large scale peaceful use of nuclear energy had just started, the prospects for non-electric applications were identified and corresponding designs were developed. However, notwithstanding several successful applications, the supply of non-electric energy by nuclear technologies remains minimal.

Technical possibilities already exist for using the heat produced in nuclear reactors for the supply of non-electric energy. The modes of heat utilization can widely differ and various applications are known from experience with non-nuclear energy technologies.

The principal reasons for using nuclear energy in the non-electric area are the same as for electricity generation:

- There are economic advantages (i.e. a relative economic superiority of the nuclear option for a given product in a given location);
- There are environmental benefits (i.e. an absence of polluting emissions, in particular GHGs, and lower fuel requirements);
- There are strategic considerations (i.e. diversification of fuel supply, protection against the volatility of fossil fuel prices, the use of existing industrial infrastructure and human resources, and expectations of spin-off effects after the introduction of nuclear technologies).

In addition, there are several specific features that confer potential advantages on the use of nuclear energy for non-electric purposes:

- Owing to the extremely high energy value of nuclear fuel, very small amounts of fuel are required for the production of a unit of energy compared with fossil fuels; as a result, the use of nuclear energy has advantages for applications for which small amounts of fuel are preferable (e.g. energy sources for long duration outer space missions) or a long operating time without refuelling is preferred (e.g. energy for ship propulsion or energy supplies for remote regions).
- Various nuclear reactor concepts can provide a wide spectrum of output temperatures, covering practically the whole range of typical heat applications (from some 200–300°C, provided by water cooled reactors, up to about 1000°C, provided by gas cooled reactors).

## 2.2. CURRENT STATUS

If the share of electricity supplied by nuclear power is compared with that of the rest of the final energy demand (see Table 3), the striking contrast between the extensive use of nuclear energy for electricity generation and its limited application for other purposes becomes evident. Nuclear energy is well represented in electricity generation (~17% of the total in 1997), but electricity generation accounts for less than 20% of the total energy demand; for the non-electric generating portion of the final energy demand, which accounts for about 80% of the total demand, the nuclear share is negligible.

Several factors have slowed the development of nuclear energy in the world and have led to the current limited role of nuclear energy for non-electric applications:

- The need for technological advances to the point of the successful industrial implementation of a nuclear design that has a wide applicability in the non-electric market.

TABLE 3. STRUCTURE OF THE GLOBAL ENERGY SUPPLY IN 1998 [3]

| Primary energy supply | | Electricity supply | | Final energy supply | |
|---|---|---|---|---|---|
| Total primary energy (Mtoe) | Nuclear share (%) | Total electricity generated (TW·h/Mtoe) | Nuclear share (%) | Total final energy (Mtoe) | Nuclear share[a] (%) |
| 9491 | 6.7 | 14 331/1232 | 17.1[b] | 6646 | 2.6 |

**Mtoe:** million tonnes of oil equivalent.

[a] Calculated from the nuclear share of electricity generation; that is, the nuclear share of electricity generation (17.1%) multiplied by the share of electricity of the final energy supply (15.2%). This ignores some use of nuclear energy for heat generation and ship propulsion. However, this simplification cannot lead to a meaningful error in the result, because the current global share of nuclear energy in these two applications is negligible.

[b] The 1998 number (~17%) is higher than the corresponding estimate for 1999 (~16%).

— The availability of relatively cheap fossil fuelled systems, in particular gas turbine combined cycle plants, coupled with an increasing deregulation of electricity and energy markets in many countries, currently favour the introduction of technologies economically effective in the short term. However, in the longer term the transition from conventional to non-conventional fossil fuel resources, as well as the inclusion of environmental externalities, will force their prices higher, thus favouring the nuclear options (where the externalities have already been largely included)[3].

— Real or perceived regulatory hurdles (in particular the safety of nuclear reactors located near population centres).

— The public attitude to nuclear energy in general (e.g. the perception of a lack of nuclear safety and concerns related to the management of long lived radioactive waste).

## 2.3. FUTURE DEVELOPMENTS

There are reasons to believe that the twenty-first century may witness not only the revival of nuclear power generation but also an increased nuclear share in the non-electric sector. Several factors may contribute to this development:

---

[3] The increase of oil prices in 1999 and 2000 made it clear that although fossil fuel prices may be relatively low at times there is always a possibility of unpredictable increases. This volatility remains an important negative feature of fossil fuels.

- An increase in energy demand, owing to the expected population growth and economic advances, in particular in today's developing countries;
- The impact of climate change considerations related to the need to mitigate GHG emissions;
- The technological advancement of non-electric nuclear designs to the point of commercial application;
- Changes in the social environment related to nuclear energy.

### 2.3.1. Demand growth

Global energy demand is expected to increase rapidly in the next 20 to 50 years. This will largely be due to population growth and the fact that most developing countries will cross the threshold of industrialization by this time. As an illustration, some typical long term projections of primary energy demand are shown in Fig. 1. By 2050 the demand will grow two- or threefold compared with the present level, depending on the assumptions used.

It is also expected that the share of electricity in the total energy demand will steadily increase, electricity being a clean and convenient final form of energy.

There are three important factors that may also lead to an increased market potential for non-electric energies and their associated applications:

- The demand for non-electric energy will grow substantially in absolute terms owing to population growth and increasing standards of living.

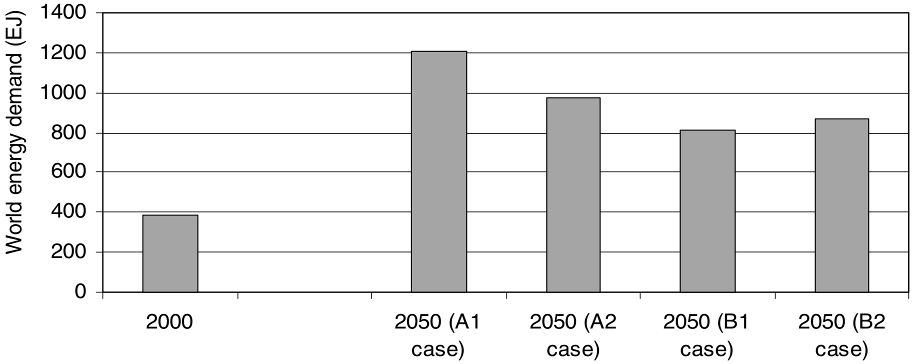

*FIG. 1. Long term trends in the world primary energy demand [4]. A1, A2, B1, B2 denominate the four scenarios that were considered in Ref. [4] as representative (out of the 40 scenarios considered). An analysis of the implications of this study for the role of nuclear energy can be found in Ref. [5].*

- Structural changes in non-electric energy carriers are likely to occur. At present, fossil fuels are extensively used for transportation, heating and domestic applications. This usage will continue to increase in the short term. In the longer term, converted forms of non-fossil fuel energy are expected to grow in importance. In particular, the use of hydrogen is likely to begin to erode the dominance of fossil fuels. These developments will create incentives for industries to develop and promote alternative technologies for non-electric energy. Nuclear energy would thus have a large potential for penetrating this market.
- The future market will include not only growth in energy demand but also the need to replace existing plants.

### 2.3.2. Impact of climate change considerations

The ongoing debate on the problem of climate change may have a profound influence on the electric sector and the market share of nuclear power plants (NPPs). As nuclear energy is the only significant mature, large scale energy technology free from GHG emissions, the share of nuclear energy in electricity generation may increase if relevant policy measures (e.g. restrictions, taxes and credits) for GHG emissions are introduced.

This factor is expected to have similar implications for the suppliers of non-electric energy. At present, electricity generation accounts for only 24% of global $CO_2$ emissions (see Fig. 2). This alone indicates the need for nuclear energy to penetrate the non-electric market in order to have an effect on the remaining larger part of $CO_2$ emissions.

### 2.3.3. Technological advancement to the point of commercial application

The non-electric applications of nuclear energy have not yet reached the same maturity as the electric applications. However, steady progress is occurring in their

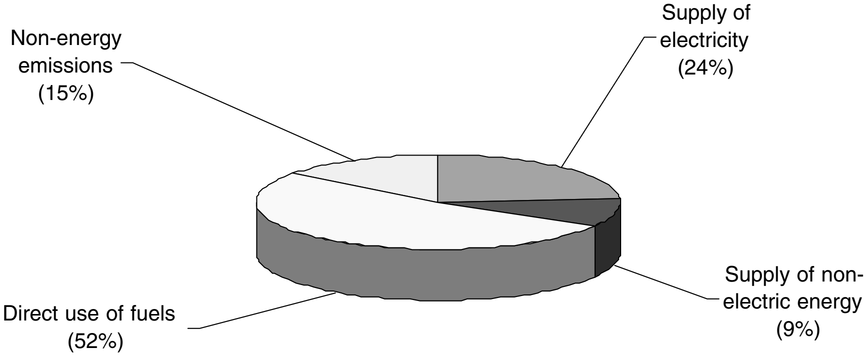

*FIG. 2. World $CO_2$ emissions in 1990 by type of final energy [4].*

TABLE 4. SUMMARY OF RECENT ADVANCES IN NUCLEAR TECHNOLOGIES FOR NON-ELECTRIC APPLICATIONS

| Area | Examples of technological progress |
|---|---|
| Nuclear district heating | A nuclear district heating station in Voronezh in the Russian Federation with an AST-500[a] is being considered; a feasibility study AST-500 for Seversk has been accomplished [6]. The Russian Federation is also designing floating nuclear heat and power stations with KLT-40 reactors for remote regions [7]. In China a promising NHR-200 concept is being developed based on the experience with the NHR-5 reactor [8]. |
| Supply of process heat | A 30 MW(th) HTTR is under development and reached first criticality in November 1998 at the JAERI [9, 10]. The HTR-10 reactor in China reached criticality in 2000 [11]. A promising GT-MHR project with a modular system is being developed jointly by France, Japan, the Russian Federation and the USA, which will be suitable for most non-electric applications [12]. South Africa is pursuing the development of a modular nuclear reactor (the PBMR) of 268 MW(th), which is potentially applicable to the supply of non-electric energy [13–15]. |
| Nuclear desalination | India is constructing a hybrid desalination facility to be connected to existing PHWR units in Kalpakkam [16]. The Republic of Korea and Morocco are considering the development and implementation of nuclear powered national desalination projects. For the Korean case, the cogeneration approach on the basis of an advanced reactor concept (SMART) has been selected [17], while in Morocco the use of a dedicated heating reactor of a Chinese design (NHR-10) is being considered [18]. Egypt is proceeding with a feasibility study of a nuclear desalination plant in El-Dabaa [19]. Russian feasibility studies of floating nuclear power desalination plants with barge-mounted KLT-40s are under way [20, 21]. A consortium of seven European and Canadian industrial and research and development organizations has recently launched the EURODESAL project for desalination in southern Europe, which is based on the use of innovative reactors [22]. |
| Nuclear powered ship propulsion | Concepts of innovative marine reactors are being developed in Japan, based on the experience with the first Japanese nuclear powered ship, the *Mutsu*, which was decommissioned in 1992 [23]. In the Russian Federation the use of nuclear powered icebreakers and a carrier continues, as well as the research and development of new designs [24–27]. |
| Nuclear outer space applications | The search for technically feasible and economically affordable applications of a nuclear reactor as a spacecraft energy source continues, in particular in the USA and the Russian Federation [28, 29]. |

[a] AST is the Russian abbreviation for nuclear heating plant.

development, as shown in Table 4. These achievements can provide competitive nuclear solutions to respond to the above noted increase in the demand for non-electric energy services.

### 2.3.4. Changes in the social environment

To a sizeable extent, the further development of nuclear energy is hindered not by technical or economic considerations but by a negative social attitude relating to the perception of problems of safety, non-proliferation and the management of long lived radioactive waste. Such concerns are especially in evidence in western Europe, where some countries, for example Germany and Sweden, intend to implement a complete phase out of nuclear energy.

There are, however, signs that the negative attitude to nuclear energy can be gradually replaced by a more balanced approach and an awareness that demonizing nuclear energy is unreasonable and potentially counter-productive. A responsible and rational approach would be to apply a comprehensive and impartial consideration of all available energy alternatives (see, as a representative example, the results of a recent study in Belgium [30]).

At the same time, the need for the nuclear industry to work on dialogue with the public remains and will remain vitally important. The social acceptability of technologies has become a key factor for market penetration. This reality will not change, and may become even more important in the future.

There is thus a large place in the market for the non-electric energy services for which nuclear technologies could be applied.

## 2.4. DEFINITION OF THE BASELINE: COMPETITIVENESS OF ELECTRICITY GENERATED BY NUCLEAR ENERGY

Before discussing the market for non-electric applications and, in particular, their economics, it is worth reviewing the economics of electricity generated by nuclear energy. This can provide a departure point for the review of non-electric applications, because, for the following reasons, the competitive positions of electric and non-electric applications are closely linked:

- Electric and non-electric applications have common design features (e.g. a similar reactor design).
- Nuclear energy in non-electric applications competes with the same alternative energy sources (e.g. coal, oil or gas).
- Many non-electric applications are based on electricity as the primary energy source, either directly (i.e. desalination using RO) or indirectly (i.e. cogeneration applications).

— The public attitude, which is an important factor for the use of nuclear energy, does not distinguish between electric and non-electric applications; if nuclear energy is not used for electricity generation because of a lack of public acceptance (and a view of a real or perceived lack of economic competitiveness), the development of non-electric applications is unlikely.

The current competitive position of nuclear energy in electricity generation is therefore a starting point for the discussion of the economics of non-electric applications. To give a summary of the current understanding of the competitiveness of electricity generated by nuclear energy, Table 5 shows the results of a recent economic study conducted by the Nuclear Energy Agency (NEA) of the OECD (OECD/NEA) and the International Energy Agency (IEA) [31], with the participation of the IAEA, the European Commission and the Union of Producers and Distributors of Electric Energy.

The study estimated and compared the costs of electricity generation by various technologies in 19 countries. Most of the countries focused on the comparison of three generation options: coal, gas and nuclear energy. The comparison criterion was the levelized electricity generation cost defined as [31, annex 10]:

$$\mathrm{LGC} = \frac{\sum_t [(I_t + M_t + F_t)(1+r)^{-t}]}{\sum_t [E_t (1+r)^{-t}]}$$

where

$I_t$ is the capital expenditure in year $t$;
$M_t$ is the operations and maintenance expenditure in year $t$;
$F_t$ is the fuel expenditure in year $t$;
$E_t$ is the electricity generation in year $t$;
$r$ is the discount rate;
$\Sigma_t$ is the summation over the period, including construction, operation during the economic lifetime and decommissioning of the plant, as applicable.

The input parameters for the calculations were partially provided by the participating countries ($I_t$, $M_t$) and partially assumed by the expert group ($F_t$). Two discount rates were considered: 5% and 10%.

Table 5 shows some results of the study expressed, for the purposes of this report in relative units, as the ratio of the levelized generation cost of nuclear plants and that of non-nuclear (coal and gas fired) plants. To present the most relevant results succinctly, two scenarios, denominated as the ‘best for nuclear’ and the ‘worst for nuclear', were considered. The former is selected from the multiple combinations of the various nuclear and non-nuclear projects in Ref. [31] as the one most favourable for nuclear power (i.e. with the lowest ratio of levelized costs) in the given country. Similarly, the worst scenario is that with the highest ratio of levelized costs. Only one scenario is presented for the countries in which only one project was considered for each generation option.

TABLE 5. PROSPECTIVE COMPETITIVENESS OF NEW NPPs [31]
*(the numbers are ratios of the levelized electricity generation costs of nuclear and non-nuclear (coal, gas) power plants)*
*(the costs are for plants that are expected to be commissioned from 2005 to 2010)*

| Country | Case for nuclear | Nuclear/coal ratio | | Nuclear/gas ratio | |
|---|---|---|---|---|---|
| | | 5% discount rate | 10% discount rate | 5% discount rate | 10% discount rate |
| Brazil | Best | 0.59 | 0.75 | 1.12 | 1.34 |
| | Worst | 1.04 | 1.19 | 1.29 | 1.57 |
| Canada | Best | 0.60 | 0.73 | 0.82 | 1.20 |
| | Worst | 1.01 | 1.28 | 0.98 | 1.43 |
| China | Best | 0.80 | 0.98 | — | — |
| | Worst | 0.97 | 1.27 | — | — |
| Finland | — | 1.17 | 1.43 | 1.04 | 1.36 |
| France | — | 0.69 | 0.83 | 0.68 | 0.92 |
| India | Best | 0.89 | 1.27 | — | — |
| | Worst | 0.995 | 1.15 | — | — |
| Japan | — | 1.03 | 1.04 | 0.73 | 0.94 |
| Korea, Republic of | — | 0.89 | 1.07 | 0.72 | 1.03 |
| Russian Federation | — | 0.58 | 0.84 | 0.76 | 1.19 |
| Spain | — | 0.97 | 1.17 | 0.86 | 1.17 |
| Turkey | Best | 0.58 | 0.74 | 1.07 | 1.53 |
| | Worst | 0.82 | 1.06 | — | — |
| USA | Best | 1.33 | 1.29 | 1.23 | 1.69 |
| | Worst | 1.34 | 1.33 | 1.43 | 1.96 |

Table 5 illustrates that the competitiveness of electricity from new nuclear plants is not assured, in particular with regard to competition with natural gas. In most cases NPPs look better under the assumption of the discount rate of 5% and in comparison with coal, but lose under the less favourable assumption of the 10% discount rate. This is a known consequence of the assumed high capital costs for NPPs. Although there are countries in which electricity generated by nuclear energy looks definitely better (France) or at least very competitive (China, Japan, the Russian Federation), there are also cases of definite economic inferiority (the USA).

A comparison with previous similar studies shows that the competitive position of electricity generated by nuclear energy has deteriorated as compared with the end of the 1980s and the beginning of the 1990s. The reasons are well known, the main ones being:

- The capital costs of NPPs have grown;
- The costs of fossil fuel prices have been historically low and were assumed in Ref. [31] not to rise substantially by 2010;
- The technical and economic parameters of the competing fossil fuel technologies, primarily combined cycle gas turbines, have improved significantly (with thermal conversion efficiencies of up to 55% and unit construction times down to two years).

The situation shown, however, must not be oversimplified. The assessments of Ref. [31] are generic in that they were built on selected representative designs and assumed generic trends in fuel prices. In a given country actual costs as well as nuclear competitiveness can depend significantly on the location of the plant (for example, there is a large difference between the west and east of China, India or the Russian Federation). Thus a more specific analysis would be necessary to determine nuclear competitiveness at a prospective site.

Moreover, it must be emphasized that the nuclear industry has long recognized the importance of lowering NPP capital costs and is already implementing relevant design solutions for practically all existing designs (see, for example, Ref. [32]). In addition to evolutionary improvements to proven designs, innovative projects are being considered that may lead to drastic cost reductions, such as the PBMR project in South Africa [14]. This project targets a specific capital cost of the order of US $1000/kW(e) [15], which is almost a twofold decrease in comparison with contemporary NPPs. Coupled with the traditionally low costs of nuclear fuel and improved operations and maintenance costs (see, for example, the review of the latest US experience in Ref. [33]), such breakthroughs may greatly facilitate the revival of nuclear power generation as well as the use of non-electric nuclear applications.

# 3. EVALUATION METHOD

The following method was adopted to treat different applications in a consistent manner based on:

- A quantitative assessment of the ultimate market size,
- A qualitative ranking of the prospects for nuclear applications to penetrate the market,
- A presentation of the results by (a) large world regions and (b) selected countries.

## 3.1. QUANTITATIVE ASSESSMENT OF THE ULTIMATE MARKET SIZE

For every application the first step is to estimate the ultimate, maximum size of the market; that is, to quantify the existing demand for the service without specifying which technology, nuclear or non-nuclear, will serve the demand. Two different types of market size are distinguished for most applications: a low and a high estimate.

Under the low estimate the market size is estimated using conservative assumptions for the potential nuclear penetration into the market. For example, for district heating the low estimate is determined on the basis of the amount of heat that is currently supplied by centralized heat sources[4]. The low estimate therefore corresponds to the situation in which only existing heat distribution networks are used, while the heat that is currently provided by decentralized energy sources is excluded.

In contrast, the high estimate assumes the possibility of a full penetration of nuclear energy into the respective markets. For the case of district heating, all the heat required (for space heating, water heating, cooking) would be supplied by centralized sources, regardless of the mode of supply (centralized or non-centralized) that exists today. This would require the development of new networks or considerable modifications of existing ones.

The exact meaning of the low and high estimates differs from application to application. However, the principle of using conservative assumptions for the low estimate and determining the high estimate as the maximum size of the market is observed consistently for all applications.

---

[4] Centralized means that the produced heat is sold for utilization to a third party; the heat thus defined corresponds to the definitions used by the IEA in Refs [34, 35]. Although this definition is not perfect (some heat sources that are technically centralized may not be covered), it is used throughout this report because of the vast amount of IEA energy statistics that can be utilized.

## 3.2. QUALITATIVE RANKING OF NUCLEAR PROSPECTS

After the size of the market has been assessed, the prospects for nuclear technologies to penetrate the market have to be estimated.

The short term prospects (i.e. for 2000–2020) can be estimated by considering the status of existing and envisaged nuclear projects. As the number of such projects is relatively small and the projects are known, this can be done with a reasonable accuracy for all countries that consider non-electric uses of nuclear energy.

For the long term prospects (i.e. 2020–2050) the situation is more complicated. Given the significant technical differences among the applications and the large uncertainties inherent in long term projections, these prospects are determined only qualitatively using a system of qualitative indicators. These indicators are designed to reflect the most characteristic factors that would determine the actual penetration of nuclear technologies into the market.

Five important indicators for nuclear penetration into the market of non-electric energy services are considered: market structure, demand pressure, technical basis, economic competitiveness and public attitude:

- Market structure: the indicator shows whether the existing structure of the market is favourable to the introduction of nuclear energy; structure here is taken to mean the use of supply patterns compatible with nuclear energy (e.g. in the case of district heating it is the use of centralized heat generation as opposed to the use of gas, oil, coal and electricity for space and water heating).
- Demand pressure: the indicator shows whether a substantial demand for the service (district heat, desalination or process heat) exists and, if so, whether it is likely to grow significantly in the future.
- Technical basis: the indicator reflects the technical ability and the existence of the appropriate infrastructure in a given country that are required to exploit nuclear energy for the considered service.
- Economic competitiveness: the indicator shows whether, qualitatively, economic competitiveness of nuclear technologies against the non-nuclear options is probable.
- Public attitude: the indicator reflects the public attitude to nuclear energy in general.

For each indicator a weighting scale of 0, 1 or 2 is used, as presented in Table 6.

After an estimation of all indicators for a country an aggregate score is calculated as a simple average of the five indicators. The obtained average is also labelled qualitatively as negligible, low, medium or high using the following convention:

TABLE 6. ASSUMED PRINCIPLES OF QUALITATIVE RANKING

| Factor | Ranked 0 | Ranked 1 | Ranked 2 |
|---|---|---|---|
| Market structure | The market structure is not suitable for the use of nuclear energy for the given service | The use of nuclear energy is possible, depending on its competitiveness | For the given service, nuclear energy is already used or is likely to be used in the near future |
| Demand pressure | Demand for the service does not exist or, if it exists, will probably decline in the future | Demand exists but is unlikely to change substantially | Demand exists and significant demand growth is likely in the future |
| Technical basis | At present there is little technical basis for the introduction of nuclear energy | Although there is no use of nuclear energy at present, the introduction of nuclear technologies is feasible because of the general level of industrial development | Nuclear energy is used or planned to be used in the near future based on either a domestic industrial basis or on imports of nuclear technologies |
| Economic competitiveness | Economic competitiveness of the nuclear option is unlikely | Economic competitiveness of the nuclear option is possible | Economic competitiveness of the nuclear option is very likely |
| Public attitude | The public attitude to nuclear energy is negative or there is no distinct attitude because nuclear energy has never been seriously considered | The public attitude to nuclear energy at present is not definite; the future attitude is likely to be dependent on its performance | The public attitude to nuclear energy is positive |

— If less than 0.6 the prospects are ranked as negligible.
— If between 0.6 and 1.0[5] the prospects are ranked as low.
— If between 1.0[6] and 1.5[7] the prospects are ranked as medium.
— If between 1.5[8] and 2.0 the prospects are ranked as high.

---

[5] Exact 1.0 is excluded; rounding by three digits is used; that is, 0.994 and below means low.

[6] Exact 1.0 is excluded; rounding by three digits is used; that is, 0.995 and above means medium.

[7] Exact 1.5 is excluded; rounding by three digits is used; that is, 0.144 and below means medium.

[8] Exact 1.5 is excluded; rounding by three digits is used; that is, 0.145 and above means high.

The simple summing of the indicators means that they are all considered equally important for nuclear applications. This is an arbitrary assumption, but was considered appropriate for a first application of the indicators.

It should be emphasized that the described method is qualitative. The judgement of 0, 1 or 2 is expert defined and cannot be formulated mathematically. Similarly, the categories of negligible, low, medium and high are assumed by convention. However, it was found that the method gave plausible and explicable results that correspond to the objectives of this study.

## 3.3. PRESENTATION OF RESULTS BY WORLD REGIONS AND SELECTED COUNTRIES

It is useful to have an aggregated, global view of the long term prospects for nuclear energy; that is, identifying the regions in which nuclear energy has the highest chances of use for a specific non-electric application. The results of the long term qualitative ranking for the prospects for nuclear energy are therefore presented by large world regions.

World regions can be defined in many ways. For this report the classification applied in a recent global study by the World Energy Council and the International Institute of Applied Systems Analysis is used [36]. The study considered 11 regions, designated as North America (NAM), Latin America and the Caribbean (LAM), sub-Saharan Africa (AFR), the Middle East and North Africa (MEA), western Europe (WEU), central and eastern Europe (EEU), the Newly Independent States of the former Soviet Union (FSU), centrally planned Asia and China (CPA), South Asia (SAS), other Pacific Asia (PAS) and Pacific OECD (PAO). The main reason for selecting this classification in this report is that it combines regional aggregations of countries with groupings by the level of economic development. A detailed, country-wise composition of the 11 regions is given in Appendix I.

When calculating the long term indicators of the prospects for nuclear energy (as described in Section 3.2) by region, countries of the regions are summed with weights depending on the non-electric application considered. For instance, the estimate for water desalination requires the use of the current water consumption per country as weighting coefficients, while for district heating it is appropriate to take into consideration the demand for space and water heating. Using such coefficients allows a quantification of the relative importance of the considered nuclear application. In particular, it helps to avoid situations in which a high ranking for a small country outweighs a low ranking for a large country.

The assumed indicators for the public acceptance of nuclear energy are shown in Appendix II. This ranking is used for all potential applications, because the acceptance of nuclear energy should not depend much on the type of application.

It must be taken into account, however, that regional aggregation can conceal important details. For example, a country for which the prospects for nuclear energy are notably high (notwithstanding the overall low ranking for the region as a whole) can become invisible within a region. It is for this reason that specific results for some countries are also included in addition to the regional representation.

A complete set of results for all countries is presented in the appendices. These results were used to obtain the regional averages. They allow calculations for any other combination of countries defining a region.

## 3.4. ILLUSTRATIVE EXAMPLES OF THE METHOD

### 3.4.1. Generic example

If, for example, a country is currently not using nuclear energy but possesses a large heat distribution network, the indicator of market structure and technical basis for the use of nuclear district heating would be assigned as:

- Market structure = 2 (a large heat distribution network exists),
- Technical basis = 0 (nuclear energy is not used at present).

If, in addition, it is assumed that the demand for any type of non-electric energy is not developing rapidly, that the economic competitiveness of prospective nuclear heat sources is unclear and that the public attitude to nuclear energy is currently negative (e.g. as a result of a successful anti-nuclear referendum), the other three indicators would be:

- Demand pressure = 1 (only moderate growth is expected),
- Economic competitiveness = 1 (nuclear energy may be competitive or non-competitive, depending on the site and the prices of fossil fuels),
- Public acceptance = 0 (an anti-nuclear referendum has revealed a negative attitude to the use of nuclear energy).

The average indicator of the long term prospects for nuclear energy for non-electric applications in this country is thus 0.8, or, in accordance with the definitions given above, the prospects for nuclear energy for this country (and for the given application) are low.

The result is obviously predetermined by the assumptions used. The five indicators are determined on the basis of the current situation. If conditions change (e.g. a new reactor appears on the market that is cheap and easily deployed), the results could change accordingly.

To illustrate this, assume for the example above that the indicators of technical basis and public attitude for the same country change to:

- Technical basis = 2 (nuclear technologies are easily deployable in the country),
- Public acceptance = 2 (the public attitude to nuclear energy is generally positive).

As a result, the average will change from 0.8 to 1.6, or, qualitatively, the long term prospects for nuclear penetration change from low to high.

### 3.4.2 Specific example: the case of nuclear desalination in North Africa and the Middle East

Another representative case can be considered for nuclear desalination in North Africa and the Middle East. Taking Morocco as a country with an interest in nuclear desalination but at present without NPPs, the set of indicators would be as follows:

- Market structure = 1 (there are large population centres with a desalination demand),
- Demand pressure = 2 (a deterioration of the water supply situation is expected),
- Technical basis = 1 (although nuclear energy is not used at present, a nuclear desalination project has been considered),
- Economic competitiveness = 1 (nuclear energy may be competitive or non-competitive, depending on the prices of fossil fuels),
- Public acceptance = 1 (the public attitude to nuclear energy in the country is neither anti- nor pro-nuclear).

The aggregate score in this case is 1.2, which means, in the assumed naming convention, there are medium prospects for nuclear desalination.

However, for countries without an interest in nuclear desalination the prospects are lower. For example, the case of Sudan would be characterized as follows:

- Market structure = 0 (there are few centres with a sufficient desalination demand);
- Demand pressure = 1 (the demand for water exists and will continue to exist but the water situation is not expected to deteriorate sharply, as the available water resources are relatively large);
- Technical basis = 0 (although desalination has been used[9], there have not been advanced nuclear desalination projects);

- Economic competitiveness = 1 (nuclear energy may be competitive or non-competitive, depending on the prices of fossil fuels);
- Public acceptance = 0 (the use of nuclear energy for electricity generation or other purposes is not close to implementation).

Consequently, the aggregate score for Sudan is 0.4, or negligible.

When determining the average score for the whole region of North Africa and the Middle East, both cases must be taken into account; that is, the countries with relatively high prospects for nuclear desalination (such as Morocco, Egypt and some others) and the countries without realistic expectations for nuclear desalination. As will be shown in more detail in Section 5, the total for the region is thus ~0.7 or low, the principal reason being the existence of several countries ranked as low or negligible.

# 4. DISTRICT HEATING

## 4.1. MARKET CHARACTERIZATION

### 4.1.1. Market size

The application of district heating is a consequence of the demand for space heating and hot water, which depends primarily on two key variables: climate (i.e. the need to warm buildings and provide hot water) and income per capita (i.e. the ability to purchase the desired heating comfort). These demands are significant in relatively cold countries, where space and water heating are used for extended periods. One of the possible methods to satisfy these demands is by centralized[10] heat generation and distribution. There are several alternative options for heat supply, such as the use of gas, coal, oil and electricity, and these options are extensively used.

The share of heat demand that can be covered by district heating depends on the historical development of the energy system. In some countries district heating has been widely used for decades. There are accordingly available heat distribution networks, which is a potential incentive for the continued use of centralized heat generation. Central European countries (such as Bulgaria, the Czech Republic,

---

[9] By the end of 1999 there were two operating desalination units in Sudan with capacities of 700 and 750 m$^3$/d [37].

[10] As mentioned in Section 3, the term centralized means that the produced heat is sold for utilization to a third party (the definition of the IEA [34, 35]).

Hungary and Slovakia) and countries from the FSU (such as Belarus, the Russian Federation and Ukraine) are typical examples. Denmark, Finland, Sweden and Switzerland in western Europe have also developed heating networks. On the other hand, there are also countries in which district heating has not developed as a notable part of the energy system, for example Canada, France and the USA. Figure 3 illustrates the varying importance of district heating in several representative countries[11].

Table 7 provides details of the role of centralized heat generation by the main world regions defined in Section 3. A country by country characterization of heat supply and demand (1996 data) can be found in Appendix III.

### 4.1.2. Market features

In addition to the size of the market, specific features that are important for the prospects for nuclear energy include the following.

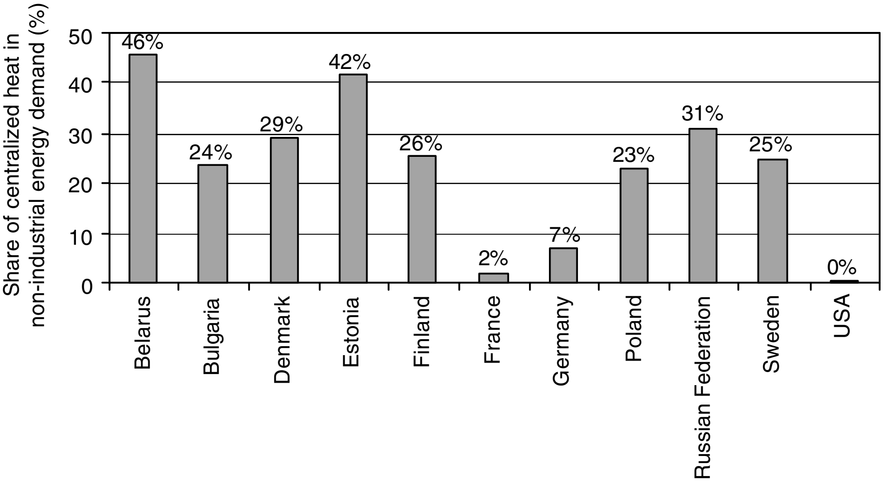

*FIG. 3. Centralized heat in the non-industrial final energy demand (based on 1996 data in Refs [34, 35]).*

---

[11] Here and below, district heating is assessed in relation to the final energy demand in the residential, agricultural and commercial sector; that is, the total demand for final energy minus the industrial part of it (the transportation sector does not use centralized heat). The reason for selecting these sectors is that it is primarily for those that district heating can be used. Industrial heat supply is considered in Section 6.

## TABLE 7. CHARACTERIZATION OF CENTRALIZED HEAT GENERATION BY REGION

*(based on 1996 data [34, 35])*

| Region/country | Final energy demand (Mtoe) | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|
| | Total | Share of RAC[a] | Total | Share of RAC | In total final energy demand[b] | In RAC[c] |
| Total NAM | 1620.1 | 517.3 | 8.1 | 2.3 | 0.5 | 0.4 |
| Canada | 184.3 | 61.1 | 0.5 | 0.0 | 0.3 | 0.0 |
| USA | 1435.8 | 456.2 | 7.6 | 2.3 | 0.5 | 0.5 |
| Total LAM | 418.0 | 114.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total AFR | 209.3 | 142.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total MEA | 280.4 | 116.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total WEU | 1104.3 | 428.6 | 22.9 | 17.9 | 2.1 | 4.2 |
| Denmark | 16.3 | 7.9 | 2.4 | 2.3 | 14.7 | 29.0 |
| Finland | 23.3 | 8.3 | 2.8 | 2.1 | 11.8 | 25.6 |
| France | 161.5 | 65.3 | 1.4 | 1.4 | 0.8 | 2.1 |
| Germany | 247.6 | 106.4 | 9.0 | 7.3 | 3.7 | 6.9 |
| Netherlands | 59.3 | 25.1 | 1.7 | 0.9 | 2.9 | 3.6 |
| Sweden | 36.3 | 14.2 | 3.6 | 3.5 | 9.9 | 24.9 |
| Total EEU | 194.0 | 79.1 | 25.1 | 16.1 | 13.0 | 20.4 |
| Bulgaria | 12.7 | 4.6 | 2.9 | 0.9 | 22.6 | 19.2 |
| Hungary | 17.7 | 9.5 | 1.8 | 1.3 | 10.0 | 13.3 |
| Poland | 72.6 | 33.5 | 9.3 | 7.6 | 12.9 | 22.7 |
| Romania | 29.1 | 9.6 | 5.6 | 4.3 | 19.3 | 45.3 |
| Total FSU | 682.1 | 358.6 | 198.8 | 82.8 | 29.2 | 23.1 |
| Belarus | 19.0 | 9.4 | 7.3 | 4.3 | 38.4 | 45.8 |
| Estonia | 2.9 | 1.4 | 0.8 | 0.6 | 27.4 | 41.8 |
| Russian Federation | 468.8 | 247.1 | 169.3 | 76.2 | 36.2 | 30.8 |
| Ukraine | 98.5 | 44.1 | 10.4 | 3.7 | 10.5 | 8.3 |
| Total CPA | 924.3 | 395.3 | 21.3 | 0.0 | 2.3 | 0.0 |
| China | 865.9 | 368.2 | 21.3 | 0.0 | 2.5 | 0.0 |
| Total SAS | 432.7 | 247.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total PAS | 392.4 | 146.1 | 1.2 | 0.0 | 0.3 | 0.0 |
| Total PAO | 415.4 | 119.7 | 0.4 | 0.4 | 0.1 | 0.3 |
| Japan | 337.0 | 103.0 | 0.4 | 0.4 | 0.1 | 0.4 |
| Total | 6673.0 | 2664.9 | 273.2 | 119.5 | 4.1 | 4.5 |

[a] RAC: residential, agricultural and commercial sectors.

[b] Total centralized heat generation/total final energy demand.

[c] Share of the residential, agricultural and commercial sectors, centralized heat generation/share of the residential, agricultural and commercial sectors, final energy demand.

#### *4.1.2.1. Principal competitors and types of competition*

As heat is a possible energy carrier for space and water heating, two competitors on the market should be distinguished: non-heat service (mostly gas and electricity) providers and non-nuclear (mostly fossil fuel) heat providers. Because of the limited scope of this review and the extreme complexity of the problem[12], the first type of competition is given less emphasis here than the second one, as comparisons with non-nuclear heat sources are easier to make. However, it is important to keep in mind that there may well be cases in which nuclear district heating may be competing not as much with fossil fuel boilers as with gas or electric heaters, including electric heaters powered by NPPs.

#### *4.1.2.2. Medium and temperature range required*

Usually, district heating systems are supplied with hot water or steam, the typical temperature range being 100–150°C. The heat source and the distribution network, usually including a steam–water heat exchanger between the supplier and the consumer, must be designed accordingly.

#### *4.1.2.3. Need for a heat transportation network*

As with electricity, heat for district heating has to be transported to the user. The availability of a heat distribution network is therefore a prerequisite. However, unlike electricity, heat transportation over longer distances involves higher losses and is expensive. As a result, the heat source must be relatively close to the customer, usually at a distance of some kilometres at most.

#### *4.1.2.4. Typical capacity ranges*

The typical heat generation capacities for district heating are determined by the size of the customer. The capacity of heat networks in large cities can be assessed as 600–1200 MW(th), but it is much lower in towns and small communities (10–50 MW(th)); large capacities of 3000–4000 MW(th) are exceptional [38].

---

[12] An analysis of this type requires consideration and comparison of energy supply options at the level of useful energy demand. While methods for such analysis are known (using the mathematical modelling of energy systems), there is not enough information on which to base general quantitative estimates within this report. Apart from the lack of data for many countries, a principal difficulty is that the modelling of useful energy demand requires a knowledge of subjective customer preferences.

#### *4.1.2.5. Intermittent supply mode*

Heat has to be supplied mostly in the colder part of the year. As a consequence, the annual load factor of a heat source in district heating is normally not higher than 50% [38], which, again, is in contrast with the much higher load factors of most electricity generators.

#### *4.1.2.6. Supply reliability*

The heat supply has to be especially reliable because of the social importance of the service. This leads to the requirement of a backup capacity to make up for a unit under a forced outage. Even relatively large heat networks are usually served not by one large source but by a number of units.

#### *4.1.2.7. Supply security*

In regions in which rail and barge transportation is difficult during winter, the high energy density of nuclear fuel as compared with coal or oil is an advantage.

#### *4.1.2.8. Impact of specific nuclear considerations*

Because of the need to site the source close to the customer, nuclear safety is very important. It is not only required that the level of safety is technically sufficient (which is the case with nuclear power reactors), but it is also necessary that the adequacy of safety be proved sufficiently to the public and confirmed by the licensing process. The latter relates to both reactor operation and the handling of nuclear fuel (including transportation to and from the reactor).

#### *4.1.2.9. Market competitiveness*

The demand for space heating can be met by various energy sources. Apart from obtaining heat from a district network, customers may opt to use gas heating supplied from gas networks, electric heating supplied from the electricity grid or heating with a coal or oil stove. All these alternatives exist and are already in competition. With the energy markets being generally deregulated and users tending to select the type of final energy that they use, it can be expected that competition in the heat market will become even more important in the future.

To illustrate the structure of the heat market, Fig. 4 shows the evolution of energy supply for space heating in the USA. It illustrates, in particular, the important role both of electricity and, especially, gas.

### 4.1.3. Market potential for nuclear penetration

In view of the above, two different types of market potential for nuclear district heating should be distinguished. One assessment can be based on the amount of heat that is currently supplied through district heating, both nuclear and non-nuclear. This heat is distributed through existing heat networks, so that the use of a nuclear heat source instead of a fossil fuelled source would not generally lead to the need for a new heat distribution network. This estimate can be called a low estimate, because although it shows the area in which nuclear energy can compete with non-nuclear energy sources it does not include the space and water heat that is supplied by means other than district heating.

The corresponding high estimate would then be the one that includes the portion of heat provided by other types of final energy, such as gas, oil, coal and electricity. Centralized heat sources providing this portion of the heat demand are unlikely in the near future. They would require the construction of new heating networks or substantial modifications to existing ones.

To calculate the high estimate it is necessary to know the amount of heat that is consumed specifically for space and water heating. As such detailed information is not available in the IEA annual statistics [34, 35], the high estimate here is based on the consumption of all energy in the residential, commercial and agricultural sectors. This overestimates the demand of the amount of energy required for purposes other than space and water heating, for example cooking and air conditioning. However, the overestimate is likely to be small enough for the results still to be meaningful. As shown in Fig. 5, even in the USA, which has a large use of appliances and air conditioning, space and water heating account for about 55% of the total.

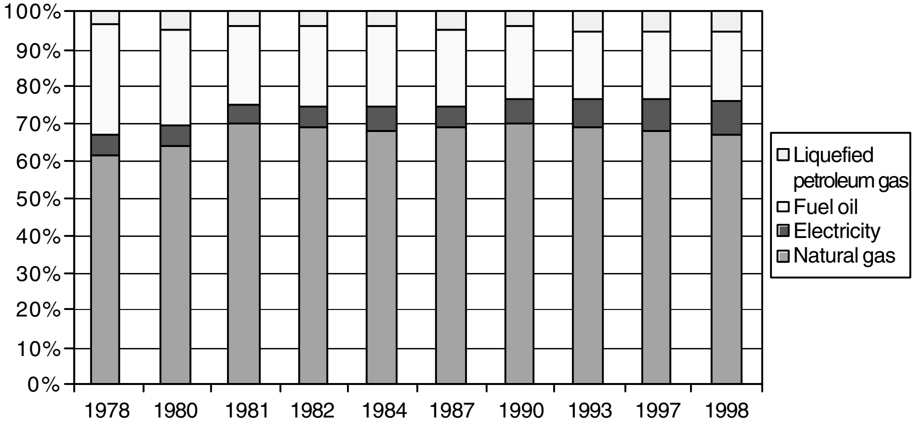

*FIG. 4. Evolution of the structure of energy supply for space heating in US households [39–41]. Other fuels of much lower importance (coal, wood, etc.) are not included here.*

Table 8 shows the low and high estimates of the market potential for the major world regions. These estimates are based on the country by country statistics shown in Appendix III. The low estimate corresponds to the total for centralized heat generation shown in the 'Share of total centralized heat in the final energy demand' column of Appendix III. The high estimate corresponds to the 'Centralized heat used in the residential, agricultural and commercial sector' column of Appendix III.

TABLE 8. ESTIMATE OF MARKET POTENTIAL FOR DISTRICT HEATING *(based on 1996 data [34, 35])*

| Region | Low estimate | | | High estimate | | |
|---|---|---|---|---|---|---|
| | Heat supply (Mtoe) | Heat production capacity (MW(th))[a] | Number of 100 MW(th) reactors needed[b] | Heat supply (Mtoe) | Heat production capacity (MW(th)) | Number of 100 MW(th) reactors needed |
| NAM | 2.3 | ~6 500 | ~70 | 517.3 | ~1 500 000 | ~15 000 |
| LAM | 0.0 | 0 | 0 | 114.2 | ~320 000 | ~3 200 |
| AFR | 0.0 | 0 | 0 | 142.1 | ~400 000 | ~4 000 |
| MEA | 0.0 | 0 | 0 | 116.3 | ~330 000 | ~3 300 |
| WEU | 17.9 | ~51 000 | ~500 | 428.6 | ~1 200 000 | ~12 000 |
| EEU | 16.1 | ~46 000 | ~500 | 79.1 | ~220 000 | ~2 200 |
| FSU | 82.8 | ~230 000 | ~2 300 | 358.6 | ~1 000 000 | ~10 000 |
| CPA | 0.0 | 0 | 0 | 395.3 | ~1 100 000 | ~11 000 |
| SAS | 0.0 | 0 | 0 | 247.6 | ~700 000 | ~7 000 |
| PAS | 0.0 | 0 | 0 | 146.1 | ~410 000 | ~4 100 |
| PAO | 0.4 | ~1 100 | ~10 | 119.7 | ~340 000 | ~3 400 |
| Total | 119.5 | ~340 000 | ~3 400 | 2 664.9 | ~7 600 000 | ~76 000 |

[a] The capacity is calculated assuming a 50% average load factor and excluding heat losses. Under these assumptions the heat production capacity needed to produce 1 Mtoe of heat is 1 [Mtoe] × 1419 [MW·year/Mtoe]/0.5 [year] = 2838 MW(th).

[b] The number of reactors needed is calculated assuming a 50% average load factor and excluding heat losses. Under these assumptions the energy output of a 100 MW(th) reactor is 100 × 0.5 [MW(th)·year] = 50 × 8760 [MW·h] = 438 GW·h ≈ 1.58 PJ ≈ 0.035 Mtoe.

Table 8 shows that there is a large market for district heating of between 340 and 7600 GW(th). This means that for the low estimate some 3400 reactors of 100 MW(th)[13] would be required. For the high estimate this number would be an order of magnitude higher.

---

[13] For simplicity the example is based on the number of dedicated heat reactors, but, in reality, a substantial part may be served by nuclear cogeneration.

## 4.2. POTENTIAL NUCLEAR SOLUTIONS

A broad range of nuclear reactors is available today for district heating applications. Future generation reactor concepts incorporating enhanced safety features and meeting stricter economic criteria are under investigation in many countries.

Nuclear reactors are capable of providing heat within the range of temperatures required for district heating. No technical impediments to coupling nuclear reactors to diverse applications have so far been observed, although a number of safety related studies of coupled systems may still be necessary.

There are two ways in which nuclear reactors can be used for this application:

- The cogeneration mode, in which heat is retrieved as steam from the turbine exhaust or intermediate stages and then supplied, usually through an intermediate heat exchanger, to the customer. The portion of the steam retrieved for heat production represents a part of the total steam produced by the reactor, the remaining portion of the steam being used to produce electricity.
- The dedicated heat only mode, in which heat is supplied directly (through a heat exchanger) from the reactor to the customer.

All existing NPP concepts (light water reactors, heavy water reactors, fast breeder reactors, gas cooled reactors and high temperature reactors (HTRs)) are potentially applicable to cogeneration. The required heat parameters at the customer's side are such that all existing NPP designs may be used.

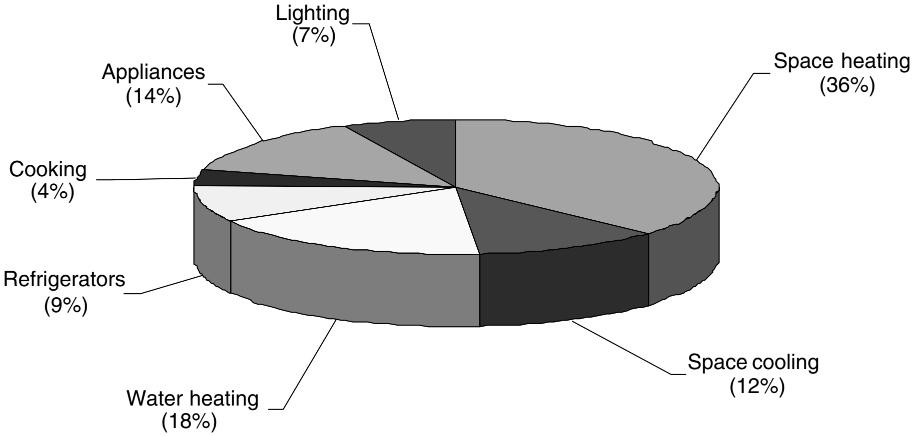

*FIG. 5. Structure of energy consumption by end use in US households in 1998 [39, 41].*

The principal advantage of dedicated production stems from heat being the main product; special designs that take advantage of heat dedication and that comply with the required heat generation capacity will therefore be required — such designs are available. It can be noted that the size effect may have negative implications on heat only reactors because, following the demand structure, many heat only plants would be of a relatively small capacity (in terms of heat generation) compared with other energy supply sources.

Extensive feedback from experience is not available for dedicated designs; however, the operation of the NHR-5 in China can be noted [42]. Ongoing projects regarding dedicated nuclear heating plants are either in the design or the construction phase (e.g. the NHR-200 in China, the AST-500 in the Russian Federation and some others [43]).

## 4.3. ECONOMIC COMPETITIVENESS

All things being equal, for any cogeneration plant electricity is the more valuable product. If electricity generated by nuclear energy is competitive, nuclear heat should therefore also be competitive. However, a group of related factors combine to undermine this simple parallel:

- Existing light water and PHWR reactor types usually produce 500 to 1500 MW of electricity plus about twice as much heat. To provide that heat at the required temperature some electricity production must be sacrificed, which increases the proportion of the energy produced as heat. This heat output is far larger than the demands likely for district heating; even industrial demands for heat on this scale are fairly rare. The application of nuclear power to non-electric applications will be improved by the development of smaller, low cost reactors and especially of small high temperature reactors (from which a lower proportion of energy emerges as heat).
- Economies of scale can be applied easily to the generation of electricity, since it is easily distributable. This is not the case for district heating.
- Economies of scale for existing reactor types are very significant (see Table 9) and are much more significant than those for fossil fuels, for which the cost of fuel dominates. Seasonal variations in the demand for district heating lower the on-stream time, further favouring fossil fuels.
- A nuclear source of district heating will either require high reliability or its scale will have to be reduced to provide some redundancy, otherwise the costs of backup heat sources will need to be absorbed. Note that since heat generation bypasses components dedicated to power generation, nuclear reliability for district heating will exceed that of electricity production.

As regards dedicated nuclear NHPs, there may still be some correlation between the competitiveness of NPPs and NHPs, owing to certain design similarities. However, in this case it is not justified to make a direct inference because:

- — Nuclear reactors for heat production usually have lower parameters in terms of temperature and pressure, which provide opportunities for cost reduction through design improvements and a wide use of inherent safety features;
- — Locating an NHP far from large population centres is not desirable because of the elevated heat transportation expenses. Locating the plant in the vicinity of a city may require specific safety features appropriate to the location, which may offset the above economic advantages.

For these reasons a comparison of the costs of nuclear heat production with those of competing technologies is necessary. Table 9 presents the estimate of heat costs from Ref. [44]. The costs are levelized heat generation costs obtained with a method analogous to the one described in Section 2.4. The calculations assumed the cost of oil as 25 US \$/boe (barrels of oil equivalent) and the cost of coal as US \$50/t[14]. The average lifetime load factor was assumed to be 80%[15]. The other key parameters are given in Table 9.

Table 9 shows that the assumed value of the discount rate plays an important role. At 10% even a large NHP is barely competitive with a large coal fired boiler.

Furthermore, the competitiveness of nuclear heating reactors improves significantly with the growth in installed capacity; that is, the scaling effect is extremely important. At 500 MW(th) the nuclear option can be competitive even at the 10% discount rate, while at 100 MW(th) the situation favours fossil fuels. This factor is important in view of prospective competitiveness because the lower the capacity the wider the potential application area. (As noted, there are many small heat consumers, for whom capacities of 100 MW(th) and below would be desirable.)

The results of this comparison should be treated with due caution. The effects of a specific site may well outweigh the general trends shown in Table 9. In particular, the actual price of fossil fuel at a given point would be one of the key parameters. If it is lower than the 25 US \$/boe assumed above, the nuclear option will lose competitiveness; if, however, it increases beyond this value NHPs will become

---

[14] Fossil fuel prices being unstable, these are assumed costs taken from IAEA documents.

