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Non-Electric Applications of Nuclear Power: Seawater Desalination, Hydrogen Production and other Industrial Applications

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NON-ELECTRIC APPLICATIONS OF NUCLEAR POWER: SEAWATER DESALINATION, HYDROGEN PRODUCTION AND OTHER INDUSTRIAL APPLICATIONS

PROCEEDINGS SERIES

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FOREWORD

Today, nuclear power plants contribute about 16% to the world's electricity generation. Because electricity represents less than one third of the primary energy uses, nuclear energy provides only about 6% of total energy consumption in the world. If nuclear energy were used for purposes other than electricity generation, it could play a more significant role in global energy supply. This could have also a significant impact on global goals for reduced greenhouse gas emissions for a cleaner environment.

Nuclear power is the only large-scale carbon-free energy source that, in the near and medium term, has the potential to significantly displace limited and uncertain fossil fuels. To do this, however, nuclear power must move beyond its historical role as solely a producer of electricity to other non-electric applications. These applications include seawater desalination, district heating, heat for industrial processes, and electricity and heat for hydrogen production among others. These applications have tremendous potential in ensuring future worldwide energy and water security for sustainable development.

In recent years, various agencies involved in nuclear energy development programmes have carried out studies on non-electric applications of nuclear power and useful reports have been published. The IAEA launched a programme on co-generation applications in the 1990's in which a number of Member States have been and continue to be actively involved. This programme, however is primarily concerned with seawater desalination, and district and process heating, utilizing the existing reactors as a source of heat and electricity. In recent years the scope of the Agency's programme has been widened to include other more promising applications such as nuclear hydrogen production and higher temperature process heat applications. OECD/NEA (OECD Nuclear Energy Agency), Euroatom (European Atomic Energy Community) and GIF (Generation IV International Forum) have also evinced interest in the non-electric applications of nuclear power based on future generation advanced and innovative nuclear reactors.

The IAEA organized a Symposium on Nuclear Desalination of Seawater hosted by Korean Atomic Energy Research Institute in Taejon, South Korea in 1997. IAEA cooperated with World Council of Nuclear Workers (WONUC) and the Moroccon Association of Nuclear Engineers (AIGAM) on an International Conference on Nuclear Desalination held at Marrakesh in 2002. In view of the widened scope of the Agency's programme, it was proposed to hold the next International Conference in 2007 on Non-electric Applications of Nuclear Power. The objective of the conference was to share the experiences of Member States already engaged in the development programme in this area with those having interest and considering research studies.

This conference, held April 16–19, 2007 at JAEA, Oarai, Japan, covered various aspects of non-electric applications of nuclear power utilizing combined heat and power (CHP). The major focus was on desalination, hydrogen production or other fuel production as a complement to CO_2-free energy sources and many newer industrial applications. This publication contains the text of all the contributory papers, summary of the sessions and the panel discussion at the conference. The proceeding will be useful to the scientists and engineers interested in research and development of the non-electric applications of nuclear power worldwide.

The IAEA officer responsible for this conference was I. Khamis. The local coordination was by T. Nishihara of JAEA. The cooperation of OECD/NEA and IDA and the contribution of the steering committee members and of the participants of the conference is also acknowledged.

EDITORIAL NOTE

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SUMMARY

1. INTRODUCTION

IAEA organized the International Conference on "Non-electric Applications of Nuclear Power: Seawater Desalination, Hydrogen Production and other Industrial Applications" at Oarai, Japan on April 16-19, 2007, in cooperation with OECD Nuclear Energy Agency (OECD/NEA) and International Desalination Association (IDA) and hosted by the Government of Japan through the Japan Atomic Energy Agency (JAEA).

There were one hundred and twenty six participants from twenty four countries and six international organizations and the host organization. Sixty papers were presented at the conference and six poster presentations were displayed.

The programme of the conference was designed to cover the wider aspects of outlook of nuclear power and process heat applications as well as technology, safety and economics of non-electric applications. The current trends in nuclear desalination and research and development in the field of high temperature process applications including nuclear hydrogen production were particularly highlighted during the conference.

1.1 The global energy scenario and nuclear energy out look

All forecasts project increases in world energy demand, especially as population and economic productivity grow. There appears however no ideal or magic solutions to avoid the unclean, uncertain and expensive energy based on fossil fuels in the coming years, as the present trends indicate. Wind power, though growing, provides only a modest amount of electricity worldwide and cannot generate the heat required for alternative applications. Solar furnaces can provide high-temperature heat and electricity, but are still under development. Both of these renewable energy options require vast land resources and favorable climate conditions and would be incompatible with the large-scale applications. Nuclear energy on the other hand has the potential for large-scale deployment in future.

All energy technologies will be therefore needed in the years to come. As far nuclear is concerned, uranium resources are available for exploitation of nuclear energy and advanced nuclear technologies are developed/ are under development. From a sustainable development perspective, nuclear energy has a major role to play in terms of reduction of CO2 emissions, security of energy supply and diversification of supply and price stability.

As a proven technology, today nuclear power provides more than 16% of world electricity supply in over than 30 countries. The net nuclear power capacity in operation in developing countries alone is close to 14% of the total worldwide. More than ten thousand reactor-years of operating experience have been accumulated over the past 5 decades. In recent years, a growing interest in harnessing nuclear power in non electric applications has been shown by many countries all over the world. However, non electric applications of nuclear power may be foreseen for a wide range of applications such as hydrogen production, nuclear seawater desalination, district heating, oil recovery, coal conversion, and other industrial applications for the petrochemical and refinery process, paper and textile etc. It is evident that the specific temperature requirements for such non electric applications vary greatly from low (less than 100˚ C in case of heating) to very high (more than 1000˚ C in Iron and steel industry).