[15] It should be noted that this value is rather high. As noted above, a heating plant would normally have lower load factors, which would negatively affect the economic parameters of nuclear plants more than those of fossil fuel plants (because of the higher capital component of the nuclear costs). A sensitivity case analysed in Ref. [44] shows that a change in the load factor from 80 to 70% can lead to an increase of 10 to 20% in the levelized heat production costs for nuclear plants.

TABLE 9. ESTIMATE OF THE COMPETITIVENESS OF NHPs [44]

| Plant type | Plant size (MW(th)) | Base construction cost[a,b] (US $/kW(th)) | Levelized heat costs (US $/MW(th)) Discount rate: 5% | Levelized heat costs (US $/MW(th)) Discount rate: 10% | Cost ratio: nuclear vs. gas–oil boilers Discount rate: 5% | Cost ratio: nuclear vs. gas–oil boilers Discount rate: 10% | Cost ratio: nuclear vs. coal boilers Discount rate: 5% | Cost ratio: nuclear vs. coal boilers Discount rate: 10% |
|---|---|---|---|---|---|---|---|---|
| Nuclear plants | | | | | | | | |
| | 50 | 1650 | 25 | 36 | 1.3 | 1.6 | 1.8 | 2.1 |
| | 100 | 1100 | 19 | 26 | 1.0 | 1.1 | 1.4 | 1.5 |
| | 200 | 825 | 16 | 22 | 0.8 | 1.0 | 1.1 | 1.3 |
| | 500 | 605 | 13 | 17 | 0.7 | 0.7 | 0.9 | 1.0 |
| Fossil fuel plants | | | | | | | | |
| Gas–oil boiler | 100 | 440 | 20 | 23 | — | — | — | — |
| Coal boiler | 500 | 440 | 14 | 17 | — | — | — | — |

[a] These estimates were made in 1992. Subsequent developments, such as the PBMR project [14], may lead to significantly lower capital costs for nuclear plants than those shown in this column.

[b] This cost includes interest accumulated during construction.

preferable in a wider range of conditions; that is, with discount rates below 10% and capacities lower than 500 MW(th).

## 4.4. CURRENT AND PROSPECTIVE MARKET

### 4.4.1. Current use of nuclear energy

There are at present cogenerating NPPs in several countries with the following reactor types [43]:

- A PWR and water moderated, water cooled reactors (WWERs) (Russian PWRs). The Beznau PWR NPP in Switzerland and the following WWERs: the Kozloduy NPP in Bulgaria, the Paks NPP in Hungary, the Bohunice NPP in Slovakia, the Balakovo NPP in the Russian Federation, the Rovno NPP in Ukraine, and others.
- Light water cooled, graphite moderated reactors : the St. Petersburg and Kursk NPPs in the Russian Federation.
- A liquid metal breeder reactor: the BN-600 unit of the Beloyarsk NPP in the Russian Federation.

Table 10 summarizes the available experience with nuclear district heating.

TABLE 10. EXPERIENCE WITH NUCLEAR DISTRICT HEATING [43]
*(the data from Ref. [43] have been complemented with the latest statistics from an IAEA database)*

| Country | Unit name | Location | Application[a] | Phase | Power (MW(e) net) | Heat output (MW(th)) |
|---|---|---|---|---|---|---|
| Bulgaria | Kozloduy 5 | Kozloduy | E, DH | Commercial | 953 | 20 |
| Bulgaria | Kozloduy 6 | Kozloduy | E, DH | Commercial | 953 | 20 |
| China | NHR-5 | Beijing | DH | Experiment | 0 | 5 |
| Hungary | PAKS 2 | Paks | E, DH | Commercial | 433 | 30 |
| Hungary | PAKS 3 | Paks | E, DH | Commercial | 433 | 30 |
| Hungary | PAKS 4 | Paks | E, DH | Commercial | 433 | 30 |
| Russian Federation | Research reactor | Obninsk | DH | Commercial | 0 | 10–20 |
| Russian Federation | Bilibino 1 | Bilibino | E, DH | Commercial | 11 | 25 |
| Russian Federation | Bilibino 2 | Bilibino | E, DH | Commercial | 11 | 25 |
| Russian Federation | Bilibino 3 | Bilibino | E, DH | Commercial | 11 | 25 |
| Russian Federation | Bilibino 4 | Bilibino | E, DH | Commercial | 11 | 25 |
| Russian Federation | Novovoronezh 3 | Novovoronezh | E, P, DH | Commercial | 385 | 32.5 |
| Russian Federation | Novovoronezh 4 | Novovoronezh | E, P, DH | Commercial | 385 | 32.5 |
| Russian Federation | Balakovo 1 | Balakovo | E, DH | Commercial | 950 | 200 |
| Russian Federation | Balakovo 2 | Balakovo | E, DH | Commercial | 950 | 200 |
| Russian Federation | Balakovo 3 | Balakovo | E, DH | Commercial | 950 | 200 |
| Russian Federation | Balakovo 4 | Balakovo | E, DH | Commercial | 950 | 200 |
| Russian Federaiton | Kalinin 1 | Udomlya | E, P, DH | Commercial | 950 | 80 |
| Russian Federation | Kalinin 2 | Udomlya | E, P, DH | Commercial | 950 | 80 |
| Russian Federation | Kola 1 | Polyarnie Zory | E, P, DH | Commercial | 411 | 25 |
| Russian Federation | Kola 2 | Polyarnie Zory | E, P, DH | Commercial | 411 | 25 |
| Russian Federation | Kola 3 | Polyarnie Zory | E, P, DH | Commercial | 411 | 25 |

TABLE 10. (cont.)

| Country | Unit name | Location | Application[a] | Phase | Power (MW(e) net) | Heat output (MW(th)) |
|---|---|---|---|---|---|---|
| Russian Federation | Kola 4 | Polyarnie Zory | E, P, DH | Commercial | 411 | 25 |
| Russian Federation | Belojarsk 3 | Zarechny | E, P, DH | Commercial | 560 | 170 |
| Russian Federation | Leningrad 1 | Sosnovy Bor | E, P, DH | Commercial | 925 | 25 |
| Russian Federation | Leningrad 2 | Sosnovy Bor | E, P, DH | Commercial | 925 | 25 |
| Russian Federation | Leningrad 3 | Sosnovy Bor | E, P, DH | Commercial | 925 | 25 |
| Russian Federation | Leningrad 4 | Sosnovy Bor | E, P, DH | Commercial | 925 | 25 |
| Russian Federation | Kursk 1 | Kurchatov | E, P, DH | Commercial | 925 | 127.5 |
| Russian Federation | Kursk 2 | Kurchatov | E, P, DH | Commercial | 925 | 175 |
| Russian Federation | Kursk 3 | Kurchatov | E, P, DH | Commercial | 925 | 175 |
| Russian Federation | Kursk 4 | Kurchatov | E, P, DH | Commercial | 925 | 175 |
| Russian Federation | Smolensk 1 | Desnogorsk | E, P, DH | Commercial | 925 | 173 |
| Russian Federation | Smolensk 2 | Desnogorsk | E, P, DH | Commercial | 925 | 173 |
| Russian Federation | Smolensk 3 | Desnogorsk | E, P, DH | Commercial | 925 | 173 |
| Slovakia | Bohunice 3 | Bohunice | E, DH | Commercial | 408 | 240 |
| Slovakia | Bohunice 4 | Bohunice | E, DH | Commercial | 408 | 240 |
| Switzerland | Beznau 1 | Beznau | E, DH | Commercial | 365 | 80 |
| Switzerland | Beznau 2 | Beznau | E, DH | Commercial | 357 | 80 |
| Ukraine | Rovno 1 | Rovno | E, DH | Commercial | 363 | 58 |
| Ukraine | Rovno 2 | Rovno | E, DH | Commercial | 377 | 58 |
| Ukraine | Rovno 3 | Rovno | E, DH | Commercial | 950 | 233 |
| Ukraine | South Ukraine 1 | Yuzhnoukrainsk | E, DH | Commercial | 950 | 151 |
| Ukraine | South Ukraine 2 | Yuzhnoukrainsk | E, DH | Commercial | 950 | 151 |
| Ukraine | South Ukraine 3 | Yuzhnoukrainsk | E, DH | Commercial | 950 | 232 |

[a] E: electricity (power), P: steam supply for process heat, DH: steam/hot water supply for heating.

TABLE 11. PROSPECTIVE NUCLEAR PROJECTS FOR DISTRICT HEATING [43] *(the data from Ref. [43] have been complemented with the latest statistics from an IAEA database)*

| Country | Plant type or site | Location | Application[a] | Project status | Power (MW(e)) | Heat output (MW(th)) |
|---|---|---|---|---|---|---|
| Bulgaria | Belene | Belene | E, DH | Design | 2 × 1000 | 400 |
| China | NHR-200 | Daqing City | DH | Dormant | — | 200 |
| Russian Federation | Ruta | Apatity | DH/air conditioning | Design | — | 4 × 55 |
| Russian Federation | Ruta | Obninsk | DH | Design | — | 55 |
| Russian Federation | ATEC-200 | — | E, DH | Design | 50–180 | 70–40 |
| Russian Federation | VGM/GT-MHR | — | P | Design | — | 600 |
| Russian Federation | KLT-40 | Floating | E, DH and desalination | Licensing | 35 | 150 |
| Russian Federation | AST-500 | Voronez | DH | Construction suspended | — | 500 |
| Russian Federation | AST-500 | Seversk | DH | Completed feasibility study, approval of the project by the State regulatory authority is nearing completion | — | 500 |

[a] E: electricity (power), P: steam supply for process heat, DH: steam/hot water supply for heating.

### 4.4.2. Prospects for nuclear energy in the near term (2000–2020)

Table 11 presents the most promising nuclear projects for district heating. In the near future the most important task will be to complete these projects and show their successful operation.

### 4.4.3. Prospects for nuclear energy in the long term (2020–2050)

Estimating the prospects for nuclear energy for the long term is difficult, for several reasons:

- Long term penetration is largely determined by the degree of technical progress that will be made by the nuclear industry from 2000 to 2020. This is highly uncertain and does not allow a precise determination of the economics of new NPPs.

- Large uncertainties also exist regarding the economies of the competing fossil fuel energy sources and on the renewable energy sources that are under development.
- As cogeneration will initially be the preferred option, cost allocation methods to take into account the multiple products (e.g. water and electricity in nuclear desalination) will need careful attention. These methods are discussed in detail in Refs [45–48].

Quantitative indicators for a long term period are therefore not considered practicable[16]. A different, qualitative approach is used instead, using the method described in Section 3. The main principles for the application of nuclear power in district heating are described below.

- The indicator of market structure is assigned 0 for those countries in which the share of centralized heat production in the final energy supply for the residential, commercial and agricultural sectors is lower than 1%; if it is between 1% and 10%, 1 is assigned; and 2 is assigned where the share exceeds 10%.
- The indicator of demand pressure is assigned 1 (i.e. medium, meaning that the demand exists but is unlikely to change much in the future) for the countries in NAM, WEU, EEU, FSU and PAO, because the population growth in most of these countries is expected to be relatively slow; for the other regions (LAM, AFR, MEA, CPA, SAS and PAS) it is also assigned 1, for the reason that these countries are mostly in areas with a relatively warm climate and therefore the demand (which exists, although is low) is unlikely to change.
- The indicator of technical basis is assigned 2 for those countries in which NPPs are operating; 1 is assigned for countries that have considered or are seriously considering the use of nuclear energy, either through imports or through local development; 0 is assigned for those countries in which the use of nuclear energy has never been seriously considered.
- The indicator of economic competitiveness is assigned 0 for those countries that have abundant domestic oil, gas or hydro-electric resources (the competitiveness of nuclear energy is likely to be questionable in such cases);

---

[16] A more accurate procedure, especially for long term cost estimates, would be to analyse the whole energy system by simulating the production of different types of useful energy and their competition. Models for such analyses exist, for example the Energy and Power Evaluation Program [49] developed by Argonne National Laboratory in the USA, which is used with the IAEA's assistance in many countries for energy studies. However, conducting such a study is a complex task that is beyond the scope of this report.

also, for island countries 0 is assigned, which reflects the difficulty of providing infrastructural support and of fuel handling; the others are assigned 1, while no cases have been assigned 2 (a definite superiority of nuclear energy), which is a conservative assumption.
— The indicators of public acceptance are as defined in Appendix II.

When obtaining the average indicators for every region, the regional value of each indicator was calculated as a weighted average for all the countries in the region. For weighting, the total final energy demand was used. The aggregated regional indicator was then obtained as a simple sum of the five separate indicators (market structure, demand pressure, etc.). The result of the estimate is summarized in Table 12 for the 11 world regions. Underlying country by country estimates can be found in Appendix IV.

The results in Table 12 show the following:

— Currently, the prospects for nuclear district heating appear most promising in EEU and in the countries of the FSU, mainly because of the availability of heat distribution networks. This is reflected by a high value for the indicator of market structure.

TABLE 12. LONG TERM (2020–2050) PROSPECTS FOR NUCLEAR PENETRATION IN DISTRICT HEATING

| Region | Indicator | | | | | Total |
|---|---|---|---|---|---|---|
| | Market structure | Demand pressure | Technical basis | Economic competitiveness | Public attitude | |
| NAM | 0.00 | 1.00 | 2.00 | 1.00 | 1.00 | 1.00 (medium) |
| LAM | 0.00 | 1.00 | 1.55 | 0.00 | 0.84 | 0.68 (low) |
| AFR | 0.00 | 1.00 | 0.52 | 0.65 | 0.52 | 0.54 (negligible) |
| MEA | 0.00 | 1.00 | 0.48 | 0.69 | 0.78 | 0.59 (negligible) |
| WEU | 0.60 | 1.00 | 1.73 | 1.00 | 0.73 | 1.01 (medium) |
| EEU | 1.78 | 1.00 | 1.56 | 1.00 | 0.94 | 1.26 (medium) |
| FSU | 1.61 | 1.00 | 1.77 | 0.92 | 0.90 | 1.24 (medium) |
| CPA | 0.00 | 1.00 | 1.93 | 0.99 | 1.91 | 1.16 (medium) |
| SAS | 0.00 | 1.00 | 1.84 | 0.99 | 1.84 | 1.13 (medium) |
| PAS | 0.00 | 1.00 | 1.31 | 0.98 | 1.19 | 0.89 (low) |
| PAO | 0.00 | 1.00 | 1.62 | 1.00 | 0.81 | 0.89 (low) |
| Total | 0.31 | 1.00 | 1.70 | 0.90 | 1.09 | 1.00 (medium) |

- The chances for nuclear penetration are also assessed as medium for NAM and WEU, where the market structure is less favourable but the technical basis is assessed as relatively high (the technical capability makes up for the present lack of heat distribution networks); a similar rating is assigned to CPA, where China largely determines the average.
- However, even for these two groups of most promising countries, the rating is only medium, which reflects the unfavourable market structure and lack of demand pressure; no regions are rated as high.
- As could be expected, in the rest of the world the prospects are ranked as low or negligible.

In addition to regional averages, it is useful to identify the countries in each region in which the prospects are the highest (see Table 13). As can be seen, these are mostly countries in which the existence of district heating networks combines with the availability of nuclear technologies. It is also worth noting that there are countries with medium prospects within regions rated as low or even negligible.

# 5. WATER DESALINATION

## 5.1. MARKET CHARACTERIZATION

### 5.1.1. Market size

Water is one of the primary necessities for humans. It is provided by a natural cycle of precipitation and condensation and is used in agriculture, in industry and for domestic purposes, as illustrated in Fig. 6.

Water desalination is required for several reasons.

- Freshwater supplies are insufficient in some areas. Table 14 illustrates this by presenting the current and expected water availability, as well as some indicators of water availability[17], for the main world regions.
- The regional and temporal distribution of fresh water is a key problem. Population increases and industrialization will further exacerbate freshwater demand.
- Metropolitan areas create a particular demand concentration that often cannot be satisfied by the local water supply. The quantity of water utilized worldwide has increased by a factor of 10 since 1900, while the current rate of increase is

---

[17] Additional detailed information can be found in Appendix V.

TABLE 13. COUNTRIES WITH THE HIGHEST PROSPECTS FOR NUCLEAR PENETRATION IN DISTRICT HEATING

| Region/country | Indicator | | | | | Total |
|---|---|---|---|---|---|---|
| | Market structure | Demand pressure | Technical basis | Economic competitiveness | Public attitude | |
| *NAM* | | | | | | |
| Canada | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| USA | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| *AFR* | | | | | | |
| South Africa | 0 | 1 | 2 | 1 | 2 | 1.2 (medium) |
| *MEA* | | | | | | |
| Iran | 0 | 1 | 1 | 1 | 2 | 1.0 (medium) |
| *WEU* | | | | | | |
| Finland | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| France | 1 | 1 | 2 | 1 | 2 | 1.4 (medium) |
| Netherlands | 1 | 1 | 2 | 1 | 1 | 1.2 (medium) |
| Sweden | 2 | 1 | 2 | 1 | 0 | 1.2 (medium) |
| Switzerland | 1 | 1 | 2 | 1 | 1 | 1.2 (medium) |
| *EEU* | | | | | | |
| Bulgaria | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| Czech Republic | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| Hungary | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| Romania | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| Slovakia | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| *FSU* | | | | | | |
| Lithuania | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| Russian Federation | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| Ukraine | 1 | 1 | 2 | 1 | 1 | 1.2 (medium) |
| *CPA* | | | | | | |
| China | 0 | 1 | 2 | 1 | 2 | 1.2 (medium) |
| *SAS* | | | | | | |
| India | 0 | 1 | 2 | 1 | 2 | 1.2 (medium) |
| Pakistan | 0 | 1 | 2 | 1 | 2 | 1.2 (medium) |
| *PAS* | | | | | | |
| Korea, Republic of | 0 | 1 | 2 | 1 | 2 | 1.2 (medium) |
| Taiwan, China | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| *PAO* | | | | | | |
| Japan | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |

still 2–3%/a. The highest growth rates are expected in the domestic and industrial sectors, particular in developing countries[18].

- Desalinizing saline water, which is two orders of magnitude more plentiful than fresh water (Fig. 7), may be an attractive solution.
- In addition to seawater desalination, the desalination of brackish and waste water plays an important role.

SAS provides a good example of a shortage of water. The region is characterized by a low per capita water supply and the expectation of a large growth in demand. Wastewater often remains non-purified. Increasing costs for clean water and the

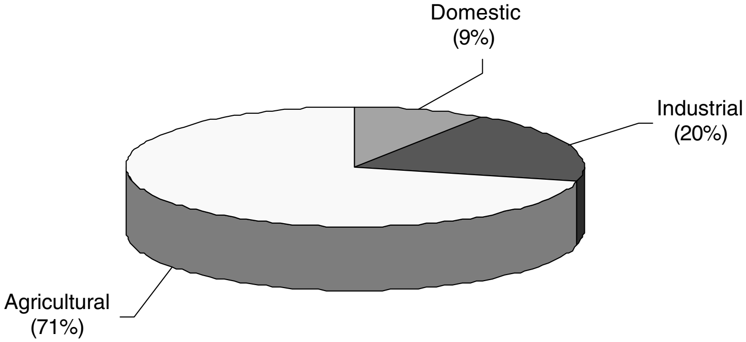

*FIG. 6. World water use by major sectors in 1990 [50–52].*

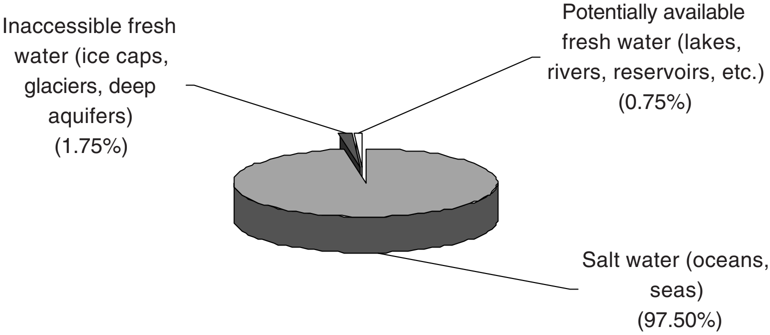

*FIG. 7. Breakdown of world water resources [53].*

---

[18] Although agriculture is usually the largest water consuming activity in any country, the specific economics of the agricultural sector virtually preclude the use of any advanced water treatment.

TABLE 14. ESTIMATE OF WATER AVAILABILITY

*(based mostly on 1990 data [50–52]; the bold numbers indicate the cases most likely to have water availability problems)*

| | Water supply for 1990 | | | | | | | Water supply for 2025[a] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Water resources and use | | | Estimate of water scarcity: share of population using | | | | Water resources and use | | | Estimate of water scarcity: share of population using | | |
| Region | Population (millions) | AWR[b] ($Gm^3$) | Annual water use ($Gm^3$) | Annual water use per capita ($m^3$) | >40% of AWR (%) | <500 $m^3$/capita of total use (%) | <36 $m^3$/capita of domestic use (%) | Population (millions) | AWR ($Gm^3$) | Annual water use ($Gm^3$) | Annual water use per capita ($m^3$) | >40% of AWR (%) | <500 $m^3$/capita of total use (%) | <36 $m^3$/capita of domestic use (%) |
| NAM | 281 | 5 379 | 512 | 1842 | 0 | 0 | 0 | 374 | 5 379 | 681 | 1 842 | 0 | 0 | 0 |
| LAM | 487 | 13 446 | 239 | 492 | 0 | **67** | 10 | 793 | 13 446 | 372 | 471 | 0 | **69** | **22** |
| AFR | 489 | 5 102 | 69 | 142 | 8 | **89** | **91** | 1 231 | 5 102 | 175 | 143 | 6 | **91** | **93** |
| MEA | 279 | 526 | 284 | 1 028 | **66** | **30** | **25** | 585 | 526 | 519 | 895 | **90** | **28** | 16 |
| WEU | 434 | 1 954 | 254 | 593 | 2 | **22** | 3 | 473 | 1 954 | 275 | 589 | 2 | **22** | 17 |
| EEU | 124 | 700 | 64 | 640 | 0 | **58** | 4 | 125 | 700 | 62 | 614 | 0 | **61** | 5 |
| FSU | 292 | 4 952 | 270 | 925 | **23** | **24** | 0 | 319 | 4 952 | 337 | 1 056 | **30** | **22** | 0 |
| CPA | 1 265 | 4 036 | 578 | 459 | 0 | **98** | **93** | 1 714 | 4 036 | 815 | 478 | 0 | **98** | 2 |
| SAS | 1 134 | 5 233 | 735 | 648 | 0 | 11 | **99** | 1 987 | 5 233 | 1 368 | 689 | **87** | 12 | **98** |
| PAS | 430 | 5 511 | 138 | 338 | 10 | **57** | **70** | 658 | 5 511 | 210 | 335 | 9 | **63** | **62** |
| PAO | 144 | 1 217 | 109 | 755 | 0 | 0 | 0 | 151 | 1 217 | 116 | 768 | 0 | 0 | 0 |
| Total | 5 359 | 48 056 | 3 251 | 614 | 6 | **50** | **60** | 8 410 | 48 056 | 4 930 | 593 | **30** | **52** | **46** |

[a] The business as usual case from Ref. [50].

[b] AWR (available water resources) = internal resources + inflow – outflow.

increasing spread of diseases, high water losses owing to leakage and theft, and a water deficit in general combine to have significant effects on the region's standard of living and on industrial output.

Worldwide, regional water use per capita[19] ranges between some 150 $m^3$/capita/a (AFR) and 1850 $m^3$/capita/a (NAM). This can be compared with indicators of water sufficiency. For example, at 500 $m^3$/capita/a water supply may become a primary constraint to life [50, 54]. According to this criterion, several regions can be considered water deficient, AFR and Asia in particular[20]; or, as Table 14 indicates, about 50% of the world's population live at present with an insufficient water supply.

The figure of 500 $m^3$/capita/a covers all water requirements, including agriculture. However, by importing food in exchange for other commodities (natural resources, manufactured products, labour) some countries may not need the agricultural water element. It may therefore be more accurate to measure water scarcity by the basic household needs. As suggested in Ref. [55], 36 $m^3$/capita/a (i.e. 100 L per person per day) can be used as the level required for a decent quality of life. If this yardstick is applied (see Table 14), about 60% of the world's population does not have sufficient water.

Yet another consideration is the sustainability of the water supply. Not only does the amount of water used matter, but also the profile of the supply. A recent United Nations study suggested [56] that the use of more than 40% of the annual renewable water resources should be considered as unsustainable (see Section 5.1.1.1). Table 14 shows that under this criterion some regions, in particular MEA, use water in an unsustainable manner, which can lead to a decrease in water availability and a deterioration of water quality. Such phenomena have already been noted in these regions [57].

Table 14 also shows a projection of water availability for 2025 developed by the International Water Management Institute [50]. This projection shows that while certain improvements in water supply are likely (especially for domestic consumption in developing countries), these improvements may be achieved at the expense of sustainability. Consequently, the problem of freshwater availability is likely to become even more serious in the future, in particular in Africa, the Middle East and Asia.

---

[19] It must be noted that by using regional aggregation Table 14 hides important intercountry differences, so for a better understanding it is desirable to review the estimates at the country level given in Appendix V.

[20] This indicator is not perfect. For example, the relatively low water supply in Europe (about 600 $m^3$/capita/a) does not mean a scarcity of water, as the region is food importing (i.e. water is imported in the form of food).

Consider, for example, water availability in SAS (see Table 14):

- The population is growing rapidly and will almost double by 2025 (mostly because of the growth in India, Bangladesh and Pakistan);
- The available water resources remain the same (an assumption of the International Water Management Institute study);
- There is some increase in the amount of water used per capita.

As a result of these three factors annual water withdrawals are predicted to double from 1990 to 2025, which would result in a sharp deterioration of the sustainability indicator.

This conclusion of Ref. [50] is consistent with several other studies. The two recent reports of the World Water Council can be noted in particular [58, 59].

It is expected that water insufficiency will lead to a search for new water resources, desalination being one. The potential users are the countries of MEA, AFR and Asia, in which the problem of water scarcity is already apparent[21].

#### *5.1.1.1. Water supply sustainability*

The nature of water supply unsustainability can be judged by the following definitions [53]:

> "It has been observed that water stress can begin as the use of fresh water rises above 10 per cent of renewable freshwater resources, and it becomes more pronounced as the use level crosses the 20 per cent level. On average, a country can only capture about one-third of the annual flow of water in its rivers using dams, reservoirs and intake pipes. A further limitation arises from the growing lack of acceptance for the social and environmental impacts of large dams. The closest and most economical sources of water are used first, and it becomes increasingly expensive to tap sources that are farther away from the needs. Another limitation to water use is that once withdrawals pass certain thresholds, which vary from site to site, lake and river levels fall to the point that other uses are harmed... Use of more than 40 per cent of available water indicates serious scarcity, and usually an increasing dependence on desalination and use of

---

[21] Water scarcity does not necessarily mean an absence of water resources, but rather a deficit of usable water. For example, Table 14 shows that some regions have water resources (AFR, CPA), but this does not transform into a sufficient water supply because of poor water quality and uneven water distribution within the region. In some other regions, in MEA in particular, there is a definite lack of available water resources, which leads to a scarcity of water.

groundwater faster than it is replenished. It means there is an urgent need for intensive management of supply and demand. Present use patterns and withdrawals may not be sustainable, and water scarcity can become the limiting factor to economic growth."

### 5.1.2. Market features

The following specific features of the market for water desalination should be noted.

#### *5.1.2.1. Principal competitors and types of competition*

Despite the rapid growth and improvement in desalination technologies, most of the demand for fresh water is still met by conventional water supply methods. Moreover, there are still unexploited sources of fresh water, although they widely differ from region to region. There are therefore two types of competition in freshwater supply that are important for desalination: the competition between the expansion of water withdrawals and desalination and the competition between various possible desalination options. Since the first type of competition is highly site specific, only the second type is considered here.

#### *5.1.2.2. Available desalination technologies*

Several technologies are commercially available for using energy for water desalination: MSF, multieffect distillation (MED), RO[22] and vapour compression (VC). The selection of a particular technology is driven by the following factors:

- — Comparative economics,
- — Customer specific water quality requirements (MSF and MED provide water of higher purity than RO),
- — Environmental considerations.

At the end of 1999 the breakdown of world desalination capacities by type was as follows: 42.4% was based on the MSF principle (a decline from 51.5% in 1993), 41.1% of capacity was RO (an increase from 32.7% in 1993), the remaining 16.5% was of several other types, including MED [37].

---

[22] Hybrid processes combining distillation and RO processes also exist.

#### *5.1.2.3. Required type of energy*

Desalination needs heat and/or electricity, depending on which process is utilized. Heat, usually in the form of steam of some 100 to 130°C, is required for distillation processes[23]; electricity is needed for RO as the primary energy source and for MSF and MED as energy for pumping. Table 15 shows the typical energy requirements for the common desalination processes.

#### *5.1.2.4. Siting and the problem of energy delivery*

For membrane processes such as RO, electricity can be supplied from the electricity grid if it is of an adequate capacity. In such a case the siting of a desalination system is independent of the energy source. However, siting an RO facility with a power station will allow the brine reject steam to be diluted with power station cooling water prior to final disposal, thus minimizing possible environmental effects.

Moreover, the productivity of RO systems can be considerably improved by feed water preheating. Large scale RO processes could therefore be consumers of both electricity and heat (generally taken from the main condensers), which favours contiguous plants, but the improved productivity would have to be balanced against the increased water transportation costs, as would also be the case for desalination by distillation processes[24].

TABLE 15. ENERGY REQUIREMENTS FOR THE COMMON DESALINATION PROCESSES [44, 48]

| Parameter | Unit | Process | | |
|---|---|---|---|---|
| | | RO | MSF | MED |
| Electricity requirements | kW·h(e)/m$^3$ | 4–7 | 3–6 | 0.9–4.5 |
| Heat requirements | kW·h(th)/m$^3$ | — | 45–120 | 25–160 |
| | GJ/m$^3$ | — | 0.16–0.43 | 0.09–0.58 |
| Total energy needed | kW·h/m$^3$ | 4–7 | 50–125 | 26–165 |
| | GJ/m$^3$ | 0.01–0.02 | 0.2–0.5 | 0.1–0.6 |

**Note:** For the latest desalination technologies energy requirements are lower than shown in this table. Seawater RO currently requires not more than 3 to 4 kW·h/m$^3$. MSF draws about 2.5 kW·h/m$^3$ in parasitic power.

---

[23] Low temperature MED plants can utilize low grade or waste heat below 100°C.

[24] MSF and MED desalination plants require the energy source to be close, because heat transportation over large distances is not economic.

#### 5.1.2.5. *Typical capacity ranges*

The required capacity of a desalination plant depends on the needs of the water customer. Accordingly, the total capacity may range from 100 $m^3$/d to 60 000 $m^3$/d. By the end of 1999 a global capacity of 13 600 desalination units (of a unit size of 100 $m^3$/d or more) with a total capacity of 25.909 $Mm^3$/d was available or contracted [37]. Thus the average unit capacity is currently about 1900 $m^3$/d. Large capacities are usually designed as modular plants.

One nuclear reactor with a 600 MW(e) capacity can supply sufficient energy even for large desalination capacities. This is illustrated in Table 16, which shows the decrease in the net saleable electricity of a 600 MW(e) unit as a function of water production capacity.

In some situations energy supply for desalination can be obtained without losses in electricity generation capacity. For example, high temperature reactors can have rejected heat with a sufficiently high thermal potential to be used in a vacuum distillation process.

When choosing the desalination capacity and an appropriate technology mix for the supply of desalination energy, typical power to water production ratios for various combinations of power stations and water plants can be used (see Table 17). Such ratios indicate the number of megawatts of generating capacity that would be most effectively coupled with a desalination plant of a given water production capacity. The demand ratio of power to water will often influence the local choice of technology.

TABLE 16. CAPACITY DECREASE OWING TO ENERGY USE FOR DESALINATION
*(data for region 2 with MED desalination and a PWR-600 power plant [60])*

| Desalination capacity ($m^3$/d) | Net saleable power (MW(e)) | Foregone electric power (MW(e)) |
|---|---|---|
| 480 000 | 000.0 | 101.1 |
| 0 | 610.5[a] | 0 |
| 6 000 | 597.9 | 12.6 |
| 120 000 | 585.3 | 25.2 |
| 240 000 | 561.8 | 48.7 |
| 480 000 | 509.4 | 101.1 |

**Note:** Region 2 is the North African, Red Sea and South East Asian regions with a seawater temperature of 25°C or higher.

[a] The lost power is calculated using a net capacity of 610.5 MW(e); this number differs from the reference capacity of 600 MW(e) because the condensing temperature assumed for the specific conditions of the study is lower than that of the reference 600 MW(e) plant.

TABLE 17. TYPICAL POWER TO WATER PRODUCTION RATIOS [61]

| Energy source and desalination process | MW(e)/1000 $m^3$/d |
|---|---|
| Seawater RO | 0.2–0.3 |
| Backpressure steam turbine — MED | 0.8 |
| Backpressure steam turbine — MSF | 1.1 |
| Gas turbine/heat recovery boiler — MSF | 1.8 |
| Gas turbine/heat recovery boiler — MED | 1.3 |
| Extraction steam turbine — MSF | 1.1 |
| Extraction steam turbine — MED | 0.8 |
| Combined cycle/GT/BPT[a] — MSF | 3.5 |
| Combined cycle/GT/BPT — MED | 2.2 |
| Combined cycle/GT/EST[b] — MSF | 4.2 |
| Combined cycle/GT/EST — MED | 2.6 |

[a] BPT: Backpressure steam turbine.

[b] EST: Extraction steam turbine.

### *5.1.2.6. Supply mode and reliability*

Water supply is usually subject to requirements for a high reliability. To ensure this reliability a backup source of energy may be required on the site of the desalination facility. The greatest cause of unscheduled downtime in evaporative plants is an interruption of the steam supply from the coupled power station. This requirement for reliability, however, is less stringent for RO plants with feed water preheating, because grid electricity can serve as a backup source if the on-site source fails. The reliability of a RO plant is generally close to that of the power grid. MSF and MED systems are usually equipped with a fossil fuelled auxiliary steam boiler.

Another means of increasing reliability is the use of water storage, with the storage capacity depending on the size of the demand and the desalination capacity. For large desalination plants storage in reservoirs or aquifers can be considered, although their limited availability and added cost are important constraints.

### *5.1.2.7. Impact of specific nuclear considerations*

The specific considerations for the use of nuclear energy are, in general, the same as for nuclear district heating: safety and waste management problems must be adequately addressed. It may be worth noting, however, that the difficulties of siting a nuclear heat source close to an area of high population density largely do not exist for the case of nuclear desalination, as water can be more economically transported over long distances than can heat. Moreover, the next generation of reactors may have sufficient safety features to permit their location close to population centres.

There is another important consideration specific to the use of nuclear desalination. As shown above, the potential users of desalination are the countries of MEA, AFR and Asia. In most of these countries nuclear energy has not so far been used; nuclear desalination may therefore be the first nuclear project to be introduced in these countries, and so the usual preparatory work for the introduction of nuclear energy in a country will be required [62, 63]. This work must be well planned and adequately implemented.

### 5.1.3. Market potential for nuclear penetration

As noted above, there is definite lack of water supply in some world regions, which is a problem that is likely to worsen. For comparison, if all existing desalination units [37] operated at their full capacity for a year, they would produce:

$25.9\ \mathrm{Mm^3/d} \times 360\ \mathrm{d/a} \approx 9.3\ \mathrm{Gm^3/a}$

This can be compared with the total world water use of some 3250 $\mathrm{Gm^3}$ — the desalination part therefore amounts only to ~0.3%. Even the share of desalinated water for the supply of household water (~300 $\mathrm{Gm^3}$) is negligible (~3%). Taking into account the likely deterioration of the water situation in the future, it can be safely assumed that the desalination market is far from saturated[25].

A comparison can also be made with the water production capacity of one 600 MW(e) nuclear reactor. As noted above, such a reactor can produce about 500 000 $\mathrm{m^3}$ of water per day (using about 17% of its generation capacity). This means that the total existing global desalination capacity (~26 $\mathrm{Mm^3/d}$) can be powered by some 50 reactors.

Four conclusions on the market potential for nuclear penetration can be made:

- The global use of desalination is still negligible in comparison with the demand for fresh water; to become a noticeable (and quantifiable) market for nuclear energy, desalination needs to compete successfully with the alternative means of increasing the freshwater supply.
- At the same time, the deteriorating trend in the water supply is visible; it can be expected that the alternatives for freshwater supply will become more limited and more expensive, which would provide additional incentives for desalination to become widespread.

---

[25] The numbers used are global averages that have been used for illustration. Regionally, the importance of desalination greatly varies and it can be much higher than the averages shown.

- The regional diversity in water requirements is an important factor; assessments of water availability, demand and supply (including the feasibility of the nuclear option) must take the regional factor into account.
- As global desalination capacities are still limited, the long term market potential for nuclear desalination cannot be accurately estimated. Competition between nuclear desalination and the non-nuclear options should be evaluated along with the competition of desalination with the alternative options for the supply of water.

## 5.2. POTENTIAL NUCLEAR SOLUTIONS

As noted, desalination needs low temperature heat and/or electricity. These types of energy can be provided by practically all existing and prospective nuclear designs. Among the designs recently considered [60, 64] are a 220 MW(e) HWR in India, a 10 MW(th) heat only PWR in Morocco, a 200 MW(th) heat only PWR in China, a 100 MW(e) PWR in the Republic of Korea, three concepts of a floating nuclear plant with a 35 MW(e) PWR (KLT-40), two sizes (15 MW(e) and 90 MW(e)) of Nika PWRs and a 55 MW(th) heat only pool type reactor, Ruta, in the Russian Federation, among others.

Nuclear technologies are therefore available and their application will be determined by the usual considerations for the introduction of nuclear energy in a country: the economic advantages of nuclear energy, safety assurance, strategic considerations such as supply security and diversification, etc.

## 5.3. ECONOMIC COMPETITIVENESS

In general, the economics of nuclear desalination are driven by the same factors as the economics of electricity generated by nuclear energy, the more so that some desalination processes use electricity as the main energy input. In this respect, it can be expected that the general trends in the comparative economics of NPPs (see, for example, the results of Ref. [31] shown in Section 2.4) would also be valid for desalination. However, the use of nuclear power for desalination is less influenced by some of the factors that weigh against nuclear energy for process or district heating. Much larger scales are likely for desalination and the demands of high reliability will be lower than for process or district heating. The economics of desalination also has its distinctive features, such as the use of rejected heat of a relatively low temperature. These need to be properly addressed. A recent IAEA study [60] explicitly considers such features using a cost estimate methodology designed for desalination [45, 47, 48].

The regions and energy technologies considered in the IAEA study are presented in Tables 18 and 19, respectively.

Table 20 presents some results of this study in the form of indicators of the relative competitiveness of nuclear desalination. More precisely, the numbers are ratios of the levelized water production costs obtained through calculations with the IAEA program DEEP [48]. The numerator of the ratio is the cost for a nuclear desalination option, while the denominator is the cost of a fossil fuel option. The case

TABLE 18. REGIONS CONSIDERED IN THE IAEA DESALINATION STUDY [60]

| Region | Geographic area |
|---|---|
| 1 | Southern Europe |
| 2 | Red Sea, Southeast Asia, North Africa |
| 3 | Arabian Sea |

TABLE 19. TECHNOLOGIES CONSIDERED IN THE IAEA DESALINATION STUDY [60]

| Energy source | Abbreviation | Description | Power level | Technology status |
|---|---|---|---|---|
| Nuclear | PWR | Pressurized light water reactor | 600 MW(e), 900 MW(e) | Existing |
| | PHWR | Pressurized heavy water reactor | 600 MW(e) | Existing |
| | PHWR | Pressurized heavy water reactor | 900 MW(e) | Under development |
| | HTR | High temperature reactor | 100 MW(e) | Under development |
| | HR | Heating reactor (steam or hot water) | 200 MW(th) | Under development |
| Fossil[a] | PC | Superheated steam boiler, pulverized coal | 600 MW(e), 900 MW(e) | Existing |
| | CC | Combined cycle gas turbine | 600 MW(e) | Existing |

[a] Owing to the prospective nature of the study and in view of the expectation that the use of oil will decrease, oil fired plants were not considered.

TABLE 20. PROSPECTIVE COMPETITIVENESS OF NPPs IN WATER DESALINATION AS SIMULATED BY DEEP [60]

| Region | Case for nuclear | Nuclear/coal ratio | | Nuclear/gas ratio | |
|---|---|---|---|---|---|
| | | $S_n$ scenario | $S_f$ scenario | $S_n$ scenario | $S_f$ scenario |
| *Desalination with RO, water production capacity 120 000 $m^3/d$* | | | | | |
| 1 | Best | 0.73 | 0.87 | 0.68 | 0.85 |
| | Worst | 0.88 | 1.02 | 0.80 | 0.99 |
| 2 | Best | 0.75 | 0.89 | 0.72 | 0.89 |
| | Worst | 0.91 | 1.05 | 0.85 | 1.04 |
| 3 | Best | 0.73 | 0.89 | 0.72 | 0.89 |
| | Worst | 0.91 | 1.06 | 0.85 | 1.04 |
| *Desalination with MED, water production capacity 120 000 $m^3/d$* | | | | | |
| 1 | Best | 0.63 | 0.82 | 0.58 | 0.80 |
| | Worst | 0.90 | 1.05 | 0.82 | 1.00 |
| 2 | Best | 0.70 | 0.87 | 0.67 | 0.86 |
| | Worst | 0.95 | 1.09 | 0.89 | 1.06 |
| 3 | Best | 0.70 | 0.87 | 0.68 | 0.86 |
| | Worst | 0.97 | 1.11 | 0.91 | 1.07 |
| *Desalination with MSF, water production capacity 120 000 $m^3/d$* | | | | | |
| 1 | The MSF option was not considered for the region | | | | |
| 2 | Best | 0.65 | 0.85 | 0.66 | 0.89 |
| | Worst | 0.95 | 1.13 | 0.93 | 1.15 |
| 3 | Best | 0.66 | 0.86 | 0.67 | 0.89 |
| | Worst | 0.96 | 1.14 | 0.94 | 1.14 |

[a] The $S_n$ scenario assumes a discount rate of 5 to 8% (5% for region 1 and 8% for regions 2 and 3), a fossil fuel price of US $30/boe, nuclear plant overnight construction costs 15% lower than the baseline and fossil fuel plant overnight construction costs 15% higher than the baseline.

[b] The $S_f$ scenario assumes a discount rate of 8 to 10% (8% for region 1 and 10% for regions 2 and 3), a fossil fuel price of US $20/boe, nuclear plant overnight construction costs 15% higher than the baseline and fossil fuel plant overnight construction costs 15% lower than the baseline.

defined as the best for nuclear selects the ratio of the lowest nuclear cost (among the considered technologies) to the highest cost among the fossil fuel options. The worst case selects the ratio of the highest nuclear cost to the lowest fossil fuel cost.

The results of the study summarized in Table 20 are discussed below.

### 5.3.1. Correlation with the competitiveness of electricity generated by nuclear energy

As could be expected, the cost ratios shown for RO desalination correlate rather well with the recent NEA/IEA estimates of the competitiveness of electricity generated by nuclear energy [31] (see Section 2.4). Although direct comparisons are not possible (the desalination study covered regions and not countries), it can be noted that in Ref. [31] the cost ratios for electricity generation in Europe are 0.7–0.9 (for France) or 0.6–1.5 (for Turkey), while the results for the RO desalination in region 1 (southern Europe) are between 0.7 and 1.05. The latter is a little more optimistic than the former, but taking into account the difference in the assumptions the correspondence seems to be good.

### 5.3.2. Competitive position of nuclear desalination

For all desalination options (RO, MED, MSF) and in all regions there are competitive nuclear solutions, both in comparison with coal and gas fired power plants, although, understandably, there are also combinations of the parameters that lead to nuclear power being uncompetitive for desalination. In particular, the combination of a higher discount rate (8–10%) with unfavourable assumptions on the ratio of the plant parameters between nuclear and non-nuclear plants (the worst case for nuclear combined with the $S_f$ scenario in Table 20) lead almost invariably to the fossil fuel options being preferable. However, there are also cases in which the nuclear option is preferable. From this it can be concluded that nuclear energy is a viable desalination option and should be considered as such in the analysed regions. To make sure that the nuclear option is definitely preferable for a given desalination project, a site specific analysis is required in order to make a more accurate estimate of where, within the range shown, the considered nuclear project would belong.

### 5.3.3. Interregional comparison and the effect of technology selection

The behaviour of cost ratios in Table 20 does not depend much either on the region or on whether RO, MED or MSF is selected for desalination. This is an understandable result of the fact that the same energy technologies were considered. It can be noted, however, that the costs in US $\$/m^3$ are substantially higher for MSF than for RO or MED [60], the principal reason being the higher capital cost of MSF installations. Another observation is that the RO option allows for off-peak load base loading of a nuclear plant that might otherwise be load following, and thereby reduces the cost of electricity by producing a storable, saleable product.

The estimates in Table 20 are for the cogeneration mode of heat supply for desalination, which is the mode that is most likely to be applied in the near term for nuclear desalination. The supply of heat by dedicated heat reactors is also considered. Generally, it has been found that the cost of water from heat only sources is 20 to 50% higher than that from cogeneration sources, which is the result of the allocation of most of the common costs (for electricity and heat) to electricity. Consequently, the heat supplied to the desalination plant benefits economically from this method of cost allocation (the power credit method), which also creates an economic benefit for the water produced. However, for heating reactors all the costs are charged to the heat and, consequently, to desalination. Similar considerations are valid for district heating and the supply of process heat (see Sections 4 and 6)[26].

As a result, the consideration of a specific project should carefully review both the cogeneration and heat generation options. Depending on whether electricity is also needed in the given location, the heat only option could be the preferable one.

## 5.4. CURRENT AND PROSPECTIVE MARKET

### 5.4.1. Current use of nuclear energy

There is experience with nuclear desalination, as Table 21 shows, although the experience has been limited in that the desalination capacities are usually small and have been used only for the supply of on-site water. Moreover, these water plants have not been truly integrated into the nuclear generating facilities. Thus although the technical feasibility of nuclear desalination can be considered as proven, large scale applications remain yet to be seen.

### 5.4.2. Prospects for nuclear energy in the near term (2000–2020)

It is expected that desalination capacity will develop steadily over the coming years (see Fig. 8), some of which can be provided by nuclear energy.

However, at present only India has an advanced project of nuclear powered desalination (a 6300 $m^3$/d MSF plant at the Kalpakkam NPP). The first stage of commissioning tests for RO for this project started in late 2001 and will last until early 2003, when the second stage for MSF will be completed. In addition to India, several other countries are considering nuclear desalination, for example the Republic

---

[26] More information about cost allocation methods can be found in Refs [44–46, 60].

TABLE 21. EXPERIENCE WITH NUCLEAR DESALINATION [37, 43]

| Country | Unit name | Location | Phase | Start of operation | | Power (MW(e) net) | Water Capacity ($m^3$/d) | Desalination process |
|---|---|---|---|---|---|---|---|---|
| | | | | Power | Heat | | | |
| Japan | Ikata 1 | Ehime | Commercial | 1977 | 1976 | 538 | 2 000 | MSF |
| Japan | Ikata 2 | Ehime | Commercial | 1982 | 1976 | 538 | | |
| Japan | Ohi 1 | Fukui | Commercial | 1979 | 1973 | 1 120 | 3 900 | MSF |
| Japan | Ohi 2 | Fukui | Commercial | 1979 | 1976 | 1 120 | | |
| Japan | Genkai 3 | Fukuoka | Commercial | 1994 | 1988 | 1 127 | 1 000 | MED |
| Japan | Genkai 4 | Fukuoka | Commercial | 1997 | 1992 | 1 127 | | |
| Japan | Takahama 3 | Fukui | Commercial | 1985 | 1983 | 830 | 1 000 | MED |
| Japan | Takahama 4 | Fukui | Commercial | 1985 | 1983 | 830 | | |
| Japan | Kashiwazaki-Kariwa 1 | Niigata | Commercial | 1985 | 1984 | 1 067 | 1 000 | MSF[a] |
| Kazakhstan | BN-350[b] | Aktau | Commercial | 1973 | 1963 | 70 | 120 000 | MED/MSF |

**Note:** All nuclear desalination plants except for the Aktau NPP in Kazakhstan are used for the supply of on-site water. The data from Ref. [43] have been complemented with the latest statistics from an IAEA database and the latest desalination inventory [37].

[a] This desalination facility was not put into service after construction because other freshwater resources were made available.

[b] BN-350 was shut down in 1999. The desalination facility is now powered by a boiler plant.

of Korea, Egypt, Morocco, Indonesia and some others, although their projects are less advanced.

In the near term nuclear penetration in desalination will therefore be slower than the development of desalination in general. The near future should be considered as a period in which nuclear desalination must prove its economic competitiveness rather than a period of notable penetration into the desalination market.

This is the main objective of the new European project EURODESAL, which is being launched by a consortium of European and Canadian industrial and research and development organizations [22].

### 5.4.3. Prospects for nuclear energy in the long term (2020–2050)

The estimate of the prospects for nuclear energy in the long term has been carried out with the same set of qualitative indicators as used for district heating (see Sections 3 and 4.4.3). The following principles were used for ranking:

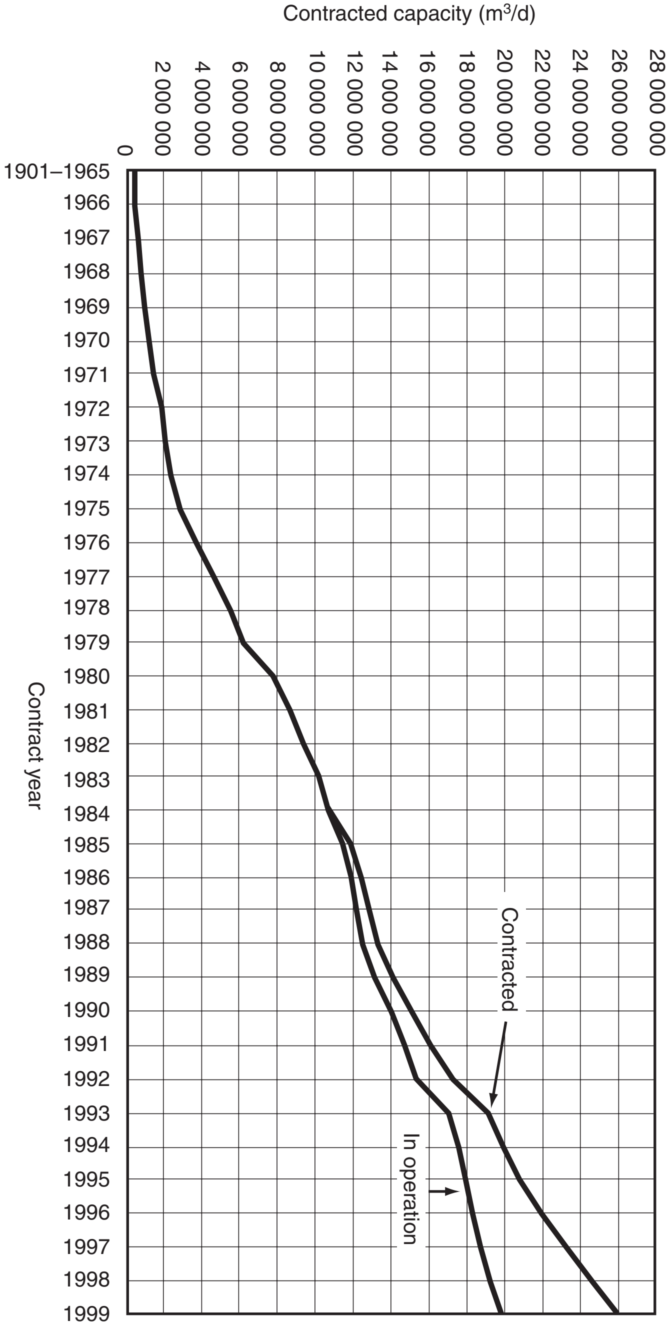

*FIG. 8. Cumulative capacity of world desalination plants. This figure is taken from Ref. [37] and reproduced here with the kind permission of Wangnick Consulting GmbH.*

- The indicator of market structure is assigned 0 for countries in which desalination has not been used or used to a negligible extent; 1 is assigned to those countries in which desalination is used but without nuclear energy; 2 is assigned to those countries in which nuclear desalination has already been used.
- The indicator of demand pressure is assigned 2 for those countries in which there will be a lack of water supply in 2025, as identified by two or three of the criteria given in Table 14 and Appendix V[27]; if the lack of water is identified only by a single criterion, 1 is assigned; all the other countries are assigned 0.
- The indicator of technical basis is assigned 2 for those countries in which NPPs are operating; 1 is assigned to countries that have considered or are seriously considering the use of nuclear energy, either through imports or through local development; 0 is assigned to those countries in which the use of nuclear energy has never been seriously considered (the same set of indicators as used for district heating).
- The indicator of economic competitiveness is assigned 0 for those countries that have abundant domestic oil, gas or hydro-electric resources (the competitiveness of nuclear energy is likely to be questionable in such cases); 0 is also assigned to countries that are islands, which reflects the difficulty of providing infrastructural support and fuel handling[28]; the others are assigned 1, while no cases have been assigned 2 (definite superiority of nuclear energy), which is a conservative assumption (the same set of indicators as used for district heating).
- The indicators of public acceptance are as defined in Appendix II.