The most prominent and economically seem competitive of nuclear power in the non electric applications are nuclear seawater desalination and hydrogen production. Currently, a great focus will be made on the latest activities on H-production economy and technology presented during the Japan conference which was held in Oarai during the period of 16–19 April 2007. Other major topic to be addressed thoroughly during the conference will be nuclear desalination. Overall, scientists of more than 170 persons are expected to attend coming from over than 40 Member states of the IAEA. The conference will constitute a large forum to exchange information on the status of process heat applications of nuclear power including high-temperature as well as low temperatures applications.

Various presentations on ongoing interest in Member States in the development and application of small and medium sized reactors will also be presented. Many innovative designs for nuclear reactors within the small-to-medium size range will be addressed. Such reactors are expected to play a positive role in the fulfillment for the need of non-electric applications of nuclear power. Recently, more than 50 concepts and designs of such innovative SMRs were developed in Argentina, Brazil, China, France, India, Japan, the Republic of Korea, Russian Federation, South Africa, and the USA.

In order for nuclear energy to contribute effectively to future global energy supplies and sustainable development, its applications should be extended beyond electricity, particularly in the transport sector where oil now supplies 95% of transport demand. The most promising way that nuclear energy might provide energy for transportation is through the production of hydrogen, either for direct use in fuel-cell vehicles or to produce synfuels. Hydrogen research is currently on the rise. Major automobile manufacturers have set ambitious targets for putting affordable fuel cell cars on the road, and significant governmental initiatives have been launched in the EU, the USA and Japan. Nuclear energy is part of these initiatives, but for nuclear energy to become a major future hydrogen supplier will require significant efforts in both reactor technology development and installing new infrastructures. Both challenges are best addressed through a global approach. Nuclear energy can also make a substantial contribution to a critical non-energy ambition – universal access to plentiful fresh water. Currently about 2.3 billion people live in water-stressed areas and among them 1.7 billion live in water-scarce areas, where the water availability per person is less than 1000 m 3/year. By 2025 the number of people suffering from water stress or scarcity could swell to 3.5 billion, with 2.4 billion expected to live in water-scarce regions. Water scarcity is a global issue, and every year new countries are affected by growing water problems. The desalination of seawater using nuclear energy (either low temperature heat or electricity) is a demonstrated option. Over 150 reactor-years of operating experience with nuclear desalination have been accumulated worldwide. Several demonstration programs are underway, with technical co-ordination support from the IAEA, to confirm its technical and economical viability under country-specific conditions. Nuclear desalination is most attractive in countries that both lack water and have the ability to use nuclear energy such as China, India and Pakistan. These three countries alone account for about 40% of the world’s population, and thus represent a potential long-term market for nuclear desalination. The market will expand as other regions with high projected water needs, such as the Middle East and North Africa, increase their nuclear expertise and capabilities.

Advocates of nuclear energy for sustainable development argue that it is a well established non-carbon technology, as demonstrated by its 16% share of the world’s electricity supply and even higher share in specific countries — 78% in France for example. Moreover, it has huge growth potential. Its resource base — uranium and thorium — is substantial and has no competing application. Nuclear energy increases the world’s stock of technological and human capital. It is ahead of other energy technologies in internalizing external costs. From safety to waste disposal to decommissioning — the costs of all of these are in most countries already included in the price of nuclear electricity. It avoids GHG emissions. The complete nuclear power chain, from resource extraction to waste disposal and including reactor and facility construction, emits only 2–6 grams of carbon per kilowatt-hour, about the same as wind and solar power and two orders of magnitude below coal, oil and even natural gas. If we were to extend our consideration beyond nuclear fission to nuclear fusion, which is largely outside the scope of this article, some of these arguments would be even stronger. The resource base for nuclear fusion, for example, is huge. However, fusion is still at an experimental stage. It is unlikely to provide a substantial share of electricity to the grid before 2050, although it is a possible contributor to global energy supplies in the second half of the century.

In industrialized countries, where most of the world's installed nuclear capacity is today, well run existing NPPs can be quite profitable. New NPPs, however, are most attractive in countries where energy demand "Nuclear energy can also make a substantial contribution to a critical non-energy ambition — universal access to plentiful fresh water. Currently about 2.3 billion people live in water-stressed areas and among them 1.7 billion live in water-scarce areas, where the water availability per person is less than 1000 m 3 /year. By 2025 the number of people suffering from water stress or scarcity could swell to 3.5 billion, with 2.4 billion expected to live in water-scarce regions.

Today, 16% of world electricity is generated by the nuclear power plants. There are 435 nuclear reactors operating in 33 countries. The existing power plants are very competitive; their load factors have remained high. Upgrading of plant capacities in a number of power plants have also taken place/ are planned. A number of older reactors are scheduled for life- time extension as it is found economical. Nuclear power production is now a mature technology.

Unfortunately, existing nuclear power plants have been branded as "cash cows" for most utilities worldwide. A remarkable change in the view of the capital markets in the last few years on nuclear being not that capital intensive seems quite encouraging. A large number of reactors are now planned in many developing countries due to their increasing energy demand and having meagre fossil sources.

However lack of confidence in the political stability, nuclear regulatory policies and financial aspects in many developing countries interested in nuclear technology has been a negative factor. The role of governments in recognizing the social benefits and in reducing various risks is highly desirable.

There are no ideal or magic solutions to avoid the unclean, uncertain and expensive energy in the coming years, as the present trends indicate. All energy technologies will be therefore needed in the years to come. As far nuclear is concerned, uranium resources are available for exploitation of nuclear energy and advanced nuclear technologies are developed/ are under development. From a sustainable development perspective, nuclear energy has a major role to play in terms of reduction of CO_2 emissions, security of energy supply and diversification of supply and price stability.