For weighting in the calculation of regional indicators from the country indicators, the total domestic water supply is used. The result of the estimate is summarized in Table 22 for the 11 world regions. The underlying country by country estimate can be found in Appendix VI.

The results in Table 22 show the following:

- In most regions of the world the long term prospects for nuclear desalination are ranked as low. At first this may seem to contradict the expectation of future freshwater shortages discussed above, but a closer look resolves the apparent contradiction. For nuclear desalination to be feasible two factors must be in place simultaneously: a lack of water and the ability to use nuclear energy for desalination. In most regions only one of the two is present.

---

[27] The criteria meant with the reference to Table 14 are: (1) the total annual use of water less than 500 m$^3$/capita, (2) the annual domestic use of water less than 36 m$^3$/capita and (3) the annual use of water exceeds 40% of the available water resources.

[28] But if nuclear energy is already used on an island, 1 is assigned, which is the case with Taiwan, China.

TABLE 22. LONG TERM (2020–2050) PROSPECTS FOR NUCLEAR DESALINATION

| Region | Indicator | | | | | Total |
|---|---|---|---|---|---|---|
| | Market structure | Demand pressure | Technical basis | Economic competitiveness | Public attitude | |
| NAM | 0.00 | 0.00 | 2.00 | 1.00 | 1.00 | 0.80 (low) |
| LAM | 0.00 | 0.68 | 1.33 | 0.00 | 0.78 | 0.56 (negligible) |
| AFR | 0.00 | 1.49 | 0.88 | 0.83 | 0.88 | 0.82 (low) |
| MEA | 0.56 | 1.21 | 0.39 | 0.80 | 0.43 | 0.68 (low) |
| WEU | 0.10 | 0.26 | 1.56 | 1.00 | 0.75 | 0.73 (low) |
| EEU | 0.00 | 0.53 | 1.75 | 1.00 | 1.00 | 0.86 (low) |
| FSU | 0.05 | 0.44 | 1.59 | 0.86 | 0.80 | 0.75 (low) |
| CPA | 0.86 | 0.96 | 1.85 | 1.00 | 1.81 | 1.29 (medium) |
| SAS | 0.88 | 1.92 | 1.76 | 0.99 | 1.76 | 1.46 (high) |
| PAS | 0.26 | 0.85 | 1.08 | 0.99 | 1.08 | 0.85 (low) |
| PAO | 1.55 | 0.00 | 1.16 | 1.00 | 0.58 | 0.86 (low) |
| Total | 0.37 | 0.57 | 1.55 | 0.86 | 1.02 | 0.87 (low) |

— The situation in the MEA region is of particular interest. Similarly to AFR and SAS the region experiences a lack of water and a high demand pressure (see the corresponding indicator in Table 22), which is why countries in the region have been looking into the possibility of using nuclear power for desalination [18, 19, 57]. However, as the technical basis for the introduction of nuclear power has not yet been created and the economic competitiveness of nuclear desalination is not definite, the overall ranking of the long term prospects for nuclear energy is still low. With the introduction of nuclear power in the region, even if only for electricity generation, this estimate will change, most likely to medium. This is indicated by the existence of countries in which, notwithstanding the regional low average, the prospects are ranked as medium (see Table 23).

— However, when the two factors — a lack of water and the ability to use nuclear technologies — are present, the prospects for nuclear desalination are much better. In CPA they are ranked as medium, mainly because the demand in China can be supported by the Chinese capability to use nuclear energy. The same factor is even more pronounced in SAS, in particular because of the potential for nuclear desalination in India and Pakistan.

— Although only two regions are ranked higher than low, at present these regions account for almost 50% of the world's population. In the long

## TABLE 23. COUNTRIES WITH THE HIGHEST PROSPECTS FOR NUCLEAR DESALINATION

| Region/country | Indicator<br>Market structure | <br>Demand pressure | <br>Technical basis | <br>Economic competitiveness | <br>Public attitude | Total |
|---|---|---|---|---|---|---|
| *AFR* | | | | | | |
| South Africa | 0 | 1 | 2 | 1 | 2 | 1.2 (medium) |
| *MEA* | | | | | | |
| Algeria | 1 | 2 | 1 | 1 | 0 | 1.0 (medium) |
| Egypt | 1 | 1 | 1 | 1 | 1 | 1.0 (medium) |
| Iran | 0 | 1 | 1 | 1 | 2 | 1.0 (medium) |
| Israel | 1 | 2 | 0 | 1 | 1 | 1.0 (medium) |
| Morocco | 1 | 2 | 1 | 1 | 1 | 1.2 (medium) |
| *WEU* | | | | | | |
| Belgium | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| Finland | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| France | 0 | 0 | 2 | 1 | 2 | 1.0 (medium) |
| Netherlands | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| Spain | 1 | 0 | 2 | 1 | 1 | 1.0 (medium) |
| Switzerland | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| United Kingdom | 0 | 2 | 2 | 1 | 1 | 1.2 (medium) |
| *EEU* | | | | | | |
| Czech Republic | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| Slovakia | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| *FSU* | | | | | | |
| Armenia | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| Belarus | 0 | 2 | 1 | 1 | 1 | 1.0 (medium) |
| Kazakhstan | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| Lithuania | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| Ukraine | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| *CPA* | | | | | | |
| China | 1 | 1 | 2 | 1 | 2 | 1.4 (medium) |
| *SAS* | | | | | | |
| India | 1 | 2 | 2 | 1 | 2 | 1.6 (high) |
| Pakistan | 1 | 2 | 2 | 1 | 2 | 1.6 (high) |
| *PAS* | | | | | | |
| Indonesia | 0 | 2 | 1 | 1 | 1 | 1.0 (medium) |
| Korea, Republic of | 1 | 1 | 2 | 1 | 2 | 1.4 (medium) |
| *PAO* | | | | | | |
| Japan | 2 | 0 | 2 | 1 | 1 | 1.2 (medium) |

term the share will remain the same, if not increase. The ranking shown therefore means a rather positive estimate of the prospects for nuclear desalination.

The countries with the best prospects in each region are shown in Table 23. India and Pakistan in SAS must be noted, as well as China in CPA, Kazakhstan in FSU and the Republic of Korea in PAS.

# 6. INDUSTRIAL PROCESS HEAT APPLICATIONS

## 6.1. MARKET CHARACTERIZATION

### 6.1.1. Market size

Notwithstanding some similarities with district heating, the market for process heat presents important differences on the demand side. The demand for process heat is not very dependent on climate or population size as a key variable. Instead, it is driven by the existing economic structures and the activities of the heat consuming industries.

A precise assessment of this market would require very detailed data. Some data can nonetheless be found and interpreted, in particular annual statistics from the IEA, which cover both OECD and non-OECD countries [34, 35]. However, although the IEA data contain the amount of final energy consumed by a given industry, they do not specify the way the energy was consumed. For example, the coal reported as consumed by an industry may be burned in a steam boiler that produces heat or may be used by a small power generator operating on an industrial site. Similarly, oil and oil derivatives may be used for electricity generation, heat production or as fuel for vehicles used within the industry.

Figures 9 and 10 illustrate the pattern of the non-electric final energy supplied to industry and a breakdown of this energy by the type of usage [40, 41, 65].

Industrial final energy consumption shows a notable structural change with time. While electricity consumption has in general steadily increased, the consumption of fuels has decreased following an initial rising trend immediately after the oil crises of the 1970s.

If electricity consumption is plotted against fuel consumption for different years, the resulting curve is shaped like a boomerang (see Fig. 11). The boomerang is less pronounced in countries with a strong consumption of domestic energy resources or in less developed countries, as illustrated in Fig. 12. The turning point of the curve

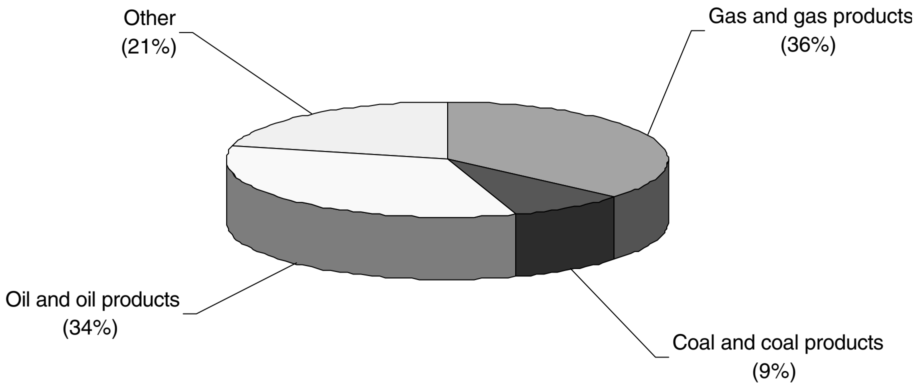

*FIG. 9. Structure of the supply of non-electric final energy to the industrial sector in the USA in 1998 [40, 41].*

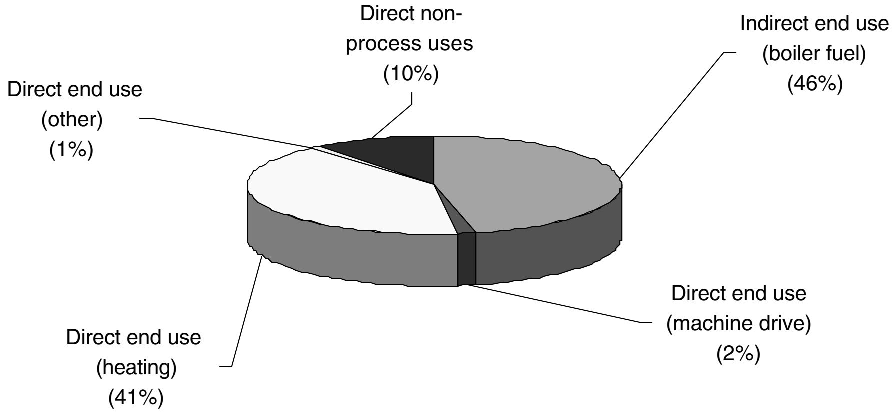

*FIG. 10. Structure of the use of non-electric final energy by the industrial sector in the USA in 1994 [40, 65].*

reflects the transition to less energy intensive industries and a slowdown in economic growth. Other examples can be found in Appendix VII.

Table 24 provides details of the industrial energy consumption and the share of centralized heat generation by world region. A more detailed country by country breakdown is given in Appendix VIII.

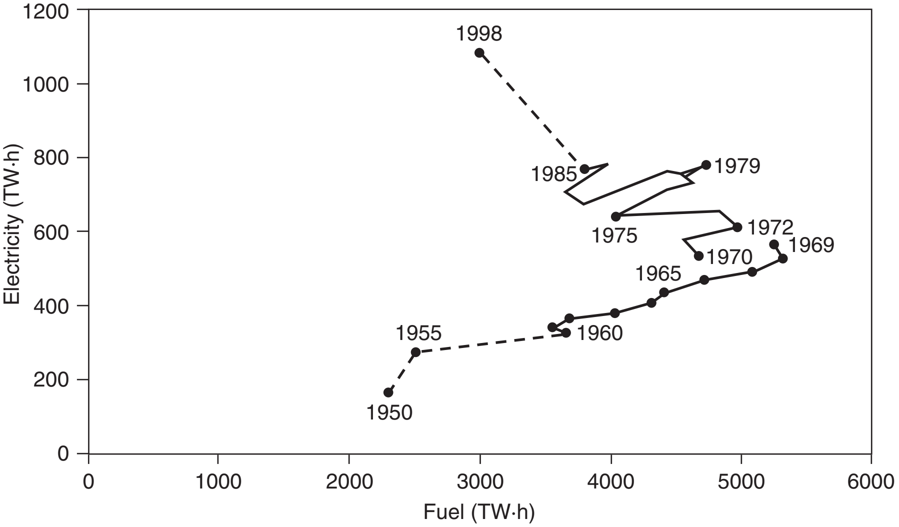

*FIG. 11. Evolution of the structure of industrial energy consumption for the USA [66, 67]. The dashed line to 1998 indicates that these data do not come from Ref. [66] but have been added to the data from Ref. [66], based on the latest statistics available in Ref. [67].*

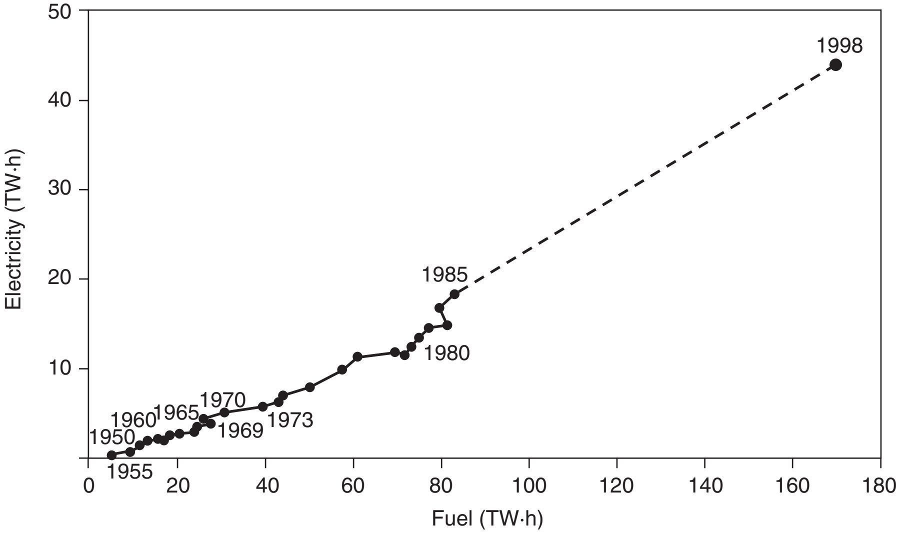

*FIG. 12. Evolution of the structure of industrial energy consumption for Turkey [66, 67]. The dashed line to 1998 indicates that these data do not come from Ref. [66] but have been added to the data from Ref. [66], based on the latest statistics available in Ref. [67].*

TABLE 24. CHARACTERIZATION OF CENTRALIZED HEAT GENERATION BY REGION
*(based on 1996 data [34, 35])*

| Region/country | Final energy demand (Mtoe) | | Centralized heat generation (Mtoe) | | Share of centralized supply (%) | |
|---|---|---|---|---|---|---|
| | Total | In industrial sector | Total | Share of industrial sector | In total final energy demand[a] | In industrial sector[b] |
| Total NAM | 1620.1 | 425.4 | 8.1 | 5.8 | 0.5 | 1.5 |
| Canada | 184.3 | 66.6 | 0.5 | 0.5 | 0.3 | 0.8 |
| USA | 1435.8 | 358.8 | 7.6 | 5.3 | 0.5 | 1.5 |
| Total LAM | 418.0 | 159.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total AFR | 209.3 | 40.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total MEA | 280.4 | 78.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total WEU | 1104.3 | 326.8 | 22.9 | 5.0 | 2.1 | 1.5 |
| Denmark | 16.3 | 3.05 | 2.4 | 0.1 | 14.7 | 3.6 |
| Finland | 23.3 | 10.2 | 2.8 | 0.7 | 11.8 | 6.1 |
| France | 161.5 | 45.1 | 1.4 | 0.0 | 0.8 | 0.0 |
| Germany | 247.6 | 70.8 | 9.0 | 1.7 | 3.7 | 2.4 |
| Netherlands | 59.3 | 18.7 | 1.7 | 0.8 | 2.9 | 4.2 |
| Sweden | 36.3 | 13.6 | 3.6 | 0.1 | 9.9 | 0.4 |
| Total EEU | 194.0 | 82.0 | 25.1 | 9.0 | 13.0 | 11.0 |
| Bulgaria | 12.7 | 7.2 | 2.9 | 2.0 | 22.6 | 27.3 |
| Hungary | 17.7 | 5.0 | 1.8 | 0.5 | 10.0 | 10.1 |
| Poland | 72.6 | 28.3 | 9.3 | 1.7 | 12.9 | 6.2 |
| Romania | 29.1 | 15.0 | 5.6 | 1.3 | 19.3 | 8.5 |
| Total FSU | 682.1 | 250.7 | 198.8 | 116.0 | 29.2 | 43.0 |
| Belarus | 19.0 | 6.6 | 7.3 | 3.0 | 38.4 | 45.7 |
| Estonia | 2.9 | 1.1 | 0.8 | 0.2 | 27.4 | 20.3 |
| Russian Federation | 468.8 | 170.9 | 169.3 | 93.1 | 36.2 | 54.5 |
| Ukraine | 98.5 | 47.0 | 10.4 | 6.7 | 10.5 | 14.2 |
| Total CPA | 924.3 | 447.3 | 21.3 | 21.3 | 2.3 | 4.8 |
| China | 865.9 | 426.3 | 21.3 | 21.3 | 2.5 | 5.0 |
| Total SAS | 432.7 | 129.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total PAS | 392.4 | 138.9 | 1.2 | 1.2 | 0.3 | 0.9 |
| Total PAO | 415.4 | 161.5 | 0.4 | 0.0 | 0.1 | 0.0 |
| Japan | 337.0 | 133.6 | 0.4 | 0.0 | 0.1 | 0.0 |
| Total | 6673.0 | 2239.6 | 273.2 | 150.1 | 4.1 | 6.7 |

**Note:** Similarly to district heating, the term centralized means that the produced heat is sold for utilization to a third party (the definition of the IEA [34, 35]). The use of this definition may be less relevant for process heat supply than for district heating because for industry the use of small on-site heat generation may be preferable. However, the data of centralized heat supply are still used here because of their availability and lack of detailed information about internal heat generation in the industrial sector.

[a] Total centralized heat generation/total final energy demand.

[b] Share of the industrial sector centralized heat generation/share of the industrial sector final energy demand.

### 6.1.2. Market features

#### 6.1.2.1. *Main heat consumers*

The industries that are the main consumers of heat are:

- — The food and products industry,
- — The paper and products industry,
- — The chemical industry,
- — The petroleum and coal processing industry,
- — The primary metal industries.

Figure 13 shows the breakdown of the total non-electric energy used by all branches of industry in the USA in 1994 [40, 65]. It confirms the predominant role of the industries listed above — all the other energy consumers account for less than 15% of the total non-electric energy used.

To be more accurate, it should be mentioned that Fig. 13 presents, similarly to Fig. 10, the total non-electric energy, which may include non-heat uses such as, for example, electricity generation on the site. To estimate whether the structure of the heat consumers is the same, Fig. 14 shows the breakdown of steam production capacities used in Germany by similar industries. The comparison of the two figures confirms the key role of the five industries in the use of process heat. They would therefore be the target clients for possible applications of nuclear energy.

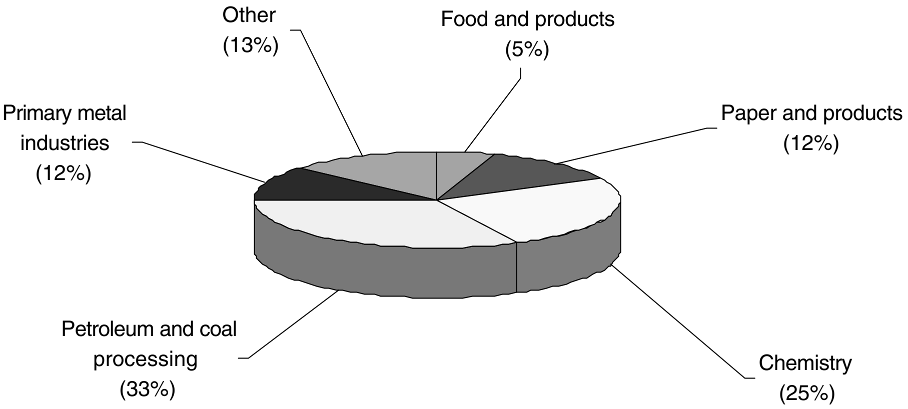

*FIG. 13. Main consumers of non-electric final energy among US industries in 1994 [40, 65].*

### *6.1.2.2. Required temperature ranges*

Industrial heat is usually required as steam under conditions specific to each technological process. The range of steam parameters is determined by the specific industry and is rather large, which represents an important feature of the demand for process heat. Figure 15 shows the typical temperature ranges for industrial heat applications.

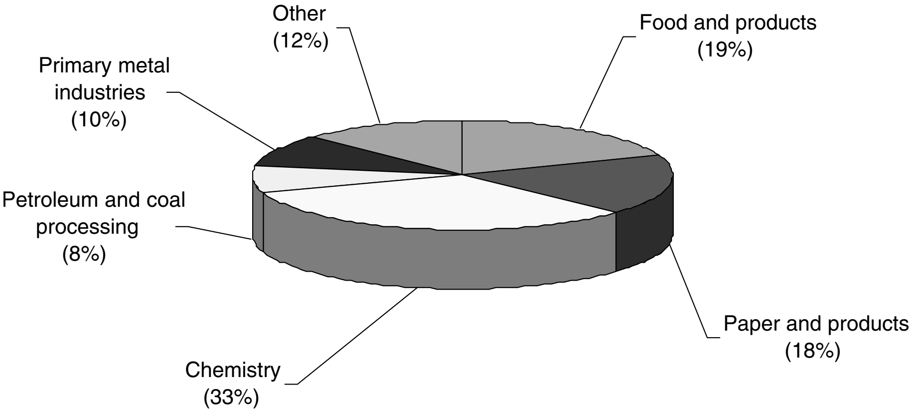

*FIG. 14. Breakdown of the steam generation capacities used by German industries in 1989 [68]. The data are for the western part of contemporary Germany; that is, excluding the eastern part that was separated from West Germany at the time of the study.*

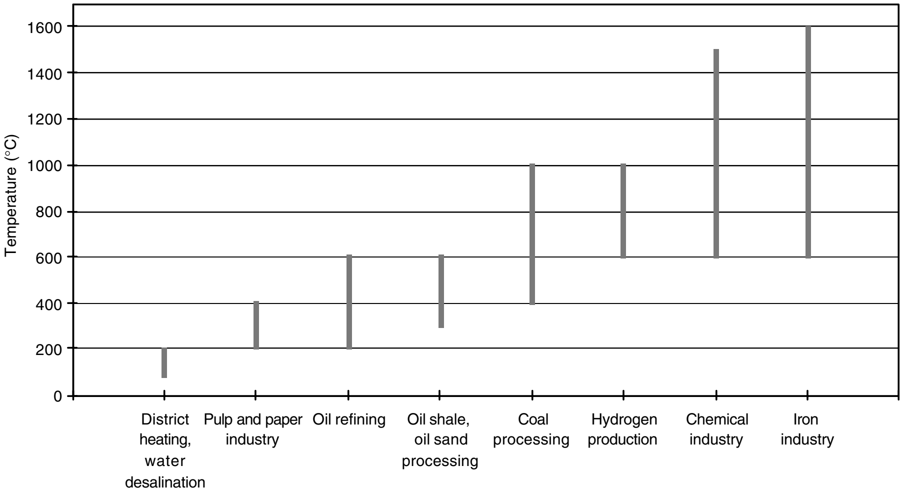

*FIG. 15. Temperature ranges for process heat applications [43, 69].*

### *6.1.2.3. Typical capacity ranges*

As noted in Ref. [38], the demand for industrial heat is highly fragmented in terms of size. Some 50% of users need less than 10 MW(th), some 90% need less than 50 MW(th) and 99% less than 300 MW(th). The remaining 1%, which covers the cases of exceptionally high demand, to 1000 MW(th) and above, represents a large proportion of energy consumption. This last category would be particularly disposed to nuclear applications.

Tables 25 and 26 illustrate the structure of industrial demand using the results of a German study [68]. Two aspects are presented: the distribution of the existing industrial boilers by size and the distribution of the industrial consumers by the amount of heat needed. As a customer can operate more than one boiler, it is the size of the boiler that would be most pertinent when deciding on the application of a nuclear boiler. However, it is important to see both aspects, because the size of individual boilers also characterizes the use of heat by the industry.

### *6.1.2.4. Heat transportation*

Table 27 shows that the costs grow significantly with distance, and hence that an on-site installation is preferable.

TABLE 25. STRUCTURE OF INDUSTRIAL PROCESS HEAT DEMAND BY SUPPLIER CAPACITY
*(based on 1987 data [68] from Germany)*

| Boiler capacity (t steam/h) | Number of boilers | Per cent of total | Total capacity (t/h) | Per cent of total | Average unit capacity (t/h) |
|---|---|---|---|---|---|
| 0–25 | 556 | 47.9 | 7 130 | 11.3 | 13 |
| 25–50 | 221 | 19.0 | 8 500 | 13.5 | 38 |
| 50–75 | 118 | 10.1 | 7 250 | 11.5 | 61 |
| 75–100 | 97 | 8.3 | 8 450 | 13.4 | 87 |
| 100–125 | 48 | 4.1 | 5 700 | 9.1 | 119 |
| 125–150 | 39 | 3.3 | 5 360 | 8.5 | 137 |
| 150–175 | 18 | 1.5 | 2 840 | 4.5 | 158 |
| 175–200 | 19 | 1.6 | 3 700 | 5.9 | 195 |
| >200 | 49 | 4.2 | 13 920 | 22.3 | 284 |
| Total | 1165 | 100 | 62 850 | 100 | 54 |

TABLE 26. STRUCTURE OF INDUSTRIAL PROCESS HEAT DEMAND BY USER CAPACITY
*(based on 1987 data [68] from Germany)*

| User demand (t steam/h) | Number of users | Per cent of total users | Total capacity (t/h) | Per cent of total capacity | Average unit capacity[a] (t/h) |
|---|---|---|---|---|---|
| 0–50 | 286 | 64.5 | 5 910 | 18.7 | 21 |
| 50–100 | 84 | 18.9 | 5 810 | 18.4 | 69 |
| 100–200 | 44 | 9.9 | 5 540 | 17.5 | 126 |
| 200–300 | 11 | 2.5 | 2 600 | 8.2 | 236 |
| 300–400 | 5 | 1.1 | 1 650 | 5.2 | 330 |
| 400–500 | 5 | 1.1 | 2 020 | 6.4 | 404 |
| 500–600 | 1 | 0.2 | 500 | 1.6 | 500 |
| 600–800 | 3 | 0.7 | 1 850 | 5.8 | 617 |
| 800–900 | 1 | 0.2 | 850 | 2.7 | 850 |
| >900 | 4 | 0.9 | 4 900 | 15.5 | 1 225 |
| Total | 444 | 100 | 31 630 | 100 | 71 |

[a] Total capacity/number of users.

TABLE 27. IMPACT OF DISTANCE ON HEAT TRANSPORTATION COSTS [70]

| Distance (km) | Cost of heat transportation (relative to the cost for 5 km)[a] |
|---|---|
| 5 | 1.0 |
| 10 | 2.5–3.5 |
| 15 | 4.5–5.5 |
| 20 | 6.5–8.0 |

[a] The range reflects the effect of varying steam parameters.

### *6.1.2.5. Supply mode*

The supply of industrial heat is less uneven than that of district heat, mainly because of the absence of a seasonal variation. Accordingly, the average load factors of industrial boilers are relatively high — between 70 and 90% [68].

#### *6.1.2.6. Supply reliability*

The supply has to be reliable. A study conducted by the Oak Ridge National Laboratory in the USA [71] identified the reliability requirements of large industrial users (see Table 28). Such high levels can be ensured only by the combination of a high reliability of the heat sources and an availability of reserve capacity. The latter is easier to implement by using several production units that are relatively small in comparison with the required capacity or by supplying steam as a relatively small co-product from a group of electricity producing reactors.

#### *6.1.2.7. Impact of specific nuclear considerations*

Similarly to nuclear district heating, the close siting of a nuclear plant to the customer may be preferable. This will require specific safety features appropriate to the location.

Some process heat applications do not necessarily need to be sited close to populated areas. For example, hydrogen production could either be concentrated in remote industrial centres, with the product transported as needed, or with electricity transmitted to low temperature electrolysers close to the demand.

#### *6.1.2.8. Competitive market with growing supply options*

The market for industrial heat is highly competitive. Heat is produced predominantly from fossil fuels, with which nuclear energy will have to compete.

### 6.1.3. Market potential for nuclear penetration

As with district heating, a low assessment of the market for process heat can be based on the amount of heat that is currently supplied (i.e. sold as a product) to industrial customers by heat producers. Such data are available in the IEA statistics. This estimate is, however, a low one, as it does not include the heat produced by the

TABLE 28. RELIABILITY REQUIREMENTS OF HEAT SUPPLY AS IDENTIFIED BY AN OAK RIDGE NATIONAL LABORATORY SURVEY [71]

| Industry | Average adequate steam supply availability (%) |
|---|---|
| Chemical processing | 98 |
| Oil refineries | 92 |
| Primary metals | 100 |

industries themselves. As illustrated in Fig. 10, this share can be significant[29] — industries with a high energy demand tend to self-generate their energy. This estimate, however, has the advantage of showing a rather definite potential for nuclear penetration into the market, because a nuclear source may be able to supply heat using the same heat transportation routes that are currently used by non-nuclear heat producers.

To reflect the self-generation of internal heat, the high estimate includes all energy that is reported as consumed by the industries, with the exception of electricity purchased by the industries from power generators. This estimate is considered high, because there are uses of this energy other than heat generation. In particular, in the USA about 50% of the consumed final energy is used as boiler fuel to generate electricity, heat or both simultaneously through cogeneration. The upper estimate thus defined may therefore exceed the actual use of heat by up to 50%.

Table 29 shows the two estimates of the market potential for the major world regions. A more detailed country by country breakdown is given in Appendix VIII.

Table 29 indicates that there is a huge market for the supply of process heat, of the same order of magnitude as that for district heating. (The amount of energy is roughly the same, but the assessed number of reactors is lower, owing to the assumed higher load factor.) Therefore, similarly to district heating, market size does not matter for nuclear penetration; the main question is whether nuclear technologies can prove to be competitive.

## 6.2. POTENTIAL NUCLEAR SOLUTIONS

There are no technological impediments to extracting heat/steam from a nuclear plant. Thus all existing and prospective reactor types can be used, supported if necessary by conventional heating. Cogeneration can also be used widely in order to provide electricity for local needs. Advanced nuclear systems could be optimized by using various coupling schemes aimed at improving overall efficiency.

At the same time, the applicability to a specific purpose will be determined by the required temperature level, depending on the specific industrial process. Figure 16 shows the correspondence between the temperatures provided by nuclear reactors and the temperatures required by heat consuming industries.

Figure 16 shows that while all reactor types have potential applications, only one concept can cover most of the range of industrial requirements — an HTGR. HTGRs could therefore be the pre-eminent candidates for the supply of industrial heat for the following reasons:

---

[29] Note the large share of energy used as boiler fuel (46%).

TABLE 29. ESTIMATE OF MARKET POTENTIAL FOR PROCESS HEAT
*(based on 1996 data [34, 35])*

| Region | Low estimate | | | High estimate | | |
|---|---|---|---|---|---|---|
| | Heat supply (Mtoe) | Heat production capacity (MW(th))[a] | Number of 100 MW(th) reactors needed[b] | Heat supply (Mtoe) | Heat production capacity (MW(th)) | Number of 100 MW(th) reactors needed |
| NAM | 5.8 | ~9 100 | ~90 | 316.9 | ~500 000 | ~5 000 |
| LAM | 0.0 | 0 | 0 | 131.9 | ~210 000 | ~2 100 |
| AFR | 0.0 | 0 | 0 | 31.0 | ~50 000 | ~500 |
| MEA | 0.0 | 0 | 0 | 70.4 | ~110 000 | ~1 100 |
| WEU | 5.0 | ~7 900 | ~80 | 246.2 | ~390 000 | ~3 900 |
| EEU | 9.0 | ~14 000 | ~140 | 70.1 | ~110 000 | ~1 100 |
| FSU | 107.8 | ~170 000 | ~1 700 | 214.2 | ~340 000 | ~3 400 |
| CPA | 21.3 | ~34 000 | ~340 | 397.4 | ~630 000 | ~6 300 |
| SAS | 0.0 | 0 | 0 | 114.8 | ~180 000 | ~1 800 |
| PAS | 1.2 | ~1 900 | ~20 | 114.2 | ~180 000 | ~1 800 |
| PAO | 0.0 | 0 | 0 | 119.9 | ~190 000 | ~1 900 |
| Total | 150.1 | ~240 000 | ~2 400 | 1 827.1 | ~2 900 000 | ~29 000 |

[a] The capacity is calculated assuming a 90% average load factor and excluding heat losses. Under these assumptions the heat production capacity needed to produce 1 Mtoe of heat is: 1 [Mtoe] × 1419 [MW·year/Mtoe]/0.9 [year] = 1577 MW(th).

[b] The number of reactors needed is calculated assuming a 90% average load factor and disregarding heat losses. Under these assumptions the energy output of a 100 MW(th) reactor is: 100 × 0.9 [MW(th)·year] = 90 × 8760 [MW·h] = 788 GW·h ≈ 2.84 PJ ≈ 0.063 Mtoe.

- Their ability to offer a wide range of temperatures;
- Their ability to provide high temperature heat (up to 1000°C) and steam (up to 530°C);
- The possibility of a modular design, with modules of 100–300 MW(th);
- The variable ratio of electricity to steam production.

HTGR technology has not yet achieved commercial maturity, and hence there accordingly are no tested process heat applications. However, there is experience with five operating plants that is supported by comprehensive experimental and theoretical programmes in China, Germany, Japan, the Russian Federation, the UK and the USA [43, 72, 73]. Process heat utilization for steam reforming and for coal gasification has been tested in Germany at the pilot plant scale under nuclear conditions. The Japanese HTTR, which has been critical since 1998, is expected to be the first NPP utilizing process heat for hydrogen production.

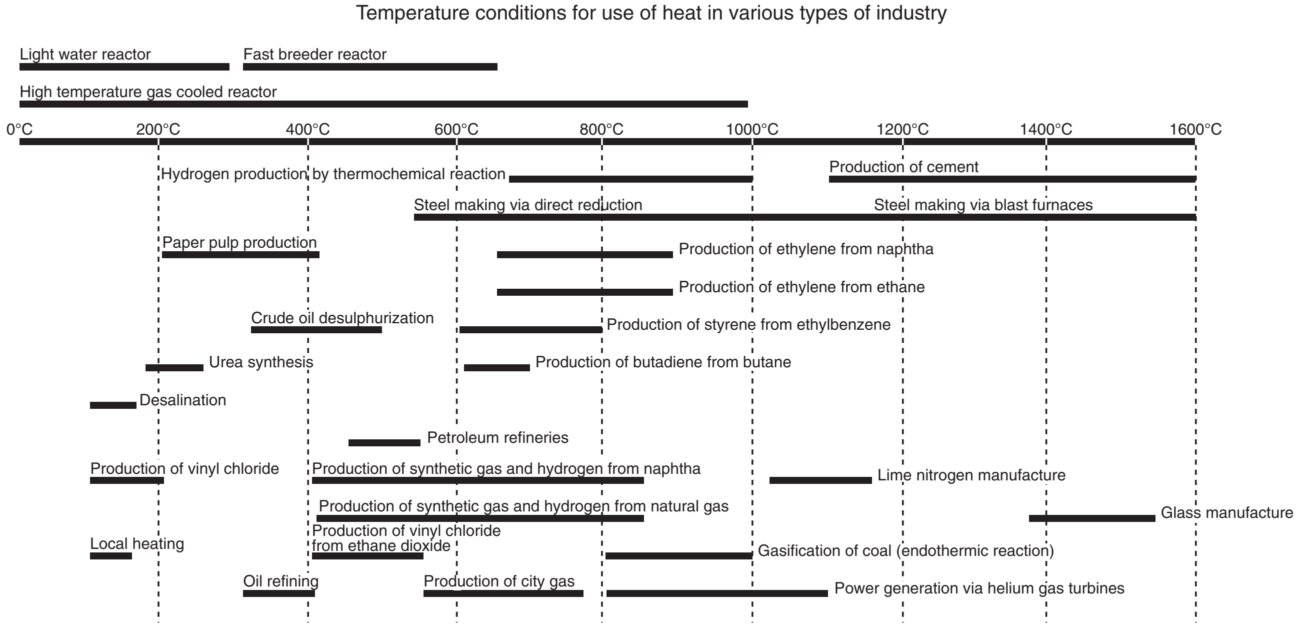

*FIG. 16. Applicability of nuclear reactors for process heat applications in terms of temperature ranges (this figure is taken from the JAERI's Internet site and reproduced here with its permission).*

## 6.3. ECONOMIC COMPETITIVENESS

With respect to economic competitiveness, many of the features described above for electricity generated by nuclear energy (Section 2.4), for nuclear district heating (Section 4.3) and desalination (Section 5.3) are valid for process heat applications.

There are also several important specific considerations for process heat applications, which include:

- The ability to locate close to the demand.
- The relatively small scale demand.
- The need for very high reliability, which could be enhanced by partitioning the load between smaller units. This could avoid the expense of a non-nuclear backup heat source.

The economics of nuclear energy for non-electric applications will therefore be improved by the development of small, low cost reactors and especially of small, high temperature reactors. Current development trends in many countries have already begun to move in this direction.

Cogeneration plants (both nuclear or fossil fuel) that operate with the relatively low temperature conditions that can be supplied by existing water cooled reactor designs derive much of their revenue from electricity. This poses considerable challenges for the nuclear option, which are similar to those for district heating (see Section 5.3):

- Existing reactor types usually produce 500 to 1500 MW of electricity plus about twice as much heat. To provide that heat at higher temperatures, some electricity production must be sacrificed, further increasing the proportion of the energy produced as heat. Industrial demands for heat on this scale are fairly rare.
- Economies of scale can be applied easily to the generation of electricity, since it is easily distributable. This is not the case for process heat.
- Economies of scale for existing reactor types are very significant (see Table 9) and are much more significant than those for fossil fuels, for which the cost of fuel dominates.

While high temperature reactors share some of the above challenges, their revenues are likely to depend much more on the value of the process heat. What is distinctly different, though, is that the HTGR concept, which is for a relatively small scale reactor, is the prime candidate for process heat applications. This section therefore concentrates on the comparative economics of HTGR reactors.

Of the studies available, the analysis conducted in Ref. [68] is selected here as most fitting into the context of this review, in particular because of the presentation of cost ranges rather than of a one number assessment. The results of this analysis are given in Table 30.

Table 30 demonstrates that a first of its kind HTGR is unlikely to be competitive with the alternative fossil fuel options, with the exception of the untypical case of a boiler using highly expensive German coal. However, the heat production cost difference is in the range of 10%, which should normally be acceptable for a prototype.

Series production HTGRs provide cost savings of some 20% as compared with their prototype. Accordingly, the nuclear option becomes competitive in general; that is, the cost of the nuclear option is within the typical cost range of the fossil fuel options. Depending on whether the fossil fuel cost is closer to the higher or lower end of the range, HTGRs become more or less competitive.

## 6.4. CURRENT AND PROSPECTIVE MARKET

### 6.4.1. Current use of nuclear energy

Table 31 summarizes the global experience with process heat applications, and shows that nuclear process heat applications are rare.

### 6.4.2. Prospects for nuclear energy in the near term (2000–2020)

In the near term the main objective is to demonstrate the feasibility of the nuclear designs most applicable to the supply of process heat, in particular the concept of HTGRs. Table 32 shows the status of ongoing HTGR projects.

Japan’s 30 MW(th) HTTR, which started power increase tests in 1999 [9, 10], will be an important milestone in HTGR development. The operation of the HTTR is expected to test the reactor concept and its applicability to the supply of process heat.

The development of the 114 MW(e) PBMR in South Africa [13, 14], which could become the first commercially available HTGR reactor, should in particular be noted. Although the reactor is intended primarily for electricity generation, its concept is such that it could also be applied to the supply of heat. The implementation of the PBMR project would provide an additional opportunity for process heat applications.

### 6.4.3. Prospects for nuclear energy in the long term (2020–2050)

The estimate of the prospects for nuclear energy in the long term follows that of the other applications. The main ranking principles for process heat applications are:

TABLE 30. ESTIMATE OF THE COMPETITIVENESS OF HTGRs [68]

| Plant type | Plant size (MW(th)) | Base construction cost (with interest during construction) (US $ (1997)/kW(th))[a] | Heat production cost[b] (US cents (1997)/ (tonne of steam)) | Cost ratio A[c] | | Cost ratio B[d] | |
|---|---|---|---|---|---|---|---|
| | | | | Best for nuclear[e] | Worst for nuclear[f] | Best for nuclear | Worst for nuclear |
| *Nuclear plants* | | | | | | | |
| 200 MW HTGR (first of its kind) | 2 × 200 | 2160 | 12.2 | 1.00 | | 0.84 | |
| 200 MW HTGR | 2 × 200 | 1780 | 10.3 | 1.19 | | 1.00 | |
| *Fossil fuel plants* | | | | | | | |
| Heavy oil boiler | 400 | 490 | 9.9–11.4 | 1.07 | 1.23 | 0.90 | 1.03 |
| Gas boiler | 400 | 450 | 8.7–11.7 | 1.04 | 1.41 | 0.88 | 1.19 |
| Coal boiler with domestic (German) coal | 400 | 910 | 15.7 | 0.78 | | 0.65 | |
| Coal boiler with imported coal | 400 | 910 | 10.4–12.1 | 1.01 | 1.18 | 0.85 | 0.99 |

**Note:** The following assumption for the costs of fossil fuels were used in Ref. [68]:

— Heavy oil: 200–250 DM/t = 170–210 US $/t = 4.1–5.1 US $/GJ (a 2.0% real price growth was also assumed).
— Natural gas: 200–300 DM/1000 $m^3$ = 170–250 US $/1000 $m^3$= 5.4–7.8 US $/GJ (a 2.0% real price growth was also assumed).
— Domestic (German) coal: 300 DM/t = 250 US $/t = 8.5 US $/GJ (a 0.5% real price growth was also assumed).
— Imported coal: 95–130 DM/t = 80–110 US $/t = 2.7–3.7 US $/GJ (a 2.5% real price growth was also assumed).

[a] The recalculation from the German currency (DM of 1989) in Ref. [68] to US $ (1997) was carried out using gross domestic product deflators from Ref. [74]; that is, the conversion is done as cost [US $ (1997)] = cost [DM (1989)] × 1.273/1.5 = cost [DM (1989)] × 0.849, where 1.273 is the DM escalation factor from 1 January 1989 to 1 January 1997 and 1.5 is the assumed exchange rate of the DM against the US $ (1.5 is the average for 1996).

[b] The costs are levelized production costs calculated using the discount rate of 7.5%; the shown ranges for fossil fuel boilers reflect the assumed range of fuel prices.

[c] Cost ratio A: first of the kind nuclear vs. others (nuclear cost divided by the cost of other options).

[d] Cost ratio B: series nuclear vs. others (nuclear cost divided by the cost of other options).

[e] The case with the lowest (i.e. most favourable for nuclear) ratio obtained by using the high value for the fossil fuel price.

[f] The case with the highest (i.e. least favourable for nuclear) ratio obtained by using the low value for the fossil fuel price.

TABLE 31. EXPERIENCE WITH NUCLEAR PROCESS HEAT APPLICATIONS [43]

| Country | Unit name | Location | Start of operation | Status | Total power (MW(e) net) | Heat delivery (MW(th)) |
|---|---|---|---|---|---|---|
| Canada | Bruce 1 | Bruce | 1977 | Suspended in 1997 | 848 | 420[a] |
| Canada | Bruce 2 | Bruce | 1977 | Suspended in 1995 | 848 | |
| Canada | Bruce 3 | Bruce | 1978 | Suspended in 1998 | 848 | |
| Canada | Bruce 4 | Bruce | 1979 | Suspended in 1998 | 848 | |
| Germany | Stade | Stade | 1972 | Commercial operation | 640 | 30 |
| Russian Federation | Belojarsk 3 (BN-600) | Zarechny | 1981 | Commercial operation | 560 | 36 |
| Russian Federation | Kola 1 | Polyarnie Zory | 1973 | Commercial operation | 411 | 3.6 |
| Russian Federation | Kola 2 | Polyarnie Zory | 1975 | Commercial operation | 411 | 3.6 |
| Russian Federation | Kola 3 | Polyarnie Zory | 1982 | Commercial operation | 411 | 3.6 |
| Russian Federation | Kola 4 | Polyarnie Zory | 1984 | Commercial operation | 411 | 3.6 |
| Russian Federation | Kursk 1 | Kurchatov | 1977 | Commercial operation | 925 | 13.9 |
| Russian Federation | Kursk 2 | Kurchatov | 1979 | Commercial operation | 925 | 13.9 |
| Russian Federation | Kursk 3 | Kurchatov | 1984 | Commercial operation | 925 | 13.9 |
| Russian Federation | Kursk 4 | Kurchatov | 1986 | Commercial operation | 925 | 13.9 |
| Russian Federation | Leningrad 1 | Sosnovy Bor | 1974 | Commercial operation | 925 | 16 |
| Russian Federation | Leningrad 2 | Sosnovy Bor | 1976 | Commercial operation | 925 | 16 |
| Russian Federation | Leningrad 3 | Sosnovy Bor | 1980 | Commercial operation | 925 | 16 |
| Russian Federation | Leningrad 4 | Sosnovy Bor | 1981 | Commercial operation | 925 | 16 |

TABLE 31. (cont.)

| Country | Unit name | Location | Start of operation | Status | Total power (MW(e) net) | Heat delivery (MW(th)) |
|---|---|---|---|---|---|---|
| Russian Federation | Novovoronezh 3 | Novovoronezh | 1972 | Commercial operation | 385 | 25 |
| Russian Federation | Novovoronezh 4 | Novovoronezh | 1973 | Commercial operation | 385 | 25 |
| Russian Federation | Novovoronezh 5 | Novovoronezh | 1981 | Commercial operation | 950 | 15 |
| Russian Federation | Smolensk 1 | Desnogorsk | 1983 | Commercial operation | 925 | 16 |
| Russian Federation | Smolensk 2 | Desnogorsk | 1985 | Commercial operation | 925 | 16 |
| Russian Federation | Smolensk 3 | Desnogorsk | 1990 | Commercial operation | 925 | 16 |
| Switzerland | Goesgen | Goesgen | 1979 | Commercial operation | 970 | 25 |

**Note:** The data from Ref. [43] have been complemented with the latest statistics from an IAEA database. Information on NPPs in Ukraine is absent because of the unavailability of the latest data.

[a] The heat came from any of the four Bruce A reactors.

TABLE 32. ONGOING NUCLEAR PROJECTS FOR THE SUPPLY OF PROCESS HEAT [43]

| Country | Location | Plant/unit name | Status | Heat output (MW(th)) |
|---|---|---|---|---|
| China | Beijing | HTR-10 | Reached criticality in 2000 | 10 |
| Japan | Oarai | HTTR | Startup tests started in 1999; full power planned for 2001 | 30 |
| France, Japan, Russian Federation, USA | — | GT-MHR | Design | 600 |
| South Africa | — | PBMR | Design | 268 |

— The indicator of market structure is assigned 0 for those countries in which the share of heat intensive industries in the total industrial heat demand is less than 10%; countries with the share equal to or exceeding 50% are assigned 2 (for comparison, the world average of this parameter is 54%); all other countries are assigned 1; 1998 data on the structure of heat demand taken from Ref. [67] are used.

— The indicator of demand pressure is assigned 2 for those countries in which the average rate of industrial growth (taken from Ref. [75]) in the latest 10 years is higher than 5%; for countries with industrial growth between 1 and 5% 1 is assigned; for all others, that is with industrial growth below 1%, 0 is assigned[30].

— The other three indicators — technical basis, economic competitiveness and public acceptance — are defined as for district heating (see Section 4.4.3).

The total final energy demand is used for weighting. The result of the estimate is summarized in Table 33 for the 11 world regions. The underlying country by country estimates can be found in Appendix IX.

The results in Table 33 show the following:

— The prospects for nuclear process heating appear low in LAM, MEA and AFR, mainly because of the unfavourable market structure (i.e. there is no significant use of centralized heat supply for industry) and the lack of a technical basis; they are also low for WEU and PAO because of slow demand growth and reserved public attitudes.

— For the rest of the world the prospects are ranked as either medium or high (in CPA); this is more favourable than for district heating, mainly because there are more opportunities for the combination of demand growth, the applicability of the market structure and the availability of a technical basis.

— The high prospects for the CPA region are explained by the expected growth of industrial demand in China combined with the availability of nuclear technologies and a positive public attitude.

The most promising countries in each region are shown in Table 34. These results are similar to those for district heating. However, there are notable differences,

---

[30] It would have been more logical to base the indicator of demand pressure on the projected growth rates instead of the actual rates for the past decade. Unfortunately, credible estimates for countries in terms of projected long term industrial growth were not found.

TABLE 33. LONG TERM (2020–2050) PROSPECTS FOR NUCLEAR PENETRATION IN PROCESS HEAT SUPPLY

| Region | Indicator | | | | | Total |
|---|---|---|---|---|---|---|
| | Market structure | Demand pressure | Technical basis | Economic competitiveness | Public attitude | |
| NAM | 2.00 | 1.00 | 2.00 | 1.00 | 1.00 | 1.40<br>(medium) |
| LAM | 0.00 | 1.03 | 1.55 | 0.00 | 0.84 | 0.68<br>(low) |
| AFR | 0.00 | 0.68 | 0.52 | 0.65 | 0.52 | 0.47<br>(negligible) |
| MEA | 0.00 | 0.69 | 0.48 | 0.69 | 0.78 | 0.53<br>(negligible) |
| WEU | 0.50 | 0.19 | 1.73 | 1.00 | 0.73 | 0.83<br>(low) |
| EEU | 1.49 | 0.52 | 1.56 | 1.00 | 0.94 | 1.10<br>(medium) |
| FSU | 1.46 | 0.00 | 1.77 | 0.92 | 0.90 | 1.01<br>(medium) |
| CPA | 1.87 | 1.94 | 1.93 | 0.99 | 1.91 | 1.73<br>(high) |
| SAS | 0.00 | 2.00 | 1.84 | 0.99 | 1.84 | 1.33<br>(medium) |
| PAS | 0.00 | 1.70 | 1.31 | 0.98 | 1.19 | 1.03<br>(medium) |
| PAO | 0.00 | 0.19 | 1.62 | 1.00 | 0.81 | 0.72<br>(low) |
| Total | 1.02 | 0.91 | 1.70 | 0.90 | 1.09 | 1.12<br>(medium) |

in particular the medium rating for many countries in WEU, notwithstanding the overall low rating for the region. This is largely because of the relatively high share of heat intensive industries in these countries and a sufficient technical basis.

TABLE 34. COUNTRIES WITH THE HIGHEST PROSPECTS FOR NUCLEAR PENETRATION IN PROCESS HEAT SUPPLY

| Region/ country | Indicator | | | | | Total |
|---|---|---|---|---|---|---|
| | Market structure | Demand pressure | Technical basis | Economic competitiveness | Public attitude | |
| *NAM* | | | | | | |
| Canada | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| USA | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| *AFR* | | | | | | |
| South Africa | 0 | 0 | 2 | 1 | 2 | 1.0 (medium) |
| *WEU* | | | | | | |
| Austria | 2 | 1 | 1 | 1 | 0 | 1.0 (medium) |
| Belgium | 1 | 0 | 2 | 1 | 1 | 1.0 (medium) |
| Denmark | 2 | 1 | 1 | 1 | 0 | 1.0 (medium) |
| Finland | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| France | 0 | 0 | 2 | 1 | 2 | 1.0 (medium) |
| Netherlands | 0 | 1 | 2 | 1 | 1 | 1.0 (medium) |
| Norway | 2 | 2 | 1 | 1 | 1 | 1.4 (medium) |
| Portugal | 2 | 0 | 1 | 1 | 1 | 1.0 (medium) |
| Spain | 1 | 0 | 2 | 1 | 1 | 1.0 (medium) |
| Switzerland | 2 | 0 | 2 | 1 | 1 | 1.2 (medium) |
| *EEU* | | | | | | |
| Bulgaria | 2 | 0 | 2 | 1 | 1 | 1.2 (medium) |
| Hungary | 2 | 0 | 2 | 1 | 1 | 1.2 (medium) |
| Poland | 2 | 1 | 1 | 1 | 1 | 1.2 (medium) |
| Romania | 2 | 0 | 2 | 1 | 1 | 1.2 (medium) |
| *FSU* | | | | | | |
| Belarus | 2 | 0 | 1 | 1 | 1 | 1.0 (medium) |
| Lithuania | 2 | 0 | 2 | 1 | 1 | 1.2 (medium) |
| Russian Federation | 2 | 0 | 2 | 1 | 1 | 1.2 (medium) |
| *CPA* | | | | | | |
| China | 2 | 2 | 2 | 1 | 2 | 1.8 (high) |
| Viet Nam | 0 | 2 | 1 | 1 | 1 | 1.0 (medium) |
| *SAS* | | | | | | |
| India | 0 | 2 | 2 | 1 | 2 | 1.4 (medium) |
| Pakistan | 0 | 2 | 2 | 1 | 2 | 1.4 (medium) |
| *PAS* | | | | | | |
| Indonesia | 0 | 2 | 1 | 1 | 1 | 1.0 (medium) |
| Korea, Republic of | 0 | 2 | 2 | 1 | 2 | 1.4 (medium) |
| Thailand | 0 | 2 | 1 | 1 | 1 | 1.0 (medium) |

# 7. SHIP PROPULSION

## 7.1. MARKET CHARACTERIZATION

### 7.1.1. Market size

The supply of energy for transportation is an important part of the total energy market. The transportation sector's global share of total final energy is 25% [3]. However, nuclear technologies are presently applicable only to a small segment of this market — international and national seaborne transportation. The global size of this segment is relatively small, about 10% of the energy demand for transportation (see Fig. 17).

However, the estimate of importance based on the share of energy may in this case be misleading, as the economic importance of the service is more adequately reflected by the amount and value of the goods transported than by the amount of energy consumed during its transportation[31]. Moreover, the transportation market varies in its importance in different regions, so the regional specifics must be an important consideration in a market analysis.

It would therefore be more appropriate to characterize the size of the market and expected trends by, for example, the amount of transported goods in tonne-miles

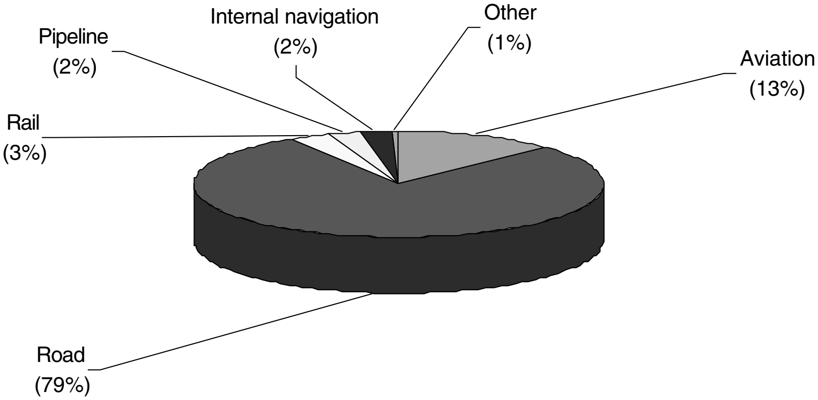

*FIG. 17. Breakdown of the world's transportation energy by use in 1996 [67].*

---

[31] This does not apply to icebreakers. They represent an important but small and very specific part of the world ship fleet.

(to characterize the expected trends in demand) and by fleet capacity (to characterize the supply side). The development trends of these two characteristics over the past ten years are shown in Figs 18 and 19. In addition, the current structure of the world fleet, broken down by world regions, is given in Table 35; relevant country by country data can be found in Appendix X.

Figures 18 and 19 show seaborne transportation growing in importance. They also indicate that two services, the transportation of oil and oil derivatives and the transportation of grain, coal and iron ore, account for a major portion of the market; the use of nuclear powered ships can therefore be considered for these services.

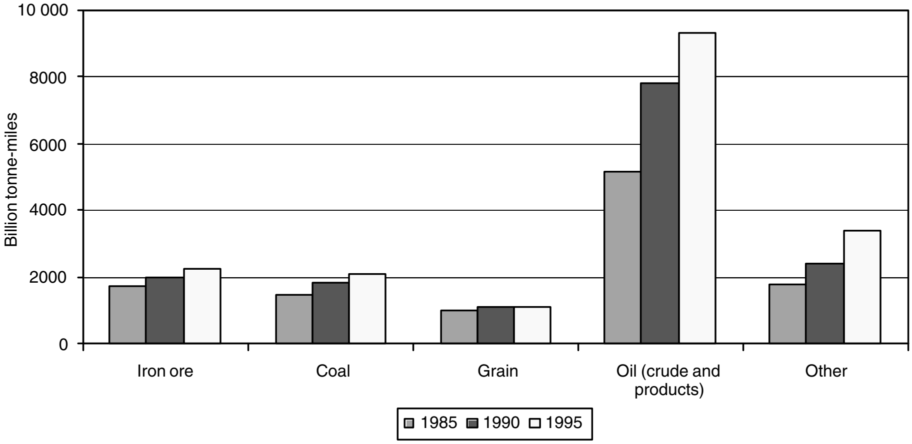

*FIG. 18. World seaborne trade of main bulk commodities in billion tonne-miles [76].*

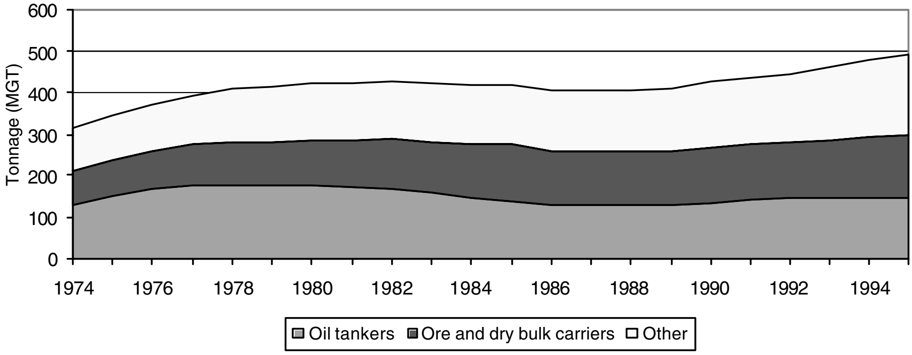

*FIG. 19. Development of the world ship fleet 1974–1995 [76].*

TABLE 35. CHARACTERIZATION OF THE WORLD SHIP FLEET
*(1995 data [76] in millions of gross tonnes (MGT))*

| Region | Oil tankers | Other ships[a] | Total |
|---|---|---|---|
| NAM | 10.9 | 4.3 | 15.2 |
| LAM | 103.9 | 11.5 | 115.4 |
| AFR | 53.0 | 6.8 | 59.8 |
| MEA | 6.3 | 1.1 | 7.4 |
| WEU | 119.8 | 22.5 | 142.3 |
| EEU | 5.4 | 0.8 | 6.2 |
| FSU | 14.2 | 7.7 | 21.9 |
| CPA | 24.4 | 1.4 | 25.7 |
| SAS | 6.4 | 0.7 | 7.1 |
| PAS | 43.9 | 4.3 | 48.2 |
| PAO | 17.1 | 6.0 | 23.1 |
| Not specified by region | 13.6 | 4.8 | 18.3 |
| Total | 418.8 | 71.7 | 490.6 |

[a] For example passenger ships and icebreakers.

In addition to fleet capacity, it is important to identify the main routes of transportation. Tables 36 and 37, respectively, show the main routes for two important types of transported goods: all goods transported by combined and bulk carriers and the transportation of oil and oil products.

### 7.1.2. Market features

The following features characterize the market for ship propulsion.

#### *7.1.2.1. Typical size*

As for other nuclear installations, the effect of scale is important for nuclear powered ships. It can be expected that nuclear propulsion would be most feasible for relatively large ships, with a size of 10 000 to 100 000 GT.

#### *7.1.2.2. Transportation mode and reliability*

The usual transportation requirements are valid for the transportation of goods and passengers. All-year round transportation is typically needed, with the important exception of deliveries into areas in which access has seasonal variations (e.g. the

## TABLE 36. INTERREGIONAL TRANSPORTATION OF GOODS BY COMBINED AND BULK CARRIERS

*(1994 data [76] in thousands of tonnes)*

| From | To | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | UK/NW Europe[a] | Mediterranean | Other Europe | Africa | North America | South America | Asia | Australia | Total |
| UK/NW Europe | 1 120 | 410 | 930 | 3 140 | 690 | 250 | 6 270 | 110 | 12 920 |
| Mediterranean | 1 350 | 620 | 310 | 300 | 90 | — | 1 930 | 50 | 4 650 |
| Other Europe | 16 230 | 1 760 | 3 160 | 1 370 | 2 500 | 50 | 8 830 | 1 230 | 35 130 |
| Africa | 22 210 | 10 890 | 19 520 | 3 850 | 2 220 | 9 620 | 22 190 | 580 | 91 080 |
| North America | 45 530 | 15 610 | 17 250 | 9 980 | 9 210 | 50 970 | 50 990 | 8 710 | 208 250 |
| South America | 65 780 | 16 600 | 13 050 | 19 060 | 2 240 | 33 360 | 40 700 | 9 300 | 200 090 |
| Asia | 8 120 | 3 170 | 1 910 | 2 680 | 1 240 | 26 540 | 28 660 | 350 | 72 670 |
| Australia | 33 330 | 7 890 | 7 150 | 3 080 | 4 660 | 116 650 | 71 010 | 5 950 | 249 720 |
| Total | 193 670 | 56 950 | 63 280 | 43 460 | 22 850 | 237 440 | 230 530 | 26 280 | 874 510 |

[a] NW Europe: northwest mainland Europe.

TABLE 37. INTERREGIONAL TRANSPORTATION OF OIL AND OIL PRODUCTS
*(1994 data [76] in thousands of tonnes)*

| From | To | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | USA | Canada | Mexico | South and Central America | OECD Europe | Africa | Austral-asia | China | Japan | Asia | Others | Total |
| USA | — | 4.0 | 5.9 | 12.3 | 8.5 | — | 1.1 | 0.7 | 1.4 | 7.7 | 3.7 | 45.3 |
| Canada | 60.7 | — | — | 0.1 | 0.2 | — | — | — | — | 0.3 | 4.0 | 65.3 |
| Mexico | 49.0 | 1.0 | — | 5.2 | 10.1 | — | — | — | 4.4 | — | 0.9 | 70.6 |
| South and Central America | 107.8 | 3.7 | 2.6 | — | 12.8 | 1.1 | — | — | 0.5 | 3.7 | — | 132.2 |
| OECD Europe | 41.9 | 17.5 | — | 4.0 | — | 7.0 | — | 0.2 | 0.1 | 5.8 | 12.3 | 88.8 |
| FSU | 1.5 | 0.1 | — | 2.7 | 81.6 | 0.4 | — | 1.4 | 0.4 | 4.4 | 32.3 | 124.8 |
| Non-OECD Europe | 0.2 | — | — | — | 4.9 | — | — | 0.1 | — | 0.2 | 0.8 | 6.2 |
| Middle East | 90.2 | 5.6 | — | 31.8 | 188.6 | 29.8 | 10.8 | 5.4 | 205.7 | 230.7 | 19.6 | 818.2 |
| North Africa | 14.3 | 1.4 | — | 1.5 | 97.3 | 3.5 | — | — | 0.9 | 3.9 | 8.0 | 130.8 |
| West Africa | 60.6 | 3.6 | — | 12.9 | 50.3 | 0.5 | — | 0.5 | 1.0 | 3.6 | 0.1 | 133.1 |
| East and South Africa | — | — | — | — | — | — | — | — | — | 0.2 | — | 0.2 |
| Australasia | 0.9 | — | — | — | — | — | — | 0.1 | 4.1 | 7.0 | — | 12.1 |
| China | 3.3 | — | — | — | — | — | — | — | 12.7 | 6.0 | 0.4 | 22.4 |
| Japan | — | — | — | — | — | — | — | 0.7 | — | 5.9 | — | 6.6 |
| South Asia | 0.1 | — | — | — | 0.1 | — | — | 0.2 | 1.1 | 0.4 | — | 1.9 |
| Other Asia | 8.9 | 0.1 | — | — | 1.9 | 0.2 | 8.7 | 17.4 | 45.3 | 4.7 | — | 87.2 |
| Others | 1.5 | 0.6 | — | — | 30.3 | — | 0.9 | — | — | 0.6 | — | 33.9 |
| Total | 440.9 | 37.6 | 8.5 | 70.5 | 486.6 | 42.5 | 21.5 | 26.7 | 277.6 | 285.1 | 82.1 | 1 779.6 |

north of the Russian Federation). For icebreaking, however, ships are used only during the required navigation period. High reliability is required in both cases, as the costs of delays may be high.

#### *7.1.2.3. Impact of specific nuclear considerations*

The specifics of nuclear powered ships have important implications. Two factors should be noted in particular. Firstly, a reactor for ships is a nuclear object in which all pertinent nuclear safety standards must be ensured [77]. Secondly, a strict set of requirements must be complied with in every port that intends to receive nuclear powered ships [77]. The second factor is a highly significant one, as it imposes constraints on port infrastructure.

#### *7.1.2.4. Market competitiveness*

Nuclear powered cargo ships are not considered competitive at present, both for economic and non-economic reasons. The several nuclear powered cargo ships built and tested have already been decommissioned, primarily for economic reasons, as petroleum derivatives are cheap enough to make competition with them in this specific area very difficult. Moreover, the market is known to be very competitive, even without the consideration of nuclear energy. Increasing ship sizes, fleet overcapacity and the possibility of using flags of convenience create incentives for keeping prices as low as possible [78]. Therefore, although there are price changes and the prices largely vary between regions and the type of service, there is no visible trend to price growth over time [78].

This is aggravated by the impact of the above mentioned nuclear safety considerations, which put nuclear powered ships at a disadvantage. Nuclear competitiveness is substantially higher for those specific situations in which the principal advantage of nuclear power (i.e. a long operating time without refuelling) is of the highest importance. Such situations occur when there is a need to provide transportation to remote areas, especially those that are difficult to reach because of ice hindered navigation, because both the need for transportation and the need for icebreaking are favourable to using nuclear propulsion. The north of the Russian Federation is a typical example, in which, in addition, there are ports that have nuclear supporting infrastructure and there is sufficient experience in ensuring nuclear safety.

### 7.1.3. Market potential for nuclear penetration

It is reasonable to assume that the market segments mostly applicable to nuclear powered ships would be those for large oil tankers, large cargo ships and icebreakers.

Based on this market characterization, two estimates of the market potential for nuclear powered ships can be made. The low estimate is based on the following assumptions:

- Only the ships in the fleets of the countries that currently use nuclear energy are considered as potentially replaceable by nuclear powered ships (this reflects the need to handle the issues of nuclear safety, which are much easier to comply with in countries that have already done so for NPPs).
- Nuclear powered ships are used only as oil tankers or cargo ships (icebreakers are thus disregarded).
- Only the medium sized part of the total fleet is considered: ships of the size of 10 000 to 40 000 deadweight tonnage (dwt) for oil tankers and 10 000 to 60 000 dwt for cargo ships (this reflects the assumption that larger nuclear powered ships are likely to enter the market only after a successful application of smaller ones).
- The average size of nuclear powered ships is assumed to be 15 000 dwt (close to the parameters of the *Otto Hahn*).

For the upper estimate, the low estimate is expanded as follows:

- All countries are included (note that this assumption may somewhat exaggerate the high assessment; for example, it implies that even small countries offering flags of convenience would be able to operate nuclear powered ships).
- All sizes are included.
- The average size of nuclear powered ships is assumed to be 100 000 t displacement (much larger than any nuclear powered ship constructed to date).
- As before, only oil tankers and cargo ships are considered; the use of icebreakers is not considered because of the lack of data and the highly specific pattern of their use; as the size of this market segment is relatively small, this assumption cannot influence the global estimate significantly.

The results of the estimates (based on country data, as shown in Appendix X) are given in Table 38. These results lead to the obvious conclusion that the market is very large. The potential number of nuclear powered ships would be measured in thousands even for the conservative, low assessment, which is equivalent to nuclear powered ships occupying 7% of the market. Thus considerations other than market saturation would determine the use of nuclear energy in ship propulsion.

## 7.2. POTENTIAL NUCLEAR SOLUTIONS

Technologies for nuclear powered ship propulsion exist; in fact, the application of nuclear energy for military submarines was the first application of nuclear energy:

TABLE 38. ESTIMATE OF THE MARKET POTENTIAL FOR NUCLEAR POWERED SHIP PROPULSION
*(based on 1995 data [76])*

| Region | Total fleet (MGT) | Low estimate: Nuclear share of total market (%) | Low estimate: Market size (tonnage) (× 1000 GT) | Low estimate: Number of nuclear powered ships needed[a] | High estimate: Nuclear share of total market (%) | High estimate: Market size (tonnage) (× 1000 GT) | High estimate: Number of nuclear powered ships needed[b] |
|---|---|---|---|---|---|---|---|
| NAM | 15.2 | 25 | 3 798 | 253 | 72 | 10 879 | 109 |
| LAM | 115.4 | 0 | 0 | 0 | 90 | 103 864 | 1 039 |
| AFR | 59.8 | 0 | 0 | 0 | 89 | 53 043 | 530 |
| MEA | 7.4 | 0 | 0 | 0 | 85 | 6 317 | 63 |
| WEU | 142.3 | 5 | 7 060 | 471 | 84 | 119 824 | 1 198 |
| EEU | 6.2 | 5 | 300 | 20 | 87 | 5 425 | 54 |
| FSU | 21.9 | 25 | 5 449 | 363 | 65 | 14 154 | 142 |
| CPA | 25.7 | 27 | 6 939 | 463 | 95 | 24 373 | 244 |
| SAS | 7.1 | 31 | 2 202 | 147 | 90 | 6 447 | 64 |
| PAS | 48.2 | 11 | 5 480 | 365 | 91 | 43 878 | 439 |
| PAO | 23.1 | 22 | 5 127 | 342 | 74 | 17 083 | 171 |
| Not specified | 18.3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 490.6 | 7 | 36 356 | 2 424 | 83 | 405 288 | 4 053 |

[a] Assuming 15 000 GT nuclear powered ships.

[b] Assuming 100 000 GT nuclear powered ships.

pressurized water reactors are usually used. Table 39 presents the reactor designs known to have been used for ship propulsion in the past.

The use of nuclear icebreakers by the former USSR was the first civil application of nuclear powered ship propulsion. The design of civil nuclear icebreakers started in 1953 based on the technical solutions of naval NPPs [79]. The first nuclear icebreaker, the *Lenin*, which was launched in 1959, operated successfully for 30 years. In total, nine nuclear icebreakers have been built in the former USSR. The last one, the *Ural*, was launched at the end of 1993.

Three other countries have built and operated nuclear powered civil on-surface ships: the USA, Germany and Japan. Their three merchant ships were the *Savannah*, *Otto Hahn* and *Mutsu*, respectively (see Table 40), and were all equipped with PWRs with cluster type elements containing slightly (4.0–4.4%) enriched $UO_2$ fuel and with the containment around the reactor cooling system.

## TABLE 39. NUCLEAR REACTOR DESIGNS FOR SHIP PROPULSION

| | Country/name/type of ship | | | | |
|---|---|---|---|---|---|
| | Russian Federation/ *Lenin*/icebreaker | | USA/ *Savannah*/ cargo and passengers | Germany/ *Otto Hahn*/ ore carrier | Japan/ *Mutsu*/ special cargo |
| | NSS (OK-150) | NSS (OK-900)[a] | | | |
| Year of start of construction | 1956 | | 1958 | 1963 | 1968 |
| Year full power achieved | 1959 | 1970 | 1962 | 1968 | 1990 |
| Year retired | 1966 | 1989 | 1971 | 1979 | 1992 |
| Number of reactors and gross thermal power (MW) | 3 × 90 (2 × 160[a]) | | 1 × 76 | 1 × 38 | 1 × 36 |
| Core diameter (cm) | 100 | 121 | 157.6 | 112 | 114.6 |
| Core height (cm) | 160 | 100 | 167.6 | 115 | 104 |
| Number of fuel elements | 7 704 | 11 253 | 5 248 | 3 128 | 3 584 |
| Power density (kW/l) | 72 | 163 | 23 | 33 | 33.5 |
| Average burnup (MW·d/t U) | 12 000 | — | 7 300 | 7 260 | 5 530 |
| Fuel material | $UO_2$ | U–Zr alloy | $UO_2$ | $UO_2$ | $UO_2$ |
| Number of coolant loops | 2 | 4 | 2 | 3 | 2 |
| Reactor pressure (bar) | 200 | 130 | 123 | 63.5 | 110 |
| Coolant temperature (entry/exit) (°C) | 248/325 | 272/318 | 257/271 | 267/278 | 271/285 |

[a] Following modernization of the nuclear steam supply system.

## TABLE 40. PARAMETERS OF CIVILIAN NUCLEAR POWERED SHIPS

| | Country/name/type of ship | | | |
|---|---|---|---|---|
| | Russian Federation/ *Lenin*/icebreaker | USA/*Savannah*/ cargo and passagers | Germany/ *Otto Hahn*/ ore carrier | Japan/*Mutsu*/ special cargo |
| Length (m) | 134 | 182 | 172 | 130 |
| Width (m) | 27.6 | 23.8 | 23.4 | 19.0 |
| Cargo (t) | 16 000 | 9 400 | 14 000 | 2 400 |
| Gross tonnage | — | 15 600 | 16 900 | 8 200 |
| Service speed (knots[a]) | 18 | 20 | 16 | 16.5 |
| Shaft horsepower | 44 000 | 22 000 | 10 000 | 10 000 |

[a] 1 knot = 1 nautical mile per hour (1.852 km/h).

These ships demonstrated the technical feasibility of nuclear powered ship propulsion. For example, the *Otto Hahn* operated for about 11 years and fulfilled all expectations with respect to safety and reliability. The ship conducted 58 research trips and 73 cargo trips, with a total distance covered of over 1 million km. The total fuel consumption was 64 kg of $^{235}$U. In the period of operation, 153 reactor scrams occurred, of which 83 happened in the startup phase. Two fuel reloads were implemented: one in 1972–1973 and one in 1979 [80].

### 7.3. ECONOMIC COMPETITIVENESS

For nuclear powered ship propulsion to occupy a noticeable place in the market, economic competitiveness must be ensured. Although it is not necessary that the first, pioneering designs be competitive, a clear indication of economic advantages in the foreseeable future must be present. In this respect the experience with nuclear powered ships has not been good. Three cargo ships have been tested, which demonstrated the technical feasibility of nuclear powered ship propulsion successfully. However, they also demonstrated that their operation was not considered economic. It is notable that the German and Japanese ships were decommissioned after the period of the oil crises, so even the increased fuel costs of conventional ships did not help to make nuclear powered ships economically attractive.

For example, the *Otto Hahn* provided a high availability (350 000 miles (563 000 km) with its first load and more than 600 000 miles (965 000 km) in total). However, the earnings per cargo were about 2 million DM/a, while the operating costs amounted to 10 million DM/a [81].

A large part of the economic losses could be attributed to the pilot status of these projects. For the *Savannah* it is estimated that while the whole subsidy for the ship was slightly above US $2 million, some US $1.9 million should be attributed to her first of the kind status. For comparison, the oil crises in 1973 and 1979 caused similar (of the order of US $2 million) increases in the annual costs of running an oil powered ship of a similar size. Nevertheless, the potential economic advantages of nuclear powered ships were not proved.

In the future it will be necessary to conduct a study of economic competitiveness for every new nuclear propulsion project under consideration. No such recent studies applicable to this review have been found, but it is interesting to quote the results of an analysis prepared in the 1960s, when the future of nuclear powered ship propulsion looked very promising [82]. The study was aimed at the determination of cost targets for nuclear powered ships. It concluded, contrary to several more optimistic assessments at the time, that “attainable costs of nuclear fuel and machinery do not appear to be low enough to make nuclear propulsion... commercially competitive in merchant ships within the foreseeable future”. It was estimated that to achieve competitiveness the costs of nuclear equipment should be not more than 25 to 50% higher than for conventional equipment. If this could not be achieved with existing reactor concepts, new concepts should be looked for. As noted, the study is old, but the subsequent history confirmed its conclusions — and they may still hold.

The use of liquid hydrogen derived from nuclear power by electrolysis can be envisaged as an alternative to direct nuclear propulsion.

## 7.4. CURRENT AND PROSPECTIVE MARKET

### 7.4.1. Current use of nuclear energy

As noted, there is experience with the use of nuclear powered ships in two civil applications: icebreakers and cargo ships. Four countries have implemented such programmes: Germany, Japan, the Russian Federation and the USA. Russian nuclear icebreakers and the cargo ship the *Sevmorput* are currently being operated; there are no nuclear powered cargo ships in operation in other countries.

In the Russian Federation nuclear powered icebreakers provide year round navigation in the western sector of the Arctic. Continuous power operation of the reactors has been as long as 10 000 h [79]. The operating record of the icebreaker the *Arctica* without a replacement of equipment exceeds 140 000 h. This operation has been successful and accident free [79]. The main parameters of Russian icebreakers are shown in Table 41.

### 7.4.2. Prospects for nuclear energy in the near term (2000–2020)

At present only the Russian Federation and Japan are conducting active studies for the development of civil ship reactors. The Russian Federation has one icebreaker under construction (the *50 Years of Victory*); in addition, advanced concepts based on the use of KLT-40 designs are being considered. The JAERI in Japan is designing two types of improved reactor: the marine reactor X for icebreakers and the deep-sea reactor X for deep water investigations [83, 84].

In consequence of the insufficient economics, the near term tasks for nuclear propulsion are:

- To sustain the current place in the market (icebreakers and a cargo carrier in the Russian Federation);
- To demonstrate other projects in which nuclear powered ship propulsion could become competitive, either owing to general factors (e.g. new competitive designs) or special situations (e.g. expensive alternative fuels).

TABLE 41. PARAMETERS OF RUSSIAN NUCLEAR POWERED ICEBREAKERS [24]

| Ship | Launched | Length (between perpendiculars) (m) | Draught (m) | Displacement (t) | Power capacity (MW) | Ice breaking capacity (m) |
|---|---|---|---|---|---|---|
| *Constructed* | | | | | | |
| *Lenin* | 1959 | 134 | 9.6 | 17 280 | 32.4 | 1.7 |
| *Arctica* (Arctic) | 1975 | 136 | 10.1 | 23 440 | 49 | 2.3 |
| *Sibir* (Siberia) | 1978 | 136 | 10.1 | 23 440 | 49 | 2.3 |
| *Rossiya* (Russia) | 1985 | 136 | 10.7 | 25 100 | 49 | 2.5 |
| *Sovetski Soyuz* (Soviet Union) | 1989 | 138 | 10.7 | 25 100 | 49 | 2.5 |
| *Yamal* | 1992 | 160 | 11 | — | 63 | 2.7–2.9 |
| *Taimyr* | 1990 | 150 | 8.1 | 18 500 | 35.5 | 1.8 |
| *Vaigach* | 1990 | 150 | 8.1 | 18 500 | 35.5 | 1.8 |
| *Sevmorput* (cargo ship) | 1988 | 230 | 11.8 | 61 800 | 29 | — |
| *Under construction* | | | | | | |
| *50 Years of Victory* | — | 160 | 10.8 | 25 165 | 55 | 2.7 |

Expecting more progress in the near term is not realistic. On the other hand, these objectives, if successfully achieved, could provide the basis for more ambitious tasks.

### 7.4.3. Prospects for nuclear energy in the long term (2020–2050)

The longer term prospects can be speculated upon, but they are strongly dependent on the actual developments of 2000 to 2020. The results of the evaluation are therefore less meaningful than similar assessments in other sections of this report.

With respect to the possible use of nuclear powered ship propulsion, two main branches of the market should be distinguished: (a) transportation (both passenger and cargo) by nuclear powered ships and (b) nuclear icebreakers[32]. For the first

---

[32] There is also a possibility of the civil use of nuclear submarines, in particular for fossil fuel transportation. This innovative application is addressed in Section 9.

branch petroleum products are the predominant energy source for nuclear energy to compete with. In the second one nuclear icebreakers have been used, in particular in the Russian Federation. The larger penetration into the second sector is explained by the fact that in this specific area the nuclear advantages (in particular a long operating time without refuelling) are substantial, which makes it more difficult for the other technologies to compete.

The market estimates for ship propulsion are different for the two branches mentioned above. In transportation the estimate should be based on the number of passengers and the amount of goods that could be potentially transported by nuclear powered ships. As the amount of passengers and goods is difficult to estimate, a rough estimate can be based on the existing capacities of the ship fleet. For icebreakers the potential routes and navigation duration play an important role.

However, for a rough qualitative estimate the difference between these two branches of the market can be disregarded. Such a qualitative estimate of the long term market potential for nuclear powered ship propulsion is shown in Table 42; detailed information can be found in Appendix XI. The estimate was done as for the other applications; the weighting coefficients in this case were the total tonnage of the registered fleet taken from Ref. [76]. The following principles were used for assigning the indicators:

- The indicator of market structure is assigned 2 for those countries in which two conditions exist: the capacity of the cargo fleet (including oil tankers) is larger than 1000 MGT and there are operating NPPs in the country (the first condition reflects the consideration that only a rather large size of fleet would make nuclear penetration desirable; the second one reflects the need for supporting infrastructure, which is much easier to provide in those countries that already have a nuclear infrastructure); 1 is assigned for countries that use nuclear energy and in which the cargo fleet capacity is between 100 and 1000 MGT; 0 is assigned for all the others.
- The indicator of demand pressure is assigned 1 for all those countries, in accordance with Ref. [76], in which there is a registered cargo fleet; 0 is assigned for all the others.
- The indicator of technical basis is assigned 2 for the four countries in which civilian nuclear powered ship propulsion has been used, that is Germany, Japan, the Russian Federation and the USA; 1 is assigned to all the countries operating NPPs; 0 is assigned otherwise.
- The indicator of economic competitiveness is assigned 1 for the Russian Federation and Japan, in which there is either a positive experience (Russian icebreakers) or an expectation of success (a new Japanese design study); 0 is assigned in all the other cases.
- The indicators of public acceptance are as defined in Appendix II.

The results in Table 42 show the following:

- The world average prospects are ranked as negligible, which reflects the existence of several large regions in which the prospects are determined as negligible: LAM, AFR, MEA and PAS.

TABLE 42. LONG TERM (2020–2050) PROSPECTS FOR CIVILIAN NUCLEAR POWERED SHIP PROPULSION

| Region | Indicator | | | | | Total |
|---|---|---|---|---|---|---|
| | Market structure | Demand pressure | Technical basis | Economic competitiveness | Public attitude | |
| NAM | 2.00 | 1.00 | 1.84 | 0.00 | 1.00 | 1.17 (medium) |
| LAM | 0.10 | 1.00 | 0.06 | 0.00 | 0.07 | 0.25 (negligible) |
| AFR | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.20 (negligible) |
| MEA | 0.00 | 1.00 | 0.00 | 0.00 | 0.95 | 0.39 (negligible) |
| WEU | 0.36 | 1.00 | 0.24 | 0.00 | 0.57 | 0.43 (negligible) |
| EEU | 1.03 | 1.00 | 0.62 | 0.00 | 1.00 | 0.73 (low) |
| FSU | 1.84 | 1.00 | 1.63 | 0.69 | 0.94 | 1.22 (medium) |
| CPA | 1.32 | 1.00 | 0.66 | 0.00 | 1.32 | 0.86 (low) |
| SAS | 2.00 | 1.00 | 1.00 | 0.00 | 2.00 | 1.20 (medium) |
| PAS | 0.79 | 1.00 | 0.27 | 0.00 | 0.69 | 0.55 (negligible) |
| PAO | 1.73 | 1.00 | 1.73 | 0.86 | 0.86 | 1.24 (medium) |
| Total | 0.56 | 1.00 | 0.39 | 0.07 | 0.51 | 0.51 (negligible) |

- The low ranking of the listed regions is understandable, especially in view of the absence of the supporting infrastructure that would be required for constructing and even receiving nuclear powered ships (e.g. nuclear safety regulation and port licensing).
- Despite the low global prospects, the prospects for nuclear powered ship propulsion are ranked as relatively high (i.e. medium) for the regions in which the existing experience with the use of nuclear energy is combined with large fleet capacities: NAM (mostly the USA), FSU (mostly the Russian Federation), SAS (India and Pakistan) and PAO (Japan).
- There are also two regions ranked as low (EEU and CPA (mostly China)); in these regions either an unfavourable public attitude or an insufficient technical basis drove the estimate lower than medium, but it is still higher than negligible, in particular in CPA.

Countries in which the use of nuclear powered ship propulsion appears promising in the long term are shown in Table 43. To a large extent, the countries with the highest prospects are the same countries that appear promising for the other non-electric applications (see Sections 4–6), but the level of ranking is in general lower than for the other applications because of the more demanding character of nuclear powered ship propulsion.

# 8. SPACE APPLICATIONS

## 8.1. MARKET CHARACTERIZATION

It should be noted that the term ‘market’ has a limited meaning in the area of the application of nuclear power in space. Agencies involved in space exploration and its use are usually either State owned or include significant governmental participation. Although economic considerations are therefore certainly part of decision making, space exploration does not operate as a free market; this is particular true for those applications that are potentially most feasible for the use of nuclear energy.

It should also be noted that this report deals only with the applications of nuclear reactors, and hence radioisotope thermoelectric generators (RTGs) are not considered here, although they are a widely used space application of nuclear energy.

### 8.1.1. Market size and potential for nuclear penetration

An energy source for a spacecraft must provide energy for the spacecraft’s launch and operation, which is propulsion energy and usually electricity,

TABLE 43. COUNTRIES WITH PROSPECTS FOR CIVILIAN NUCLEAR POWERED SHIP PROPULSION

| Region/ country | Indicator | | | | | Total |
|---|---|---|---|---|---|---|
| | Market structure | Demand pressure | Technical basis | Economic competitiveness | Public attitude | |
| *NAM* | | | | | | |
| Canada | 2 | 1 | 1 | 0 | 1 | 1.0 (medium) |
| USA | 2 | 1 | 2 | 0 | 1 | 1.2 (medium) |
| *LAM* | | | | | | |
| Brazil | 2 | 1 | 1 | 0 | 1 | 1.0 (medium) |
| *WEU* | | | | | | |
| France | 2 | 1 | 1 | 0 | 2 | 1.2 (medium) |
| Germany | 2 | 1 | 2 | 0 | 0 | 1.0 (medium) |
| Netherlands | 2 | 1 | 1 | 0 | 1 | 1.0 (medium) |
| UK | 2 | 1 | 1 | 0 | 1 | 1.0 (medium) |
| *EEU* | | | | | | |
| Romania | 2 | 1 | 1 | 0 | 1 | 1.0 (medium) |
| *FSU* | | | | | | |
| Russian Federation | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |
| Ukraine | 2 | 1 | 1 | 0 | 1 | 1.0 (medium) |
| *CPA* | | | | | | |
| China | 2 | 1 | 1 | 0 | 2 | 1.2 (medium) |
| *SAS* | | | | | | |
| India | 2 | 1 | 1 | 0 | 2 | 1.2 (medium) |
| *PAS* | | | | | | |
| Korea, Republic of | 2 | 1 | 1 | 0 | 2 | 1.2 (medium) |
| Taiwan, China | 2 | 1 | 1 | 0 | 1 | 1.0 (medium) |
| *PAO* | | | | | | |
| Japan | 2 | 1 | 2 | 1 | 1 | 1.4 (medium) |

respectively. For propulsion energy chemical fuels are presently used; the use of nuclear energy was under consideration for a long time (e.g. for the US Rover programme of 1955 to 1973 [85]), but it has not been successful. For electricity the possible energy sources are solar cells, chemical fuel cells, rechargeable batteries (in combination with the others) and nuclear energy, produced either by RTGs or by nuclear reactors.

For a discussion of the potential role of nuclear energy, it is useful to structure the market for space services into three main segments:

- Earth orbit applications (energy for launching and operating satellites);
- Energy supply to space stations (mainly electricity);
- Energy for outer space missions (for short, medium and long durations).

Non-nuclear energy sources have been extensively and successfully used for the first two applications and, to a lesser extent, for short duration outer space missions. However, they have limitations with respect to load weight (i.e. the required power) and mission duration (the period of reactor operation). Permanent and sufficient exposure to sun is needed for solar cells; the size of the solar panels increases significantly with an increase in the power level needed. Chemical fuels are not rechargeable and, owing to the low energy content of the fuel, cannot support the load requirements for long duration missions.

RTGs are the nuclear sources that have been used successfully, but they have limited power: achieving loads beyond 1 kW(e) is difficult; beyond this level nuclear reactors become preferable. Nuclear reactors can provide higher power levels over a wide range and, owing to the extremely high energy content of nuclear fuel, can provide the load requirements for long duration missions.

Thus the most suitable market for nuclear reactors is that for missions that require high power levels and/or long operating times. For low level and short duration applications, non-nuclear energy sources are available and considered preferable. Figure 20 shows the potential area of nuclear space applications graphically.

An important implication of this, in terms of market size, is that medium and long duration missions are not numerous. In contrast with the thousands of Earth orbiting satellites launched, each outer space mission is unique and specifically planned. Although the market terminology is still therefore retained here for uniformity, the applications of nuclear energy in space are of a non-market character and it is not justified to make assessments of the market size in the same sense as for the nuclear applications reviewed in the previous sections. Outer space exploration is not at present driven by profit considerations. This may change in the future, but not in the short term.

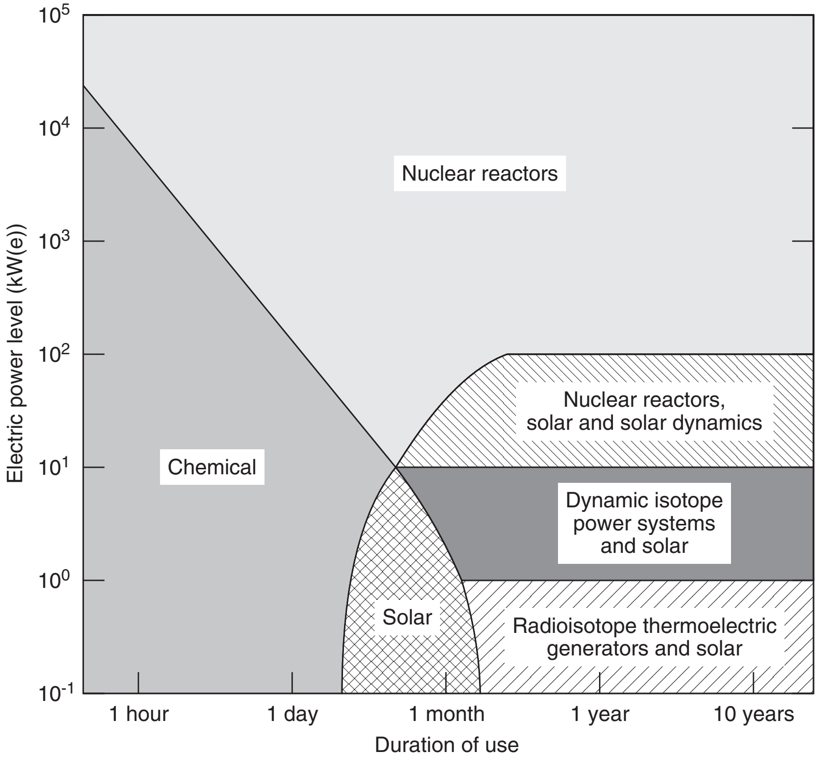

*FIG. 20. Market for various energy sources in space [86]. This figure is taken from the electronic version of Ref. [86].*

### 8.1.2. Market features

#### *8.1.2.1. Typical power ranges*

Table 44 presents the key requirements for nuclear powered missions. It shows that power levels of 10 to 200 kW(e) would be required, depending on the mission.

#### *8.1.2.2. Supply duration*

The requirements of long duration operations are important, because it is for long duration missions that nuclear energy becomes the energy source of preference. Lifetimes of 10 years or more may be required, as shown in Table 44.

TABLE 44. KEY REQUIREMENTS FOR POTENTIAL NUCLEAR POWERED SPACE MISSIONS [87]

| Mission | Key requirements |
|---|---|
| *Near-Earth applications* | |
| Military applications (surveillance, communications, jamming devices) | 10–40 kW, lifetime 7–10 years |
| Verification of treaties | Up to 40 kW, lifetime 7–10 years |
| Anti-collision aircraft radar | 20–40 kW, lifetime 7–10 years |
| Commercial applications (electronic communications, television broadcast) | 25–100 kW |
| Environmental monitoring | >10 kW, lifetime 7–10 years |
| *Solar system exploration* | |
| Neptune orbiter/probe | Payload 1.8 Mg, 100 kW, power system mass 3.7 Mg |
| Pluto orbiter/probe | Payload 1.4 Mg, 56 kW, power system mass 2.8 Mg |
| Uranus orbiter | Payload 1.4 Mg, 100 kW, power system mass 3.7 Mg |
| Jupiter grand tour | Payload 1.4 Mg, 58 kW, power system mass 2.9 Mg |
| Rendezvous | Payload 1.4 Mg, 40 kW, power system mass 2.35 Mg |
| Comet sample/return | Payload 1.8 Mg, 100 kW, power system mass 3.7 Mg |
| *Lunar–Martian exploration* | |
| First lunar outpost | >12 kW |
| Enhanced outpost | >200 kW |
| Mars stationary (600 d) | 75–150 kW |
| Mars in situ resources | >200 kW |
| Mars comsats | 20 kW |

### *8.1.2.3. Supply reliability*

Spacecraft require highly reliable energy sources, as, unlike land based facilities, their repair may not be possible and important information and/or materials may be permanently lost as a result of a failure.

### *8.1.2.4. Impact of specific nuclear considerations*

As with other nuclear applications, it is crucially important to ensure nuclear safety [88]. In addition to the usual requirement of ensuring the absence of inadvertent criticality during reactor operation, two phases of space missions are of particular importance: launching and, if required, return to the Earth. An incident with a release of nuclear fuel would be especially dangerous in the latter case, as it could lead to a release of the highly radioactive fission products accumulated in nuclear reactors during the mission. Such accidents are known, in particular two accidents with satellites equipped with nuclear reactors have occurred: Cosmos 954 in 1978 and Cosmos 1402 in 1983. Their consequences, especially the fallout of reactor debris over a large area in Canada after the 1978 accident, reinforced the primary importance of nuclear safety [89].

## 8.2. POTENTIAL NUCLEAR SOLUTIONS

Various designs are applied to the applications of nuclear energy in space. Figure 21 shows the main types of nuclear reactor structured into two main groups: propulsion energy and electricity production.

Of these possible designs, two types should be noted as the most advanced [87]:

- Thermionic technology (used in the TOPAZ reactors in the Russian Federation);

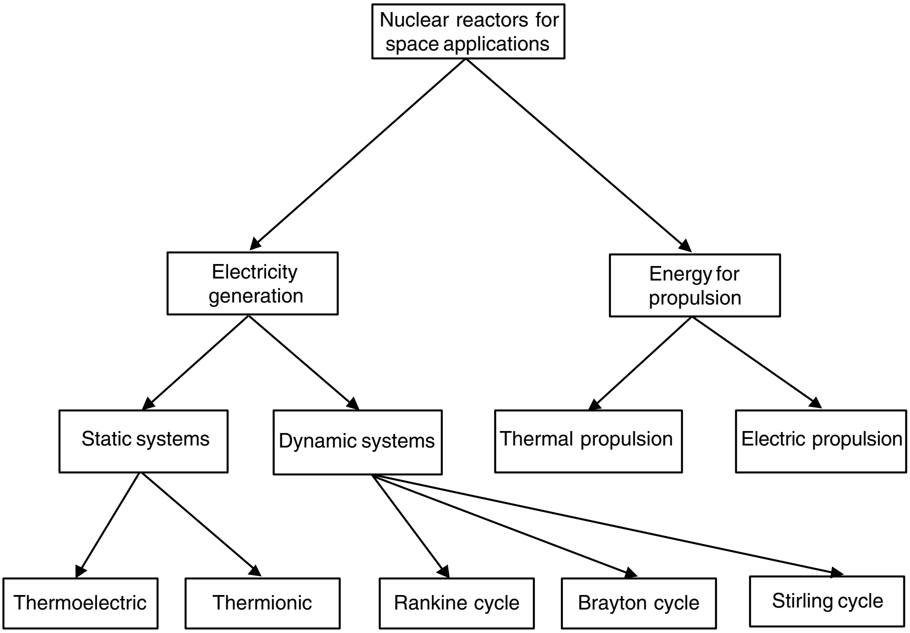

*FIG. 21. Classification of nuclear systems for space applications.*

— Thermoelectric technology (used in the SP-100 project in the USA)[33].

There have been recent advances in heatpipe reactor systems, for heatpipe power systems (HPS) and heatpipe bimodal systems (HBS) [28, 29]. They can use both thermoelectric and thermionic technologies as a primary energy source.

Some representative parameters of the most advanced projects are shown in Table 45.

## 8.3. ECONOMIC COMPETITIVENESS

As has been noted, the market for space services can only conditionally be called a market; nevertheless, economic considerations play an important role. The costs of non-nuclear applications are well established (although not necessarily openly disclosed); the task of proving economic efficiency therefore exists for nuclear energy sources unless the mission is definitely of a non-commercial nature.

The longer the mission, the greater the potential advantage of nuclear energy, owing to the high energy concentration of nuclear energy and the consequent low weights that can be achieved.

Only limited information on the costs of the latest nuclear projects is available at present. Moreover, such information is somewhat questionable because of the relative immaturity of these projects. As an example, an estimate for the development

TABLE 45. CHARACTERIZATION OF SOME NUCLEAR REACTOR PROJECTS FOR SPACE APPLICATIONS

| Project | Key parameters |
|---|---|
| RORSAT reactors | ~1–2 kW(e), <100 kW(th), power system mass <390 kg [90] |
| TOPAZ I reactor | 5–6 kW(e) [87] |
| TOPAZ II reactor | ~6 kW(e), 115–135 kW(th), power system mass 1061 kg [87] |
| SP-100 reactor | ~100 kW(e) (reference value assuming 10 units of 10 kW(e), power may vary between 10–15 000 kW(e), depending on the number of units), 2500 kW(th), power system mass 4600 kg [87] |
| HPS/HBS systems | ~10–1000 kW(th) [29] |

---

[33] Thermionic technology is based on the use of ion emission from a nuclear heated cathode; thermoelectric technology is based on the use of the current generated by a temperature difference between two ends of a conductor, one of them being nuclear heated.

of a HPS or a HBS [28] can be cited (see Table 46). It is estimated that the development, manufacturing and testing of the first flight ready reactor would take 5 to 6 years and cost up to US $100 million; this figure is a factor of three to four times higher than shown in Table 46, as it is assumed to account for all the uncertainties associated with the development of the applications in space of nuclear energy. It is important to note that manufacturing is anticipated to be carried out mainly in the Russian Federation, so the costs are lower than they would be for similar activities in the USA.

## 8.4. CURRENT AND PROSPECTIVE MARKET

At present, the application of nuclear reactors for space exploration and their use is limited. Thousands of satellites have been launched over the past two to three decades, although of these only several dozen were powered by nuclear reactors[34], such as SNAP-10A in 1965 (0.5 kW, launched by the USA), some 30 RORSAT satellites in the 1970s and 1980s (~1–2 kW, launched by the former Soviet Union), Cosmos 1818 in 1987 (~5 kW with a TOPAZ I reactor, launched by the former Soviet Union) and Cosmos 1867 in 1988 (~5 kW with a TOPAZ I reactor, launched by the former Soviet Union) [87].

At the same time, space exploration may become an important market in the future. The use of near-Earth satellites is already to a notable extent a commercial

TABLE 46. COST ESTIMATES FOR THE FABRICATION AND TESTING OF HPS/HBS REACTORS [28]

| Cost component | Cost (× 1000 US $) | | |
|---|---|---|---|
| | HPS60 | HPS7N | HBS100 |
| Manufacturing of reactor components | 22 080 | 23 010 | 31 120 |
| Reactor assembly | 650 | 700 | 850 |
| Zero power critical testing | 500 | 500 | 500 |
| Payload shield fabrication | 1 900 | 1 600 | 1 900 |
| Shield attenuation testing | 300 | 300 | 300 |
| Core and shield vibration testing | 400 | 400 | 400 |
| Total | 25 830 | 26 510 | 35 070 |

---

[34] The numerous missions powered by RTGs are not considered here.

activity, but nuclear reactors will most probably not be used much for such purposes in the near future.

The most important task for space applications of nuclear reactors is a first demonstration of a spacecraft powered by a nuclear reactor. The demonstration must prove compliance with all the relevant safety requirements and correspondence, at the level of a pilot project, with the requirements for a number of applications, medium and long duration missions in particular.

The long term future of nuclear space applications will critically depend on success in this respect. The demand for outer space exploration will surely exist and grow in the future. As nuclear energy is the most feasible energy source for this and the technical developments are well in progress, it is reasonable to hope for a breakthrough that would make the use of nuclear reactors in space exploration widespread.

# 9. INNOVATIVE APPLICATIONS

This section reviews several innovative non-electric applications of nuclear energy. The term innovative is used to underline that they are less mature than the applications described above in that they have not yet been demonstrated. However, the market segments concerned are large, which makes these innovative applications potentially important.

This section is focused on three such applications, in decreasing order of their market potential and irrespective of their technological level of maturity:

- Fuel synthesis, including hydrogen production and coal gasification (Section 9.1);
- Oil extraction (Section 9.2);
- The use of nuclear submarines for fossil fuel transportation (Section 9.3).

## 9.1. FUEL SYNTHESIS

As noted in Section 2.1, the small share of nuclear energy in the non-electric part of energy demand is largely attributable to the absence of nuclear penetration into the transportation sector. At present, this sector accounts for about one quarter of the total final energy demand (Fig. 22) and is served almost exclusively by petroleum products (Fig. 23).

It is widely expected that the demand for transportation energy will grow significantly in the future, following, in particular, industrial growth and rising standards of living in today’s developing countries.

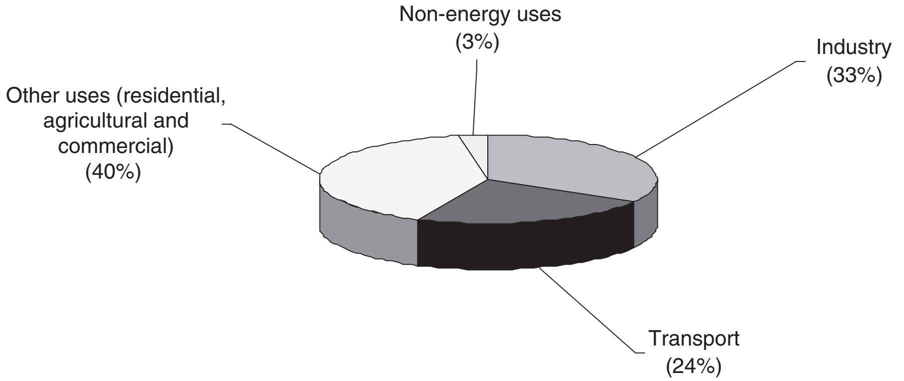

*FIG. 22. Breakdown of the world's final energy by main uses in 1998 [3].*

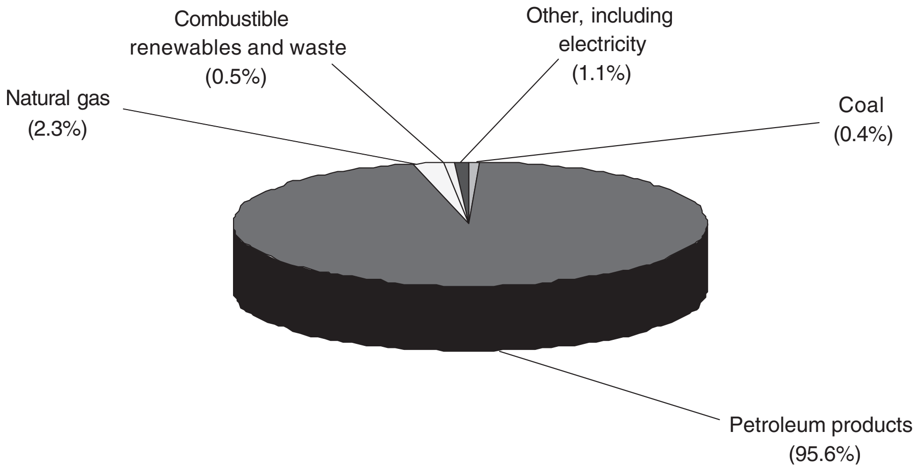

*FIG. 23. Breakdown of the world's transportation energy by energy carrier in 1998 [3].*

The present use of nuclear energy for transportation is limited to the use of electricity generated by nuclear energy in electric motors and to ship propulsion. However, there is a promising opportunity of using nuclear energy for transportation indirectly, through fuel production. Various transportation fuels are considered, all of them already in use to varying degrees alongside traditional petroleum derivatives such as gasoline and diesel fuel:

- Alcohol fuels (methanol, ethanol and their derivatives, such as M85 and E85 containing 15% gasoline[35]);
- Compressed natural gas;
- Liquefied natural gas;
- Liquefied petroleum gas;
- Electricity;
- Hydrogen;
- Coal derived liquid fuels;
- Fuels derived from biological materials.