1.2 IAEA's priorities

The growing awareness of the need for environmental protection together with a recognition of energy supply security that nuclear power is offering has lead in many parts of the world to renewed discussion about the nuclear power option to meet increasing energy and electricity demands, particularly in developing countries. The IAEA has reflected this new trend of rising expectation in its programme by putting emphasis on assistance to those countries, which are planning to introduce nuclear power or intend to expand its capacity. IAEA and the nuclear community would have three priorities. First, to ensure that when nuclear energy is used to produce electricity for district heating, desalination or hydrogen production, it is used safely, securely, and with minimal proliferation risk. Second, to ensure continued technological innovation for improved economic viability, enhanced safety, security and proliferation resistance. Third, to ensure that the needs of developing countries are taken into account.

1.3 Non-electric applications of nuclear power

About one-fifth of the world's energy consumption is used for electricity generation. Most of the world's energy consumption is for heat and transportation. Nuclear energy has considerable potential to penetrate these energy sectors now served by fossil fuels that are characterized by price volatility and finite supply. The newer applications using combined heat and power from nuclear reactors include seawater desalination, district heating, heat for industrial processes, and electricity and heat for hydrogen production.

Non-electric applications of nuclear energy have been considered since the very beginning of nuclear energy development. These have for various reasons not been deployed so far to a significant industrial scale. With the dramatic increase in oil and gas prices in the last few years and also due to rising concerns of the green house gas emissions and its impact on climate change, there is renewed worldwide interest in considering nuclear energy sources for the above applications for the energy and water security in a sustainable manner.

Recent statistics show that currently 2.3 billion people live in water stressed areas and among them 1.7 billion live in water scarce areas. The situation is going to worsen further in the coming years. Better water conservation, water management, pollution control and water reclamation are all part of the solution to projected water stress. So too are new sources of fresh water, including seawater desalination. Desalination technologies have been now well established and the contracted capacity of the desalination plants worldwide is about 37 million m3/d. Interest in nuclear desalination is driven by the expanding global demand for fresh water, by concern about Green House Gases (GHG) emissions and pollutions from fossil fuels and in developments in small and medium sized reactors that might be more suitable than large power reactors.

Nuclear energy is a clean, safe, and powerful greenhouse gas emission-free option to help meet the world's demand for energy. It has a still unexploited potential of producing, in the Combined heat and power (CHP) mode, process heat and steam in a broad temperature range. There is experience with nuclear in the heat and steam market in the low temperature range. An extension appears possible on a short term in the areas of desalination, district heating, and tertiary oil recovery. In the higher-temperature heat/steam range, a significant potential for nuclear exists for hydrogen production and in the petro-chemical industries including the production of liquid fuels for the transportation sector. It still needs, however, a broader deployment of respective nuclear heat sources. The VHTR represents a highly promising, near-term option of a Gen IV type nuclear reactor of the future.

Nuclear heat applications have been considered for long time, but not much has succeeded. Effective and practical measures to gain the advantages of aspects of climate change/green house gas reduction need to be taken now. Nuclear technology and its related institutions should advance and address to the real world as other technologies and environmental institutions do. Practical application would be possible based on exchange of experiences and further international collaboration.

1.4 Seawater desalination

Desalination has decisively proven during last 30 years its reliability to deliver large quantities of fresh water from the sea. Unlike oil, fresh water has no viable substitute. The sea is the unlimited source to create new fresh water through desalination. The future requires effective integration of energy resources to produce power and desalinated water economically with proper consideration for the environment.

The significant increase in fuel-energy and material cost has a dramatic impact on capital and operational cost of desalination and power plants. Impact of US$ 80-95 per barrel oil (and equivalent increase in price of gas), high demand for raw materials, (steel, copper, nickel) has dramatically increased pressure to develop novel solutions which can minimize fossil energy consumption and reduce capital expenditure of desalination plants. All of these lead to renewed global interest in the nuclear energy as a source for desalination.

Since nuclear energy is nearly carbon free generation and is long-term sustainable solution and potentially competitive with fossil fuels, it is necessary to consider it as a choice for desalination projects. Particularly in cases when power and heat for desalination is generated from using heavy crude oil or coal, which requires significant cost for pollution control and is an inefficient generation solution, resulting in significant increase of the penalty for CO_2 emission and greenhouse impact.

1.5 Hydrogen production

As an alternative path to the current fossil fuel economy, a hydrogen economy is envisaged in which hydrogen would play a major role in energy systems and serve all sectors of the economy, substituting for fossil fuels. Hydrogen as an energy carrier can be stored in large quantities, unlike electricity, and converted into electricity in fuel cells, with only heat and water as by-products. It is also compatible with combustion turbines and reciprocating engines to produce power with near-zero emission of pollutants.

Nuclear-generated hydrogen has important potential advantages over other sources that will be considered for a growing hydrogen economy. Nuclear hydrogen requires no fossil fuels, results in lower greenhouse-gas emissions and other pollutants, and lends itself to large-scale production. These advantages do not ensure that nuclear hydrogen will prevail, however, especially given strong competition from other hydrogen sources. There are technical uncertainties in nuclear hydrogen processes, certainly, which need to be addressed through a vigorous research and development effort. The hydrogen storage and distribution are also important area of research to be undertaken for bringing in a successful hydrogen economy regime in future.