It is likely that no fuel can be judged the best in the near or medium term. Each fuel has certain advantages and may have a place in the future fuel economy. The future fuel mix will be determined primarily by interfuel economic competition and environmental considerations, such as the amount and type of emissions. The applicability of nuclear energy to the production of the listed fuels is reviewed in Sections 9.1.1–9.1.3.

### 9.1.1. Hydrogen production

Hydrogen possesses a number of attractive features that could allow it to become a key secondary energy carrier in the future:

- Hydrogen combustion (either hot or cold) is generally clean in that it does not produce the emissions characteristic of fossil fuel combustion. The problem of $NO_x$ production from high temperature combustion is practically eliminated in modern engine designs.
- Technologies similar to those used for the combustion of fossil fuels can be used for hydrogen combustion to generate heat, electricity and propulsion energy; for example, hydrogen can be used as fuel in catalytic combustion (in diffusion burners, fuel cells), in internal combustion engines and in gas turbines.

---

[35] Other mixes are also used, for example a so-called gasahol, in which ethanol is a blending component (15%) with 85% gasoline, and gasahol-II, with 4.75% methanol, 4.75% t-butyl alcohol and 90.5% gasoline.

- Hydrogen is storable, which is convenient for an energy carrier and gives the possibility of making the energy system much more flexible than at present, in particular by using the conversion of electricity to hydrogen (through water electrolysis) and vice versa (through fuel cells), as necessary[36].
- Hydrogen can be produced from natural gas (or, indeed, from any other hydrocarbon fuel) and could replace it at the point of use, but $CO_2$ emissions would be similar to those produced by using the natural gas directly (and greater where the natural gas is first converted to methanol) unless the $CO_2$ is sequestered at the point of hydrogen production.
- Hydrogen can be produced from water by electrolysis, utilizing either electricity alone (low temperature electrolysis), by a combination of electricity and heat (high temperature electrolysis) or by heat alone (using thermochemical cycles); hydrogen production by low temperature electrolysis can either be done at the power plant site or closer to the point of use by using electricity grids for distribution; hydrogen produced by water electrolysis also has the advantage of high purity, which makes it applicable to special applications.
- Hydrogen could thus be a third product from power plants, in addition to electricity and heat.

Making the fullest possible use of the above advantages, hydrogen can be considered a key element of an environmentally benign and sustainable energy system, including transportation, as illustrated in Fig. 24.

With respect to the role of nuclear energy in hydrogen production, two important aspects must be distinguished: the penetration of hydrogen into the energy system (irrespective of the energy sources used for its production) and the use of nuclear energy for hydrogen production.

#### *9.1.1.1. Prospects for hydrogen penetration in the energy system*

Many studies have addressed the prospects for hydrogen based clean energy systems [73, 91–102]. However, at present, hydrogen plays only a negligible role in the supply of energy. The annual world hydrogen production is about $500 \times 10^9$ $m^3$ [43]. Assuming 12.7 $MJ/m^3$ as the hydrogen energy content, this corresponds to about 6.4 EJ, or about 1.5% of the world's primary energy consumption in 1996 (425 EJ

---

[36] The characterization of the complementary character of electricity and hydrogen should be noted:

- Hydrogen can be stored in enormous quantities, whereas electricity can not;
- Electricity can transmit energy without moving material, whereas hydrogen can not;
- Hydrogen can be a chemical or material feedstock, whereas electricity can not;
- Electricity can process, transmit and store information, whereas hydrogen can not.

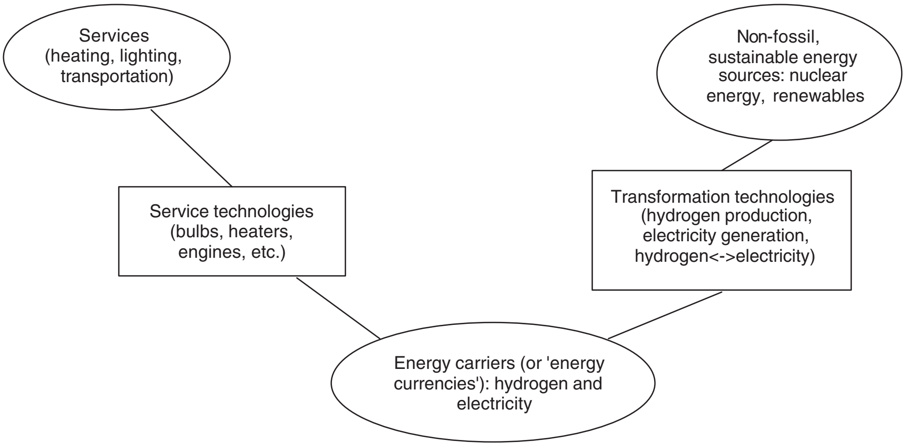

*FIG. 24. Outline of a hydrogen based energy system.*

[103]). Even this small amount is, however, not applied entirely for energy purposes. Energy applications account only for a half of the total hydrogen produced [100]:

- 48% is consumed for non-energy purposes, such as chemical raw materials and intermediate products;
- 32% is consumed for energy purposes directly as fuel for process heat;
- 20% is consumed for energy purposes indirectly through the production of synthetic fuel.

The negligible share of hydrogen of the world's energy supply is explained by the serious practical difficulties in its introduction in the energy system. Hydrogen is not available in a form ready for use and has therefore to be produced, which requires suitable technologies and a primary source of energy. The overall energy efficiency of the use of hydrogen must therefore take into account the energy required in its production, which has implications for the economics of hydrogen production and use.

Current hydrogen production methods are the steam reforming of natural gas, which is the predominant method today, coal gasification, electrolysis, a thermochemical cycle and photolysis. Table 47 illustrates the energy requirements for hydrogen production by several typical technologies.

For the large scale penetration of hydrogen technological developments such as those of competitively priced fuel cells or cars with a hydrogen powered internal combustion engine are needed [104].

The safety issues associated with the use of hydrogen as a fuel are comparable with those for gasoline; the public has, however, to be reassured in this regard.

TABLE 47. ENERGY REQUIREMENTS FOR HYDROGEN PRODUCTION
*(as estimated from various sources in Ref. [73])*

| Process | Process cost relative to methane steam reforming | Energy requirements (not including the energy in the feedstock) (kW·h/(m$^3$ $H_2$)/MJ/(m$^3$ $H_2$)) | |
|---|---|---|---|
| | | Theoretical | In practice |
| Energy content of hydrogen | — | 3.5 (12.7) | — |
| Steam methane reforming | 1.0 | 0.8 (2.8) | 2.5 (9.0) |
| Partial oxidation of heavy oil | >1.0 | 0.9 (3.4) | 4.9 (17.6) |
| Coal gasification | 1.4–2.6 | 1.0 (3.6) | 8.6 (31.0) |
| Water electrolysis (low temperature) by fossil power plants (40% efficiency) | 5–10 | 3.5 (12.7) | 4.9 (17.6) |
| Water electrolysis (low temperature) by NPPs (33% efficiency) | 5–10 | 3.5 (12.7) | 4.9 (17.6) |

For the large scale application of hydrogen there is a need to develop supporting infrastructure for its production, distribution and use. This requirement is similar to that for electricity, oil and gas. Given the specific nature of hydrogen infrastructures, large investments and a long lead time could be required [104, 105].

To mitigate the negative impact of the need for high initial investments, governmental support is likely to be needed for hydrogen introduction in the foreseeable future. Such forms of support as laws, regulations, requirements, tax incentives, emission standards, etc., can be considered [104, 105]. This will probably lead to the first hydrogen applications having a centralized fuel supply, for example city bus transportation and government or company car fleets.

### *9.1.1.2. Prospects for nuclear energy for hydrogen production*

As illustrated in Table 47, hydrogen production requires a primary energy source. This means that for hydrogen to become a noticeable part of the energy system, another non-hydrogen energy source is required. As the overall thermal efficiency of the energy system is likely to decrease with the use of hydrogen (because of the energy spent for hydrogen production, in particular for the case of water electrolysis), the overall amount of primary energy would be larger than for a system without hydrogen unless this conversion loss is offset by a higher efficiency in the hydrogen fuelled power plant. (Fuel cells generally have efficiencies of at least 50%.)

Possible sources of primary energy for hydrogen production are fossil fuels, nuclear energy and renewable energy sources.

As nuclear reactors can produce both the heat and electricity required for hydrogen production, the use of nuclear energy is particularly appropriate for hydrogen production. Moreover, as nuclear energy is now the most significant commercially mature non-fossil fuel energy source, there is a potential for basing large scale hydrogen production on nuclear technologies. This would radically mitigate the emissions of greenhouse gases from the energy sector [73, 91].

The production of hydrogen by nuclear reactors can be realized by the use of various technological processes, which provides considerable flexibility:

- Using electricity from NPPs;
- Using high temperature heat from an HTGR for steam reforming;
- Using hybrid processes (heat plus electricity) for high temperature electrolysis, thermochemical cycles, etc.

The first option is to be noted in particular, because it implies that all available nuclear designs for electricity generation would fit into a hydrogen based energy system. For the second and third options the HTGR is a suitable and promising technology for reforming natural gas and synthesis gas production as a feedstock for hydrogen production.

In comparison with the use of fossil fuels for hydrogen production, nuclear energy has the advantages of having a large resource base and of the absence of most air emissions, carbon dioxide in particular. Moreover, the use of nuclear energy in combination with water electrolysis avoids burning natural gas, which is the dominant raw material for hydrogen production. These advantages are especially important in view of the large amount of primary energy required for an energy system with a noticeable share of hydrogen use.

In comparison with the use of renewable energy sources for hydrogen production, nuclear energy has the advantage of being a mature, available technology and has the important feature of a high energy concentration. Apart from their relative technological immaturity, renewable energy sources, although potentially large and inexhaustible, are very diffuse and available only at a low energy density. The collection of significant amounts of renewable energy represents a challenge even for electricity generation. Large scale hydrogen production would exacerbate this difficulty. In contrast, the high energy concentration in nuclear fuel enables either hydrogen production concentrated in multiproduct energy centres or distributed hydrogen production using existing electricity grids to power low temperature electrolysis.

As can be seen from, for example, Ref. [92], the advantages of nuclear power for hydrogen production were recognized long ago. The key features of energy systems based on the use of hydrogen as a key energy carrier are (see also Fig. 24) the:

- Use of GHG free primary energy sources,
- Use of hydrogen and electricity as interchangeable main secondary energy carriers,
- Marginal use of fossil fuels (for end use niches only).

There is a need for successful pilot projects to demonstrate, for example, the use of surplus nuclear capacity for hydrogen production using cheap off-peak electricity, the operation of the first high temperature reactor and the creation of local hydrogen markets near existing NPPs. Hydrogen production using conventional low temperature electrolysis could open up the market for hydrogen fuelled vehicles in the near term. The key requirement for this electrolysis is a very low unit capital cost, since the overall economics are very dependent on operating the electrolysis cells intermittently, during off-peak periods when the cost of electricity is low.

### 9.1.2. Coal gasification

Coal gasification invloves converting solid coal into a gaseous fuel that can be used similarly to natural gas. The objective of the conversion is to mitigate some of the drawbacks associated with the combustion of solid coal. In particular, gasification allows a significant reduction of air emissions from the direct combustion of coal (e.g. particulates, sulphur oxides and heavy metals).

An important advantage of coal gasification is that of the resource base. In general, the use of gasified coal has the same advantages as the use of natural gas. However, the current reserves of coal are much larger than those of natural gas. Introducing a clean route for coal combustion therefore has large and long term advantages. The use of coal will most probably increase in the future, in particular in the developing countries, such as China and India, in which large populations, high rates of industrial growth and large indigenous coal resources coincide. While the prospects for the large scale use of renewable energy resources remain speculative at the moment, the increased utilization of coal may represent a feasible development path to meet expanding energy needs in many countries.

Integrated gasification combined cycle plants are currently in the demonstration phase. A five year programme of the 100 MW(e) integrated gasification combined cycle demonstration plant at Cool Water, California, was completed in 1989; a number of other demonstration projects are on the way in Europe, Japan and North America [106, 107]. A 235 MW(e) unit at Buggenum in the

Netherlands started up in 1993. There are three plants in the USA, at Wabash River in Indiana, Polk Power near Tampa in Florida and Piñon Pine in Nevada. The largest unit is that at Puertollano in Spain, which has a capacity of 330 MW(e). The Spanish electric utility Iberdrola and the energy company Repsol have selected Texaco's integrated gas combined cycle technology for a US $1000 million, 824 MW plant it is building at the Petronor refinery near Bilbao.

The results of such projects will determine the feasibility of coal gasification and allow a more accurate assessment of the long term prospects for this technology.

If coal gasification becomes widespread, incentives for looking for alternative (i.e. non-coal) sources of gasification energy will appear. Nuclear energy in the form of an HTGR would be a credible, non-polluting technology for this purpose.

### 9.1.3. Other synthetic fuels

Another option for short term nuclear penetration into the transportation sector would be the production of synthetic liquid fuels. Well known possible candidates are methanol, ethanol and their derivatives. They are applicable as fuel, processes for their production are known and these processes require energy in the form of heat, which creates an opportunity for nuclear energy. Table 48 compares the energy content of various liquid fuels.

The application of nuclear energy for the production of such fuels would be a process heat application, and would have all the pros and cons discussed in Section 6. There is essentially very little difference between hydrogen production and the

TABLE 48. ENERGY CONTENT OF THE MAIN LIQUID FUELS

| Fuel | Net calorific value (LHV)[a] (MJ/kg) |
|---|---|
| Crude oil | 42.6 |
| Gasoline | 43.9 |
| Diesel fuel | 49.3 |
| Ethanol | 28.5 |
| E85 | 30.8 |
| Methanol | 21.5 |
| M85 | 24.8 |
| Liquefied natural gas | 52.7 |
| Hydrogen | 119.9 |

[a] LHV: low heating value

production of other fuels. The greatest difference lies not in its production but in its infrastructure requirements, which are easier to realize for other fuels.

In general, the nuclear applications described in Section 6 and in this section will be subject to similar penetration drivers. In particular, the availability of a proven and economic HTGR technology will be important, and a broad spectrum of process heat applications can then be expected. The role of each specific application (e.g. hydrogen production vs. the production of synthetic fuels from coal) will be determined not as much by the parameters of nuclear reactors as by the demand side; that is, by the relative advantages and disadvantages of hydrogen vs. synthetic fuels.

## 9.2. OIL EXTRACTION

Another possible application of nuclear energy is the use of nuclear generated heat for oil extraction. More specifically, two categories are relevant: the extraction of heavy oil (and oil from tar and oil sands) and the extraction of the oil remaining in depleted deposits. These resources, in particular the first one, are often referred to as unconventional oil resources.

The prospects for these applications are related to the fact that the resources of unconventional oil are larger than those of conventional oil (see Table 49). Increases in the price of conventional oil can make the extraction of unconventional oil economic.

The resources of conventional oil are limited, and methods of unconventional oil recovery have been developed, in particular in those countries in which such resources are large, such as Canada and Venezuela (see Table 50).

Nuclear energy is applicable for oil extraction by the use of steam injection[37]. Steam and electricity may also be needed in the course of oil processing following

TABLE 49. WORLD OIL RESOURCES [108]

| Resource | Resource amount (stock) in ZJ (1000 EJ) | | | | |
|---|---|---|---|---|---|
| | Consumed by the end of 1998 | Consumed in 1998 | Reserves | Resources[a] | Resource base[b] |
| Conventional oil | 4.85 | 0.13 | 6.00 | 6.07 | 12.08 |
| Unconventional oil | 0.29 | 0.01 | 5.11 | 15.24 | 20.35 |
| Total | 5.14 | 0.14 | 11.11 | 21.31 | 32.42 |

[a] Resources are the reserves to be discovered or resources to be developed as reserves.

[b] Resource base is the sum of reserves and resources.

TABLE 50. CONVENTIONAL AND UNCONVENTIONAL OIL IN CANADA AND VENEZUELA [109]

| Country | Conventional oil (millions of tonnes of oil) | | | Unconventional oil (oil and tar sands, extra-heavy oil) (millions of tonnes of oil) | | |
|---|---|---|---|---|---|---|
| | Reserves | Resources | Annual production (1996 data) | Reserves | Resources | Annual production (1996 data) |
| Canada | 849 | 13 005 | 65 | 717 | 46 795 | 25 |
| Venezuela | 10 097 | 370 964 | 164 | 364 | 808 | 0.003 |

extraction. A nuclear reactor producing steam of the required quality and quantity is therefore needed. It has been shown [69] that HTGR technology fulfils the requirements for using nuclear energy in oil extraction. However, new methods of steam injection, such as steam assisted gravity drainage, also make other reactor concepts applicable [110] because the required steam parameters are sufficiently low. For example, the application of steam assisted gravity drainage in Canada using CANDU reactors is a promising concept with long term benefits [111].

Independent of the reactor type, the option of supplying heat with nuclear reactors must be economically competitive with the alternative steam generation technologies, otherwise the nuclear option would probably be rejected for economic reasons, notwithstanding its availability, unless certain environmental considerations, such as the amount of GHG emissions, influence the decision significantly. An analysis of the latter factor conducted in Ref. [111] for Canada shows that its role can be important.

With respect to the feasibility of this application, the general need for unconventional oil resources is important. The expectation of sustained high prices for conventional oil will lead to significant developments in the extraction of unconventional oil, in addition to the cases (as, for example, in Canada) in which the resources of unconventional oil are large and already developed.

## 9.3. NUCLEAR SUBMARINES FOR FOSSIL FUEL TRANSPORTATION

The idea of submarine transportation vessels (STVs) has been envisaged in the Russian Federation; the primary incentive being the expected growth of goods transportation along the northern sea route. In particular, it is expected that the

---

[37] There are several technological options within the broad category of 'steam injection'.

extraction of large fossil fuel resources (oil and gas) in the Arctic may commence in the near future, which would result in a demand for economical transportation modes.

STVs have the potential advantages of being able to use the shortest route, being free of the condition of the water's surface and enabling a high and constant speed of movement.

At present, a large part of transportation by the northern sea route is provided by the use of icebreakers. Estimates, however, show that in order to ensure year round navigation of on-surface ships in the eastern part of the northern sea route icebreakers need to have the ability to break ice three metres thick, which is beyond the capability of existing ships. Icebreakers of 130 to 150 MW(e) of capacity would be needed, which would result in high construction costs. Moreover, a correspondence between icebreaker power and the capacity of the supporting on-shore infrastructure must exist (such as the size of the ships used for transportation from the icebreaker to the shore). This would further increase the infrastructure costs.

Using STVs for goods transportation in the Arctic may therefore have economic advantages in comparison with the traditional transportation ship–icebreaker scheme.

Between 1990 and 1997 technical and economic research on STVs (tankers, container transporters, supply ships) for use in Arctic conditions was conducted in the Russian Federation [25]. As a result, the technical outlook of the vessels was determined. Two specific technical designs for STVs were prepared:

- — Container transporters for 912 20-foot (6.1 m) containers,
- — Tankers of 30 000 dwt displacement.

The submarine tanker was designed for the year round transportation of oil, liquefied natural gas or liquid hydrocarbons from Arctic deposits. Similar technical, operational and technological requirements for the container transporter and the

TABLE 51. MAIN STV PARAMETERS [25]

| | |
|---|---|
| Maximum displacement | 30 000 t |
| Maximum length | 238 m |
| Maximum width | 26.8 m |
| Side height | 20.2 m |
| Draught when unloaded | 10.5 m |
| Draught when loaded: | |
| Container transportation (depending on the containers' mass) | 12.0–10.5 m |
| Tanker | 16.5 m |
| Full speed | 20 knots |
| Navigation autonomy | 60 days |
| Crew | 35 persons |

tanker resulted in unified technical solutions. As a result, their architecture and basic equipment (except the cargo equipment) are similar (see Table 51).

In accordance with the International Maritime Organization's Code of Nuclear Trade Vessels Safety, measures to ensure accident free operation and to exclude radioactive contamination of the environment and the cargo need to be implemented. To access ports, STVs need to be equipped with an auxiliary diesel generator installation, which provides power for the motion and other needs when the reactor is out of operation.

The successful use of STVs in the northern sea route would allow the consideration of using other STV applications.

# 10. OVERALL MARKET POTENTIAL FOR ALL NON-ELECTRIC APPLICATIONS

Tables 1, 2 and 52 summarize the estimated market potential of the non-electric applications of nuclear energy. Table 1 shows the status of nuclear applications, the ongoing activities and the estimated market size. Table 2 presents the results of the qualitative assessment of the long term prospects for nuclear penetration into the market of non-electric energy services. Table 52 shows the most promising countries for non-electric nuclear applications in the long term. This table includes countries in which at least two applications are ranked highest in the corresponding region.

These estimates are based on the analyses in Sections 4–9. They assume, in accordance with the assumptions described above, that applications of nuclear energy, both for power generation and for non-electric purposes, will continue to develop. This includes technical development, infrastructural support and the licensing environment, the latter being particularly important for certain applications. These estimations also assume, implicitly, that nuclear energy will remain socially acceptable (policies leading to a global nuclear phase-out are not considered here, except through the application of indicators of social acceptance).

For interpreting the tables, Table 2 in particular, caution in treating regional and world averages is recommended. Although such numbers do provide a consistent general view, they may hide important regional details, such as, for example, a high competitiveness of a specific nuclear project in a country notwithstanding the general low estimate for the region. For such details the relevant appendices should be referred to as referenced in the corresponding sections above, in addition to the information on selected countries in Table 52.

TABLE 52. MOST PROMISING COUNTRIES FOR THE LONG TERM PROSPECTS OF NON-ELECTRIC APPLICATIONS OF NUCLEAR ENERGY

| Region/country | District heating | Water desalination | Process heat | Ship propulsion |
|---|---|---|---|---|
| *NAM* | | | | |
| Canada | M | L | M | M |
| USA | M | L | M | M |
| *LAM* | | | | |
| Argentina | L | L | L | L |
| Brazil | L | L | L | M |
| Mexico | L | L | L | L |
| *AFR* | | | | |
| South Africa | M | M | M | L |
| *MEA* | | | | |
| Egypt | L | M | L | — |
| Iran | M | M | M | L |
| Morocco | L | M | L | — |
| *WEU* | | | | |
| Belgium | M | M | M | L |
| Finland | M | M | M | L |
| France | M | M | M | M |
| Netherlands | M | M | M | M |
| Spain | M | M | M | L |
| Switzerland | M | M | M | L |
| UK | M | M | L | M |
| *EEU* | | | | |
| Bulgaria | M | L | M | L |
| Czech Republic | M | M | M | L |
| Romania | M | L | M | M |
| Slovakia | M | M | M | — |
| *FSU* | | | | |
| Belarus | M | M | M | — |
| Lithuania | M | M | M | L |
| Russian Federation | M | L | M | M |
| Ukraine | M | M | L | M |
| *CPA* | | | | |
| China | M | M | H | M |
| Viet Nam | L | L | M | — |

TABLE 52. (cont.)

| Region/country | District heating | Water desalination | Process heat | Ship propulsion |
|---|---|---|---|---|
| *SAS* | | | | |
| India | M | H | M | M |
| Pakistan | M | H | M | L |
| *PAS* | | | | |
| Indonesia | L | M | M | L |
| Korea, Republic of | M | M | M | M |
| Taiwan, China | M | L | L | M |
| *PAO* | | | | |
| Japan | M | M | L | M |

**Abbreviations:** — = negligible, L = low, M = medium, H = high; the meaning is as defined in Section 3.

# 11. CONCLUSIONS

## 11.1. GENERAL CONCLUSIONS

The analysis of the market potential for the non-electric applications of nuclear energy leads to the following conclusions:

(a) For the foreseeable future, power generation will remain the main application of nuclear energy, the main reasons being the advanced status of nuclear power production technologies and an increasing share of electricity in the final energy demand.

(b) Currently, nuclear power has little penetration of the non-electric energy market. However, a large demand for non-electric nuclear energy is expected to emerge and grow rapidly, owing to:
  - Increased energy use due to population growth and development;
  - The finite availability of fossil fuels;
  - The replacement of the direct use of fossil fuels;
  - An increased sensitivity to the environmental impacts of fossil fuel combustion.

(c) Because of the dominance of power generation, nuclear penetration into the markets for non-electric services will proceed with cogeneration applications wherever possible. Dedicated reactors for heat generation could eventually emerge for some applications.

(d) Many non-electric applications require energy sources that are relatively small (100–1000 MW(th)) in comparison with the size of existing power reactors. The development of nuclear reactors of small and medium size would therefore facilitate the non-electric applications of nuclear energy.

(e) Some non-electric applications require a close siting of the nuclear plant to the customer. This will require specific safety features appropriate to the location.

(f) Economically, the non-electric applications of nuclear energy are subject to the same trends as nuclear power generation. Growing capital costs of nuclear plants have affected the cost estimations of most non-electric applications. Evolutionary and innovative design improvements in nuclear reactor concepts, coupled with stable nuclear fuel prices, will result in an improved competitiveness of the non-electric nuclear applications.

(g) Depending upon the regions and conditions, nuclear energy is already competitive for district heating, desalination and certain process heat applications.

(h) Using nuclear energy to produce hydrogen is likely to facilitate the indirect application of nuclear energy in transportation markets, most of which are not readily amenable to the direct use of nuclear reactors.

(i) Non-electric applications of nuclear energy are most likely to be implemented in countries already having the appropriate nuclear infrastructure and institutional support.

(j) The implementation of some non-electric applications (e.g. desalination) is likely to enhance the public acceptance of nuclear energy.

## 11.2. SPECIFIC CONCLUSIONS (BY APPLICATION)

Five main non-electric applications of nuclear energy have been considered: district heating, water desalination, process heat supply, ship propulsion and the supply of spacecraft energy. The following specific findings for these applications can be formulated, in addition to the general conclusions above.

### 11.2.1. District heating

Nuclear applications for district heating are technically mature and exist in several countries. The future use of nuclear energy will be determined by a combination of the following factors: the size and growth of the demand for space and water heating, competition between heat and non-heat energy carriers for space and water heating and competition between nuclear and non-nuclear heating. The availability of a heat distribution network plays an important role in the prospects for nuclear district heating.

### 11.2.2. Water desalination

For desalination, low temperature heat and/or electricity is required. Consequently, all existing nuclear designs can be used; the relevant experience is already available. The use of nuclear heat assumes a close location of the nuclear plant to the desalination plant; the use of electricity generated by nuclear energy (for the RO desalination process) does not differ from any other electricity use — the energy source may be located far from the customer, electricity being provided through the electricity grid. (It should be noted, however, that a distant location would not allow the use of low temperature steam for water preheating, which is an advantage of coproduction plants.) With regard to the market size, it is expected that freshwater requirements will grow in the future, which will increase the attractiveness of nuclear desalination.

### 11.2.3. Process heat supply

For process heat supply there is a wide range of required heat parameters that determine the applicability of different reactor concepts. One particular concept, the HTGR, covers practically the whole temperature range and is therefore considered to be a prime candidate for nuclear process heat supply. The development and demonstration of such a reactor would provide a strong impetus for the process heat applications of nuclear energy.

### 11.2.4. Ship propulsion

Nuclear powered ship propulsion has been tested technically in several countries. However, so far it has appeared non-economic and the use of nuclear powered ship propulsion has been discontinued, with the exception of the nuclear powered ships operating off the north of the Russian Federation. Although the market for large tankers and cargo ships is large, the future of nuclear powered ships will depend on their ability to offer competitive service in this highly competitive market. The need to observe safety and licensing requirements in receiving ports is an additional obstacle for the application of nuclear powered ship propulsion.

### 11.2.5. Supply of spacecraft energy

The application of nuclear reactors for the supply of spacecraft energy has been tested — dozens of nuclear powered missions have been launched in the past. With the exception of the SNAP-10A mission launched by the USA in 1965, all missions have been Soviet. However, at present there is a need to develop a concept that would correspond to the current safety requirements and, at the same time, possesses features that would be superior to the non-nuclear options. Achieving this goal is more likely for medium and long duration space missions, in which, in terms of power level, load weight and mission duration, there is no other energy carrier that is comparable with nuclear energy. No such nuclear design is currently flight ready, but there is active research with chances for success.

### 11.2.6. Hydrogen production

Two aspects must be distinguished: the penetration of hydrogen into the energy system and the use of nuclear energy for hydrogen production. At present, the share of hydrogen in the world's energy supply is negligible, owing to the absence of a significant market and the need to develop an adequate transmission and distribution infrastructure. However, the potential advantages of hydrogen are huge and the appearance of a hydrogen based energy system is probable. In comparison with the use of fossil fuels for hydrogen production, nuclear energy has the advantages of a large resource base and the absence of most air emissions, carbon dioxide in particular. In comparison with the use of renewable energy sources for hydrogen production, nuclear energy has the advantage of being a mature, available technology and has the important feature of a high energy concentration, which will allow hydrogen production to be concentrated in multiproduct energy centres. The share of nuclear energy in a hydrogen based system will depend on its competitiveness with the other energy options. Successful demonstration projects, such as the use of surplus nuclear capacity for hydrogen production using cheap off-peak electricity, the operation of the first large HTGR and the creation of local hydrogen markets near existing NPPs, would help to promote the nuclear–hydrogen link.

### 11.2.7. Coal gasification

Coal gasification has the following advantages: the mitigation of air emissions from coal combustion, an increased thermal efficiency of combustion and the use of a large resource base. If coal gasification becomes widespread, economic and environmentally benign technologies for the supply of gasification energy will be required. Nuclear energy, being an industrially mature and non-polluting technology, is a valid candidate for this purpose. Such applications would be similar to the other process heat applications of nuclear energy.

### 11.2.8. Other synthetic fuels

The demand for transportation energy amounts to about one quarter of the world's final energy and will grow significantly in the future following, in particular, industrial growth and an increase in the standards of living in developing countries.

The direct use of nuclear energy for transportation is limited to the use of electric driven motors and ship and spacecraft propulsion. However, using nuclear energy for transportation indirectly, through fuel production, is possible. The related fuels, in addition to electricity and hydrogen, include alcohol fuels (methanol, ethanol and their derivatives), compressed natural gas, liquefied natural gas, liquefied petroleum gas and coal derived liquid fuels. It is likely that no fuel can be judged the best in the short and medium term. Each fuel has certain advantages and may have a place in the future fuel economy. The future fuel mix will be determined primarily by interfuel economic competition and environmental considerations such as the amount and type of GHGs and other polluting emissions.

### 11.2.9. Oil extraction

Nuclear energy can be used for the extraction of unconventional oil resources such as heavy oil, oil from tar and oil sands and the oil remaining in depleted deposits. These unconventional oil resources are about two times larger than the resources of conventional oil. However, if the price of conventional oil is low it is not realistic to expect significant developments in the extraction of unconventional oil, except in the cases (as, for example, in Canada) in which the resources of unconventional oil are large and already developed. The case of Canada is especially notable because, on one hand, the resources of unconventional oil are very large, and, on the other, nuclear technologies suitable for such applications are available.

### 11.2.10. Use of nuclear submarines for fossil fuel transportation

The idea of STVs has been considered in the Russian Federation to facilitate the transportation of goods through the northern sea route, including the transportation of oil and gas from prospective deposits in the Arctic. STVs have the potential advantages of being able to use the shortest route, being free of the condition of the water's surface and enabling a high and constant speed of movement. Technical and economic research on STVs for use in Arctic conditions was conducted in the Russian Federation between 1990 and 1997. As a result, two specific technical designs were determined: a container transporter and a tanker. The successful implementation of such projects would allow the consideration of other STV applications in addition to transportation in the Russian Arctic.

# Appendix I

## DEFINITIONS OF WORLD REGIONS

TABLE 53. DEFINITIONS OF WORLD REGIONS [36]

| Region | Abbreviation | Countries and territories included |
|---|---|---|
| North America | NAM | Canada, Guam, Puerto Rico, USA, Virgin Islands |
| Latin America and the Caribbean | LAM | Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guyana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela |
| Sub-Saharan Africa | AFR | Angola, Benin, Botswana, British Indian Ocean Territory, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, St. Helena, Swaziland, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe |
| Middle East and North Africa | MEA | Algeria, Bahrain, Egypt, Iraq, Iran, Islamic Republic of, Israel, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Morocco, Oman, Qatar, Saudi Arabia, Sudan, Syrian Arab Republic, Tunisia, United Arab Emirates, Yemen |
| Western Europe | WEU | Andorra, Austria, Azores, Belgium, Canary Islands, Channel Islands, Cyprus, Denmark, Faeroe Islands, Finland, France, Germany, Gibraltar, Greece, Greenland, Iceland, Ireland, Isle of Man, Italy, Liechtenstein, Luxembourg, Madeira, Malta, Monaco, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, UK |

TABLE 53. (cont.)

| Region | Abbreviation | Countries and territories included |
|---|---|---|
| Central and eastern Europe | EEU | Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, The Former Yugoslav Republic of Macedonia, Yugoslavia, Federal Republic of |
| Newly Independent States of the former Soviet Union | FSU | Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan |
| Centrally planned Asia and China | CPA | Cambodia, China, Democratic People’s Republic of Korea, Hong Kong, China, Lao People’s Democratic Republic, Mongolia, Viet Nam |
| South Asia | SAS | Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka |
| Other Pacific Asia | PAS | American Samoa, Brunei Darussalam, Fiji, French Polynesia, Indonesia, Kiribati, Malaysia, Myanmar, New Caledonia, Papua New Guinea, Philippines, Korea, Republic of, Samoa, Singapore, Solomon Islands, Taiwan, China, Thailand, Tonga, Vanuatu |
| Pacific OECD | PAO | Australia, Japan, New Zealand |

# Appendix II

## QUALITATIVE INDICATORS FOR THE PUBLIC ACCEPTANCE OF NUCLEAR ENERGY

Tables 54 and 55 show the results of the described qualitative ranking for the public acceptance of nuclear energy. This ranking is used for all potential applications, as the acceptance of nuclear energy does not much depend on the type of application to be used.

TABLE 54. ESTIMATES BY COUNTRY/TERRITORY

| Region | Country/territory | Population (in 1990) (millions)[a] | Ranking for public attitude |
|---|---|---|---|
| NAM | Canada | 27.8 | 1 |
| | Guam | 0.1 | 0 |
| | Puerto Rico | 3.5 | 0 |
| | USA | 249.9 | 1 |
| | Virgin Islands | 0.1 | 0 |
| Total for NAM | | 281.5 | 1.0 |
| | | | |
| LAM | Antigua and Barbuda | 0.1 | 0 |
| | Argentina | 32.5 | 1 |
| | Bahamas | 0.3 | 0 |
| | Barbados | 0.3 | 0 |
| | Belize | 0.2 | 0 |
| | Bermuda | 0.1 | 0 |
| | Bolivia | 6.6 | 0 |
| | Brazil | 148.5 | 1 |
| | Chile | 13.2 | 1 |
| | Colombia | 32.3 | 0 |
| | Costa Rica | 3.3 | 0 |
| | Cuba | 10.6 | 1 |
| | Dominica | 0.1 | 0 |
| | Dominican Republic | 7.1 | 0 |
| | Ecuador | 10.3 | 0 |
| | El Salvador | 6.3 | 0 |
| | French Guiana | 0.1 | 0 |
| | Grenada | 0.1 | 0 |
| | Guadeloupe | 0.4 | 0 |
| | Guatemala | 9.2 | 0 |

TABLE 54. (cont.)

| Region | Country/territory | Population (in 1990) (millions)$^{a}$ | Ranking for public attitude |
|---|---|---|---|
| | Guyana | 0.8 | 0 |
| | Haiti | 6.5 | 0 |
| | Honduras | 4.9 | 0 |
| | Jamaica | 2.4 | 0 |
| | Martinique | 0.4 | 0 |
| | Mexico | 84.5 | 1 |
| | Netherlands Antilles | 0.2 | 0 |
| | Nicaragua | 3.7 | 0 |
| | Panama | 2.4 | 0 |
| | Paraguay | 4.3 | 0 |
| | Peru | 21.6 | 1 |
| | Saint Kitts and Nevis | 0 | 0 |
| | Saint Lucia | 0.1 | 0 |
| | Saint Vincent and the Grenadines | 0.1 | 0 |
| | Suriname | 0.4 | 0 |
| | Trinidad and Tobago | 1.2 | 0 |
| | Uruguay | 3.1 | 1 |
| | Venezuela | 19.5 | 1 |
| Total for LAM | | 437.4 | 0.7 |
| | | | |
| AFR | Angola | 9.9 | 0 |
| | Benin | 4.6 | 0 |
| | Botswana | 1.3 | 0 |
| | British Indian Ocean Territory | 0 | 0 |
| | Burkina Faso | 9.0 | 0 |
| | Burundi | 5.5 | 0 |
| | Cameroon | 11.5 | 0 |
| | Cape Verde | 0.3 | 0 |
| | Central African Republic | 2.9 | 0 |
| | Chad | 5.6 | 0 |
| | Comoros | 0.5 | 0 |
| | Congo | 2.2 | 0 |
| | Cote d’Ivoire | 12.0 | 0 |
| | Democratic Republic of the Congo | 37.4 | 0 |
| | Djibouti | 0.5 | 0 |

TABLE 54. (cont.)

| Region | Country/territory | Population (in 1990) (millions)[a] | Ranking for public attitude |
|---|---|---|---|
| | Equatorial Guinea | 0.4 | 0 |
| | Eritrea | 3.6 | 0 |
| | Ethiopia | 47.0 | 0 |
| | Gabon | 1.1 | 0 |
| | Gambia | 0.9 | 0 |
| | Ghana | 15.0 | 0 |
| | Guinea | 5.8 | 0 |
| | Guinea-Bissau | 1.0 | 0 |
| | Kenya | 23.6 | 0 |
| | Lesotho | 1.8 | 0 |
| | Liberia | 2.6 | 0 |
| | Madagascar | 12.6 | 0 |
| | Malawi | 8.3 | 0 |
| | Mali | 9.2 | 0 |
| | Mauritania | 2.0 | 0 |
| | Mauritius | 1.0 | 0 |
| | Mozambique | 14.2 | 0 |
| | Namibia | 1.3 | 0 |
| | Niger | 7.7 | 0 |
| | Nigeria | 96.2 | 0 |
| | Reunion | 0.6 | 0 |
| | Rwanda | 7.2 | 0 |
| | Sao Tome and Principe | 0.1 | 0 |
| | Senegal | 7.3 | 0 |
| | Seychelles | 0.1 | 0 |
| | Sierra Leone | 4 | 0 |
| | Somalia | 8.7 | 0 |
| | South Africa | 37.1 | 2 |
| | St. Helena | 0.1 | 0 |
| | Swaziland | 0.8 | 0 |
| | Togo | 3.5 | 0 |
| | Uganda | 18.0 | 0 |
| | United Republic of Tanzania | 25.6 | 0 |
| | Zambia | 8.2 | 0 |
| | Zimbabwe | 9.9 | 0 |
| Total for AFR | | 489.7 | 0.2 |
| MEA | Algeria | 24.9 | 0 |
| | Bahrain | 0.5 | 0 |

TABLE 54. (cont.)

| Region | Country/territory | Population (in 1990) (millions)$^a$ | Ranking for public attitude |
|---|---|---|---|
| | Egypt | 56.3 | 1 |
| | Iraq | 58.9 | 0 |
| | Iran, Islamic Republic of | 18.1 | 2 |
| | Israel | 4.7 | 1 |
| | Jordan | 4.3 | 0 |
| | Kuwait | 2.1 | 0 |
| | Lebanon | 2.6 | 0 |
| | Libyan Arab Jamahiriya | 4.5 | 0 |
| | Morocco | 24.3 | 1 |
| | Oman | 1.8 | 0 |
| | Qatar | 1.8 | 0 |
| | Saudi Arabia | 16.0 | 0 |
| | Sudan | 24.6 | 0 |
| | Syrian Arab Republic | 12.3 | 0 |
| | Tunisia | 8.1 | 0 |
| | United Arab Emirates | 1.7 | 0 |
| | Yemen | 11.3 | 0 |
| Total for MEA | | 278.8 | 0.4 |
| WEU | Andorra | 0.1 | 0 |
| | Austria | 7.7 | 0 |
| | Azores | 0 | 0 |
| | Belgium | 10.0 | 1 |
| | Canary Islands | 0 | 0 |
| | Channel Islands | 0 | 0 |
| | Cyprus | 0.7 | 0 |
| | Denmark | 5.1 | 0 |
| | Faeroe Islands | 0.1 | 0 |
| | Finland | 5.0 | 1 |
| | France | 56.7 | 2 |
| | Germany | 79.4 | 0 |
| | Gibraltar | 0 | 0 |
| | Greece | 10.2 | 1 |
| | Greenland | 0.1 | 0 |
| | Iceland | 0.3 | 0 |
| | Ireland | 3.5 | 0 |
| | Isle of Man | 0 | 0 |
| | Italy | 57.0 | 0 |
| | Liechtenstein | 0 | 0 |

TABLE 54. (cont.)

| Region | Country/territory | Population (in 1990) (millions)[a] | Ranking for public attitude |
|---|---|---|---|
| | Luxembourg | 0.4 | 0 |
| | Madeira | 0 | 0 |
| | Malta | 0.4 | 0 |
| | Monaco | 0 | 0 |
| | Netherlands | 15.0 | 1 |
| | Norway | 4.2 | 1 |
| | Portugal | 9.9 | 1 |
| | Spain | 39.3 | 1 |
| | Sweden | 8.6 | 0 |
| | Switzerland | 6.8 | 1 |
| | Turkey | 56.1 | 1 |
| | UK | 57.4 | 1 |
| Total for WEU | | 433.9 | 0.8 |
| EEU | Albania | 3.8 | 0 |
| | Bosnia and Herzegovina | 4.4 | 0 |
| | Bulgaria | 9.0 | 1 |
| | Croatia | 4.8 | 1 |
| | Czech Republic | 10.3 | 1 |
| | Hungary | 10.4 | 1 |
| | Poland | 38.1 | 1 |
| | Romania | 23.2 | 1 |
| | Slovakia | 5.4 | 1 |
| | Slovenia | 2.0 | 1 |
| | The Former Yugoslav Republic of Macedonia | 2.1 | 0 |
| | Yugoslavia, Federal Republic of | 10.5 | 0 |
| Total for EEU | | 123.9 | 0.8 |
| FSU | Armenia | 3.7 | 1 |
| | Azerbaijan | 7.3 | 0 |
| | Belarus | 10.3 | 1 |
| | Estonia | 1.5 | 0 |
| | Georgia | 5.5 | 0 |
| | Kazakhstan | 16.9 | 1 |
| | Kyrgyzstan | 4.5 | 0 |
| | Latvia | 2.6 | 0 |

TABLE 54. (cont.)

| Region | Country/territory | Population (in 1990) (millions)[a] | Ranking for public attitude |
|---|---|---|---|
| | Lithuania | 3.7 | 1 |
| | Republic of Moldova | 4.4 | 0 |
| | Russian Federation | 148.3 | 1 |
| | Tajikistan | 5.6 | 0 |
| | Turkmenistan | 4.0 | 0 |
| | Ukraine | 52.2 | 1 |
| | Uzbekistan | 21.4 | 0 |
| Total for FSU | | 291.8 | 0.8 |
| CPA | Cambodia | 8.8 | 0 |
| | China | 1155.3 | 2 |
| | Democratic People's Republic of Korea | 21.8 | 0 |
| | Hong Kong, China | 5.7 | 0 |
| | Lao People's Democratic Republic | 4.2 | 0 |
| | Mongolia | 2.2 | 0 |
| | Viet Nam | 66.7 | 1 |
| Total for CPA | | 1264.7 | 1.9 |
| SAS | Afghanistan | 15.0 | 0 |
| | Bangladesh | 108.1 | 0 |
| | Bhutan | 1.5 | 0 |
| | India | 851.0 | 2 |
| | Maldives | 0.2 | 0 |
| | Nepal | 19.3 | 0 |
| | Pakistan | 121.9 | 2 |
| | Sri Lanka | 17.2 | 0 |
| Total for SAS | | 1134.0 | 1.7 |
| PAS | American Samoa | 0.1 | 0 |
| | Brunei Darussalam | 0.3 | 0 |
| | Fiji | 0.7 | 0 |
| | French Polynesia | 0.2 | 0 |
| | Indonesia | 182.8 | 1 |
| | Malaysia | 17.9 | 0 |
| | Myanmar | 41.8 | 0 |
| | New Caledonia | 0.2 | 0 |

TABLE 54. (cont.)

| Region | Country/territory | Population (in 1990) (millions)[a] | Ranking for public attitude |
|---|---|---|---|
| | Papua New Guinea | 3.6 | 0 |
| | Philippines | 60.8 | 1 |
| | Kiribati | 0.1 | 0 |
| | Korea, Republic of | 42.9 | 2 |
| | Samoa | 0.2 | 0 |
| | Singapore | 2.7 | 0 |
| | Solomon Islands | 0.3 | 0 |
| | Taiwan, China | 20.4 | 1 |
| | Thailand | 55.6 | 1 |
| | Tonga | 0.1 | 0 |
| | Vanuatu | 0.2 | 0 |
| Total for PAS | | 430.8 | 0.9 |
| | | | |
| PAO | Australia | 16.9 | 0 |
| | Japan | 123.5 | 1 |
| | New Zealand | 3.4 | 0 |
| Total for PAO | | 143.8 | 0.9 |
| | | | |
| World total | | 5359.2 | 1.2 |

[a] Used for weighting.

TABLE 55. SUMMARY BY WORLD REGIONS

| Region | Number of countries | Population (in 1990) (millions)[a] | Ranking for public attitude |
|---|---|---|---|
| NAM | 5 | 281 | 1.0 (medium) |
| LAM | 38 | 437 | 0.7 (low) |
| AFR | 50 | 489 | 0.2 (negligible) |
| MEA | 19 | 279 | 0.4 (negligible) |
| WEU | 32 | 434 | 0.8 (low) |
| EEU | 12 | 124 | 0.8 (low) |
| FSU | 15 | 292 | 0.8 (low) |
| CPA | 7 | 1265 | 1.9 (high) |
| SAS | 8 | 1134 | 1.7 (high) |
| PAS | 19 | 430 | 0.9 (low) |
| PAO | 3 | 144 | 0.9 (low) |
| Total | 208 | 5359 | 1.2 (medium) |

[a] Used for weighting.