As a greenhouse-gas-free alternative, the U.S., Japan, and other nations are exploring ways to produce hydrogen from water by means of electrolytic, thermochemical, and hybrid processes. Most of the work has concentrated on high-temperature processes such as high temperature steam electrolysis (HTE) and the sulphur–iodine (SI) and calcium-bromine cycles. These processes require higher temperatures (>750^oC) than can be achieved by water cooled reactors. Advanced reactors such as the very high temperature gas cooled reactor (VHTGR) can generate heat at these temperatures, but will require several years before they are commercially deployed. There are estimates that for SI or even for HTE process, the hydrogen cost can be brought to \$2/kg levels, if O_2 credit is also taken in to account. If the natural gas price ranges between \$6-8 /MBtu and CO_2 sequestering costs are also included, hydrogen by steam methane reforming (SMR) would cost more than nuclear hydrogen.

A greater appreciation is emerging of the economic and financial aspects of hydrogen production particularly the suggestion that the ability to switch between two possible product streams e.g. electricity and hydrogen; heating and desalination may improve economics. The economics of an integrated complex of nuclear production of electricity, hydrogen and fresh water may look further more attractive.

The current worldwide hydrogen production is roughly 50 million tonnes per year. Although current use of hydrogen in energy systems is very limited, its future use could become enormous, especially if fuel-cell vehicles would be deployed on a large commercial scale. Meanwhile in near term, the developments on plug-in-vehicles and hybrid vehicles could provide enough experience on the hydrogen use in transport sector. The hydrogen economy is getting higher visibility and stronger political support in several parts of the world.

1.6 Other industrial applications

Economic studies generally indicate that district heating costs from nuclear power are in the same range as costs associated with fossil-fuelled plants. In the past, the low prices of fossil fuels have stunted the introduction of single-purpose nuclear district heating plants. Although many concepts of small-scale heat-producing nuclear plants have been presented during the years, very few have been built. However, as environmental concerns mount over the use of fossil fuels, nuclear-based district heating systems have potential.

Although nuclear industrial process heat applications have significant potential, it has not been realized to a large extent. In fact, currently only the Goesgen reactor in Switzerland and the RAPS–2 reactor in India continue to provide industrial process heat, whereas other process heat systems have been discontinued after successful use. Among the reasons cited for closure of these units, one is availability of cheaper alternate energy sources, including waste heat near the industrial complexes.

Of potential future applications of nuclear process heat, one is the use of nuclear energy for oil sand open-pit mining and deep-deposit extraction in Canada. Alberta's oil sand deposits are the second largest oil reserves in the world, and have emerged as the fastest growing, soon to be dominant, source of crude oil in Canada.

Coal gasification/liquefactions as a relatively cleaner fossil fuel source is an area of active interest. Production of synfuels and other hydrocarbons using nuclear heat is another area of greater promise. CO_2 can be used as feedstock together with water, nuclear heat and electricity for producing synthetic hydrocarbons, which may be better energy carrier than hydrogen. This can also act as CO_2 sink reducing its emission to the environment. Preliminary estimates indicate that synfuels could be produced at prices comparable or even lower than fossil fuels. Further work on integrated nuclear-chemical complex is desirable to gain vital experience in this area.

1.7 Future prospects of nuclear energy applications

As an alternative path to the current fossil fuel economy, a hydrogen economy is envisaged in which hydrogen would play a major role in energy systems and serve all sectors of the economy, substituting for fossil fuels. Hydrogen as an energy carrier can be stored in large quantities, unlike electricity, and converted into electricity in fuel cells, with only heat and water as by-products. It is also compatible with combustion turbines and reciprocating engines to produce power with near-zero emission of pollutants.

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As a greenhouse-gas-free alternative, the U.S., Japan, and other nations are exploring ways to produce hydrogen from water by means of electrolytic, thermochemical, and hybrid processes. Most of the work has concentrated on high-temperature processes such as high temperature steam electrolysis (HTE) and the sulphur–iodine (SI) and calcium-bromine cycles. There are many ongoing national programmes aiming at the development of a hydrogen economy such as the Hydrogen Initiative of the United States, the European Hydrogen and Fuel Cell Technology Platform, and fuel cell/hydrogen programmes in Japan and Korea. There are also various international efforts for the realization of a hydrogen economy.

In recent years, various agencies involved in nuclear energy development programmes worldwide have carried out studies on advanced applications of nuclear power.

- The IAEA launched a programme on co-generation applications and has published two TECDOCs (923 and 1184) and a Guidebook on Introduction of Nuclear Desalination (TRS-400) in 2000. IAEA also published a report in 2002 on the Market Potential for Non-electric Applications of Nuclear Energy (TRS-410).

- The Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency carried out a comprehensive survey of published literature on the non-electric applications, including reports from international organizations, national institutes and other parts of NEA and published a report summarizing the findings and recommendations.

- The Generation IV International Forum (GIF) project aims at development of innovative reactors with temperatures up to 1000oC. The GIF road map recommends necessary R&D.

- The Michelangelo Network (MICANET) started within the 5th EUROATOM has been examining the role of nuclear energy in near and medium term missions; i.e. the transition phase from the present fossil era to CO_2 emission-free technologies in the future. The programme results were reported in November 2005 as a work package on "Non-electric application of nuclear energy".

Nuclear heat applications have been considered for long time, but not much has succeeded. Effective and practical measures to gain the advantages of aspects of climate change / green house gas reduction need to be taken now. Nuclear technology and its related institutions should advance and address to the real world as other technologies and environmental institutions do. Practical application would be possible based on exchange of experiences and further international collaboration.

In considering the deployment of nuclear energy into newer potential applications, challenges and difficulties should not be overlooked. Moving from their potential to realities is undoubtedly feasible, but will need time, investments, and policy measures to address a wide range of techno-economic and socio-political challenges. Public acceptance is a major issue for nuclear energy. Non-electric applications of nuclear energy can play an important role in enhancing public acceptance.