# Appendix III

## STATISTICS OF HEAT SUPPLY AND DEMAND

TABLE 56. STATISTICS OF HEAT SUPPLY AND DEMAND IN 1996 [34, 35]

| Region | Country/territory | Final energy demand (Mtoe) | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|
| | | Total | Share of RAC[a] | Total | Share of RAC[a] | In RAC[b] | In total final energy demand[c] |
| NAM | Canada | 184.3 | 61.1 | 0.5 | 0.0 | 0.0 | 0.3 |
| | Guam | | | | | | |
| | Puerto Rico | | | | | | |
| | USA | 1435.8 | 456.2 | 7.6 | 2.3 | 0.5 | 0.5 |
| | Virgin Islands | | | | | | |
| Total for NAM | | 1620.1 | 517.3 | 8.1 | 2.3 | 0.4 | 0.5 |
| | | | | | | | |
| LAM | Antigua and Barbuda | | | | | | |
| | Argentina | 39.8 | 13.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Bahamas | | | | | | |
| | Barbados | | | | | | |
| | Belize | | | | | | |
| | Bermuda | | | | | | |
| | Bolivia | 2.7 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Brazil | 138.2 | 31.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Chile | 16.4 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 |

TABLE 56. (cont.)

| Region | Country/territory | Final energy demand (Mtoe) | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|
| | | Total | Share of RAC[a] | Total | Share of RAC[a] | In RAC[b] | In total final energy demand[c] |
| | Colombia | 26.0 | 9.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Costa Rica | 2.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Cuba | 12.5 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Dominica | | | | | | |
| | Dominican Republic | 3.6 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Ecuador | 6.8 | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | El Salvador | 3.2 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | French Guiana | | | | | | |
| | Grenada | | | | | | |
| | Guadeloupe | | | | | | |
| | Guatemala | 4.9 | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Guyana | | | | | | |
| | Haiti | 1.6 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Honduras | 2.9 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Jamaica | 2.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Martinique | | | | | | |
| | Mexico | 94.1 | 22.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Netherlands Antilles | 0.8 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Nicaragua | 1.8 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Panama | 1.8 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Paraguay | 3.9 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Peru | 12.3 | 6.2 | 0.0 | 0.0 | 0.0 | 0.0 |

TABLE 56. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Saint Kitts and Nevis | | | | | | |
| | Saint Lucia | | | | | | |
| | Saint Vincent and the Grenadines | | | | | | |
| | Suriname | | | | | | |
| | Trinidad and Tobago | 5.2 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Uruguay | 2.4 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Venezuela | 33.5 | 5.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for LAM | | 418.0 | 114.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | | | | | |
| AFR | Angola | 4.3 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Benin | 1.9 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Botswana | | | | | | |
| | British Indian Ocean Territory | | | | | | |
| | Burkina Faso | | | | | | |
| | Burundi | | | | | | |
| | Cameroon | 5.1 | 3.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Cape Verde | | | | | | |
| | Central African Republic | | | | | | |
| | Chad | | | | | | |
| | Comoros | | | | | | |
| | Congo | 1.1 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Cote d’Ivoire | 3.4 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Democratic Republic of the Congo | | | | | | |
| | Djibouti | | | | | | |
| | Equatorial Guinea | | | | | | |

TABLE 56. (cont.)

| Region | Country/territory | Final energy demand (Mtoe) | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|
| | | Total | Share of RAC[a] | Total | Share of RAC[a] | In RAC[b] | In total final energy demand[c] |
| | Eritrea | | | | | | |
| | Ethiopia | 15.9 | 15.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Gabon | 1.4 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Gambia | | | | | | |
| | Ghana | 5.1 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Guinea | | | | | | |
| | Guinea-Bissau | | | | | | |
| | Kenya | 10.1 | 7.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Lesotho | | | | | | |
| | Liberia | | | | | | |
| | Madagascar | | | | | | |
| | Malawi | | | | | | |
| | Mali | | | | | | |
| | Mauritania | | | | | | |
| | Mauritius | | | | | | |
| | Mozambique | 6.2 | 6.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Namibia | | | | | | |
| | Niger | | | | | | |
| | Nigeria | 73.1 | 58.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Reunion | | | | | | |
| | Rwanda | | | | | | |
| | Sao Tome and Principe | | | | | | |

TABLE 56. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Senegal | 2.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Seychelles | | | | | | |
| | Sierra Leone | | | | | | |
| | Somalia | | | | | | |
| | South Africa | 54.3 | 17.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | St. Helena | | | | | | |
| | Swaziland | | | | | | |
| | Togo | | | | | | |
| | Uganda | | | | | | |
| | United Republic of Tanzania | 12.5 | 10.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Zambia | 4.4 | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Zimbabwe | 8.5 | 6.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for AFR | | 209.3 | 142.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| MEA | Algeria | 14.4 | 7.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Bahrain | 3.9 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Egypt | 25.2 | 6.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Iraq | 20.0 | 4.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Iran, Islamic Republic of | 87.1 | 35.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Israel | 11.3 | 4.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Jordan | 3.3 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Kuwait | 5.8 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Lebanon | 3.7 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Libyan Arab Jamahiriya | 9.0 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 |

TABLE 56. (cont.)

| Region | Country/territory | Final energy demand (Mtoe) | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|
| | | Total | Share of RAC[a] | Total | Share of RAC[a] | In RAC[b] | In total final energy demand[c] |
| | Morocco | 6.9 | 4.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Oman | 2.7 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Qatar | 2.9 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Saudi Arabia | 52.4 | 29.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Sudan | 5.2 | 4.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Syrian Arab Republic | 11.0 | 7.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Tunisia | 5.2 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | United Arab Emirates | 8.0 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Yemen | 2.4 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for MEA | | 280.4 | 116.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| WEU | Andorra | | | | | | |
| | Austria | 22.2 | 9.4 | 0.9 | 0.0 | 0.0 | 4.0 |
| | Azores | | | | | | |
| | Belgium | 40.2 | 15.9 | 0.3 | 0.0 | 0.0 | 0.7 |
| | Canary Islands | | | | | | |
| | Channel Islands | | | | | | |
| | Cyprus | 1.5 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Denmark | 16.3 | 7.9 | 2.4 | 2.3 | 29.0 | 14.7 |
| | Faeroe Islands | | | | | | |
| | Finland | 23.3 | 8.3 | 2.8 | 2.1 | 25.6 | 11.8 |
| | France | 161.5 | 65.3 | 1.4 | 1.4 | 2.1 | 0.8 |

TABLE 56. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Germany | 247.6 | 106.4 | 9.0 | 7.3 | 6.9 | 3.7 |
| | Gibraltar | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Greece | 17.6 | 6.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Greenland | | | | | | |
| | Iceland | 1.9 | 1.0 | 0.2 | 0.0 | 0.0 | 8.7 |
| | Ireland | 8.8 | 3.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Isle of Man | | | | | | |
| | Italy | 124.3 | 40.7 | 0.2 | 0.0 | 0.0 | 0.2 |
| | Liechtenstein | | | | | | |
| | Luxembourg | 3.2 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Madeira | | | | | | |
| | Malta | 0.5 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Monaco | | | | | | |
| | Netherlands | 59.3 | 25.1 | 1.7 | 0.9 | 3.6 | 2.9 |
| | Norway | 19.4 | 6.9 | 0.1 | 0.1 | 1.3 | 0.6 |
| | Portugal | 15.1 | 3.7 | 0.1 | 0.0 | 0.0 | 0.3 |
| | Spain | 71.7 | 17.7 | 0.0 | 0.0 | 0.1 | 0.0 |
| | Sweden | 36.3 | 14.2 | 3.6 | 3.5 | 24.9 | 9.9 |
| | Switzerland | 20.6 | 10.0 | 0.3 | 0.3 | 2.6 | 1.6 |
| | Turkey | 51.8 | 20.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | UK | 161.3 | 65.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for WEU | | 1104.3 | 428.6 | 22.9 | 17.9 | 4.2 | 2.1 |
| EEU | Albania | 0.8 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Bosnia and Herzegovina | 0.8 | 0.3 | 0.0 | 0.0 | 0.0 | 3.1 |
| | Bulgaria | 12.7 | 4.6 | 2.9 | 0.9 | 19.2 | 22.6 |

TABLE 56. (cont.)

| Region | Country/territory | Final energy demand (Mtoe) | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|
| | | Total | Share of RAC[a] | Total | Share of RAC[a] | In RAC[b] | In total final energy demand[c] |
| | Croatia | 5.2 | 0.2 | 0.3 | 0.0 | 0.0 | 5.0 |
| | Czech Republic | 27.6 | 9.0 | 3.7 | 1.3 | 14.8 | 13.6 |
| | Hungary | 17.7 | 9.5 | 1.8 | 1.3 | 13.3 | 10.0 |
| | Poland | 72.6 | 33.5 | 9.3 | 7.6 | 22.7 | 12.9 |
| | Romania | 29.1 | 9.6 | 5.6 | 4.3 | 45.3 | 19.3 |
| | Slovakia | 12.7 | 4.8 | 0.8 | 0.7 | 15.2 | 5.9 |
| | Slovenia | 4.5 | 1.7 | 0.2 | 0.0 | 0.0 | 4.6 |
| | The Former Yugoslav Republic of Macedonia | 2.0 | 0.8 | 0.1 | 0.0 | 0.0 | 6.1 |
| | Yugoslavia, Federal Republic of | 8.4 | 4.7 | 0.5 | 0.0 | 0.0 | 5.4 |
| Total for EEU | | 194.0 | 79.1 | 25.1 | 16.1 | 20.4 | 13.0 |
| FSU | Armenia | 0.7 | 0.4 | 0.1 | 0.0 | 0.0 | 10.8 |
| | Azerbaijan | 10.9 | 5.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Belarus | 19.0 | 9.4 | 7.3 | 4.3 | 45.8 | 38.4 |
| | Estonia | 2.9 | 1.4 | 0.8 | 0.6 | 41.8 | 27.4 |
| | Georgia | 1.7 | 1.2 | 0.5 | 0.0 | 0.0 | 28.3 |
| | Kazakhstan | 23.1 | 11.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Kyrgyzstan | 2.4 | 1.5 | 0.5 | 0.0 | 0.0 | 19.2 |
| | Latvia | 3.6 | 2.1 | 1.1 | 0.8 | 36.3 | 30.6 |

TABLE 56. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Lithuania | 5.1 | 2.1 | 1.4 | 0.9 | 44.8 | 28.4 |
| | Republic of Moldova | 3.1 | 2.1 | 0.3 | 0.0 | 0.0 | 10.5 |
| | Russian Federation | 468.0 | 247.1 | 169.3 | 76.2 | 30.8 | 36.2 |
| | Tajikistan | 2.9 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Turkmenistan | 7.8 | 7.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Ukraine | 98.5 | 44.1 | 10.4 | 3.7 | 8.3 | 10.5 |
| | Uzbekistan | 32.4 | 21.4 | 2.6 | 0.0 | 0.0 | 7.9 |
| Total for FSU | | 682.1 | 358.6 | 194.2 | 86.5 | 24.1 | 28.5 |
| CPA | Cambodia | | | | | | |
| | China | 865.9 | 368.2 | 21.3 | 0.0 | 0.0 | 2.5 |
| | Democratic People's Republic of Korea | 18.6 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Hong Kong, China | 10.0 | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Lao People's Democratic Republic | | | | | | |
| | Mongolia | | | | | | |
| | Viet Nam | 29.9 | 22.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for CPA | | 924.3 | 395.3 | 21.3 | 0.0 | 0.0 | 2.5 |
| SAS | Afghanistan | | | | | | |
| | Bangladesh | 22.3 | 13.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Bhutan | | | | | | |
| | India | 350.3 | 198.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Maldives | | | | | | |
| | Nepal | 7.0 | 6.5 | 0.0 | 0.0 | 0.0 | 0.0 |

TABLE 56. (cont.)

| Region | Country/territory | Final energy demand (Mtoe) | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|
| | | Total | Share of RAC[a] | Total | Share of RAC[a] | In RAC[b] | In total final energy demand[c] |
| | Pakistan | 46.8 | 25.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Sri Lanka | 6.3 | 3.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for SAS | | 432.7 | 247.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| PAS | American Samoa | | | | | | |
| | Brunei Darussalam | 0.7 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Fiji | | | | | | |
| | French Polynesia | | | | | | |
| | Indonesia | 99.8 | 58.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Malaysia | 26.4 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Myanmar | 10.4 | 8.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | New Caledonia | | | | | | |
| | Papua New Guinea | | | | | | |
| | Philippines | 24.3 | 11.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Kiribati | | | | | | |
| | Korea, Republic of | 120.4 | 37.4 | 1.2 | 0.0 | 0.0 | 1.0 |
| | Samoa | | | | | | |
| | Singapore | 9.4 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Solomon Islands | | | | | | |
| | Taiwan, China | 46.4 | 8.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Thailand | 54.7 | 15.1 | 0.0 | 0.0 | 0.0 | 0.0 |

TABLE 56. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Tonga | | | | | | |
| | Vanuatu | | | | | | |
| Total for PAS | | 392.4 | 146.1 | 1.2 | 0.0 | 0.0 | 0.3 |
| | | | | | | | |
| PAO | Australia | 66.3 | 14.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Japan | 337.0 | 103.0 | 0.4 | 0.4 | 0.4 | 0.1 |
| | New Zealand | 12.2 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for PAO | | 415.4 | 119.7 | 0.4 | 0.4 | 0.3 | 0.1 |
| | | | | | | | |
| Total | | 6673.0 | 2664.9 | 273.2 | 123.2 | 4.6 | 4.1 |

**Note:** Data are not available if none are shown.

[a] RAC: residential, agricultural and commercial sectors.

[b] Share of the residential, agricultural and commercial sectors, centralized heat generation/share of the residential, agricultural and commercial sectors, final energy demand.

[c] Total centralized heat generation/total final energy demand.

## Appendix IV

## ESTIMATE OF THE LONG TERM PROSPECTS FOR NUCLEAR PENETRATION IN DISTRICT HEATING

TABLE 57. ESTIMATE OF THE LONG TERM PROSPECTS FOR NUCLEAR PENETRATION IN DISTRICT HEATING

| Region | Country/territory | Total final energy demand in 1996 (Mtoe)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| NAM | Canada | 184.3 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Guam | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Puerto Rico | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | USA | 1435.8 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Virgin Islands | | 0 | 1 | 0 | 0 | 0 | 0.0 |
| Total for NAM | | 1620.1 | 0.00 | 1.00 | 2.00 | 1.00 | 1.00 | 1.00 |
| | | | | | | | | |
| LAM | Antigua and Barbuda | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Argentina | 39.8 | 0 | 1 | 2 | 0 | 1 | 0.8 |
| | Bahamas | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Barbados | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Belize | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Bermuda | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Bolivia | 2.7 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Brazil | 138.2 | 0 | 1 | 2 | 0 | 1 | 0.8 |
| | Chile | 16.4 | 0 | 1 | 1 | 0 | 1 | 0.6 |
| | Colombia | 26.0 | 0 | 1 | 1 | 0 | 0 | 0.4 |

TABLE 57. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Costa Rica | 2.0 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Cuba | 12.5 | 0 | 1 | 1 | 0 | 1 | 0.6 |
| Dominica | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Dominican Republic | 3.6 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Ecuador | 6.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| El Salvador | 3.2 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| French Guiana | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Grenada | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Guadeloupe | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Guatemala | 4.9 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Guyana | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Haiti | 1.6 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Honduras | 2.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Jamaica | 2.0 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Martinique | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Mexico | 94.1 | 0 | 1 | 2 | 0 | 1 | 0.8 |
| Netherlands Antilles | 0.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Nicaragua | 1.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Panama | 1.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Paraguay | 3.9 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Peru | 12.3 | 0 | 1 | 1 | 0 | 1 | 0.6 |
| Saint Kitts and Nevis | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Saint Lucia | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Saint Vincent and the Grenadines | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Suriname | | 0 | 1 | 0 | 0 | 0 | 0.2 |

TABLE 57. (cont.)

| Region | Country/territory | Total final energy demand in 1996 (Mtoe)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Trinidad and Tobago | 5.2 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Uruguay | 2.4 | 0 | 1 | 1 | 0 | 1 | 0.6 |
| | Venezuela | 33.5 | 0 | 1 | 1 | 0 | 1 | 0.6 |
| Total for LAM | | 418.0 | 0.00 | 1.00 | 1.55 | 0.00 | 0.84 | 0.68 |
| AFR | Angola | 4.3 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Benin | 1.9 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Botswana | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | British Indian Ocean Territory | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Burkina Faso | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Burundi | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Cameroon | 5.1 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Cape Verde | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Central African Republic | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Chad | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Comoros | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Congo | 1.1 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Cote d'Ivoire | 3.4 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Democratic Republic of the Congo | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Djibouti | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Equatorial Guinea | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Eritrea | | 0 | 1 | 0 | 1 | 0 | 0.4 |

TABLE 57. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ethiopia | 15.9 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Gabon | 1.4 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Gambia | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Ghana | 5.1 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Guinea | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Guinea-Bissau | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Kenya | 10.1 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Lesotho | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Liberia | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Madagascar | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Malawi | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Mali | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Mauritania | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Mauritius | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Mozambique | 6.2 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Namibia | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Niger | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Nigeria | 73.1 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Reunion | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Rwanda | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Sao Tome and Principe | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Senegal | 2.0 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Seychelles | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Sierra Leone | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Somalia | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| South Africa | 54.3 | 0 | 1 | 2 | 1 | 2 | 1.2 |

TABLE 57. (cont.)

| Region | Country/territory | Total final energy demand in 1996 (Mtoe)$^a$ | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | St. Helena | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Swaziland | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Togo | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Uganda | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | United Republic of Tanzania | 12.5 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Zambia | 4.4 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Zimbabwe | 8.5 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Total for AFR | | 209.3 | 0.00 | 1.00 | 0.52 | 0.65 | 0.52 | 0.54 |
| MEA | Algeria | 14.4 | 0 | 1 | 1 | 1 | 0 | 0.6 |
| | Bahrain | 3.9 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Egypt | 25.2 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | Iraq | 20.0 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Iran, Islamic Republic of | 87.1 | 0 | 1 | 1 | 1 | 2 | 1.0 |
| | Israel | 11.3 | 0 | 1 | 0 | 1 | 1 | 0.6 |
| | Jordan | 3.3 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Kuwait | 5.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Lebanon | 3.7 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Libyan Arab Jamahiriya | 9.0 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Morocco | 6.9 | 0 | 1 | 1 | 1 | 1 | 0.8 |

TABLE 57. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Oman | 2.7 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Qatar | 2.9 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Saudi Arabia | 52.4 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Sudan | 5.2 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Syrian Arab Republic | 11.0 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Tunisia | 5.2 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | United Arab Emirates | 8.0 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Yemen | 2.4 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Total for MEA | | 280.4 | 0.00 | 1.00 | 0.48 | 0.69 | 0.78 | 0.59 |
| | | | | | | | | |
| WEU | Andorra | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Austria | 22.2 | 0 | 1 | 1 | 1 | 0 | 0.6 |
| | Azores | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Belgium | 40.2 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Canary Islands | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Channel Islands | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Cyprus | 1.5 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Denmark | 16.3 | 2 | 1 | 1 | 1 | 0 | 1.0 |
| | Faeroe Islands | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Finland | 23.3 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | France | 161.5 | 1 | 1 | 2 | 1 | 2 | 1.4 |
| | Germany | 247.6 | 1 | 1 | 2 | 1 | 0 | 1.0 |
| | Gibraltar | 0.1 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Greece | 17.6 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | Greenland | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Iceland | 1.9 | 0 | 1 | 0 | 0 | 0 | 0.2 |

TABLE 57. (cont.)

| Region | Country/territory | Total final energy demand in 1996 (Mtoe)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Ireland | 8.8 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Isle of Man | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Italy | 124.3 | 0 | 1 | 1 | 1 | 0 | 0.6 |
| | Liechtenstein | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Luxembourg | 3.2 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Madeira | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Malta | 0.5 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Monaco | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Netherlands | 59.3 | 1 | 1 | 2 | 1 | 1 | 1.2 |
| | Norway | 19.4 | 1 | 1 | 1 | 1 | 1 | 1.0 |
| | Portugal | 15.1 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | Spain | 71.7 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Sweden | 36.3 | 2 | 1 | 2 | 1 | 0 | 1.2 |
| | Switzerland | 20.6 | 1 | 1 | 2 | 1 | 1 | 1.2 |
| | Turkey | 51.8 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | UK | 161.3 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| Total for WEU | | 1104.3 | 0.60 | 1.00 | 1.73 | 1.00 | 0.73 | 1.01 |
| EEU | Albania | 0.8 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Bosnia and Herzegovina | 0.7 | 0 | 1 | 1 | 1 | 0 | 0.6 |
| | Bulgaria | 12.7 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | Croatia | 5.2 | 0 | 1 | 2 | 1 | 1 | 1.0 |

TABLE 57. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Czech Republic | 27.6 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | Hungary | 17.7 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | Poland | 72.6 | 2 | 1 | 1 | 1 | 1 | 1.2 |
| | Romania | 29.1 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | Slovakia | 12.7 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | Slovenia | 4.5 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | The Former Yugoslav Republic of Macedonia | 2.0 | 0 | 1 | 1 | 1 | 0 | 0.6 |
| | Yugoslavia, Federal Republic of | 8.4 | 0 | 1 | 1 | 1 | 0 | 0.6 |
| Total for EEU | | 194.0 | 1.78 | 1.00 | 1.56 | 1.00 | 0.94 | 1.26 |
| FSU | Armenia | 0.7 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Azerbaijan | 10.9 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Belarus | 19.0 | 2 | 1 | 1 | 1 | 1 | 1.2 |
| | Estonia | 2.9 | 2 | 1 | 0 | 1 | 0 | 0.8 |
| | Georgia | 1.7 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Kazakhstan | 23.1 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Kyrgyzstan | 2.4 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Latvia | 3.6 | 2 | 1 | 0 | 1 | 0 | 0.8 |
| | Lithuania | 5.1 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | Republic of Moldova | 3.1 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Russian Federation | 468.0 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | Tajikistan | 2.9 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Turkmenistan | 7.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Ukraine | 98.5 | 1 | 1 | 2 | 1 | 1 | 1.2 |

TABLE 57. (cont.)

| Region | Country/territory | Total final energy demand in 1996 (Mtoe)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Uzbekistan | 32.4 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Total for FSU | | 682.1 | 1.61 | 1.00 | 1.77 | 0.92 | 0.90 | 1.24 |
| CPA | Cambodia | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | China | 865.9 | 0 | 1 | 2 | 1 | 2 | 1.2 |
| | Democratic People's Republic of Korea | 18.6 | 0 | 1 | 1 | 1 | 0 | 0.6 |
| | Hong Kong, China | 10.0 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Lao People's Democratic Republic | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Mongolia | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Viet Nam | 29.9 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| Total for CPA | | 924.3 | 0.00 | 1.00 | 1.93 | 0.99 | 1.91 | 1.16 |
| SAS | Afghanistan | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Bangladesh | 22.3 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Bhutan | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | India | 350.0 | 0 | 1 | 2 | 1 | 2 | 1.2 |
| | Maldives | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Nepal | 6.9 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Pakistan | 46.8 | 0 | 1 | 2 | 1 | 2 | 1.2 |
| | Sri Lanka | 6.3 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Total for SAS | | 432.7 | 0.00 | 1.00 | 1.84 | 0.99 | 1.84 | 1.13 |

TABLE 57. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PAS | American Samoa | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Brunei Darussalam | 0.7 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Fiji | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | French Polynesia | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Indonesia | 99.8 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | Malaysia | 26.4 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Myanmar | 10.4 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | New Caledonia | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Papua New Guinea | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Philippines | 24.3 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | Kiribati | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Korea, Republic of | 120.4 | 0 | 1 | 2 | 1 | 2 | 1.2 |
| | Samoa | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Singapore | 9.4 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Solomon Islands | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Taiwan, China | 46.4 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Thailand | 54.7 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | Tonga | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Vanuatu | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Total for PAS | | 392.4 | 0.00 | 1.00 | 1.31 | 0.98 | 1.19 | 0.89 |
| | | | | | | | | |
| PAO | Australia | 66.3 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Japan | 337.0 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | New Zealand | 12.2 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Total for PAO | | 415.4 | 0.00 | 1.00 | 1.62 | 1.00 | 0.81 | 0.89 |
| | | | | | | | | |
| World total | | 6673.0 | 0.3 | 1.0 | 1.7 | 0.9 | 1.1 | 1.0 |

**Note:** Data are not available if none are shown.

[a] Used for weighting.

# Appendix V

## WATER SUPPLY AND DEMAND IN THE WORLD

TABLE 58. WATER SUPPLY AND DEMAND IN THE WORLD [50–52]

| Region | Country/ territory | Available water sources (km$^3$) | Assessment for 1990 | | | | | Assessment for 2025 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total water withdrawal (km$^3$) | Domestic (m$^3$/capita) | Industrial (m$^3$/capita) | Agricultural (m$^3$/capita) | Total (m$^3$/capita) | Total water withdrawal (km$^3$) | Domestic (m$^3$/capita) | Industrial (m$^3$/capita) | Agricultural (m$^3$/capita) | Total (m$^3$/capita) |
| NAM | Canada | 2901.0 | 44.5 | 288 | 1121 | 192 | 1602 | 61 | 288 | 1121 | 193 | 1602 |
| | Guam | 0.1 | 0.1 | 285 | 95 | 8 | 395 | 0 | 285 | 95 | 8 | 388 |
| | Puerto Rico | | 0.0 | | | | 0 | 0 | | | | |
| | USA | 2478.0 | 467.3 | 243 | 842 | 785 | 1870 | 619 | 243 | 842 | 785 | 1870 |
| | Virgin Islands | | | | | | 0 | 0 | | | | |
| Total for NAM | | 5379 | 512 | | | | 1842 | 681 | 248 | 871 | 724 | 1842 |
| LAM | Antigua and Barbuda | | | | | | | 0 | | | | |
| | Argentina | 994.0 | 33.9 | 94 | 188 | 761 | 1043 | 49 | 109 | 188 | 761 | 1058 |
| | Bahamas | | 0.0 | | | | | 0 | | | | |
| | Barbados | | 0.0 | | | | | 0 | | | | |
| | Belize | 16.0 | 0.0 | 11 | 0 | 98 | 109 | 0 | 22 | 1 | 0 | 23 |
| | Bermuda | | 0.0 | | | | 0 | 0 | | | | |
| | Bolivia | 300.0 | 1.3 | 20 | 10 | 171 | 201 | 3 | 29 | 20 | 168 | 217 |
| | Brazil | 6950.0 | 36.5 | 54 | 47 | 145 | 246 | 71 | 77 | 84 | 145 | 306 |
| | Chile | 468.0 | 21.4 | 358 | 309 | 959 | 1626 | 32 | 358 | 309 | 961 | 1628 |
| | Colombia | 1070.0 | 5.6 | 71 | 28 | 75 | 174 | 10 | 71 | 53 | 75 | 199 |

TABLE 58. (cont.)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Costa Rica | 95.0 | 2.6 | 31 | 55 | 694 | 780 | 5 | 57 | 55 | 695 | 807 |
| Cuba | 34.5 | 9.2 | 78 | 17 | 774 | 870 | 11 | 78 | 26 | 774 | 878 |
| Dominica | | 0.0 | | | | 0 | 0 | | | | |
| Dominican Republic | 20.0 | 3.2 | 22 | 27 | 397 | 446 | 5 | 45 | 40 | 394 | 479 |
| Ecuador | 314.0 | 6.0 | 41 | 17 | 523 | 581 | 11 | 45 | 35 | 523 | 603 |
| El Salvador | 68.5 | 19.7 | 53 | 79 | 218 | 350 | 7 | 34 | 20 | 22 | 76 |
| French Guiana | | 0.0 | | | | | 0 | | | | |
| Grenada | | 0.0 | | | | | 0 | | | | |
| Guadeloupe | | 0.0 | | | | | 0 | | | | |
| Guatemala | 116.0 | 1.3 | 13 | 24 | 103 | 139 | 3 | 25 | 25 | 101 | 151 |
| Guyana | 241.0 | 1.4 | 18 | 0 | 1794 | 1812 | 2 | 33 | 1 | 1753 | 1787 |
| Haiti | 11.0 | 0.1 | 2 | 1 | 5 | 7 | 0 | 3 | 1 | 8 | 12 |
| Honduras | 63.4 | 1.4 | 12 | 15 | 268 | 294 | 3 | 24 | 20 | 272 | 316 |
| Jamaica | 8.3 | 0.4 | 11 | 11 | 137 | 159 | 1 | 22 | 22 | 152 | 196 |
| Martinique | | 0.0 | | | | | 0 | | | | |
| Mexico | 357.4 | 76.0 | 54 | 72 | 773 | 899 | 123 | 58 | 72 | 773 | 903 |
| Netherlands Antilles | | 0.0 | | | | | 0 | | | | |
| Nicaragua | 175.0 | 1.4 | 92 | 77 | 198 | 367 | 3 | 92 | 77 | 198 | 367 |
| Panama | 144.0 | 1.8 | 90 | 83 | 581 | 754 | 3 | 90 | 83 | 584 | 757 |
| Paraguay | 314.0 | 0.5 | 16 | 8 | 85 | 109 | 1 | 33 | 15 | 89 | 137 |
| Peru | 40.0 | 6.5 | 57 | 27 | 216 | 300 | 12 | 58 | 54 | 215 | 327 |
| Saint Kitts and Nevis | | 0.0 | | | | | 0 | | | | |
| Saint Lucia | | 0.0 | | | | | 0 | | | | |
| Saint Vincent and the Grenadines | | 0.0 | | | | | 0 | | | | |

TABLE 58. (cont.)

| Region | Country/ territory | Available water sources ($km^3$) | Assessment for 1990 | | | | | Assessment for 2025 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total water withdrawal ($km^3$) | Domestic ($m^3$/capita) | Industrial ($m^3$/capita) | Agricultural ($m^3$/capita) | Total ($m^3$/capita) | Total water withdrawal ($km^3$) | Domestic ($m^3$/capita) | Industrial ($m^3$/capita) | Agricultural ($m^3$/capita) | Total ($m^3$/capita) |
| | Suriname | 200.0 | 0.5 | 71 | 59 | 1058 | 1189 | 1 | 71 | 59 | 1002 | 1132 |
| | Trinidad and Tobago | 5.1 | 0.2 | 33 | 47 | 43 | 123 | 0 | 33 | 47 | 43 | 123 |
| | Uruguay | 124.0 | 0.7 | 14 | 7 | 219 | 241 | 1 | 29 | 14 | 217 | 260 |
| | Venezuela | 1317.0 | 7.5 | 164 | 42 | 176 | 382 | 14 | 164 | 71 | 175 | 410 |
| Total for LAM | | 13 446 | 239.0 | | | | 492 | 372 | 73 | 72 | 325 | 471 |
| AFR | Angola | 184.0 | 0.6 | 8 | 6 | 43 | 57 | 2 | 16 | 11 | 45 | 72 |
| | Benin | 25.8 | 0.1 | 6 | 3 | 19 | 28 | 0 | 13 | 6 | 16 | 35 |
| | Botswana | 14.7 | 0.1 | 27 | 17 | 41 | 85 | 0 | 54 | 35 | 34 | 123 |
| | British Indian Ocean Territory | | 0.0 | | | | | 0 | | | | |
| | Burkina Faso | 17.5 | 0.4 | 8 | 0 | 32 | 40 | 1 | 16 | 1 | 32 | 49 |
| | Burundi | 3.6 | 0.1 | 7 | 0 | 13 | 20 | 0 | 14 | 1 | 15 | 30 |
| | Cameroon | 268.0 | 0.4 | 14 | 6 | 11 | 31 | 1 | 23 | 12 | 10 | 45 |
| | Cape Verde | | 0.0 | | | | | 0 | | | | |
| | Central African Republic | 141.0 | 0.1 | 5 | 1 | 19 | 26 | 0 | 11 | 3 | 16 | 30 |
| | Chad | 43.0 | 0.2 | 5 | 1 | 28 | 34 | 1 | 11 | 1 | 31 | 43 |
| | Comoros | | 0.0 | | | | | 0 | | | | |
| | Congo | 832.0 | 0.0 | 12 | 5 | 2 | 20 | 0 | 25 | 11 | 0 | 36 |
| | Cote d’Ivoire | 77.7 | 0.8 | 14 | 7 | 43 | 64 | 3 | 28 | 14 | 44 | 86 |

TABLE 58. (cont.)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Democratic Republic of the Congo | 1019.0 | 0.3 | 5 | 1 | 2 | 9 | 2 | 11 | 3 | 2 | 16 |
| Djibouti | | 0.0 | | | | | 0 | | | | |
| Equatorial Guinea | 30.0 | 0.0 | 23 | 4 | 2 | 29 | 0 | 23 | 4 | 2 | 29 |
| Eritrea | | 0.0 | | | | | 0 | | | | |
| Ethiopia | 88.0 | 2.4 | 6 | 2 | 44 | 51 | 7 | 11 | 3 | 44 | 58 |
| Gabon | 164.0 | 0.1 | 41 | 13 | 3 | 57 | 0 | 77 | 25 | 0 | 102 |
| Gambia | 8.0 | 0.0 | 2 | 1 | 26 | 29 | 0 | 4 | 1 | 48 | 53 |
| Ghana | 53.2 | 0.5 | 12 | 5 | 18 | 35 | 2 | 20 | 9 | 18 | 47 |
| Guinea | 226.0 | 0.8 | 14 | 4 | 121 | 139 | 2 | 21 | 8 | 119 | 148 |
| Guinea-Bissau | 27.0 | 0.0 | 10 | 1 | 6 | 17 | 0 | 20 | 1 | 0 | 21 |
| Kenya | 30.2 | 2.0 | 17 | 3 | 66 | 87 | 6 | 20 | 7 | 66 | 93 |
| Lesotho | 5.2 | 0.1 | 7 | 7 | 17 | 31 | 0 | 14 | 14 | 24 | 52 |
| Liberia | 232.0 | 0.1 | 15 | 7 | 33 | 55 | 0 | 20 | 14 | 28 | 62 |
| Madagascar | 337.0 | 20.6 | 16 | 0 | 1622 | 1638 | 57 | 20 | 1 | 1621 | 1642 |
| Malawi | 18.6 | 0.9 | 1 | 3 | 98 | 113 | 2 | 1 | 3 | 98 | 102 |
| Mali | 100.0 | 1.5 | 3 | 2 | 156 | 161 | 4 | 6 | 3 | 155 | 164 |
| Mauritania | 11.4 | 1.9 | 57 | 17 | 849 | 923 | 4 | 57 | 20 | 855 | 932 |
| Mauritius | 2.2 | 0.4 | 56 | 24 | 269 | 350 | 1 | 56 | 25 | 269 | 350 |
| Mozambique | 208.0 | 0.6 | 6 | 3 | 30 | 39 | 2 | 13 | 5 | 31 | 49 |
| Namibia | 45.5 | 0.2 | 49 | 5 | 117 | 171 | 1 | 49 | 11 | 131 | 191 |
| Niger | 32.5 | 0.5 | 11 | 1 | 57 | 69 | 2 | 20 | 3 | 58 | 81 |
| Nigeria | 280.0 | 3.6 | 11 | 6 | 20 | 37 | 12 | 20 | 11 | 20 | 51 |
| Reunion | | 0.0 | | | | | 0 | | | | |
| Rwanda | 6.3 | 0.8 | 5 | 2 | 101 | 107 | 2 | 5 | 2 | 101 | 108 |

TABLE 58. (cont.)

| Region | Country/territory | Available water sources (km$^3$) | Assessment for 1990 | | | | | Assessment for 2025 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total water withdrawal (km$^3$) | Domestic (m$^3$/capita) | Industrial (m$^3$/capita) | Agricultural (m$^3$/capita) | Total (m$^3$/capita) | Total water withdrawal (km$^3$) | Domestic (m$^3$/capita) | Industrial (m$^3$/capita) | Agricultural (m$^3$/capita) | Total (m$^3$/capita) |
| | Sao Tome and Principe | | 0.0 | | | | | 0 | | | | |
| | Senegal | 39.4 | 1.5 | 10 | 6 | 185 | 201 | 4 | 20 | 12 | 184 | 216 |
| | Seychelles | | 0.0 | | | | | 0 | | | | |
| | Sierra Leone | 160.0 | 0.4 | 6 | 4 | 82 | 93 | 1 | 7 | 4 | 82 | 93 |
| | Somalia | 13.5 | 0.9 | 3 | 0 | 96 | 99 | 2 | 6 | 1 | 94 | 101 |
| | South Africa | 50.0 | 20.8 | 96 | 61 | 404 | 561 | 40 | 96 | 61 | 405 | 562 |
| | St. Helena | | 0.0 | | | | | 0 | | | | |
| | Swaziland | 4.5 | 0.7 | 17 | 17 | 823 | 857 | 2 | 17 | 17 | 823 | 857 |
| | Togo | 12.0 | 0.1 | 16 | 3 | 6 | 26 | 0 | 16 | 3 | 6 | 26 |
| | Uganda | 66.0 | 0.4 | 6 | 2 | 12 | 20 | 1 | 13 | 3 | 13 | 29 |
| | United Republic of Tanzania | 89.0 | 1.0 | 3 | 1 | 36 | 40 | 3 | 7 | 2 | 35 | 44 |
| | Zambia | 116.0 | 1.5 | 29 | 13 | 144 | 186 | 4 | 29 | 20 | 141 | 190 |
| | Zimbabwe | 20.0 | 1.3 | 19 | 9 | 107 | 135 | 3 | 23 | 19 | 107 | 149 |
| Total for AFR | | 5102 | 68 | | | | 142 | 175 | 21 | 10 | 113 | 143 |
| MEA | Algeria | 14.3 | 4.5 | 45 | 27 | 108 | 180 | 8 | 45 | 27 | 108 | 180 |
| | Bahrein | | 0.0 | | | | | 0 | | | | |
| | Egypt | 68.5 | 51.4 | 53 | 79 | 781 | 913 | 89 | 53 | 79 | 781 | 913 |
| | Iraq | 137.5 | 133.5 | 65 | 22 | 2178 | 2265 | 116 | 71 | 118 | 752 | 941 |
| | Iran, Islamic Republic of | 75.4 | 21.6 | 71 | 118 | 1004 | 1193 | 128 | 65 | 36 | 2907 | 3008 |

TABLE 58. (cont.)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Israel | 2.2 | 1.9 | 65 | 20 | 322 | 408 | 4 | 126 | 41 | 320 | 487 |
| | Jordan | 0.9 | 1.1 | 54 | 7 | 185 | 247 | 3 | 54 | 15 | 183 | 252 |
| | Kuwait | 0.2 | 0.8 | 129 | 7 | 212 | 348 | 1 | 129 | 14 | 214 | 357 |
| | Lebanon | 4.4 | 1.1 | 124 | 18 | 302 | 444 | 2 | 124 | 36 | 294 | 454 |
| | Libyan Arab Jamahiriya | 0.6 | 4.0 | 96 | 19 | 765 | 880 | 11 | 96 | 20 | 768 | 884 |
| | Morocco | 30.0 | 10.6 | 21 | 13 | 402 | 436 | 19 | 42 | 25 | 401 | 468 |
| | Oman | 1.0 | 1.3 | 36 | 15 | 677 | 728 | 5 | 73 | 29 | 673 | 775 |
| | Qatar | | 0.0 | | | | | 0 | | | | |
| | Saudi Arabia | 2.4 | 16.7 | 94 | 10 | 936 | 1040 | 45 | 94 | 21 | 936 | 1051 |
| | Sudan | 154.0 | 15.6 | 28 | 7 | 597 | 633 | 37 | 28 | 1 | 598 | 627 |
| | Syrian Arab Republic | 26.3 | 12.6 | 41 | 20 | 956 | 1017 | 34 | 41 | 23 | 955 | 1019 |
| | Tunisia | 3.9 | 3.1 | 32 | 11 | 339 | 382 | 5 | 49 | 21 | 339 | 409 |
| | United Arab Emirates | 0.2 | 1.9 | 266 | 100 | 742 | 1107 | 3 | 266 | 100 | 744 | 1110 |
| | Yemen | 4.1 | 2.8 | 18 | 3 | 231 | 251 | 9 | 20 | 5 | 232 | 257 |
| Total for MEA | | 526 | 284 | | | | 1028 | 519 | 58 | 51 | 786 | 895 |
| WEU | Andorra | | 0.0 | | | | | 0 | | | | |
| | Austria | 90.3 | 2.3 | 100 | 176 | 27 | 304 | 3 | 100 | 176 | 24 | 300 |
| | Azores | | 0.0 | | | | | 0 | | | | |
| | Belgium | 12.5 | 9.1 | 101 | 779 | 37 | 917 | 9 | 101 | 779 | 0 | 880 |
| | Canary Islands | | 0.0 | | | | | 0 | | | | |
| | Channel Islands | | 0.0 | | | | | 0 | | | | |
| | Cyprus | | 0.0 | | | | | 0 | | | | |
| | Denmark | 13.0 | 1.2 | 70 | 63 | 100 | 233 | 1 | 70 | 63 | 98 | 231 |
| | Faeroe Islands | | 0.0 | | | | | 0 | | | | |

TABLE 58. (cont.)

| Region | Country/ territory | Available water sources (km$^3$) | Assessment for 1990 | | | | | Assessment for 2025 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total water withdrawal (km$^3$) | Domestic (m$^3$/capita) | Industrial (m$^3$/capita) | Agricultural (m$^3$/capita) | Total (m$^3$/capita) | Total water withdrawal (km$^3$) | Domestic (m$^3$/capita) | Industrial (m$^3$/capita) | Agricultural (m$^3$/capita) | Total (m$^3$/capita) |
| | Finland | 113.0 | 2.2 | 53 | 198 | 189 | 440 | 2 | 53 | 198 | 185 | 436 |
| | France | 198.0 | 37.7 | 106 | 459 | 100 | 665 | 41 | 106 | 459 | 100 | 665 |
| | Germany | 171.0 | 46.0 | 64 | 405 | 110 | 579 | 44 | 64 | 405 | 110 | 579 |
| | Gibraltar | | 0.0 | | | | | 0 | | | | |
| | Greece | 58.7 | 5.4 | 42 | 152 | 329 | 523 | 6 | 84 | 180 | 334 | 598 |
| | Greenland | | 0.0 | | | | | 0 | | | | |
| | Iceland | | 0.0 | | | | | 0 | | | | |
| | Ireland | | 0.0 | | | | | 0 | | | | |
| | Isle of Man | | 0.0 | | | | | 0 | | | | |
| | Italy | 167.0 | 56.2 | 138 | 266 | 582 | 986 | 52 | 138 | 266 | 581 | 985 |
| | Liechtenstein | | 0.0 | | | | | 0 | | | | |
| | Luxembourg | | 0.0 | | | | | 0 | | | | |
| | Madeira | | 0.0 | | | | | 0 | | | | |
| | Malta | | 0.0 | | | | | 0 | | | | |
| | Monaco | | 0.0 | | | | | 0 | | | | |
| | Netherlands | 90.0 | 7.7 | 26 | 316 | 176 | 518 | 9 | 26 | 316 | 178 | 520 |
| | Norway | 392.0 | 2.1 | 98 | 351 | 39 | 488 | 2 | 98 | 351 | 42 | 491 |
| | Portugal | 69.6 | 7.3 | 111 | 273 | 355 | 739 | 7 | 126 | 273 | 351 | 750 |
| | Spain | 94.3 | 30.7 | 94 | 203 | 484 | 781 | 31 | 126 | 203 | 484 | 813 |
| | Sweden | 180.0 | 2.9 | 123 | 188 | 31 | 341 | 3 | 123 | 188 | 31 | 342 |
| | Switzerland | 50.0 | 1.2 | 40 | 126 | 7 | 173 | 1 | 40 | 126 | 13 | 179 |
| | Turkey | 183.7 | 30.4 | 87 | 60 | 395 | 541 | 52 | 87 | 86 | 395 | 568 |

TABLE 58. (cont.)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UK | 71.0 | 11.8 | 41 | 158 | 6 | 205 | 13 | 8 | 158 | 42 | 208 |
| Total for WEU | | 1954 | 254 | | | | 593 | 275 | 83 | 264 | 243 | 589 |
| EEU | Albania | 21.3 | 0.4 | 6 | 17 | 71 | 94 | 0 | 11 | 20 | 64 | 95 |
| | Bosnia and Herzegovina | | 0.0 | | | | | 0 | | | | |
| | Bulgaria | 205.0 | 13.9 | 46 | 1173 | 324 | 1544 | 12 | 46 | 1173 | 322 | 1541 |
| | Croatia | | 0.0 | | | | | 0 | | | | |
| | Czech Republic | 58.2 | 2.7 | 109 | 151 | 5 | 265 | 3 | 109 | 151 | 5 | 265 |
| | Hungary | 120.0 | 6.9 | 59 | 364 | 238 | 661 | 6 | 80 | 364 | 234 | 678 |
| | Poland | 56.2 | 12.2 | 42 | 244 | 35 | 321 | 14 | 58 | 244 | 36 | 338 |
| | Romania | 208.0 | 26.3 | 91 | 374 | 669 | 1134 | 25 | 91 | 374 | 667 | 1132 |
| | Slovakia | 30.8 | 1.8 | 136 | 190 | 7 | 333 | 2 | 136 | 190 | 7 | 333 |
| | Slovenia | | 0.0 | | | | | 0 | | | | |
| | The Former Yugoslav Republic of Macedonia | | 0.0 | | | | | 0 | | | | |
| | Yugoslavia, Federal Republic of | | 0.0 | | | | | 0 | | | | |
| Total for EEU | | 700 | 64 | | | | 640 | 62 | 73 | 332 | 209 | 614 |
| FSU | Armenia | 5.4 | 2.9 | 238 | 32 | 524 | 794 | 4 | 238 | 32 | 524 | 794 |
| | Azerbaijan | 30.3 | 16.5 | 113 | 566 | 1585 | 2264 | 23 | 113 | 566 | 1585 | 2264 |
| | Belarus | 3.1 | 2.7 | 58 | 114 | 93 | 265 | 3 | 58 | 114 | 93 | 265 |
| | Estonia | 12.8 | 0.2 | 58 | 41 | 5 | 104 | 0 | 58 | 41 | 5 | 104 |

TABLE 58. (cont.)

| Region | Country/ territory | Available water sources ($km^3$) | Assessment for 1990 | | | | | Assessment for 2025 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total water withdrawal ($km^3$) | Domestic ($m^3$/capita) | Industrial ($m^3$/capita) | Agricultural ($m^3$/capita) | Total ($m^3$/capita) | Total water withdrawal ($km^3$) | Domestic ($m^3$/capita) | Industrial ($m^3$/capita) | Agricultural ($m^3$/capita) | Total ($m^3$/capita) |
| | Georgia | 43.1 | 3.5 | 133 | 127 | 374 | 634 | 5 | 133 | 127 | 374 | 634 |
| | Kazakhstan | 77.6 | 33.7 | 40 | 339 | 1614 | 1992 | 46 | 40 | 339 | 1614 | 1992 |
| | Kyrgyzstan | 36.8 | 10.1 | 67 | 67 | 2110 | 2245 | 14 | 67 | 67 | 2110 | 2245 |
| | Latvia | 35.4 | 0.3 | 61 | 35 | 14 | 110 | 0 | 61 | 35 | 14 | 110 |
| | Lithuania | 24.9 | 0.3 | 54 | 11 | 2 | 67 | 0 | 54 | 11 | 2 | 67 |
| | Republic of Moldova | 0.7 | 3.0 | 61 | 442 | 177 | 680 | 3 | 61 | 442 | 177 | 681 |
| | Russian Federation | 4444.2 | 77.9 | 99 | 322 | 104 | 520 | 78 | 99 | 322 | 104 | 525 |
| | Tajikistan | 29.7 | 11.8 | 64 | 85 | 1961 | 2131 | 16 | 64 | 85 | 1961 | 2110 |
| | Turkmenistan | 18.4 | 23.8 | 59 | 59 | 5783 | 5901 | 41 | 59 | 59 | 5783 | 5901 |
| | Ukraine | 139.6 | 26.0 | 90 | 259 | 150 | 498 | 26 | 90 | 259 | 150 | 498 |
| | Uzbekistan | 50.4 | 58.1 | 109 | 54 | 2555 | 2718 | 79 | 109 | 54 | 2555 | 2718 |
| Total for FSU | | 4952 | 271 | | | | 925 | 337 | 92 | 258 | 705 | 1056 |
| CPA | Cambodia | 498.1 | 0.6 | 3 | 1 | 60 | 64 | 1 | 6 | 1 | 61 | 68 |
| | China | 2800.0 | 532.8 | 28 | 32 | 401 | 461 | 740 | 46 | 38 | 401 | 485 |
| | Democratic People's Republic of Korea | 67.0 | 15.0 | 76 | 110 | 502 | 687 | 23 | 76 | 110 | 500 | 686 |
| | Hong Kong, China | | 0.0 | | | | | 0 | | | | |

TABLE 58. (cont.)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lao People's Democratic Republic | 270.0 | 1.0 | 19 | 24 | 193 | 236 | 1 | 19 | 24 | 193 | 236 |
| | Mongolia | 24.6 | 0.6 | 28 | 68 | 156 | 252 | 1 | 28 | 68 | 156 | 252 |
| | Viet Nam | 376.0 | 27.6 | 54 | 37 | 323 | 414 | 49 | 54 | 37 | 323 | 414 |
| Total for CPA | | 4036 | 577 | | | | 459 | 815<br>0 | 47 | 39 | 393 | 478 |
| SAS | Afghanistan | 65.0 | 25.6 | 102 | 34 | 1566 | 1702 | 76 | 102 | 1 | 1566 | 1669 |
| | Bangladesh | 2357.0 | 23.8 | 7 | 2 | 211 | 220 | 45 | 13 | 4 | 211 | 228 |
| | Bhutan | 95.0 | 0.0 | 5 | 1 | 7 | 13 | 0 | 5 | 1 | 7 | 13 |
| | India | 2085.0 | 520.6 | 18 | 24 | 569 | 612 | 864 | 28 | 24 | 569 | 621 |
| | Maldives | | 0.0 | | | | | 0 | | | | |
| | Nepal | 170.0 | 2.9 | 6 | 2 | 143 | 151 | 6 | 12 | 3 | 143 | 158 |
| | Pakistan | 418.3 | 155.7 | 26 | 26 | 1226 | 1277 | 364 | 26 | 26 | 1226 | 1278 |
| | Sri Lanka | 43.2 | 8.7 | 10 | 10 | 483 | 503 | 13 | 20 | 20 | 483 | 523 |
| Total for SAS | | 5233 | 737 | | | | 648 | 1368 | 27 | 21 | 640 | 689 |
| PAS | American Samoa | | 0.0 | | | | | 0 | | | | |
| | Brunei Darussalam | | 0.0 | | | | | 0 | | | | |
| | Fiji | 28.6 | 0.0 | 8 | 8 | 25 | 41 | 0 | 8 | 8 | 25 | 41 |
| | French Polynesia | | 0.0 | | | | | 0 | | | | |
| | Indonesia | 2530.0 | 17.6 | 12 | 11 | 73 | 96 | 33 | 25 | 21 | 73 | 119 |
| | Malaysia | 456.0 | 13.7 | 177 | 230 | 361 | 768 | 13 | 25 | 21 | 361 | 407 |
| | Myanmar | 1082.0 | 4.2 | 7 | 3 | 91 | 101 | 8 | 14 | 6 | 91 | 111 |
| | New Caledonia | | 0.0 | | | | | 0 | | | | |
| | Papua New Guinea | 801.0 | 0.1 | 8 | 6 | 13 | 28 | 0 | 8 | 6 | 14 | 28 |
| | Philippines | 323.0 | 41.7 | 123 | 144 | 418 | 686 | 72 | 123 | 144 | 418 | 685 |
| | Kiribati | | 0.0 | | | | | 0 | | | | |

TABLE 58. (cont.)

| Region | Country/ territory | Available water sources ($km^3$) | Assessment for 1990 | | | | | Assessment for 2025 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total water withdrawal ($km^3$) | Domestic ($m^3$/capita) | Industrial ($m^3$/capita) | Agricultural ($m^3$/capita) | Total ($m^3$/capita) | Total water withdrawal ($km^3$) | Domestic ($m^3$/capita) | Industrial ($m^3$/capita) | Agricultural ($m^3$/capita) | Total ($m^3$/capita) |
| | Korea, Republic of | 66.1 | 27.1 | 120 | 221 | 291 | 632 | 35 | 126 | 221 | 290 | 637 |
| | Samoa | | 0.0 | | | | | 0 | | | | |
| | Singapore | 0.6 | 0.2 | 38 | 43 | 3 | 85 | 1 | 82 | 86 | 0 | 168 |
| | Solomon Islands | 44.7 | 0.0 | 7 | 3 | 7 | 17 | 0 | 7 | 3 | 7 | 17 |
| | Taiwan, China | | 0.0 | | | | | 0 | | | | |
| | Thailand | 179.0 | 33.5 | 24 | 36 | 542 | 602 | 49 | 48 | 72 | 542 | 662 |
| | Tonga | | 0.0 | | | | | 0 | | | | |
| | Vanuatu | | 0.0 | | | | | 0 | | | | |
| Total for PAS | | 5511 | 138 | | | | 338 | 210 | 52 | 63 | 220 | 335 |
| PAO | Australia | 343.0 | 15.8 | 606 | 19 | 308 | 933 | 24 | 606 | 37 | 308 | 951 |
| | Japan | 547.0 | 90.9 | 125 | 243 | 368 | 736 | 89 | 125 | 243 | 368 | 736 |
| | New Zealand | 327.0 | 2.0 | 271 | 59 | 259 | 589 | 3 | 271 | 118 | 251 | 640 |
| Total for PAO | | 1217 | 109 | | | | 755 | 116 | 208 | 206 | 354 | 768 |
| World total | | 48 056 | 3254 | | | | 614 | 4930 | 58 | 101 | 434 | 593 |

**Note:** Data are not available if none are shown.

# Appendix VI

## ESTIMATE OF THE LONG TERM PROSPECTS FOR NUCLEAR PENETRATION IN WATER DESALINATION

TABLE 59. ESTIMATE OF THE LONG TERM PROSPECTS FOR NUCLEAR PENETRATION IN WATER DESALINATION

| Region | Country/ territory | Total domestic water use in 1990 (km$^3$) | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| NAM | Canada | 8.0 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | Guam | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Puerto Rico | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | USA | 60.8 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | Virgin Islands | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Total for NAM | | 68.8 | 0.00 | 0.00 | 2.00 | 1.00 | 1.00 | 0.80 |
| LAM | Antigua and Barbuda | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Argentina | 3.1 | 0 | 0 | 2 | 0 | 1 | 0.6 |
| | Bahamas | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Barbados | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Belize | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Bermuda | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Bolivia | 0.1 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Brazil | 8.0 | 0 | 1 | 2 | 0 | 1 | 0.8 |
| | Chile | 4.7 | 0 | 0 | 1 | 0 | 1 | 0.4 |
| | Colombia | 2.3 | 0 | 1 | 1 | 0 | 0 | 0.4 |
| | Costa Rica | 0.1 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Cuba | 0.8 | 0 | 0 | 1 | 0 | 1 | 0.4 |
| | Dominica | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Dominican Republic | 0.2 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Ecuador | 0.4 | 0 | 0 | 0 | 0 | 0 | 0.0 |

TABLE 59. (cont.)

| Region | Country/ territory | Total domestic water use in 1990 (km$^3$) | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | El Salvador | 3.0 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | French Guiana | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Grenada | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Guadeloupe | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Guatemala | 0.1 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Guyana | 0.0 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Haiti | 0.0 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Honduras | 0.1 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Jamaica | 0.0 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Martinique | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Mexico | 4.6 | 0 | 0 | 2 | 0 | 1 | 0.6 |
| | Netherlands Antilles | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Nicaragua | 0.3 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Panama | 0.2 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Paraguay | 0.1 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Peru | 1.2 | 0 | 1 | 1 | 0 | 1 | 0.6 |
| | Saint Kitts and Nevis | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Saint Lucia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Saint Vincent and the Grenadines | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Suriname | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Trinidad and Tobago | 0.0 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Uruguay | 0.0 | 0 | 2 | 1 | 0 | 1 | 0.8 |
| | Venezuela | 3.2 | 0 | 1 | 1 | 0 | 1 | 0.6 |
| Total for LAM | | 32.7 | 0.00 | 0.68 | 1.33 | 0.00 | 0.78 | 0.56 |

TABLE 59. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AFR | Angola | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Benin | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Botswana | 0.0 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | British Indian Ocean Territory | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Burkina Faso | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Burundi | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Cameroon | 0.2 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Cape Verde | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Central African Republic | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Chad | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Comoros | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Congo | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Cote d'Ivoire | 0.2 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Democratic Republic of the Congo | 0.2 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Djibouti | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Equatorial Guinea | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Eritrea | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Ethiopia | 0.3 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Gabon | 0.1 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Gambia | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Ghana | 0.2 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Guinea | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Guinea-Bissau | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Kenya | 0.4 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Lesotho | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Liberia | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |

TABLE 59. (cont.)

| Region | Country/ territory | Total domestic water use in 1990 (km$^3$) | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Madagascar | 0.2 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Malawi | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Mali | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Mauritania | 0.1 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Mauritius | 0.1 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Mozambique | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Namibia | 0.1 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Niger | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Nigeria | 1.1 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Reunion | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Rwanda | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Sao Tome and Principe | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Senegal | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Seychelles | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Sierra Leone | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Somalia | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | South Africa | 3.6 | 0 | 1 | 2 | 1 | 2 | 1.2 |
| | St. Helena | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Swaziland | 0.0 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Togo | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Uganda | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | United Republic of Tanzania | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Zambia | 0.2 | 0 | 2 | 0 | 1 | 0 | 0.6 |

TABLE 59. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Zimbabwe | 0.2 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| Total for AFR | | 8.1 | 0.00 | 1.49 | 0.88 | 0.83 | 0.88 | 0.82 |
| | | | | | | | | |
| MEA | Algeria | 1.1 | 1 | 2 | 1 | 1 | 0 | 1.0 |
| | Bahrain | 0.0 | 1 | 0 | 0 | 0 | 0 | 0.2 |
| | Egypt | 3.0 | 1 | 1 | 1 | 1 | 1 | 1.0 |
| | Iraq | 3.9 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Iran, Islamic Republic of | 1.3 | 0 | 1 | 1 | 1 | 2 | 1.0 |
| | Israel | 0.3 | 1 | 2 | 0 | 1 | 1 | 1.0 |
| | Jordan | 0.2 | 1 | 2 | 0 | 0 | 0 | 0.6 |
| | Kuwait | 0.3 | 1 | 2 | 0 | 0 | 0 | 0.6 |
| | Lebanon | 0.3 | 1 | 2 | 0 | 1 | 0 | 0.8 |
| | Libyan Arab Jamahiriya | 0.4 | 1 | 1 | 0 | 0 | 0 | 0.4 |
| | Morocco | 0.5 | 1 | 2 | 1 | 1 | 1 | 1.2 |
| | Oman | 0.1 | 1 | 1 | 0 | 0 | 0 | 0.4 |
| | Qatar | 0.0 | 1 | 0 | 0 | 0 | 0 | 0.2 |
| | Saudi Arabia | 1.5 | 1 | 1 | 0 | 0 | 0 | 0.4 |
| | Sudan | 0.7 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Syrian Arab Republic | 0.5 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Tunisia | 0.3 | 1 | 2 | 0 | 1 | 0 | 0.8 |
| | United Arab Emirates | 0.4 | 1 | 1 | 0 | 0 | 0 | 0.4 |
| | Yemen | 0.2 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| Total for MEA | | 15.0 | 0.56 | 1.21 | 0.39 | 0.80 | 0.43 | 0.68 |
| | | | | | | | | |
| WEU | Andorra | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Austria | 0.8 | 0 | 1 | 1 | 1 | 0 | 0.6 |
| | Azores | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Belgium | 1.0 | 0 | 1 | 2 | 1 | 1 | 1.0 |

TABLE 59. (cont.)

| Region | Country/ territory | Total domestic water use in 1990 (km$^3$) | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Canary Islands | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Channel Islands | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Cyprus | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Denmark | 0.4 | 0 | 1 | 1 | 1 | 0 | 0.6 |
| | Faeroe Islands | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Finland | 0.3 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | France | 6.0 | 0 | 0 | 2 | 1 | 2 | 1.0 |
| | Germany | 5.1 | 0 | 0 | 2 | 1 | 0 | 0.6 |
| | Gibraltar | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Greece | 0.4 | 0 | 0 | 1 | 1 | 1 | 0.6 |
| | Greenland | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Iceland | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Ireland | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Isle of Man | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Italy | 7.9 | 0 | 0 | 1 | 1 | 0 | 0.4 |
| | Liechtenstein | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Luxembourg | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Madeira | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Malta | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Monaco | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Netherlands | 0.4 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Norway | 0.4 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | Portugal | 1.1 | 0 | 0 | 1 | 1 | 1 | 0.6 |
| | Spain | 3.7 | 1 | 0 | 2 | 1 | 1 | 1.0 |

TABLE 59. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sweden | 1.0 | 0 | 1 | 2 | 1 | 0 | 0.8 |
| | Switzerland | 0.3 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Turkey | 4.9 | 0 | 0 | 1 | 1 | 1 | 0.6 |
| | UK | 2.4 | 0 | 2 | 2 | 1 | 1 | 1.2 |
| Total for WEU | | 35.9 | 0.10 | 0.26 | 1.56 | 1.00 | 0.75 | 0.73 |
| EEU | Albania | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Bosnia and Herzegovina | 0.0 | 0 | 0 | 1 | 1 | 0 | 0.4 |
| | Bulgaria | 0.4 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | Croatia | 0.0 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | Czech Republic | 1.1 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Hungary | 0.6 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | Poland | 1.6 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | Romania | 2.1 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | Slovakia | 0.7 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Slovenia | 0.0 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | The Former Yugoslav Republic of Macedonia | 0.0 | 0 | 0 | 1 | 1 | 0 | 0.4 |
| | Yugoslavia, Federal Republic of | 0.0 | 0 | 0 | 1 | 1 | 0 | 0.4 |
| Total for EEU | | 6.6 | 0.00 | 0.53 | 1.75 | 1.00 | 1.00 | 0.86 |
| FSU | Armenia | 0.9 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Azerbaijan | 0.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Belarus | 0.6 | 0 | 2 | 1 | 1 | 1 | 1.0 |
| | Estonia | 0.1 | 0 | 1 | 0 | 1 | 0 | 0.4 |

TABLE 59. (cont.)

| Region | Country/ territory | Total domestic water use in 1990 (km$^3$) | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Georgia | 0.7 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Kazakhstan | 0.7 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | Kyrgyzstan | 0.3 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Latvia | 0.2 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Lithuania | 0.2 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Republic of Moldova | 0.3 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Russian Federation | 14.7 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | Tajikistan | 0.4 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Turkmenistan | 0.2 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Ukraine | 4.7 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Uzbekistan | 2.3 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Total for FSU | | 27.0 | 0.05 | 0.44 | 1.59 | 0.86 | 0.80 | 0.75 |
| | | | | | | | | |
| CPA | Cambodia | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | China | 32.0 | 1 | 1 | 2 | 1 | 2 | 1.4 |
| | Democratic People's Republic of Korea | 1.7 | 0 | 0 | 1 | 1 | 0 | 0.4 |
| | Hong Kong, China | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Lao People's Democratic Republic | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Mongolia | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Viet Nam | 3.6 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| Total for CPA | | 37.4 | 0.86 | 0.96 | 1.85 | 1.00 | 1.81 | 1.29 |

TABLE 59. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SAS | Afghanistan | 1.5 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Bangladesh | 0.7 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Bhutan | 0.0 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | India | 15.6 | 1 | 2 | 2 | 1 | 2 | 1.6 |
| | Maldives | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Nepal | 0.1 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Pakistan | 3.1 | 1 | 2 | 2 | 1 | 2 | 1.6 |
| | Sri Lanka | 0.2 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Total for SAS | | 21.3 | 0.88 | 1.92 | 1.76 | 0.99 | 1.76 | 1.46 |
| | | | | | | | | |
| PAS | American Samoa | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Brunei Darussalam | 0.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Fiji | 0.0 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | French Polynesia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Indonesia | 2.3 | 0 | 2 | 1 | 1 | 1 | 1.0 |
| | Malaysia | 3.2 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Myanmar | 0.3 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | New Caledonia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Papua New Guinea | 0.0 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Philippines | 7.5 | 0 | 0 | 1 | 1 | 1 | 0.6 |
| | Kiribati | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Korea, Republic of | 5.2 | 1 | 1 | 2 | 1 | 2 | 1.4 |
| | Samoa | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Singapore | 0.1 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Solomon Islands | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Taiwan, China | 0.0 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | Thailand | 1.3 | 0 | 0 | 1 | 1 | 1 | 0.6 |
| | Tonga | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |

TABLE 59. (cont.)

| Region | Country/ territory | Total domestic water use in 1990 (km$^3$) | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Vanuatu | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Total for PAS | | 19.9 | 0.26 | 0.85 | 1.08 | 0.99 | 1.08 | 0.85 |
| PAO | Australia | 10.2 | 1 | 0 | 0 | 1 | 0 | 0.4 |
| | Japan | 15.4 | 2 | 0 | 2 | 1 | 1 | 1.2 |
| | New Zealand | 0.9 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| Total for PAO | | 26.6 | 1.55 | 0.00 | 1.16 | 1.00 | 0.58 | 0.86 |
| World total | | 299.3 | 0.37 | 0.57 | 1.55 | 0.86 | 1.02 | 0.87 |

## Appendix VII

# INTERRELATION OF ELECTRICITY AND FUEL CONSUMPTION IN SOME COUNTRIES

Figures 25–29, which are taken from Ref. [66], illustrate the boomerang-like historical changes in electricity and fuel consumption in some countries. This shows, in particular, a trend to less energy intensive industries. The dashed lines to 1998 indicate that the data do not come from Ref. [66] but have been added based on the latest statistics available in Ref. [67].

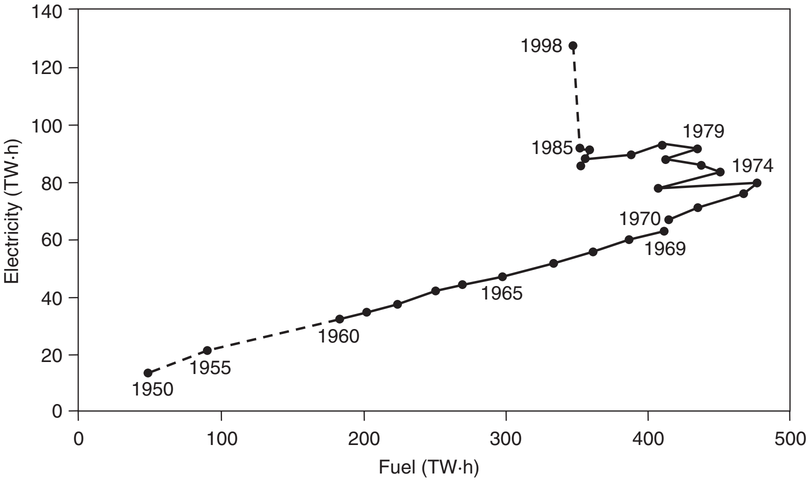

*FIG. 25. Evolution of the structure of industrial energy consumption for Italy [66, 67].*

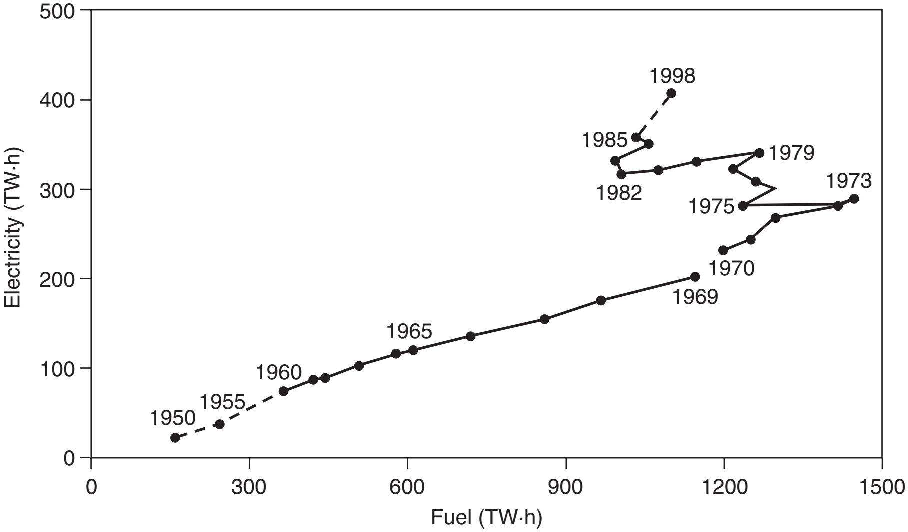

*FIG. 26. Evolution of the structure of industrial energy consumption for Japan [66, 67].*

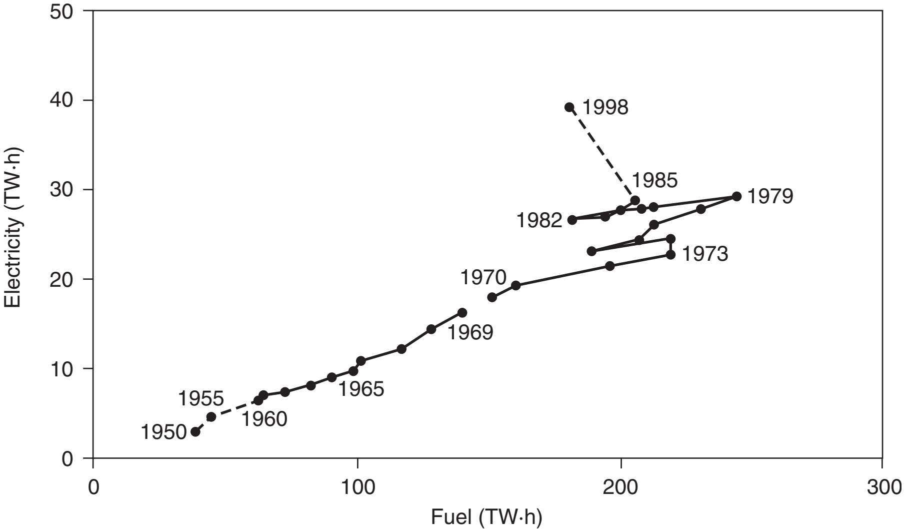

FIG. 27. *Evolution of the structure of industrial energy consumption for the Netherlands [66, 67].*

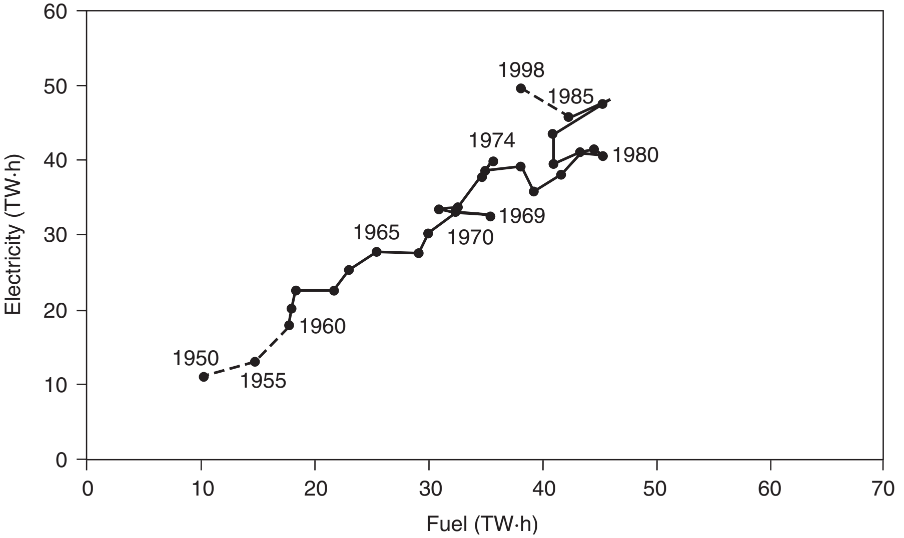

FIG. 28. *Evolution of the structure of industrial energy consumption for Norway [66, 67].*

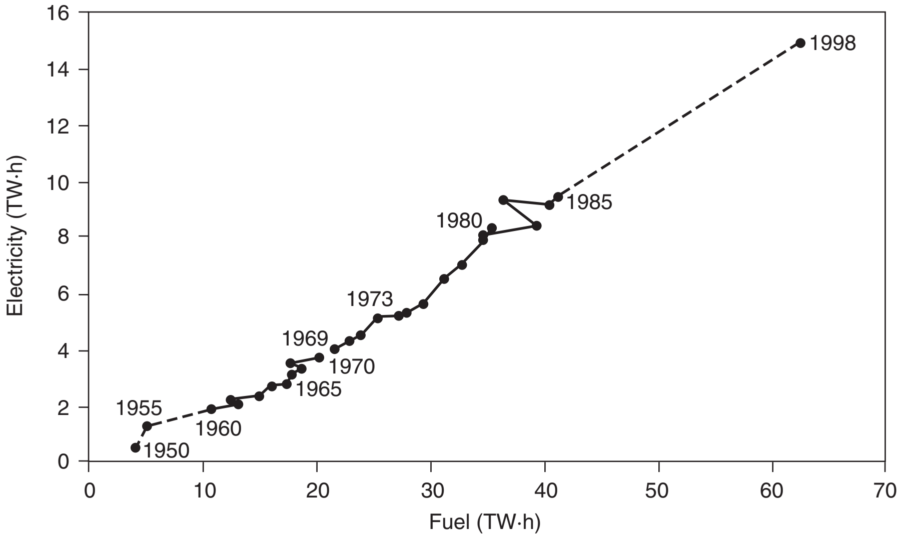

*FIG. 29. Evolution of the structure of industrial energy consumption for Portugal [66, 67].*

# Appendix VIII

## STATISTICS OF INDUSTRIAL HEAT SUPPLY AND DEMAND

TABLE 60. STATISTICS OF INDUSTRIAL HEAT SUPPLY AND DEMAND IN 1996 [34, 35]

| Region | Country/territory | Final energy demand (Mtoe) | | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|---|
| | | Total | In industrial sector | Non-electric part — industrial sector | Total | In industrial sector | In industrial sector$^a$ | In total final energy demand$^b$ |
| NAM | Canada | 184.3 | 66.6 | 49.3 | 0.5 | 0.5 | 0.8 | 0.3 |
| | Guam | | | 0 | 0 | 0 | | |
| | Puerto Rico | | | 0 | 0 | 0 | | |
| | USA | 1435.8 | 358.8 | 267.6 | 7.6 | 5.3 | 1.5 | 0.5 |
| | Virgin Islands | | | 0 | 0 | 0 | | |
| Total for NAM | | 1620.1 | 425.4 | 316.9 | 8.1 | 5.8 | 1.4 | 0.5 |
| LAM | Antigua and Barbuda | | | 0 | 0 | 0 | | |
| | Argentina | 39.8 | 11.4 | 9.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Bahamas | | | 0 | 0 | 0 | | |
| | Barbados | | | 0 | 0 | 0 | | |
| | Belize | | | 0 | 0 | 0 | | |
| | Bermuda | | | 0 | 0 | 0 | | |
| | Bolivia | 2.7 | 0.6 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Brazil | 138.2 | 59.4 | 48.3 | 0.0 | 0.0 | 0.0 | 0.0 |

TABLE 60. (cont.)

| Region | Country/territory | Final energy demand (Mtoe) | | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|---|
| | | Total | In industrial sector | Non-electric part — industrial sector | Total | In industrial sector | In industrial sector[a] | In total final energy demand[b] |
| | Chile | 16.4 | 6.3 | 4.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Colombia | 26.0 | 7.2 | 6.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Costa Rica | 2.0 | 0.5 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Cuba | 12.5 | 7.7 | 7.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Dominica | | | 0 | 0 | 0 | | |
| | Dominican Republic | 3.6 | 0.8 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Ecuador | 6.8 | 1.3 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | El Salvador | 3.2 | 0.6 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | French Guiana | | | 0 | 0 | 0 | | |
| | Grenada | | | 0 | 0 | 0 | | |
| | Guadeloupe | | | 0 | 0 | 0 | | |
| | Guatemala | 4.9 | 0.7 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Guyana | | | 0 | 0 | 0 | | |
| | Haiti | 1.6 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Honduras | 2.9 | 0.8 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Jamaica | 2.0 | 0.5 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Martinique | | | 0 | 0 | 0 | | |
| | Mexico | 94.1 | 36.9 | 30.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Netherlands Antilles | 0.8 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |

TABLE 60. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Nicaragua | 1.8 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Panama | 1.8 | 0.5 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Paraguay | 3.9 | 1.4 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Peru | 12.3 | 2.1 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Saint Kitts and Nevis | | | 0 | 0 | 0 | | |
| | Saint Lucia | | | 0 | 0 | 0 | | |
| | Saint Vincent and the Grenadines | | | 0 | 0 | 0 | | |
| | Suriname | | | 0 | 0 | 0 | | |
| | Trinidad and Tobago | 5.2 | 4.4 | 4.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Uruguay | 2.4 | 0.5 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Venezuela | 33.5 | 15.0 | 12.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for LAM | | 418.0 | 159.1 | 132.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| AFR | Angola | 4.3 | 0.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Benin | 1.9 | 0.4 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Botswana | | | 0 | 0 | 0 | | |
| | British Indian Ocean Territory | | | 0 | 0 | 0 | | |
| | Burkina Faso | | | 0 | 0 | 0 | | |
| | Burundi | | | 0 | 0 | 0 | | |
| | Cameroon | 5.1 | 0.9 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Cape Verde | | | 0 | 0 | 0 | | |
| | Central African Republic | | | 0 | 0 | 0 | | |

TABLE 60. (cont.)

| Region | Country/territory | Final energy demand (Mtoe) | | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|---|
| | | Total | In industrial sector | Non-electric part — industrial sector | Total | In industrial sector | In industrial sector[a] | In total final energy demand[b] |
| | Chad | | | 0 | 0 | 0 | | |
| | Comoros | | | 0 | 0 | 0 | | |
| | Congo | 1.1 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Cote d'Ivoire | 3.4 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Democratic Republic of the Congo | | | 0 | 0 | 0 | | |
| | Djibouti | | | 0 | 0 | 0 | | |
| | Equatorial Guinea | | | 0 | 0 | 0 | | |
| | Eritrea | | | 0 | 0 | 0 | | |
| | Ethiopia | 15.9 | 0.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Gabon | 1.4 | 0.3 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Gambia | | | 0 | 0 | 0 | | |
| | Ghana | 5.1 | 0.7 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Guinea | | | 0 | 0 | 0 | | |
| | Guinea-Bissau | | | 0 | 0 | 0 | | |
| | Kenya | 10.1 | 1.2 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Lesotho | | | 0 | 0 | 0 | | |
| | Liberia | | | 0 | 0 | 0 | | |
| | Madagascar | | | 0 | 0 | 0 | | |
| | Malawi | | | 0 | 0 | 0 | | |
| | Mali | | | 0 | 0 | 0 | | |

TABLE 60. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Mauritania | | | 0 | 0 | 0 | | |
| | Mauritius | | | 0 | 0 | 0 | | |
| | Mozambique | 6.2 | 0.6 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Namibia | | | 0 | 0 | 0 | | |
| | Niger | | | 0 | 0 | 0 | | |
| | Nigeria | 73.1 | 8.0 | 7.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Reunion | | | 0 | 0 | 0 | | |
| | Rwanda | | | 0 | 0 | 0 | | |
| | Sao Tome and Principe | | | 0 | 0 | 0 | | |
| | Senegal | 2.0 | 0.4 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Seychelles | | | 0 | 0 | 0 | | |
| | Sierra Leone | | | 0 | 0 | 0 | | |
| | Somalia | | | 0 | 0 | 0 | | |
| | South Africa | 54.3 | 23.0 | 15.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | St. Helena | | | 0 | 0 | 0 | | |
| | Swaziland | | | 0 | 0 | 0 | | |
| | Togo | | | 0 | 0 | 0 | | |
| | Uganda | | | 0 | 0 | 0 | | |
| | United Republic of Tanzania | 12.5 | 1.5 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Zambia | 4.4 | 1.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Zimbabwe | 8.5 | 1.5 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for AFR | | 209.3 | 40.3 | 31.0 | 0.0 | 0.0 | 0.0 | 0.0 |

TABLE 60. (cont.)

| Region | Country/territory | Final energy demand (Mtoe) | | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|---|
| | | Total | In industrial sector | Non-electric part — industrial sector | Total | In industrial sector | In industrial sector[a] | In total final energy demand[b] |
| MEA | Algeria | 14.4 | 3.2 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Bahrain | 3.9 | 2.7 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Egypt | 25.2 | 12.7 | 10.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Iraq | 20.0 | 5.5 | 5.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Iran, Islamic Republic of | 87.1 | 25.9 | 24.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Israel | 11.3 | 2.6 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Jordan | 3.3 | 0.6 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Kuwait | 5.8 | 1.5 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Lebanon | 3.7 | 0.9 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Libyan Arab Jamahiriya | 9.0 | 2.9 | 2.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Morocco | 6.9 | 1.6 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Oman | 2.7 | 0.9 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Qatar | 2.9 | 1.5 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Saudi Arabia | 52.4 | 9.7 | 8.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Sudan | 5.2 | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Syrian Arab Republic | 11.0 | 2.3 | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Tunisia | 5.2 | 1.2 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |

TABLE 60. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | United Arab Emirates | 8.0 | 2.2 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Yemen | 2.4 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for MEA | | 280.4 | 78.5 | 70.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| WEU | Andorra | | | 0 | 0 | 0 | | |
| | Austria | 22.2 | 5.2 | 3.6 | 0.9 | 0.9 | 17.2 | 4.0 |
| | Azores | | | 0 | 0 | 0 | | |
| | Belgium | 40.2 | 14.1 | 11.1 | 0.3 | 0.3 | 1.9 | 0.7 |
| | Canary Islands | | | 0 | 0 | 0 | | |
| | Channel Islands | | | 0 | 0 | 0 | | |
| | Cyprus | 1.5 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Denmark | 16.3 | 3.1 | 2.2 | 2.4 | 0.1 | 3.6 | 14.7 |
| | Faeroe Islands | | | 0 | 0 | 0 | | |
| | Finland | 23.3 | 10.2 | 7.0 | 2.8 | 0.6 | 6.1 | 11.8 |
| | France | 161.5 | 45.1 | 34.4 | 1.4 | 0.0 | 0.0 | 0.8 |
| | Germany | 247.6 | 70.8 | 53.5 | 9.0 | 1.7 | 2.4 | 3.7 |
| | Gibraltar | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Greece | 17.6 | 4.4 | 3.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Greenland | | | 0 | 0 | 0 | | |
| | Iceland | 1.9 | 0.5 | 0.2 | 0.2 | 0.2 | 33.3 | 8.7 |
| | Ireland | 8.8 | 2.3 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Isle of Man | | | 0 | 0 | 0 | | |
| | Italy | 124.3 | 40.0 | 29.7 | 0.2 | 0.2 | 0.5 | 0.2 |
| | Liechtenstein | | | 0 | 0 | 0 | | |
| | Luxembourg | 3.2 | 1.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 |

TABLE 60. (cont.)

| Region | Country/territory | Final energy demand (Mtoe) | | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|---|
| | | Total | In industrial sector | Non-electric part — industrial sector | Total | In industrial sector | In industrial sector[a] | In total final energy demand[b] |
| | Madeira | | | 0 | 0 | 0 | | |
| | Malta | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Monaco | | | 0 | 0 | 0 | | |
| | Netherlands | 59.3 | 18.7 | 15.4 | 1.7 | 0.8 | 4.2 | 2.9 |
| | Norway | 19.4 | 7.2 | 3.3 | 0.1 | 0.0 | 0.4 | 0.6 |
| | Portugal | 15.1 | 5.7 | 4.5 | 0.1 | 0.1 | 0.9 | 0.3 |
| | Spain | 71.7 | 22.6 | 17.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Sweden | 36.3 | 13.6 | 9.1 | 3.6 | 0.0 | 0.4 | 9.9 |
| | Switzerland | 20.6 | 3.7 | 2.3 | 0.3 | 0.1 | 1.9 | 1.6 |
| | Turkey | 51.8 | 16.9 | 13.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | UK | 161.3 | 41.7 | 32.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for WEU | | 1104.3 | 326.8 | 246.2 | 22.9 | 5.0 | 1.5 | 2.1 |
| EEU | Albania | 0.8 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Bosnia and Herzegovina | 0.8 | 0.1 | 0.1 | 0.0 | 0.0 | 39.5 | 3.1 |
| | Bulgaria | 12.7 | 7.2 | 6.2 | 2.9 | 2.0 | 27.3 | 22.6 |
| | Croatia | 5.2 | 2.0 | 1.8 | 0.3 | 0.3 | 13.1 | 5.0 |
| | Czech Republic | 27.6 | 13.5 | 12.0 | 3.7 | 2.4 | 17.8 | 13.6 |

TABLE 60. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hungary | 17.7 | 5.0 | 4.2 | 1.8 | 0.5 | 10.1 | 10.0 |
| | Poland | 72.6 | 28.3 | 24.3 | 9.3 | 1.7 | 6.2 | 12.9 |
| | Romania | 29.1 | 15.0 | 12.9 | 5.6 | 1.3 | 8.5 | 19.3 |
| | Slovakia | 12.7 | 6.0 | 5.1 | 0.8 | 0.0 | 0.5 | 5.9 |
| | Slovenia | 4.5 | 1.2 | 0.8 | 0.2 | 0.2 | 16.7 | 4.6 |
| | The Former Yugoslav Republic of Macedonia | 2.0 | 0.6 | 0.5 | 0.1 | 0.1 | 19.5 | 6.1 |
| | Yugoslavia, Federal Republic of | 8.4 | 2.8 | 2.3 | 0.5 | 0.5 | 16.1 | 5.4 |
| Total for EEU | | 194.0 | 82.0 | 70.2 | 25.1 | 9.0 | 11.0 | 13.0 |
| FSU | Armenia | 0.7 | 0.2 | 0.1 | 0.1 | 0.1 | 34.9 | 10.8 |
| | Azerbaijan | 10.9 | 3.4 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Belarus | 19.0 | 6.6 | 5.6 | 7.3 | 3.0 | 45.7 | 38.4 |
| | Estonia | 2.9 | 1.1 | 0.9 | 0.8 | 0.2 | 20.3 | 27.4 |
| | Georgia | 1.7 | 0.4 | 0.2 | 0.5 | 0.5 | 109.7 | 28.3 |
| | Kazakhstan | 23.1 | 9.1 | 7.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Kyrgyzstan | 2.4 | 0.5 | 0.4 | 0.5 | 0.5 | 89.7 | 19.2 |
| | Latvia | 3.6 | 0.8 | 0.7 | 1.1 | 0.3 | 40.6 | 30.6 |
| | Lithuania | 5.1 | 1.6 | 1.4 | 1.4 | 0.5 | 30.1 | 28.4 |
| | Republic of Moldova | 3.1 | 0.6 | 0.5 | 0.3 | 0.3 | 52.7 | 10.5 |
| | Russian Federation | 468.0 | 170.9 | 146.4 | 169.3 | 93.1 | 54.5 | 36.2 |

TABLE 60. (cont.)

| Region | Country/territory | Final energy demand (Mtoe) | | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|---|
| | | Total | In industrial sector | Non-electric part — industrial sector | Total | In industrial sector | In industrial sector[a] | In total final energy demand[b] |
| | Tajikistan | 2.9 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Turkmenistan | 7.8 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Ukraine | 98.5 | 47.0 | 41.2 | 10.4 | 6.7 | 14.2 | 10.5 |
| | Uzbekistan | 32.4 | 7.7 | 6.5 | 2.6 | 2.6 | 33.5 | 7.9 |
| Total for FSU | | 682.1 | 250.7 | 214.2 | 194.2 | 107.8 | 43.0 | 28.5 |
| CPA | Cambodia | | | 0 | 0 | 0 | | |
| | China | 865.9 | 426.3 | 377.3 | 21.3 | 21.3 | 5.0 | 2.5 |
| | Democratic People's Republic of Korea | 18.6 | 15.6 | 15.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Hong Kong, China | 10.0 | 2.3 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Lao People's Democratic Republic | | | 0 | 0 | 0 | | |
| | Mongolia | | | 0 | 0 | 0 | | |
| | Viet Nam | 29.9 | 3.1 | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for CPA | | 924.3 | 447.3 | 397.4 | 21.3 | 21.3 | 4.8 | 2.3 |

TABLE 60. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SAS | Afghanistan | | | 0 | 0 | 0 | | |
| | Bangladesh | 22.3 | 7.9 | 7.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Bhutan | | | 0 | 0 | 0 | | |
| | India | 350.3 | 106.6 | 93.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Maldives | | | 0 | 0 | 0 | | |
| | Nepal | 7.0 | 0.3 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Pakistan | 46.8 | 13.3 | 12.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Sri Lanka | 6.3 | 1.2 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for SAS | | 432.7 | 129.3 | 114.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | | | | | | |
| PAS | American Samoa | | | 0 | 0 | 0 | | |
| | Brunei Darussalam | 0.7 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Fiji | | | 0 | 0 | 0 | | |
| | French Polynesia | | | 0 | 0 | 0 | | |
| | Indonesia | 99.8 | 20.9 | 18.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Malaysia | 26.4 | 10.4 | 8.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Myanmar | 10.4 | 0.8 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| | New Caledonia | | | 0 | 0 | 0 | | |
| | Papua New Guinea | | | 0 | 0 | 0 | | |
| | Philippines | 24.3 | 8.6 | 7.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Kiribati | | | 0 | 0 | 0 | | |
| | Korea, Republic of | 120.4 | 51.7 | 41.1 | 1.2 | 1.2 | 2.4 | 1.0 |
| | Samoa | | | 0 | 0 | 0 | | |
| | Singapore | 9.4 | 3.2 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Solomon Islands | | | 0 | 0 | 0 | | |
| | Taiwan, China | 46.4 | 25.3 | 20.7 | 0.0 | 0.0 | 0.0 | 0.0 |

TABLE 60. (cont.)

| Region | Country/territory | Final energy demand (Mtoe) | | | Centralized heat generation (Mtoe) | | Share of centralized heat supply (%) | |
|---|---|---|---|---|---|---|---|---|
| | | Total | In industrial sector | Non-electric part — industrial sector | Total | In industrial sector | In industrial sector[a] | In total final energy demand[b] |
| | Thailand | 54.7 | 17.8 | 14.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Tonga | | | 0 | 0 | 0 | | |
| | Vanuatu | | | 0 | 0 | 0 | | |
| Total for PAS | | 392.4 | 138.9 | 114.3 | 1.2 | 1.2 | 0.9 | 0.3 |
| PAO | Australia | 66.3 | 22.9 | 17.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Japan | 337.0 | 133.6 | 98.7 | 0.4 | 0.0 | 0.0 | 0.1 |
| | New Zealand | 12.2 | 5.0 | 3.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total for PAO | | 415.4 | 161.5 | 119.9 | 0.4 | 0.0 | 0.0 | 0.1 |
| World total | | 6673.0 | 2239.6 | 1827.1 | 273.2 | 150.1 | 6.7 | 4.1 |

**Note:** Data are not available if none are shown.

[a] Share of the industrial sector centralized heat generation/share of the industrial sector final energy demand.

[b] Total centralized heat generation/total final energy demand.

# Appendix IX

## ESTIMATE OF THE LONG TERM PROSPECTS FOR NUCLEAR PENETRATION IN PROCESS HEAT SUPPLY

TABLE 61. ESTIMATE OF THE LONG TERM PROSPECTS FOR NUCLEAR PENETRATION IN PROCESS HEAT SUPPLY

| Region | Country/territory | Total final energy demand in 1996 (Mtoe)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| NAM | Canada | 184.3 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | Guam | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Puerto Rico | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | USA | 1435.8 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | Virgin Islands | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Total for NAM | | 1620.1 | 2.00 | 1.00 | 2.00 | 1.00 | 1.00 | 1.40 |
| LAM | Antigua and Barbuda | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Argentina | 39.8 | 0 | 1 | 2 | 0 | 1 | 0.8 |
| | Bahamas | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Barbados | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Belize | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Bermuda | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Bolivia | 2.7 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Brazil | 138.2 | 0 | 1 | 2 | 0 | 1 | 0.8 |
| | Chile | 16.4 | 0 | 2 | 1 | 0 | 1 | 0.8 |
| | Colombia | 26.0 | 0 | 1 | 1 | 0 | 0 | 0.4 |

TABLE 61. (cont.)

| Region | Country/territory | Total final energy demand in 1996 (Mtoe)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Costa Rica | 2.0 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Cuba | 12.5 | 0 | 0 | 1 | 0 | 1 | 0.4 |
| | Dominica | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Dominican Republic | 3.6 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Ecuador | 6.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | El Salvador | 3.2 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | French Guiana | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Grenada | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Guadeloupe | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Guatemala | 4.9 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Guyana | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Haiti | 1.6 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Honduras | 2.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Jamaica | 2.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Martinique | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Mexico | 94.1 | 0 | 1 | 2 | 0 | 1 | 0.8 |
| | Netherlands Antilles | 0.8 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Nicaragua | 1.8 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Panama | 1.8 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Paraguay | 3.9 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Peru | 12.3 | 0 | 2 | 1 | 0 | 1 | 0.8 |
| | Saint Kitts and Nevis | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Saint Lucia | | 0 | 0 | 0 | 0 | 0 | 0.0 |

TABLE 61. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Saint Vincent and the Grenadines | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Suriname | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Trinidad and Tobago | 5.1 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Uruguay | 2.4 | 0 | 0 | 1 | 0 | 1 | 0.4 |
| | Venezuela | 33.5 | 0 | 1 | 1 | 0 | 1 | 0.6 |
| Total for LAM | | 418.0 | 0.00 | 1.03 | 1.55 | 0.00 | 0.84 | 0.68 |
| AFR | Angola | 4.3 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Benin | 1.9 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Botswana | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | British Indian Ocean Territory | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Burkina Faso | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Burundi | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Cameroon | 5.1 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Cape Verde | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Central African Republic | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Chad | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Comoros | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Congo | 1.1 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Cote d’Ivoire | 3.4 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Democratic Republic of the Congo | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Djibouti | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Equatorial Guinea | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Eritrea | | 0 | 0 | 0 | 1 | 0 | 0.2 |

TABLE 61. (cont.)

| Region | Country/territory | Total final energy demand in 1996 (Mtoe)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Ethiopia | 15.9 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Gabon | 1.4 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Gambia | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Ghana | 5.1 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Guinea | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Guinea-Bissau | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Kenya | 10.1 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Lesotho | | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Liberia | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Madagascar | | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Malawi | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Mali | | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Mauritania | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Mauritius | | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Mozambique | 6.2 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Namibia | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Niger | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Nigeria | 73.1 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Reunion | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Rwanda | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Sao Tome and Principe | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Senegal | 2.0 | 0 | 1 | 0 | 1 | 0 | 0.4 |

TABLE 61. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Seychelles | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Sierra Leone | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Somalia | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | South Africa | 54.3 | 0 | 0 | 2 | 1 | 2 | 1.0 |
| | St. Helena | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Swaziland | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Togo | | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Uganda | | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | United Republic of Tanzania | 12.5 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Zambia | 4.4 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Zimbabwe | 8.5 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| Total for AFR | | 209.3 | 0.00 | 0.68 | 0.52 | 0.65 | 0.52 | 0.47 |
| MEA | Algeria | 14.4 | 0 | 0 | 1 | 1 | 0 | 0.4 |
| | Bahrain | 3.9 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Egypt | 25.2 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | Iraq | 20.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Iran, Islamic Republic of | 87.1 | 0 | 1 | 1 | 1 | 2 | 1.0 |
| | Israel | 11.3 | 0 | 0 | 0 | 1 | 1 | 0.4 |
| | Jordan | 3.3 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Kuwait | 5.8 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Lebanon | 3.7 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Libyan Arab Jamahiriya | 9.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Morocco | 6.9 | 0 | 1 | 1 | 1 | 1 | 0.8 |

TABLE 61. (cont.)

| Region | Country/territory | Total final energy demand in 1996 (Mtoe)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Oman | 2.7 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Qatar | 2.9 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Saudi Arabia | 52.4 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Sudan | 5.2 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Syrian Arab Republic | 11.0 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Tunisia | 5.2 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | United Arab Emirates | 8.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Yemen | 2.4 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| Total for MEA | | 280.4 | 0.00 | 0.69 | 0.48 | 0.69 | 0.78 | 0.53 |
| WEU | Andorra | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Austria | 22.2 | 2 | 1 | 1 | 1 | 0 | 1.0 |
| | Azores | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Belgium | 40.2 | 1 | 0 | 2 | 1 | 1 | 1.0 |
| | Canary Islands | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Channel Islands | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Cyprus | 1.5 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Denmark | 16.3 | 2 | 1 | 1 | 1 | 0 | 1.0 |
| | Faeroe Islands | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Finland | 23.3 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | France | 161.5 | 0 | 0 | 2 | 1 | 2 | 1.0 |
| | Germany | 247.6 | 1 | 0 | 2 | 1 | 0 | 0.8 |
| | Gibraltar | 0.1 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Greece | 17.6 | 0 | 0 | 1 | 1 | 1 | 0.6 |

TABLE 61. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Greenland | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Iceland | 1.9 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Ireland | 8.8 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Isle of Man | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Italy | 124.3 | 0 | 0 | 1 | 1 | 0 | 0.4 |
| | Liechtenstein | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Luxembourg | 3.2 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Madeira | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Malta | 0.5 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Monaco | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Netherlands | 59.3 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Norway | 19.4 | 2 | 2 | 1 | 1 | 1 | 1.4 |
| | Portugal | 15.1 | 2 | 0 | 1 | 1 | 1 | 1.0 |
| | Spain | 71.7 | 1 | 0 | 2 | 1 | 1 | 1.0 |
| | Sweden | 36.3 | 0 | 0 | 2 | 1 | 0 | 0.6 |
| | Switzerland | 20.6 | 2 | 0 | 2 | 1 | 1 | 1.2 |
| | Turkey | 51.8 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | UK | 161.3 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| Total for WEU | | 1104.3 | 0.50 | 0.19 | 1.73 | 1.00 | 0.73 | 0.83 |
| EEU | Albania | 0.8 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Bosnia and Herzegovina | 0.7 | 0 | 0 | 1 | 1 | 0 | 0.4 |
| | Bulgaria | 12.7 | 2 | 0 | 2 | 1 | 1 | 1.2 |
| | Croatia | 5.2 | 1 | 0 | 2 | 1 | 1 | 1.0 |
| | Czech Republic | 27.6 | 0 | 1 | 2 | 1 | 1 | 1.0 |
| | Hungary | 17.7 | 2 | 0 | 2 | 1 | 1 | 1.2 |

TABLE 61. (cont.)

| Region | Country/territory | Total final energy demand in 1996 (Mtoe)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Poland | 72.6 | 2 | 1 | 1 | 1 | 1 | 1.2 |
| | Romania | 29.1 | 2 | 0 | 2 | 1 | 1 | 1.2 |
| | Slovakia | 12.7 | 1 | 0 | 2 | 1 | 1 | 1.0 |
| | Slovenia | 4.5 | 1 | 0 | 2 | 1 | 1 | 1.0 |
| | The Former Yugoslav Republic of Macedonia | 2.0 | 1 | 0 | 1 | 1 | 0 | 0.6 |
| | Yugoslavia, Federal Republic of | 8.4 | 0 | 0 | 1 | 1 | 0 | 0.4 |
| Total for EEU | | 194.0 | 1.49 | 0.52 | 1.56 | 1.00 | 0.94 | 1.10 |
| FSU | Armenia | 0.7 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | Azerbaijan | 10.9 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Belarus | 19.0 | 2 | 0 | 1 | 1 | 1 | 1.0 |
| | Estonia | 2.9 | 1 | 0 | 0 | 1 | 0 | 0.4 |
| | Georgia | 1.7 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Kazakhstan | 23.1 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | Kyrgyzstan | 2.4 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Latvia | 3.6 | 2 | 0 | 0 | 1 | 0 | 0.6 |
| | Lithuania | 5.1 | 2 | 0 | 2 | 1 | 1 | 1.2 |
| | Republic of Moldova | 3.1 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Russian Federation | 468.0 | 2 | 0 | 2 | 1 | 1 | 1.2 |
| | Tajikistan | 2.9 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Turkmenistan | 7.8 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Ukraine | 98.5 | 0 | 0 | 2 | 1 | 1 | 0.8 |

TABLE 61. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Uzbekistan | 32.4 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Total for FSU | | 682.1 | 1.46 | 0.00 | 1.77 | 0.92 | 0.90 | 1.01 |
| CPA | Cambodia | | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | China | 865.9 | 2 | 2 | 2 | 1 | 2 | 1.8 |
| | Democratic People's Republic of Korea | 18.6 | 0 | 0 | 1 | 1 | 0 | 0.4 |
| | Hong Kong, China | 10.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Lao People's Democratic Republic | | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Mongolia | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Viet Nam | 29.9 | 0 | 2 | 1 | 1 | 1 | 1.0 |
| Total for CPA | | 924.3 | 1.87 | 1.94 | 1.93 | 0.99 | 1.91 | 1.73 |
| SAS | Afghanistan | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Bangladesh | 22.3 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Bhutan | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | India | 350.0 | 0 | 2 | 2 | 1 | 2 | 1.4 |
| | Maldives | | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Nepal | 6.9 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Pakistan | 46.8 | 0 | 2 | 2 | 1 | 2 | 1.4 |
| | Sri Lanka | 6.3 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| Total for SAS | | 432.7 | 0.00 | 2.00 | 1.84 | 0.99 | 1.84 | 1.33 |
| PAS | American Samoa | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Brunei Darussalam | 0.7 | 0 | 0 | 0 | 1 | 0 | 0.2 |
| | Fiji | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | French Polynesia | | 0 | 0 | 0 | 0 | 0 | 0.0 |

TABLE 61. (cont.)

| Region | Country/territory | Total final energy demand in 1996 (Mtoe)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Indonesia | 99.8 | 0 | 2 | 1 | 1 | 1 | 1.0 |
| | Malaysia | 26.4 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | Myanmar | 10.4 | 0 | 2 | 0 | 1 | 0 | 0.6 |
| | New Caledonia | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Papua New Guinea | | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Philippines | 24.3 | 0 | 1 | 1 | 1 | 1 | 0.8 |
| | Kiribati | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Korea, Republic of | 120.4 | 0 | 2 | 2 | 1 | 2 | 1.4 |
| | Samoa | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Singapore | 9.4 | 0 | 2 | 0 | 0 | 0 | 0.4 |
| | Solomon Islands | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Taiwan, China | 46.4 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | Thailand | 54.7 | 0 | 2 | 1 | 1 | 1 | 1.0 |
| | Tonga | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Vanuatu | | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Total for PAS | | 392.4 | 0.00 | 1.70 | 1.31 | 0.98 | 1.19 | 1.03 |
| PAO | Australia | 66.3 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| | Japan | 337.0 | 0 | 0 | 2 | 1 | 1 | 0.8 |
| | New Zealand | 12.2 | 0 | 1 | 0 | 1 | 0 | 0.4 |
| Total for PAO | | 415.4 | 0.00 | 0.19 | 1.62 | 1.00 | 0.81 | 0.72 |
| World total | | 6673.0 | 1.02 | 0.91 | 1.70 | 0.90 | 1.09 | 1.12 |

**Note:** Date are not available if none are shown.

[a] Used for weighting.