1.8 IAEA's roles and programmes and likely future direction

Various utilization of non-electrical applications of nuclear energy i.e. high and low temperatures of nuclear produced steam such as seawater desalination; hydrogen production; district heating; and other industrial applications, has been drawing broad interest in IAEA Member States. The IAEA has an active programme for supporting these activities. For example, the IAEA supports the demonstration of nuclear seawater desalination in the Member States through various activities including the optimization of the coupling of nuclear reactors with desalination systems, economic research and assessment of nuclear desalination projects, development of software for the economic evaluation of nuclear desalination plants as well as fossil fuel based plants (DEEP). It also provides training to interested Member States in the above areas. It cooperates with various international organizations involved in promoting major activities such as seawater desalination and hydrogen production.

As nuclear desalination is a very rapidly evolving field, more and more countries are opting for dual purpose integrated nuclear desalination systems, the need for R&D efforts to improve the hard technology on the one hand and the calculation methods on the other hand would also evolve asymptotically. The need for advances in technologies leading to more efficient and economic systems is obvious. What is still not commonly perceived is the need for advanced calculation methods for nuclear desalination systems. These, like in any other technology, are a pre-requisite to the conception of advanced systems. Yet another, more important requirement for more precise methods of calculations is the need by decision makers in many countries to access reliable and accurate information regarding the performances and economics of the proposed systems. Therefore, the IAEA is launching a new CRP on some specific advances in the field of nuclear desalination technologies which will be implemented in the forthcoming cycle (2008-2011). This new CRP will focus on integrating further activities on DEEP.

The IAEA's DEEP computer code has been widely used by engineers and researchers for preliminary economic evaluation of desalination (by a wide range of fossil and nuclear energy sources, coupled to selected desalination technologies). Various development stages, drawbacks, and achievement were presented and analyzed. Rational for the current activity and expected outcomes were discussed.

The IAEA has already started a CRP on Advances in nuclear power process heat Applications. The objective of the CRP is to evaluate the potential of all advanced reactor designs in process heat applications. Indeed, global concern over growing populations, peaking reserves of fossil fuels and greenhouse emissions associated with them, is driving the increased interest in nuclear power process heat applications, such as hydrogen production and seawater desalination. High Temperature Gas Cooled Reactors (HTGRs) are poised to play a potential role due to their high temperature output of 850-950 ºC, which improves hydrogen production efficiency and their available and free waste heat, which lowers the cost of thermal desalination. In parallel, there has been increasing interest and new research aiming at overcoming efficiency limitations at lower process temperatures, which would improve the potential of other reactor designs of lower temperature capacity, in process heat applications. Therefore, the challenges to be addressed by this CRP are related to process technologies, coupling safety, high temperature material technology and the economic merits of centralized or distributed production units.

The International Atomic Energy Agency (IAEA) is developing software to perform economic analysis and scoping studies related to hydrogen production. The software is expected to be based on few of the most promising processes for hydrogen production such as: high and low temperature electrolysis, thermochemical processes including S-I process, and typical conventional methods applicable for high and low temperature processes of hydrogen production. In addition, HEEP is expected to include conventional electrolysis and steam reforming for comparison purposes with nuclear hydrogen production. Furthermore, the HEEP software is expected to be building on other many activities on hydrogen production and cost assessments within the hydrogen economy.

HEEP is expected to be similar to the IAEA software DEEP which is being used to perform economic analysis and feasibility studies related to nuclear desalination in the IAEA and other Member States. It is expected that HEEP will have similar architecture to DEEP but with the possibility of easy update and future expansion. This HEEP development was initiated following a technical advisory meeting in September 2007. The meeting has helped catalyze the activities in many countries towards the development and testing of the HEEP software. The meeting covered:

- Design aspects of high temperature nuclear reactors suitable for hydrogen production;
- Most promising hydrogen production processes;
- Allocation of cost of hydrogen production using high temperature reactors;
- Available models for the production and delivery of hydrogen;
- Assessment of hydrogen economy

Among other future direction of the IAEA activities on non electric application of nuclear power will include: support to demonstrate nuclear desalination projects, enhance safety aspects of integrated nuclear desalination systems as well as nuclear hydrogen facilities, addressing the socio and environmental impacts of non electric applications of nuclear power, and continuing the validation/development of software for the economic evaluation of desalination technologies and hydrogen production. This will be achieved through technical meetings on non electric applications of nuclear energy in major areas such as desalination and hydrogen production, information exchange on advances in nuclear desalination technologies, addressing status of nuclear desalination; hydrogen production processes;

district heating; as well as other industrial applications, and safety issues. The results of such activities will be published as technical reports.

2. SUMMARY OF PRESENTATIONS

Technical Session 1
OUTLOOK FOR NUCLEAR POWER AND THE FUTURE OF PROCESS HEAT APPLICATION

Chairpersons: **L. Awerbuch** (IDA)
T. Dujardin (OECD/NEA)

Five papers were presented in this session by representatives from OECD/NEA, IAEA, JAEA, FZJ Jülich and the IDA.

The OECD/NEA paper dealt with the World Energy Outlook from present till 2030. The projected two scenarios include the Reference Scenario with present trends and an Alternate Policy Scenario in which technologies to help curb emission growth are likely to be implemented widely with consequent impact on different energy sources.

In the Reference Scenario (RS), global demand will grow by more than half over the next quarter of a century, with coal use rising most in absolute terms. World oil demand will grow by just over half between 2004 and 2030. Most of the increase in oil demand will come from developing countries, where economic growth -the main driver of oil demand- is most rapid. Oil remains by far the most heavily traded fuel, but trade in natural gas will expand faster. World electricity demand will double between 2004 and 2030. Most of the additional demand for electricity is expected to be met by coal, which remains the world's largest source of electricity up to 2030.

In the Alternative Policy Scenario (APS), global savings in energy related CO_2 emissions, improved end-use efficiency of electricity & fossil fuels accounts for two-thirds of avoided emissions in 2030. More favourable policies on nuclear could significantly accelerate the growth in global capacity especially in OECD countries. Electricity supply investments are lower than in Reference Scenario, but renewables and nuclear investment are higher. Over a quarter of global electricity comes from renewable energy sources in 2030 in APS. A dozen policies in the US, EU & China account for around 40% of the global emissions reduction in 2030 in the Alternative Policy Scenario. The share of nuclear power drops much less than in the Reference Scenario, helping to curb emissions growth

Nuclear energy main features are: mature technology, nearly carbon-free electricity generation source, stable cost and low marginal cost, geopolitical distribution of uranium resources and domestic source of energy. Today, nuclear power plants generate 16% of world electricity. There are 442 nuclear reactors operating in 33 countries. The existing power plants are very competitive; their load factors have remained very high. Upgrading of plant capacities in many cases have also taken place. A number of older reactors are scheduled for life- time extension as it is found economical. Nuclear power production is now a mature technology. Gas-fired electricity is no longer the cheapest form of generation; gas prices assumed to remain between 6 and $9 per Mbtu and even more.

Unfortunately, existing nuclear power plants have been branded as "cash cows" for most utilities worldwide. Decisions to build new plants "future cash cows" were thus difficult to make. A remarkable change in the view of the capital markets in the last two years on nuclear being not that capital intensive is quite encouraging. Economic competitiveness is no more an issue. A large number of reactors are planned in many developing countries with increasing energy demand and having meagre fossil sources. Capital markets expect new construction in some countries of Europe too. Resources to invest in new NPP are available.

However lack of confidence in the political stability, nuclear regulatory policies and financial aspects in many countries interested in nuclear technology was a negative factor. To overcome this, partnership of utilities/large industrials (‘the Finnish solution’) are welcome. The role of governments in recognizing the social benefits and in reducing the risks is also desirable.

The concluding remarks outlined by the author on Energy Policy are:
“There are no ideal or magic solutions to avoid the unclean, uncertain and expensive energy in near future as the present trends indicate. All energy technologies will be therefore needed in the years to come. As far nuclear is concerned, uranium resources are available for exploitation of nuclear energy and advanced nuclear technologies are developed/ are under development. From a sustainable development perspective, nuclear energy has a major role to play in terms of reduction of CO_2 emissions, security of energy supply and diversification of supply and price stability.”

The paper also discussed the OECD/NEA activities on non-electric applications. These primarily include; information exchange meetings on nuclear production of hydrogen, isotope production, R&D activities and exchange of information with the VHTR system project and processes applicable to systems other than VHTR.

The IAEA paper indicated that growing awareness of the need for environmental protection together with recognition of energy supply security that nuclear power is offering, has lead in many parts of the world to renewed discussion about the nuclear power option to meet increasing energy and electricity demands, particularly in developing countries. The IAEA has reflected this new trend of rising expectation in its programme by putting emphasis on assistance to those countries, which are planning to introduce nuclear power or intend to extend its capacity. More recently the Department of Nuclear Energy of IAEA has increased its scope of interest and included new activities on Non-electric Application of Nuclear Energy.

The IAEA programme is based on three pillars: Science and Technology; Safety and Security; and Verification. IAEA and the nuclear community would have three priorities: First to ensure protection when nuclear energy is used to produce electricity, for district heating, desalination or hydrogen production, it is used safely, securely, and with minimal proliferation risk. Second, to ensure continued technological innovation for improved economic viability, enhanced safety, security and proliferation resistance. Third, to ensure that the needs of developing countries are taken into account.

The paper from JAEA reported that JAIF Committees on Nuclear Heat Application were established as early as in 1969. A number of useful publications were made covering the subject of industrial uses of nuclear heat, uses of LWR and HTR heat and contribution towards global environment protection.

The paper first discussed about the operating nuclear desalination plants in a number of Japanese reactor sites. The salient details the VHTR applications and utilization systems were then presented. The objectives of this study were:

- Propose promising VHTR applications and utilization systems.
- Estimate possible fossil energy savings and CO_2 reduction.
- Identify technological gaps for practical use.

An outline of the VHTR deployment scenario, the scenario for FCVs and scenario for a "Hydrogen Town" were put forward.

In author's opinion, nuclear heat applications have been considered for long time, but not much has succeeded. Effective and practical measures to gain the advantages of aspects of climate change/green house gas reduction need to be taken now. Nuclear technology and its related institutions should advance and address to the real world as other technologies and environmental institutions do. Practical application would be possible based on exchange of experiences and further international collaboration.

The paper from FZJ Jülich dealt with present role of nuclear energy in power generation and suggested combined heat and power (CHP) and nuclear process heat (NPH) as other forms of nuclear energy utilization. The strong points of nuclear CHP are;.more independence of energy imports, increase in efficiency by ~ 15 %, reduced heat waste and CO_2 emissions, adaptation to industrial needs (modular size) and good social acceptance.

The operating experiences of the industrial heat supply in Canada, Germany and Switzerland, the district heating in European countries and of nuclear desalination in Kazakhstan and Japan were presented by the author. The prospects of nuclear production of synthetic crude oil, heat supply for SMR process and a nuclear refinery for production of hydrocarbons and liquid fuels were also indicated.