# Appendix X

## CHARACTERIZATION OF THE WORLD SHIP FLEET

TABLE 62. CHARACTERIZATION OF THE WORLD SHIP FLEET [76]

| | | Tonnage (1000 GT) of ships of more than 100 GT | | | | | Breakdown (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Region | Country/territory | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet |
| NAM | Canada | 117.7 | 1 335.3 | 115.6 | 832.4 | 2 401.0 | 4.9 | 55.6 | 4.8 | 34.7 | 100.0 |
| | Guam | | | | | | | | | | |
| | Puerto Rico | | | | | | | | | | |
| | USA | 3 987.2 | 1 513.3 | 3 810.0 | 3 450.3 | 12 760.8 | 31.2 | 11.9 | 29.9 | 27.0 | 100.0 |
| | Virgin Islands | | | | | | | | | | |
| Total for NAM | | 4 104.9 | 2 848.6 | 3 925.6 | 4 282.7 | 15 161.8 | 27.1 | 18.8 | 25.9 | 28.2 | 100.0 |
| LAM | Antigua and Barbuda | 3.7 | 102.4 | 1 708.1 | 27.8 | 1 842.0 | 0.2 | 5.6 | 92.7 | 1.5 | 100.0 |
| | Argentina | 107.2 | 61.7 | 148.8 | 277.2 | 594.9 | 18.0 | 10.4 | 25.0 | 46.6 | 100.0 |
| | Bahamas | 10 326.0 | 4 501.2 | 5 955.9 | 2 819.7 | 23 602.8 | 43.7 | 19.1 | 25.2 | 11.9 | 100.0 |
| | Barbados | | | | | | | | | | |
| | Belize | | | | | | | | | | |
| | Bermuda | 1 586.5 | 247.6 | 346.6 | 866.8 | 3 047.5 | 52.1 | 8.1 | 11.4 | 28.4 | 100.0 |
| | Bolivia | | | | | | | | | | |
| | Brazil | 2 090.1 | 2 076.8 | 565.0 | 344.8 | 5 076.7 | 41.2 | 40.9 | 11.1 | 6.8 | 100.0 |
| | Chile | | | | | | | | | | |
| | Colombia | | | | | | | | | | |
| | Costa Rica | | | | | | | | | | |

TABLE 62. (cont.)

| Region | Country/territory | Tonnage (1000 GT) of ships of more than 100 GT | | | | | Breakdown (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet |
| | Cuba | | | | | | | | | | |
| | Dominica | | | | | | | | | | |
| | Dominican Republic | | | | | | | | | | |
| | Ecuador | | | | | | | | | | |
| | El Salvador | | | | | | | | | | |
| | French Guiana | | | | | | | | | | |
| | Grenada | | | | | | | | | | |
| | Guadeloupe | | | | | | | | | | |
| | Guatemala | | | | | | | | | | |
| | Guyana | | | | | | | | | | |
| | Haiti | | | | | | | | | | |
| | Honduras | 96.7 | 137.8 | 710.6 | 260.9 | 1 206.0 | 8.0 | 11.4 | 58.9 | 21.6 | 100.0 |
| | Jamaica | | | | | | | | | | |
| | Martinique | | | | | | | | | | |
| | Mexico | 424.5 | | 180.4 | 524.3 | 1 129.2 | 37.6 | 0.0 | 16.0 | 46.4 | 100.0 |
| | Netherlands Antilles | | | | | | | | | | |
| | Nicaragua | | | | | | | | | | |
| | Panama | 19 513.3 | 26 726.4 | 19 936.3 | 5 745.7 | 71 921.7 | 27.1 | 37.2 | 27.7 | 8.0 | 100.0 |
| | Paraguay | | | | | | | | | | |
| | Peru | | | | | | | | | | |
| | Saint Kitts and Nevis | | | | | | | | | | |
| | Saint Lucia | | | | | | | | | | |
| | Saint Vincent and the Grenadines | 1 101.4 | 2 328.0 | 2 345.0 | 390.3 | 6 164.7 | 17.9 | 37.8 | 38.0 | 6.3 | 100.0 |

TABLE 62. (cont.)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Suriname | | | | | | | | | | |
| | Trinidad and Tobago | | | | | | | | | | |
| | Uruguay | | | | | | | | | | |
| | Venezuela | 361.0 | 111.1 | 63.8 | 251.2 | 787.1 | 45.9 | 14.1 | 8.1 | 31.9 | 100.0 |
| Total for LAM | | 35 610.4 | 36 293.0 | 31 960.5 | 11 508.7 | 115 372.6 | 30.9 | 31.5 | 27.7 | 10.0 | 100.0 |
| AFR | Angola | | | | | | | | | | |
| | Benin | | | | | | | | | | |
| | Botswana | | | | | | | | | | |
| | British Indian Ocean Territory | | | | | | | | | | |
| | Burkina Faso | | | | | | | | | | |
| | Burundi | | | | | | | | | | |
| | Cameroon | | | | | | | | | | |
| | Cape Verde | | | | | | | | | | |
| | Central African Republic | | | | | | | | | | |
| | Chad | | | | | | | | | | |
| | Comoros | | | | | | | | | | |
| | Congo | | | | | | | | | | |
| | Cote d’Ivoire | | | | | | | | | | |
| | Democratic Republic of the Congo | | | | | | | | | | |
| | Djibouti | | | | | | | | | | |
| | Equatorial Guinea | | | | | | | | | | |
| | Eritrea | | | | | | | | | | |
| | Ethiopia | | | | | | | | | | |
| | Gabon | | | | | | | | | | |
| | Gambia | | | | | | | | | | |

TABLE 62. (cont.)

| Region | Country/territory | Tonnage (1000 GT) of ships of more than 100 GT | | | | | Breakdown (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet |
| | Ghana | | | | | | | | | | |
| | Guinea | | | | | | | | | | |
| | Guinea-Bissau | | | | | | | | | | |
| | Kenya | | | | | | | | | | |
| | Lesotho | | | | | | | | | | |
| | Liberia | 29 001.9 | 16 373.3 | 7 668.0 | 6 757.5 | 59 800.7 | 48.5 | 27.4 | 12.8 | 11.3 | 100.0 |
| | Madagascar | | | | | | | | | | |
| | Malawi | | | | | | | | | | |
| | Mali | | | | | | | | | | |
| | Mauritania | | | | | | | | | | |
| | Mauritius | | | | | | | | | | |
| | Mozambique | | | | | | | | | | |
| | Namibia | | | | | | | | | | |
| | Niger | | | | | | | | | | |
| | Nigeria | | | | | | | | | | |
| | Reunion | | | | | | | | | | |
| | Rwanda | | | | | | | | | | |
| | Sao Tome and Principe | | | | | | | | | | |
| | Senegal | | | | | | | | | | |
| | Seychelles | | | | | | | | | | |
| | Sierra Leone | | | | | | | | | | |
| | Somalia | | | | | | | | | | |
| | South Africa | | | | | | | | | | |
| | St. Helena | | | | | | | | | | |

TABLE 62. (cont.)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Swaziland | | | | | | | | | | |
| | Togo | | | | | | | | | | |
| | Uganda | | | | | | | | | | |
| | United Republic of Tanzania | | | | | | | | | | |
| | Zambia | | | | | | | | | | |
| | Zimbabwe | | | | | | | | | | |
| Total for AFR | | 29 001.9 | 16 373.3 | 7 668.0 | 6 757.5 | 59 800.7 | 48.5 | 27.4 | 12.8 | 11.3 | 100.0 |
| MEA | Algeria | | | | | | | | | | |
| | Bahrain | | | | | | | | | | |
| | Egypt | 221.5 | 510.1 | 400.7 | 136.5 | 1 268.8 | 17.5 | 40.2 | 31.6 | 10.8 | 100.0 |
| | Iraq | | | | | | | | | | |
| | Iran, Islamic Republic of | 1 233.8 | 1 014.6 | 485.1 | 168.9 | 2 902.4 | 42.5 | 35.0 | 16.7 | 5.8 | 100.0 |
| | Israel | | | | | | | | | | |
| | Jordan | | | | | | | | | | |
| | Kuwait | 1 342.5 | | 273.1 | 441.4 | 2 057.0 | 65.3 | 0.0 | 13.3 | 21.5 | 100.0 |
| | Lebanon | | | | | | | | | | |
| | Libyan Arab Jamahiriya | | | | | | | | | | |
| | Morocco | | | | | | | | | | |
| | Oman | | | | | | | | | | |
| | Qatar | | | | | | | | | | |
| | Saudi Arabia | 237.5 | 11.7 | 586.4 | 351.3 | 1 186.9 | 20.0 | 1.0 | 49.4 | 29.6 | 100.0 |
| | Sudan | | | | | | | | | | |
| | Syrian Arab Republic | | | | | | | | | | |
| | Tunisia | | | | | | | | | | |
| | United Arab Emirates | | | | | | | | | | |
| | Yemen | | | | | | | | | | |
| Total for MEA | | 3 035.3 | 1 536.4 | 1 745.3 | 1 098.1 | 7 415.1 | 40.9 | 20.7 | 23.5 | 14.8 | 100.0 |

TABLE 62. (cont.)

| Region | Country/territory | Tonnage (1000 GT) of ships of more than 100 GT |  |  |  |  | Breakdown (%) |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet |
| WEU | Andorra |  |  |  |  |  |  |  |  |  |  |
|  | Austria |  |  | 91.9 |  | 91.9 | 0.0 | 0.0 | 100.0 | 0.0 | 100.0 |
|  | Azores |  |  |  |  |  |  |  |  |  |  |
|  | Belgium | 2.4 |  | 9.5 | 227.9 | 239.8 | 1.0 | 0.0 | 4.0 | 95.0 | 100.0 |
|  | Canary Islands |  |  |  |  |  |  |  |  |  |  |
|  | Channel Islands |  |  |  |  |  |  |  |  |  |  |
|  | Cyprus | 4 341.1 | 13 084.4 | 6 145.6 | 1 081.4 | 24 652.5 | 17.6 | 53.1 | 24.9 | 4.4 | 100.0 |
|  | Denmark | 1 053.8 | 493.3 | 2 617.1 | 1 687.3 | 5 851.5 | 18.0 | 8.4 | 44.7 | 28.8 | 100.0 |
|  | Faeroe Islands |  |  |  |  |  |  |  |  |  |  |
|  | Finland | 302.9 | 80.1 | 431.7 | 704.0 | 1 518.7 | 19.9 | 5.3 | 28.4 | 46.4 | 100.0 |
|  | France | 2 018.5 | 291.4 | 852.3 | 1 032.2 | 4 194.4 | 48.1 | 6.9 | 20.3 | 24.6 | 100.0 |
|  | Germany | 14.2 | 284.7 | 4 375.2 | 952.2 | 5 626.3 | 0.3 | 5.1 | 77.8 | 16.9 | 100.0 |
|  | Gibraltar |  |  |  |  |  |  |  |  |  |  |
|  | Greece | 12 835.7 | 12 794.8 | 2 086.9 | 1 717.3 | 29 434.7 | 43.6 | 43.5 | 7.1 | 5.8 | 100.0 |
|  | Greenland |  |  |  |  |  |  |  |  |  |  |
|  | Iceland | 1.6 | 0.4 | 37.8 | 168.8 | 208.6 | 0.8 | 0.2 | 18.1 | 80.9 | 100.0 |
|  | Ireland | 9.2 |  | 86.8 | 117.4 | 213.4 | 4.3 | 0.0 | 40.7 | 55.0 | 100.0 |
|  | Isle of Man |  |  |  |  |  |  |  |  |  |  |
|  | Italy | 1 955.6 | 1 535.0 | 1 154.4 | 2 054.4 | 6 699.4 | 29.2 | 22.9 | 17.2 | 30.7 | 100.0 |
|  | Liechtenstein |  |  |  |  |  |  |  |  |  |  |
|  | Luxembourg | 3.3 | 365.1 | 128.5 | 383.9 | 880.8 | 0.4 | 41.5 | 14.6 | 43.6 | 100.0 |
|  | Madeira |  |  |  |  |  |  |  |  |  |  |
|  | Malta | 6 792.8 | 6 857.3 | 3 319.8 | 708.4 | 17 678.3 | 38.4 | 38.8 | 18.8 | 4.0 | 100.0 |
|  | Monaco |  |  |  |  |  |  |  |  |  |  |

TABLE 62. (cont.)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Netherlands | 543.9 | 169.2 | 2 327.9 | 1 565.0 | 4 606.0 | 11.8 | 3.7 | 50.5 | 34.0 | 100.0 |
| | Norway | 8 778.7 | 4 005.6 | 3 641.2 | 5 125.4 | 21 550.9 | 40.7 | 18.6 | 16.9 | 23.8 | 100.0 |
| | Portugal | 490.5 | 126.6 | 129.8 | 151.8 | 898.7 | 54.6 | 14.1 | 14.4 | 16.9 | 100.0 |
| | Spain | 236.1 | 67.7 | 282.0 | 1 032.8 | 1 618.6 | 14.6 | 4.2 | 17.4 | 63.8 | 100.0 |
| | Sweden | 385.2 | 51.9 | 1 502.3 | 1 016.0 | 2 955.4 | 13.0 | 1.8 | 50.8 | 34.4 | 100.0 |
| | Switzerland | | 350.9 | 12.6 | 17.5 | 381.0 | 0.0 | 92.1 | 3.3 | 4.6 | 100.0 |
| | Turkey | 821.3 | 4 007.0 | 1 155.0 | 284.3 | 6 267.6 | 13.1 | 63.9 | 18.4 | 4.5 | 100.0 |
| | UK | 1 987.4 | 488.0 | 1 808.5 | 2 431.7 | 6 715.6 | 29.6 | 7.3 | 26.9 | 36.2 | 100.0 |
| Total for WEU | | 42 574.2 | 45 053.4 | 32 196.8 | 22 459.7 | 14 2284.1 | 29.9 | 31.7 | 22.6 | 15.8 | 100.0 |
| | | | | | | | | | | | |
| EEU | Albania | | | | | | | | | | |
| | Bosnia and Herzegovina | | | | | | | | | | |
| | Bulgaria | 0.2 | 501.6 | 419.9 | 244.4 | 1 166.1 | 0.0 | 43.0 | 36.0 | 21.0 | 100.0 |
| | Croatia | | | | | | | | | | |
| | Czech Republic | | 98.3 | 42.0 | | 140.3 | 0.0 | 70.1 | 29.9 | 0.0 | 100.0 |
| | Hungary | | | | | | | | | | |
| | Poland | 6.6 | 1 455.0 | 589.0 | 307.4 | 2 358.0 | 0.3 | 61.7 | 25.0 | 13.0 | 100.0 |
| | Romania | 429.3 | 850.0 | 1 033.1 | 224.1 | 2 536.5 | 16.9 | 33.5 | 40.7 | 8.8 | 100.0 |
| | Slovakia | | | | | | | | | | |
| | Slovenia | | | | | | | | | | |
| | The Former Yugoslav Republic of Macedonia | | | | | | | | | | |
| | Yugoslavia, Federal Republic of | | | | | | | | | | |
| Total for EEU | | 436.1 | 2 904.9 | 2 084.0 | 775.9 | 6 200.9 | 7.0 | 46.8 | 33.6 | 12.5 | 100.0 |
| | | | | | | | | | | | |
| FSU | Armenia | 12.0 | | 23.4 | 35.7 | 71.1 | 16.9 | 0.0 | 32.9 | 50.2 | 100.0 |
| | Azerbaijan | | | | | | | | | | |
| | Belarus | | | | | | | | | | |
| | Estonia | 9.9 | 159.6 | 216.7 | 211.5 | 597.7 | 1.7 | 26.7 | 36.3 | 35.4 | 100.0 |

TABLE 62. (cont.)

| | | Tonnage (1000 GT) of ships of more than 100 GT | | | | | Breakdown (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Region | Country/territory | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet |
| | Georgia | | | | | | | | | | |
| | Kazakhstan | | | | | | | | | | |
| | Kyrgyzstan | | | | | | | | | | |
| | Latvia | 322.5 | | 285.9 | 189.7 | 798.1 | 40.4 | 0.0 | 35.8 | 23.8 | 100.0 |
| | Lithuania | 8.2 | 110.7 | 206.5 | 284.8 | 610.2 | 1.3 | 18.1 | 33.8 | 46.7 | 100.0 |
| | Republic of Moldova | | | | | | | | | | |
| | Russian Federation | 2 294.3 | 1 768.4 | 5 303.1 | 5 836.5 | 15 202.3 | 15.1 | 11.6 | 34.9 | 38.4 | 100.0 |
| | Tajikistan | | | | | | | | | | |
| | Turkmenistan | | | | | | | | | | |
| | Ukraine | 80.8 | 728.8 | 2 623.5 | 1 179.8 | 4 612.9 | 1.8 | 15.8 | 56.9 | 25.6 | 100.0 |
| | Uzbekistan | | | | | | | | | | |
| Total for FSU | | 2 727.7 | 2 767.5 | 8 659.1 | 7 738.0 | 21 892.3 | 12.5 | 12.6 | 39.6 | 35.3 | 100.0 |
| CPA | Cambodia | | | | | | | | | | |
| | China | 2 295.1 | 6 677.0 | 6 741.9 | 1 229.2 | 16 943.2 | 13.5 | 39.4 | 39.8 | 7.3 | 100.0 |
| | Democratic People's Republic of Korea | | | | | | | | | | |
| | Hong Kong, China | 668.9 | 6 405.3 | 1 585.2 | 135.4 | 8 794.8 | 7.6 | 72.8 | 18.0 | 1.5 | 100.0 |
| | Lao People's Democratic Republic | | | | | | | | | | |
| | Mongolia | | | | | | | | | | |
| | Viet Nam | | | | | | | | | | |
| Total for CPA | | 2 964.0 | 13 082.3 | 8 327.1 | 1 364.6 | 25 738.0 | 11.5 | 50.8 | 32.4 | 5.3 | 100.0 |
| SAS | Afghanistan | | | | | | | | | | |
| | Bangladesh | | | | | | | | | | |

TABLE 62. (cont.)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bhutan | | | | | | | | | | |
| | India | 2 553.1 | 3 183.4 | 710.2 | 680.1 | 7 126.8 | 35.8 | 44.7 | 10.0 | 9.5 | 100.0 |
| | Maldives | | | | | | | | | | |
| | Nepal | | | | | | | | | | |
| | Pakistan | | | | | | | | | | |
| | Sri Lanka | | | | | | | | | | |
| Total for SAS | | 2 553.1 | 3 183.4 | 710.2 | 680.1 | 7 126.8 | 35.8 | 44.7 | 10.0 | 9.5 | 100.0 |
| PAS | American Samoa | | | | | | | | | | |
| | Brunei Darussalam | | | | | | | | | | |
| | Fiji | | | | | | | | | | |
| | French Polynesia | | | | | | | | | | |
| | Indonesia | 738.5 | 205.3 | 1 264.1 | 562.6 | 2 770.5 | 26.7 | 7.4 | 45.6 | 20.3 | 100.0 |
| | Malaysia | 411.6 | 981.8 | 892.1 | 997.4 | 3 282.9 | 12.5 | 29.9 | 27.2 | 30.4 | 100.0 |
| | Myanmar | | | | | | | | | | |
| | New Caledonia | | | | | | | | | | |
| | Papua New Guinea | | | | | | | | | | |
| | Philippines | 147.0 | 6 137.7 | 1 928.2 | 530.9 | 8 743.8 | 1.7 | 70.2 | 22.1 | 6.1 | 100.0 |
| | Kiribati | | | | | | | | | | |
| | Korea, Republic of | 399.2 | 3 705.8 | 2 011.4 | 855.6 | 6 972.0 | 5.7 | 53.2 | 28.8 | 12.3 | 100.0 |
| | Samoa | | | | | | | | | | |
| | Singapore | 5 101.7 | 3 766.4 | 3 948.7 | 793.9 | 13 610.7 | 37.5 | 27.7 | 29.0 | 5.8 | 100.0 |
| | Solomon and Marshall Islands | 1 502.1 | 701.5 | 872.7 | 22.3 | 3 098.6 | 48.5 | 22.6 | 28.2 | 0.7 | 100.0 |
| | Taiwan, China | 959.4 | 2 431.1 | 2 540.6 | 173.1 | 6 104.2 | 15.7 | 39.8 | 41.6 | 2.8 | 100.0 |
| | Thailand | 196.4 | 386.7 | 1 042.9 | 117.4 | 1 743.4 | 11.3 | 22.2 | 59.8 | 6.7 | 100.0 |
| | Tonga | | | | | | | | | | |
| | Vanuatu | 38.5 | 840.7 | 726.1 | 268.9 | 1 874.2 | 2.1 | 44.9 | 38.7 | 14.3 | 100.0 |
| Total for PAS | | 9 494.4 | 19 157.0 | 15 226.8 | 4 322.1 | 48 200.3 | 19.7 | 39.7 | 31.6 | 9.0 | 100.0 |

TABLE 62. (cont.)

| | | Tonnage (1000 GT) of ships of more than 100 GT | | | | | Breakdown (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Region | Country/territory | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet | Oil tankers | Ore and dry bulk | General cargo | Misc. | Total fleet |
| PAO | Australia | 578.9 | 1 011.0 | 234.7 | 1 028.5 | 2 853.1 | 20.3 | 35.4 | 8.2 | 36.0 | 100.0 |
| | Japan | 6 032.9 | 5 444.8 | 3 602.4 | 4 833.1 | 19 913.2 | 30.3 | 27.3 | 18.1 | 24.3 | 100.0 |
| | New Zealand | 75.8 | 25.1 | 77.1 | 133.5 | 311.5 | 24.3 | 8.1 | 24.8 | 42.9 | 100.0 |
| Total for PAO | | 6 687.6 | 6 480.9 | 3 914.2 | 5 995.1 | 23 077.8 | 29.0 | 28.1 | 17.0 | 26.0 | 100.0 |
| Others and unaccounted for | | 4 192.5 | 2 013.6 | 7 347.20 | 4 751.10 | 18 304.4 | 22.9 | 11.0 | 40.1 | 26.0 | 100.0 |
| World total | | 143 382.1 | 151 694.3 | 123 764.8 | 71 733.6 | 490 574.8 | 29.2 | 30.9 | 25.2 | 14.6 | 100.0 |

**Note:** Data are not available if none are shown.

# Appendix XI

## ESTIMATE OF THE LONG TERM PROSPECTS FOR NUCLEAR POWERED SHIP PROPULSION

TABLE 63. ESTIMATE OF THE LONG TERM PROSPECTS FOR NUCLEAR POWERED SHIP PROPULSION

| Region | Country/territory | Total fleet tonnage in 1995 (1000 GT)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| NAM | Canada | 2 401.0 | 2 | 1 | 1 | 0 | 1 | 1.0 |
| | Guam | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Puerto Rico | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | USA | 12 760.8 | 2 | 1 | 2 | 0 | 1 | 1.2 |
| | Virgin Islands | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Total for NAM | | 15 161.8 | 2.00 | 1.00 | 1.84 | 0.00 | 1.00 | 1.17 |
| LAM | Antigua and Barbuda | 1 842.0 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Argentina | 594.9 | 1 | 1 | 1 | 0 | 1 | 0.8 |
| | Bahamas | 23 602.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Barbados | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Belize | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Bermuda | 3 047.5 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Bolivia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Brazil | 5 076.7 | 2 | 1 | 1 | 0 | 1 | 1.0 |
| | Chile | 0.0 | 0 | 0 | 0 | 0 | 1 | 0.2 |
| | Colombia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Costa Rica | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |

TABLE 63. (cont.)

| Region | Country/territory | Total fleet tonnage in 1995 (1000 GT)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Cuba | 0.0 | 0 | 0 | 0 | 0 | 1 | 0.2 |
| | Dominica | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Dominican Republic | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Ecuador | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | El Salvador | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | French Guiana | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Grenada | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Guadeloupe | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Guatemala | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Guyana | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Haiti | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Honduras | 1 206.0 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Jamaica | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Martinique | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Mexico | 1 129.2 | 1 | 1 | 1 | 0 | 1 | 0.8 |
| | Netherlands Antilles | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Nicaragua | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Panama | 71 921.7 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Paraguay | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Peru | 0.0 | 0 | 0 | 0 | 0 | 1 | 0.2 |
| | Saint Kitts and Nevis | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Saint Lucia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |

TABLE 63. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Saint Vincent and the Grenadines | 6 164.7 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Suriname | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Trinidad and Tobago | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Uruguay | 0.0 | 0 | 0 | 0 | 0 | 1 | 0.2 |
| | Venezuela | 787.1 | 0 | 1 | 0 | 0 | 1 | 0.4 |
| Total for LAM | | 115 372.6 | 0.10 | 1.00 | 0.06 | 0.00 | 0.07 | 0.25 |
| AFR | Angola | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Benin | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Botswana | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | British Indian Ocean Territory | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Burkina Faso | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Burundi | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Cameroon | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Cape Verde | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Central African Republic | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Chad | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Comoros | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Congo | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Cote d’Ivoire | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Democratic Republic of the Congo | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Djibouti | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Equatorial Guinea | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |

TABLE 63. (cont.)

| Region | Country/territory | Total fleet tonnage in 1995 (1000 GT)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Eritrea | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Ethiopia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Gabon | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Gambia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Ghana | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Guinea | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Guinea-Bissau | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Kenya | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Lesotho | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Liberia | 59 800.7 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Madagascar | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Malawi | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Mali | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Mauritania | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Mauritius | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Mozambique | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Namibia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Niger | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Nigeria | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Reunion | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Rwanda | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Sao Tome and Principe | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |

TABLE 63. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Senegal | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Seychelles | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Sierra Leone | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Somalia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | South Africa | 0.0 | 0 | 0 | 1 | 0 | 2 | 0.6 |
| | St. Helena | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Swaziland | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Togo | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Uganda | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | United Republic of Tanzania | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Zambia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Zimbabwe | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Total for AFR | | 59 800.7 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| MEA | Algeria | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Bahrain | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Egypt | 1 268.8 | 0 | 1 | 0 | 0 | 1 | 0.4 |
| | Iraq | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Iran, Islamic Republic of | 2 902.4 | 0 | 1 | 0 | 0 | 2 | 0.6 |
| | Israel | 0.0 | 0 | 0 | 0 | 0 | 1 | 0.2 |
| | Jordan | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Kuwait | 2 057.0 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Lebanon | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Libyan Arab Jamahiriya | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Morocco | 0.0 | 0 | 0 | 0 | 0 | 1 | 0.2 |
| | Oman | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |

TABLE 63. (cont.)

| Region | Country/territory | Total fleet tonnage in 1995 (1000 GT)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Qatar | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Saudi Arabia | 1 186.9 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Sudan | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Syrian Arab Republic | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Tunisia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | United Arab Emirates | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Yemen | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Total for MEA | | 7 415.1 | 0.00 | 1.00 | 0.00 | 0.00 | 0.95 | 0.39 |
| WEU | Andorra | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Austria | 91.9 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Azores | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Belgium | 2 39.8 | 0 | 1 | 1 | 0 | 1 | 0.6 |
| | Canary Islands | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Channel Islands | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Cyprus | 24 652.5 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Denmark | 5 851.5 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Faeroe Islands | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Finland | 1 518.7 | 1 | 1 | 1 | 0 | 1 | 0.8 |
| | France | 4 194.4 | 2 | 1 | 1 | 0 | 2 | 1.2 |
| | Germany | 5 626.3 | 2 | 1 | 2 | 0 | 0 | 1.0 |
| | Gibraltar | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |

TABLE 63. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Greece | 29 434.7 | 0 | 1 | 0 | 0 | 1 | 0.4 |
| | Greenland | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Iceland | 208.6 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Ireland | 213.4 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Isle of Man | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Italy | 6 699.4 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Liechtenstein | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Luxembourg | 880.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Madeira | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Malta | 17 678.3 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Monaco | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Netherlands | 4 606.0 | 2 | 1 | 1 | 0 | 1 | 1.0 |
| | Norway | 21 550.9 | 0 | 1 | 0 | 0 | 1 | 0.4 |
| | Portugal | 898.7 | 0 | 1 | 0 | 0 | 1 | 0.4 |
| | Spain | 1 618.6 | 1 | 1 | 1 | 0 | 1 | 0.8 |
| | Sweden | 2 955.4 | 2 | 1 | 1 | 0 | 0 | 0.8 |
| | Switzerland | 381.0 | 1 | 1 | 1 | 0 | 1 | 0.8 |
| | Turkey | 6 267.6 | 0 | 1 | 0 | 0 | 1 | 0.4 |
| | UK | 6 715.6 | 2 | 1 | 1 | 0 | 1 | 1.0 |
| Total for WEU | | 142 284.1 | 0.36 | 1.00 | 0.24 | 0.00 | 0.57 | 0.43 |
| EEU | Albania | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Bosnia and Herzegovina | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Bulgaria | 1 166.1 | 1 | 1 | 1 | 0 | 1 | 0.8 |
| | Croatia | 0.0 | 0 | 0 | 1 | 0 | 1 | 0.4 |
| | Czech Republic | 140.3 | 1 | 1 | 1 | 0 | 1 | 0.8 |

TABLE 63. (cont.)

| Region | Country/territory | Total fleet tonnage in 1995 (1000 GT)[a] | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| | Hungary | 0.0 | 0 | 0 | 1 | 0 | 1 | 0.4 |
| | Poland | 2 358.0 | 0 | 1 | 0 | 0 | 1 | 0.4 |
| | Romania | 2 536.5 | 2 | 1 | 1 | 0 | 1 | 1.0 |
| | Slovakia | 0.0 | 0 | 0 | 1 | 0 | 1 | 0.4 |
| | Slovenia | 0.0 | 0 | 0 | 1 | 0 | 1 | 0.4 |
| | The Former Yugoslav Republic of Macedonia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Yugoslavia, Federal Republic of | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Total for EEU | | 6 200.9 | 1.03 | 1.00 | 0.62 | 0.00 | 1.00 | 0.73 |
| | | | | | | | | |
| FSU | Armenia | 71.1 | 0 | 1 | 1 | 0 | 1 | 0.6 |
| | Azerbaijan | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Belarus | 0.0 | 0 | 0 | 0 | 0 | 1 | 0.2 |
| | Estonia | 597.7 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Georgia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Kazakhstan | 0.0 | 0 | 0 | 0 | 0 | 1 | 0.2 |
| | Kyrgyzstan | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Latvia | 798.1 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Lithuania | 610.2 | 1 | 1 | 1 | 0 | 1 | 0.8 |
| | Republic of Moldova | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Russian Federation | 15 202.3 | 2 | 1 | 2 | 1 | 1 | 1.4 |

TABLE 63. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Tajikistan | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Turkmenistan | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Ukraine | 4 612.9 | 2 | 1 | 1 | 0 | 1 | 1.0 |
| | Uzbekistan | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Total for FSU | | 21 892.3 | 1.84 | 1.00 | 1.63 | 0.69 | 0.94 | 1.22 |
| CPA | Cambodia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | China | 16 943.2 | 2 | 1 | 1 | 0 | 2 | 1.2 |
| | Democratic People's Republic of Korea | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Hong Kong, China | 8 794.8 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Lao People's Democratic Republic | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Mongolia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Viet Nam | 0.0 | 0 | 0 | 0 | 0 | 1 | 0.2 |
| Total for CPA | | 25 738.0 | 1.32 | 1.00 | 0.66 | 0.00 | 1.32 | 0.86 |
| SAS | Afghanistan | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Bangladesh | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Bhutan | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | India | 7 126.8 | 2 | 1 | 1 | 0 | 2 | 1.2 |
| | Maldives | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Nepal | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Pakistan | 0.0 | 0 | 0 | 1 | 0 | 2 | 0.6 |
| | Sri Lanka | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Total for SAS | | 7 126.8 | 2.00 | 1.00 | 1.00 | 0.00 | 2.00 | 1.20 |

TABLE 63. (cont.)

| Region | Country/territory | Total fleet tonnage in 1995 (1000 GT)$^a$ | Ranking for market structure | Ranking for demand pressure | Ranking for technical basis | Ranking for economic competitiveness | Ranking for public attitude | Average |
|---|---|---|---|---|---|---|---|---|
| PAS | American Samoa | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Brunei Darussalam | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Fiji | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | French Polynesia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Indonesia | 2 770.5 | 2 | 1 | 0 | 0 | 1 | 0.8 |
| | Malaysia | 3 282.9 | 2 | 1 | 0 | 0 | 0 | 0.6 |
| | Myanmar | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | New Caledonia | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Papua New Guinea | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Philippines | 8 743.8 | 0 | 1 | 0 | 0 | 1 | 0.4 |
| | Kiribati | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Korea, Republic of | 6 972.0 | 2 | 1 | 1 | 0 | 2 | 1.2 |
| | Samoa | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Singapore | 13 610.7 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Solomon Islands | 3 098.6 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| | Taiwan, China | 6 104.2 | 2 | 1 | 1 | 0 | 1 | 1.0 |
| | Thailand | 1 743.4 | 0 | 1 | 0 | 0 | 1 | 0.4 |
| | Tonga | 0.0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | Vanuatu | 1 874.2 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Total for PAS | | 48 200.3 | 0.79 | 1.00 | 0.27 | 0.00 | 0.69 | 0.55 |
| PAO | Australia | 2853.1 | 0 | 1 | 0 | 0 | 0 | 0.2 |

TABLE 63. (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Japan | 19 913.2 | 2 | 1 | 2 | 1 | 1 | 1.4 |
| | New Zealand | 311.5 | 0 | 1 | 0 | 0 | 0 | 0.2 |
| Total for PAO | | 23 077.8 | 1.73 | 1.00 | 1.73 | 0.86 | 0.86 | 1.24 |
| World total | | 472 270.4 | 0.56 | 1.00 | 0.39 | 0.07 | 0.51 | 0.51 |

[a] Used for weighting.

# ABBREVIATIONS

| | |
|---|---|
| AFR | sub-Saharan Africa |
| AST | nuclear heating plant (a Russian abbreviation) |
| boe | barrels of oil equivalent |
| CC | combined cycle |
| CPA | centrally planned Asia and China |
| dwt | dead weight tonnage |
| EEU | central and eastern Europe |
| FSU | Newly Independent States of the former Soviet Union |
| GHG | greenhouse gas |
| GT | gross tonnes (used in maritime transportation) |
| HBS | heatpipe bimodal system |
| HPS | heatpipe power system |
| HR | heating reactor |
| HTR | high temperature reactor |
| HTGR | high temperature gas cooled reactor |
| HTTR | High Temperature Engineering Test Reactor |
| HWR | heavy water reactor |
| IEA | International Energy Agency |
| JAERI | Japan Atomic Energy Research Institute |
| LAM | Latin America and the Caribbean |
| LHV | low heating value |
| MEA | Middle East and North Africa |
| MED | multieffect distillation |
| MGT | millions of gross tonnes |
| MSF | multistage flash distillation |
| Mtoe | million tonnes of oil equivalent |
| NAM | North America |
| NEA | Nuclear Energy Agency |
| NHP | nuclear heating plant |
| NHR | nuclear heating reactor |
| NPP | nuclear power plant |
| OECD | Organisation for Economic Co-operation and Development |
| PAO | Pacific OECD |
| PAS | other Pacific Asia |
| PBMR | pebble bed modular reactor |
| PC | pulverized coal |
| PHWR | pressurized heavy water reactor |
| PWR | pressurized water reactor |
| RO | reverse osmosis |

| | |
|---|---|
| RTG | radioisotope thermoelectric generator |
| SAS | South Asia |
| SMART | System Integrated Modular Advanced Reactor |
| STV | submarine transportation vessel |
| WEU | western Europe |
| WWER | water moderated, water cooled reactor |

# REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Power Reactors in the World, Reference Data Series No. 2 (2001 edition), IAEA, Vienna (2001).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Energy, Electricity and Nuclear Power Estimates for the Period up to 2020, Reference Data Series No. 1 (2001 edition), IAEA, Vienna (2001).

[3] INTERNATIONAL ENERGY AGENCY, Key World Energy Statistics from the IEA (2000 edition), OECD, Paris (1999).

[4] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, Emission Scenarios, Cambridge University Press, Cambridge (2000).

[5] KAGRAMANIAN, V., KONONOV, S., ROGNER, H.-H., Climate change driving forces: Nuclear energy and the latest IPCC emission scenarios, IAEA Bull. **42** 2 (2000) 31–35.

[6] GUREEVA, L.V., KURACHENKOV, A.V., “Creation of nuclear heating plants in Russia: present status and prospects for the future”, Nuclear Heat Applications: Design Aspects and Operating Experience, IAEA-TECDOC-1056, IAEA, Vienna (1998) 55–60.

[7] KIRYUSHIN, A.I., PANOV, Yu.K., POLUNICHEV, V.I., VESHNYAKOV, K.B., “Floating nuclear heat and power station ‘Pevek’ with KLT-40 type reactor plant for remote regions of Russia”, N’Ocean 2000, Utilization of Nuclear Power in Oceans (Proc. Int. Workshop Tokyo, 2000), Ship Research Institute of the Ministry of Transport, Tokyo (2000) 104–112.

[8] SUN, Y., ZHONG, D., XU, Y., “Nuclear reactor development in China for non-electrical applications”, Nuclear Heat Applications: Design Aspects And Operating Experience, IAEA-TECDOC-1056, IAEA, Vienna (1998) 201–208.

[9] JAPAN ATOMIC ENERGY RESEARCH INSTITUTE, High temperature gas-cooled reactor in Japan reached initial criticality, JAERI News FF No. 43 1999/4 (1999).

[10] JAPAN ATOMIC ENERGY RESEARCH INSTITUTE, High temperature engineering test reactor (HTTR) used for R&D on diversified applications of nuclear energy, JAERI News FF No. 45 1999/8 (1999).

[11] SUN, Y., XU, Y., Der gasgekühlte 10-MW-Hochtemperaturreaktor in Peking, VGB Kraftwerkstechnik Nov. (1999) 19–23.

[12] KIRYUSHIN, A.I., et al., Project of the GT-MHR high-temperature helium reactor with a gas turbine, Nuc. Eng. Design **173** (1997) 119–129.

[13] Second international investor expected for PBMR project, Nucleonics Week **41** 29 (2000).

[14] ESKOM, What is a Pebble-bed Modular Reactor (PBMR)?, PBMR Project Press Release (2000).

[15] NICHOLLS, D., “Utility requirements for HTGRs”, High Temperature Gas Cooled Reactor Technology Development, IAEA-TECDOC-988, IAEA, Vienna (1996) 13–17.

[16] VERMA, R.K., “Technical Aspects of Coupling a 6300 $m^3$/day MSF-RO Desalination Plant to a PHWR Nuclear Power Plant”, Nuclear Heat Applications: Design Aspects and Operating Experience, IAEA-TECDOC-1056, IAEA, Vienna (1998) 263–269.

[17] CHANG, M.-H., HWANG, Y.-D., KIM, S.-H., “An integrated nuclear desalination plant concept using an advanced small PWR-SMART”, International Desalination

Association Conference (Proc. Conf. San Diego, 1999), Vol. IV, International Desalination Association, Topsfield, MA (1999) 289–319.

[18] RIGHI, M., WENXIANG, Z., "Pre-project study of a nuclear desalination demonstration plant for Tan-Tan, Morocco", ibid., pp. 351–380.

[19] HASSAN, A.S., FLORIDO, P.C., "Feasibility of nuclear desalination costs in Egypt", ibid., pp. 301–330.

[20] MITENKOV, F.M., POLUNICHEV, V.I., Small nuclear heat and power co-generation stations and water desalination complexes on the basis of marine reactor plants, Nuc. Eng. Design **173** (1997) 183–191.

[21] POLUNICHEV, V.I., "Prospects of small nuclear plants utilization for civil ships, floating heat and power stations and power-seawater desalination complexes", Trombay Symposium on Desalination and Water Reuse (Proc. Symp. Mumbai, 1999), Indian Desalination Association, Mumbai (1999) 128–137.

[22] NISAN, S., et al., "Applications of innovative nuclear reactors for sea water desalination", Southern Europe: The EURODESAL Project (Proc. FISA-2001 Conf. Luxembourg, 2001), European Commission, Brussels (2001).

[23] JAPAN ATOMIC ENERGY RESEARCH INSTITUTE, "Nuclear ship research and development", Annual Report: April 1998–March 1999, JAERI, Tokyo (2000).

[24] KHLOPKIN, N.S., ZOTOV, A.P., Merchant marine nuclear powered vessels, Nucl. Eng. Design **173** (1997) 201–206.

[25] BYKOV, V.P., KHLOPKIN, N.S., KUZNETSOV, V.P., VELIKHOV, E.P., "Nuclear energy using for marine oil and gas field development on Russian Arctic Shelf", N'Ocean 2000, Utilization of Nuclear Power in Oceans (Proc. Int. Workshop Tokyo, 2000), Ship Research Institute of the Ministry of Transport, Tokyo (2000).

[26] VASYUKOV, V.I., KIRYUSHIN, A.I., PANOV, Yu.K., POLUNICHEV, V.I., "Civil ship propulsion reactor plants development and operation experience, and prospects for their improvement", ibid.

[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Small Power and Heat Generation Systems on the Basis of Propulsion and Innovative Reactor Technologies, IAEA-TECDOC-1172, IAEA, Vienna (2000).

[28] ADAMS, B.T., et al., "The feasibility of a near-term, low-cost space nuclear power", Space Technology and Applications International Forum — 1999 (EL-GENK, M.S., Ed.), American Institute of Physics, New York (1999).

[29] POSTON, D.I., HOUTS, M.G., EMRICH, W.J., "Development status of heatpipe power and bimodal systems", ibid.

[30] HOENRAET, C., "The energy sources and nuclear energy: a point of view of the Belgian Catholic Church", ibid.

[31] OECD NUCLEAR ENERGY AGENCY, OECD INTERNATIONAL ENERGY AGENCY, Projected Costs of Generating Electricity: Update 1998, OECD, Paris (1998).

[32] OECD NUCLEAR ENERGY AGENCY, Reduction of Capital Costs of Nuclear Power Plants, OECD, Paris (2000).

[33] Nuclear O&M continues to drop; Sequoyah is cheapest in 1999, Nucleonics Week **41** 27 (2000).

[34] OECD INTERNATIONAL ENERGY AGENCY, Energy Statistics and Balances of Non-OECD Countries: 1995–1996 (1998 edition), OECD, Paris (1998).

[35] OECD INTERNATIONAL ENERGY AGENCY, Energy Balances of OECD Countries: 1996–1997 (1999 edition), OECD, Paris (1999).

[36] INTERNATIONAL INSTITUTE FOR APPLIED SYSTEM ANALYSIS, WORLD ENERGY COUNCIL, Global Energy Perspectives (NAKICENOVIC, N., GRÜBLER, A., MCDONALD, A., Eds), Cambridge University Press, Cambridge (1998).

[37] WANGNICK, K., 2000 IDA Worldwide Desalting Plants Inventory Report No. 16, Wangnick Consulting, Gnarrenburg, Germany (2000).

[38] CSIK, B.J., KUPITZ, J., Nuclear power applications: supplying heat for homes and industries, IAEA Bull. **39** 2 (1997) 21–25.

[39] UNITED STATES ENERGY INFORMATION ADMINISTRATION, Household Energy Consumption and Expenditures 1993, Rep. DOE/EIA-0321(93), United States Department of Energy/USEIA, Washington, DC (1995).

[40] UNITED STATES ENERGY INFORMATION ADMINISTRATION, Annual Energy Review 1998, Rep. DOE/EIA-0384(98), United States Department of Energy/USEIA, Washington, DC (1999).

[41] UNITED STATES ENERGY INFORMATION ADMINISTRATION, Annual Energy Outlook 2000, Rep. DOE/EIA-0383(2000), United States Department of Energy/USEIA, Washington, DC (1999).

[42] ZHANG, D., DONG, D., "Experiments on safety features and comprehensive applications of the 5 MW nuclear heating reactor", Nuclear Heat Applications: Design Aspects and Operating Experience, IAEA-TECDOC-1056, IAEA, Vienna (1998) 339–357.

[43] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Heat Applications: Design Aspects and Operating Experience, IAEA-TECDOC-1056, IAEA, Vienna (1998).

[44] INTERNATIONAL ATOMIC ENERGY AGENCY, Technical and Economic Evaluation of Potable Water Production through Desalination of Seawater by Using Nuclear Energy and Other Means, IAEA-TECDOC-666, IAEA, Vienna (1992).

[45] INTERNATIONAL ATOMIC ENERGY AGENCY, Guide to the Costing of Water from Nuclear Desalination Plants, Technical Reports Series No. 151, IAEA, Vienna (1989).

[46] INTERNATIONAL ATOMIC ENERGY AGENCY, Thermodynamic and Economic Evaluation of Co-Production Plants for Electricity and Potable Water, IAEA-TECDOC-942, IAEA, Vienna (1997).

[47] INTERNATIONAL ATOMIC ENERGY AGENCY, Methodology for the Economic Evaluation of Cogeneration/Desalination Options: A User's Manual, IAEA Computer Manual Series No. 12, IAEA, Vienna (1997).

[48] INTERNATIONAL ATOMIC ENERGY AGENCY, Desalination Economic Evaluation Programme (DEEP): A User's Manual, IAEA Computer Manual Series No. 14, IAEA, Vienna (2000).

[49] JUSKO, M.J., et al., Energy and Power Evaluation Program (ENPEP), Documentation and User's Manual, Vols 1–2, Argonne National Laboratory, Argonne, IL (1992).

[50] SECKLER, D., AMARASINGHE, U., MOLDEN, D., DE SILVA, R., BARKER, R., World Water Demand and Supply, 1990 to 2025: Scenarios and Issues, Research Rep. 19, International Water Management Institute, Colombo (1998).

[51] WORLD RESOURCES INSTITUTE, UNITED NATIONS ENVIRONMENT PROGRAMME, UNITED NATIONS DEVELOPMENT PROGRAMME, INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT (WORLD BANK), World Resources 1998–99: A Guide to the Global Environment, Oxford University Press, Oxford (1998).

[52] UNITED NATIONS ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC, Guidebook to Water Resources, Use and Management in Asia and the Pacific, Volume One: Water Resources and Water Use, Water Resource Series No. 74, UN, New York (1995).

[53] UNITED NATIONS COMMISSION ON SUSTAINABLE DEVELOPMENT, Comprehensive Assessment of the Freshwater Resources of the World, UN, New York (1997).

[54] FALKENMARK, M., LUNDQVIST, J., WIDSTRAND, C., Macro-scale water scarcity requires micro-scale approaches: Aspects of vulnerability in semi-arid development, Nat. Resour. Forum **13** (1989) 258–267.

[55] FALKENMARK, M., Meeting water requirements of an expanding world population, Phil. Trans. R. Soc., Lond., Ser. B **352** (1997) 929–936.

[56] RASKIN, P., Water Futures: Assessment of Long-Range Patterns and Problems, Stockholm Environment Institute, Stockholm (1997).

[57] INTERNATIONAL ATOMIC ENERGY AGENCY, Potential for Nuclear Desalination as a Source of Low Cost Potable Water in North Africa, IAEA-TECDOC-917, IAEA, Vienna (1996).

[58] COSGROVE, W.J., RIJSBERMAN, F.R., World Water Vision: Making Water Everybody’s Business, Report for the World Water Council, Earthscan, London (2000).

[59] WORLD WATER COUNCIL, World Water Vision: A Water Secure World, WWC Commission Report, WWC, Marseille (2000).

[60] INTERNATIONAL ATOMIC ENERGY AGENCY, Examining the Economics of Seawater Desalination using the DEEP Code, IAEA-TECDOC-1186, IAEA, Vienna (2000).

[61] AWERBUCH, L., “Power — desalination and the importance of hybrid ideas”, World Congress on Desalination and Water Reuse (Proc. Congr. Madrid, 1997), Vol. 4, International Desalination Association, Topsfield, MA (1997) 181–192.

[62] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidebook on the Introduction of Nuclear Power, Technical Reports Series No. 217, IAEA, Vienna (1982).

[63] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidebook on Research and Development Support for Nuclear Power, Technical Reports Series No. 298, IAEA, Vienna (1989).

[64] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Desalination of Sea Water (Proc. Symp. Taejon, 1997), IAEA, Vienna (1997).

[65] UNITED STATES ENERGY INFORMATION ADMINISTRATION, Manufacturing Consumption of Energy 1994, Rep. DOE/EIA-0512(94), United States Department of Energy/USEIA, Washington, DC (1997).

[66] KRETSCHMER, W., STOY, B., Der industrielle Strom- und Brennstoffverbrauch, Energiewirtsch, Tagesfragen **37** (1987) 732–739.

[67] OECD INTERNATIONAL ENERGY AGENCY, Statistics from the Database of Energy Statistics & Balances of OECD and Non-OECD Countries, OECD, Paris (2000).

[68] JOBSKY, T., Ermittlung von Potentialen zur industriellen Prozessdampfversorgung mit nuklearen Anlagen, Rep. No. 2411, Forschungszentrum Jülich, Jülich (1990).

[69] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Applications for Steam and Hot Water Supply, IAEA-TECDOC-615, IAEA, Vienna (1991).

[70] GAS COOLED REACTOR ASSOCIATES, Direct Steam Transmission Design and Costs, GCRA Rep. GCRA-82-005, GCRS, San Diego, (1982).

[71] SULLIVAN, W.G., WEST, T.M., Process Energy Reliability Requirements for Selected Industries, Rep. ORNL/ITM-5428, Oak Ridge Natl Lab., TN (1976).

[72] INTERNATIONAL ATOMIC ENERGY AGENCY, Non-electric Applications of Nuclear Energy, IAEA-TECDOC-923, IAEA, Vienna (1997).

[73] INTERNATIONAL ATOMIC ENERGY AGENCY, Hydrogen as an Energy Carrier and its Production by Nuclear Power, IAEA-TECDOC-1085, IAEA, Vienna (1999).

[74] ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, OECD Economic Outlook, OECD, Paris (1997).

[75] INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT (WORLD BANK), World Development Indicators 1999, IBRD, Washington, DC (1999).

[76] ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, Maritime Transport 1995, OECD, Paris (1997).

[77] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Considerations in the Use of Ports and Approaches by Nuclear Merchant Ships, Safety Series No. 27, IAEA, Vienna (1968).

[78] PETERS, H.J., Seatrade, Logistics, and Transport. Policy and Research Series No. 6, International Bank for Reconstruction and Development (World Bank), Washington, DC (1989).

[79] KHLOPKIN, N.S., “Conversion of military technology: naval nuclear propulsion techniques for marine and other peaceful applications”, paper presented at the 4th Annual Scientific and Technical Conference of the Russian Nuclear Society, Nizhni Novgorod, 1993.

[80] SCHAFSTALL, H.G., “Kernenergieschiff NS Otto Hahn”, Proc. Kolloquium über die Stillegung des NS Otto Hahn, Geesthacht, Germany, Rep. GKSS 83/E/69, GKSS-Forschungszentrum, Geesthacht (1983).

[81] Der Spiegel, 18 December (1978) 101–102.

[82] BENFORD, H., “Economic goals for nuclear ships”, A Forum Report: The Role of Nuclear Propulsion in Merchant Shipping (Proc. Mtg New York, 1960), Atomic Industrial Forum, New York (1960) 8–25.

[83] JAPAN ATOMIC ENERGY RESEARCH INSTITUTE, Present State of Development of Nuclear Powered Ships, JAERI, Tokyo (1993).

[84] HOSHI, T., ISHIDA, T., OCHIAI, M., “Advanced marine reactor MRX and its application for electricity and heat co-generation”, Small Power and Heat Generation Systems on the Basis of Propulsion and Innovative Reactor Technologies, IAEA-TECDOC-1172, IAEA, Vienna (2000) 85–106.

[85] BENNETT, G.L., et al., “Prelude to the future: a brief history of nuclear thermal propulsion in the United States”, A Critical Review of Space Nuclear Power and Propulsion: 1984–1993 (EL-GENK, M.S., Ed.), American Institute of Physics, New York (1994) 221–268.

[86] AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS, Space Nuclear Power: Key to Outer Solar System Exploration, an AIAA Position Paper, AIAA, Reston, VA (1995).

[87] BUDEN, D., “Summary of Space Nuclear Reactor Power Systems (1983–1992)”, A Critical Review of Space Nuclear Power and Propulsion: 1984–1993 (EL-GENK, M.S., Ed.), American Institute of Physics, New York (1994) 21–86.

[88] INTERNATIONAL ATOMIC ENERGY AGENCY, Emergency Planning and Preparedness for Re-entry of a Nuclear Powered Satellite, Safety Series No. 119, IAEA, Vienna (1996).

[89] OECD NUCLEAR ENERGY AGENCY, SWEDISH NATIONAL INSTITUTE OF RADIATION PROTECTION, Emergency Preparedness for Nuclear-powered Satellites (Rep. Mtg Stockholm, 1989), OECD, Paris (1990).

[90] BENNETT, G.L. “A look at the Soviet space nuclear power program”, 24th Intersociety Energy Conversion Engineering Conference (Proc. Conf., Arlington, VA, 1989), Vol. 2, Institute of Electrical and Electronic Engineers, Piscataway, NJ (1989) 1187–1194.

[91] DUFFEY, R.B., MILLER, A.I., HANCOX, W.T., PENDERGAST, D.R., Hydrogen and nuclear energy: Building non-carbon bridges to the future, Can. Nucl. Soc. Bull **20** (1999) 9–19.

[92] LEGASOV, V.A., et al. (Eds), Atomno-Vodorodnaya Ehnergetika I Tekhnologiya, 3 vols, Energoizdat, Moscow (1978–1982) (in Russian).

[93] BOCKRIS, J.O’M., Energy Options: Real Economics and the Solar-Hydrogen System, Taylor and Francis, London (1980).

[94] BOCKRIS, J.O’M., JUSTI, E.M., Wasserstoff: Die Energie für alle Zeiten; Konzept einer Sonnen-Wasserstoff-Wirtschaft, Udo Pfriemer Verlag, Munich (1980).

[95] HÄFELE, W., MARTINSEN, D., WALBECK, M., “The concept of a novel horizontally integrated energy system: Ways to reduce $CO_2$ emissions”, Automatic Control (10th World Congr. Munich, 1987), preprints Vol. 5, International Federation of Automatic Control, Laxenburg, Austria (1987) 155–161.

[96] HART, D., Hydrogen Power: the Commercial Future of the Ultimate Fuel, Financial Times Energy Publishing, London (1997).

[97] INTERNATIONAL ASSOCIATION FOR HYDROGEN ENERGY, 3rd World Hydrogen Energy Conference (Proc. Conf. Tokyo, 1980), Pergamon Press, Oxford and New York (1981).

[98] INTERNATIONAL ASSOCIATION FOR HYDROGEN ENERGY, Hydrogen Energy Progress XI (Proc. 11th World Hydrogen Energy Conf. Stuttgart, 1996), Schön and Wetzel, Frankfurt (1996).

[99] JUSTI, E., Leitungsmechanismus und Energieumwandlung in Festkörpern, Vandenhoeck and Ruprecht, Göttingen (1965).

[100] PESCHKA, W., Liquid Hydrogen: Fuel of the Future, Springer-Verlag, Vienna (1992).

[101] SCOTT, D.S., HÄFELE, W., The coming hydrogen age: Preventing world climatic disruption, Int. J. Hydrogen Energy **15** (1990) 727–737.

[102] UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION, Hydrogen Energy Technologies, Emerging Technology Series, UNIDO, Vienna (1998).

[103] OECD INTERNATIONAL ENERGY AGENCY, World Energy Outlook (1998 edition), OECD, Paris (1998).

[104] NATIONAL RENEWABLE ENERGY LABORATORY, The Green Hydrogen Report (the 1995 Progress Report of the Secretary of Energy's Hydrogen Technical Advisory Panel), Rep. DOE/GO-10095-179, NREL, Golden, CO (1995).

[105] OHI, J., Blueprint for Hydrogen Fuel Infrastructure Development, Rep. NREL/MP-540-27770, National Renewable Energy Laboratory, Golden, CO (2000).

[106] TAVOULAREAS, E.S., CHARPENTIER, J.-P., Clean Coal Technologies for Developing Countries, World Bank Technical Paper No. 286 (Energy Series), International Bank for Reconstruction and Development (World Bank), Washington, DC (1995).

[107] SORIA, A., RUSS, P., "Integrated gasification combined cycle: Environmentally friendly coal power plants for tomorrow's energy supply", Rep. 9, Institute for Prospective Technological Studies, Seville (1996).

[108] UNITED NATIONS DEVELOPMENT PROGRAMME, UNITED NATIONS DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS, WORLD ENERGY COUNCIL, World Energy Assessment, UNDP, New York (2000).

[109] WORLD ENERGY COUNCIL, Survey of Energy Resources 1998, WEC, London (1999).

[110] GEORGE, R.L., Mining for oil, Sci. Am. March (1998) 66–67.

[111] DONNELLY, J.K., PENDERGAST, D.R., "Nuclear energy in industry: Application to oil production", 20th Annual Canadian Nuclear Society Conference (Proc. Conf. Montreal, 1999), Canadian Nuclear Society, Toronto (CD-ROM).

# CONTRIBUTORS TO DRAFTING AND REVIEW

| | |
|---|---|
| Aronne, I.D. | Centro de Desenvolvimento da Tecnologia Nuclear, Brazil |
| Ben Kraiem, H. | Centre national des sciences et technologies nucléaires, Tunisia |
| Birkett, J. | West Neck Strategies, United States of America |
| Condu, M. | International Atomic Energy Agency |
| Csik, B. | International Atomic Energy Agency |
| Friedmann, P. | Siemens Nuclear Power GmbH, Germany |
| Gagarinsky, A. | Kurchatov Institute, Russian Federation |
| Gowin, P. | International Atomic Energy Agency |
| Grechko, A. | Research and Development Institute of Power Engineering, Russian Federation |
| Kagramanian, V. | International Atomic Energy Agency |
| Kendall, J. | International Atomic Energy Agency |
| Konishi, T. | International Atomic Energy Agency |
| Kononov, S. | International Atomic Energy Agency |
| Kupitz, J. | International Atomic Energy Agency |
| Lozek, D. | Slovenské Elektràme a.s., Slovakia |
| Luo, J. | Institute of Nuclear Technology of Tsinghua University, China |
| Miller, A. | Atomic Energy of Canada Ltd, Canada |
| Minato, A. | Central Research Institute of Electric Power Industry, Japan |
| Miyamoto, Y. | Japan Atomic Energy Research Institute, Japan |
| Nisan, S. | Commissariat à l'énergie atomique, France |
| Ogawa, M. | Japan Atomic Energy Research Institute, Japan |
| Pakan, M. | Atomic Energy of Canada Ltd, Canada |
| Polunichev, V. | OKB Mechanical Engineering, Russian Federation |
| Rogner, H.-H. | International Atomic Energy Agency |
| Stroud, B. | ESKOM, South Africa |
| Verfondern, K. | Forschungszentrum Jülich, Germany |
| Wade, D. | Argonne National Laboratory, United States of America |

**Consultants Meetings**

Vienna, Austria: 18–19 November 1999, 18–20 December 2000

**Advisory Group Meeting**

Vienna, Austria: 18–20 October 2000