In conclusion the author pointed out the following;
Nuclear energy is a clean, safe, and powerful greenhouse gas emission-free option to help meet the world‘s demand for energy. It has a still unexploited potential of producing, in the CHP mode, process heat and steam in a broad temperature range. There is experience with nuclear in the heat and steam market in the low temperature range. An extension appears possible on a short term in the areas of desalination, district heating, and tertiary oil recovery.

In the higher/temperature heat/steam range, a significant potential for nuclear is given in the petro-chemical industries including the production process of liquid fuels for the transportation sector. It still needs, however, a broader deployment of respective nuclear heat sources. The VHTR represents a highly promising, near-term option of a Gen IV type nuclear reactor of the future.

The IDA paper gave a detailed account of the current status of desalination technology, future developments and prospects of nuclear energy as a source for future large-scale desalination on a sustainable basis. The details of the commonly operated desalination processes, MSF, MED, RO and hybrid plants including the capital costs and the energy consumption and their efficiencies were discussed. The salient aspects of the paper are as follows:

Worldwide Desalination Inventory Report includes a total of 17,348 desalting units with a total capacity of 37,750,000 m^3/d or 8.3 billion imperial gallons per day, installed or contracted as on July 2006. Desalination is already used in 125 countries around the world. Desalination has decisively proven during last 30 years its reliability to deliver large quantities of fresh water from the sea. Unlike oil, fresh water has no viable substitute. The sea is the unlimited source to create new fresh water through desalination. The future requires effective integration of energy resources to produce power and desalinated water economically with proper consideration for the environment.

The significant increase in fuel-energy and material cost has a dramatic impact on capital and operational cost of desalination and power plants. Impact of US$ 60-75 per barrel oil and high demand for raw materials, steel, copper, nickel has dramatically increased pressure to develop novel solutions which can minimize fossil energy consumption and reduce capital expenditure of desalination plants. All of this leads to renewed global interest in the nuclear energy.

In an era of high energy and material cost, an integrated use of technology can compensate the impact on rising cost. As desalination and water reuse expansion in the world continues at a rapid pace, these innovations must be integrated into the next generation of water facilities. Desalination provides hope to the world community that we can provide water, the essence of life, at a reasonable cost, solving the scarcity of existing water supplies, avoiding regional and territorial conflicts, and providing the water resource for sustainable development.

Since nuclear energy is nearly carbon free generation and is long-term sustainable solution and potentially competitive with fossil fuels it is necessary to consider as a choice for desalination projects. Particularly in cases when power and heat for desalination is generated from using heavy crude oil or coal, which requires significant cost for pollution control and is an inefficient generation solution, resulting in significant increase of the penalty for CO_2 emission and greenhouse impact.

Technical Session 2
NUCLEAR ENERGY FOR NON-ELECTRIC APPLICATIONS: TECHNOLOGY & SAFETY

Chairpersons: A. Omoto, IAEA

The Session 3 dealt with nuclear energy for non-electric applications: technology and safety. There were a total of 10 papers in this session. Some papers introduced the status of the national or international projects concerning the nuclear energy for non-electric applications. Some of the papers stressed needs for the nuclear applications, and suggested possible global markets in general and also local markets specific to desalination and district heat.

Although there was not much discussion on the needs and markets of the nuclear energy for the other promising non-electric applications, it was generally well recognized in the conference deliberations.

Some papers also introduced the status of technology development and future plans dealing with technical issues. Those are mainly concerning the economy or improvement of thermal efficiency. The economic competitiveness of the many nuclear application was found to be not so obvious compared to the conventional fossil applications.

In addition to this, issues related to the importance of materials of construction were brought out by the participants. In conceptual design, issues of materials are left behind, but it is thought to be critical for commercialization. Thus, the issues of materials need a better look and may be discussed more in a global sense.

It seems that the technical issues would be solved in the near future provided the R&D plan is executed as expected. However it is not clear that those will be fully funded as proposed. Also it is not desirable that each country takes up the same technical issues.

Therefore, a certain international cooperation is thought to be necessary in an effective way. The Agency can work to foster the necessary international cooperation by holding information exchange meetings and/or cooperative R&D such as CRP.

Several interesting ideas were given on the heat application systems, which include the alternative of current exiting ideas. However, it seems that those ideas are not systematically organized even in one country. There are too many ideas and some of them were already evaluated to be not worthwhile. It may be a good idea to have a seminar to discuss and argue on the new idea on the heat applications in the Agency.

Regarding safety for the non-electric applications, many speakers summarized the general and technical issues on the safety. It seems that the technical issues would be solved in a proper way. An interesting question was raised from the audience whether the heat application systems can be categorized to be non- nuclear grade, because the application system is a part of nuclear system, as it works as a cooling system of the reactor, for example. For this question, a Japanese paper gave one of the possible solutions, which was developed for the HTTR - IS process demonstration plant, where the IS process is to be connected to an actual reactor of the HTTR. The idea how the application system can be treated as non-nuclear system was introduced in the paper.

Therefore the common standards and evaluation methodology shall be developed in a global manner. The Agency may make a significant contribution to develop and authorize such a global safety standards.

The safety aspects of non-electric applications using low temperature heat such as desalination, district heating and a few industrial process heat applications have been the subject matter of intense study and many useful reports were published. There is already over 1000 reactor years of accumulated experience of safe operation of such systems.

With regard to combined nuclear and chemical facilities, apart from their own specific categories of hazards, a qualitatively new class of events will have to be taken into account which is characterized by interacting influences. Arising problems to be covered by a decent overall safety concept are the question of safety of the nuclear plant in case of a flammable gas cloud explosion, or the tolerable contamination of the product. In addition, there are the comparatively more frequently expected situations of thermodynamic feedback in case of a loss of heat source (nuclear) or heat sink (chemical).

The risk analysis of a nuclear hydrogen production plant by coupling of the nuclear reactor and the chemical plant, with higher temperature & pressure and corrosive environment and also having explosive contents, is an important issue. The risk can be reduced by the enhanced safety of the VHTR as well as the separation of the reactor and the chemical plant. Release of any radioactivity such as tritium from nuclear fission that can contaminate the product hydrogen also need to be monitored.

The siting of nuclear heat application systems from a public acceptance point of view is also a subject matter of great importance. In general, nuclear reactor must be built near the heat demands district, because the distance of the heat transport is limited due to the heat loss considerations. This is a tough question to be solved and the Agency should take a leading role for the public acceptance.

Technical Session 3
ECONOMICS AND DEMAND FOR NON-ELECTRIC APPLICATIONS

Chairpersons: **L. Brey** (United States of America)
M. Megahed (Egypt)

This session featured nine papers from six Member States and the IAEA. Most of the author's focus centered on the economic and financial aspects of seawater desalination. In many cases, the tool utilized in the economic analyses was the IAEA's Desalination Economic Evaluation Program (DEEP) software code, which provides an economic basis for comparing different fossil and nuclear energy sources coupled to various desalination systems. The salient feature of this code and the pertinent information from the corresponding Coordinated Research Programme on *"Economic Research on, and Assessment of, Selected Nuclear Desalination Projects and Case Studies"* was the subject of a presentation by the IAEA.

Specific site related studies were presented by the Member States for possible desalination plants in Tunisia, Brazil, Indonesia and for various regions throughout the Mediterranean and Arabian Gulf. Many of these featured co-generation applications of electricity production and seawater desalination. For Tunisia, combinations of nuclear and fossil (at 70 to 120 $/bbl fuel cost) energy sources were considered coupled with RO and MED/RO hybrid desalination systems for an output of up to 192,000 m^3/day. Results from this study indicated the nuclear co-generation/desalination plants exhibited costs lower than fossil fired systems with the GT-MHR/RO plant being the lowest cost system.

Economic results for a co-generation plant located in Northern Brazil indicated that the nuclear plant, with its high capital cost, was less competitive than a natural gas fuelled plant, However, with a long term trends of lower capital and operating costs for nuclear coupled with the trend of rising natural gas cost, the nuclear co-generation plant becomes attractive.

A representative of Indonesia's BATAN supplied the results of an economic and financial study for setting up a co-generation plant utilizing the South Korea's SMART modular reactor coupled to a MED desalination system on Madura Island. Again the IAEA's DEEP software was utilized as the economic software to investigate this plant with an output of 40,000 m^3/day. The resulting calculations showed the SMART/MED plant to be both feasible and beneficial.

The economics associated with desalination utilizing different co-generation energy sources and desalination methods was addressed in a paper authored by technical experts from France and Germany. Of special consideration was the effective credit or penalty associated with green house gas emissions from the burning of fossil fuels. Sensitivity studies utilizing different values for fossil fuel prices, interest, discount rates, etc. were considered for these different systems in order to provide techno-economic options for decision makers in considering the appropriate plant type for specific sites.

A comparative economic analysis for the siting of desalination plants in three distinct world regions was provided by the Nuclear Power Institute of China. This study also used the IAEA DEEP software for comparing a number of nuclear and fossil energy sources, including the seawater desalination pool shell type reactor (SDPSR). The results showed the SDPSR to be competitive with other nuclear technology and fossil fuelled plants for water production in Region 1 (Southern Europe) and Region 2 (SE Asia and N. Africa).

Authors from Japan, France and the USA addressed the Power Credit (PC) economic modelling approach for evaluation of joint product production utilizing nuclear energy. This approach, utilized within both Generation IV and in the IAEA's DEEP process for economics of nuclear desalination, was described in detail with focus on the calculation of levelized unit costs for non-electricity products and jointly produced outputs such as electricity with fresh water, hydrogen, heat or actinide incineration services.

Economic and environmental aspects of applying China's PSNR200 nuclear heating reactor to provide 1.5MPa steam as an energy source for industrial applications in the Shanghai area were explored. When compared to a coal fired plant to produce the same quantity of energy, an annual reduction in CO_2 emission of 675,000 tonnes was possible. Factoring this environmental benefit into the economic analysis (with the recent trade price of 25US$/ton of CO_2 between England and China) results in total annual revenue of 406.27 million RMB (8 RMB = 1 US$) for an internal rate of return of 22.58%.

The industrial activities of Japan relative to non-electric applications of nuclear power, specifically the HTGR, were considered. Recent areas of focus in Japan include the following: Development of fuel cell vehicles to utilize hydrogen production via nuclear energy; use of steam and/or hydrogen and electricity via nuclear power to replace aging fossil fired chemical complexes to limit carbon based gas emissions, and the proposed establishment of “Hydrogen Towns” in selected areas of Japan which are aimed at utilization of hydrogen as the energy of the future.

Technical Session 4
HIGH-TEMPERATURE APPLICATIONS

Chairpersons: **S.J. Herring**, (United States of America)
A.I. Miller, (Canada)

This session had 18 presentations, interestingly equally from OECD countries and the emerging countries. The session provided an exceptional opportunity for sharing of technical information between countries — especially with countries with little opportunity for such sharing. Extensive new interest from many countries in producing hydrogen using nuclear power, especially using the SI process was clearly noted.

The majority of the papers dealt with thermochemical water splitting SI process for hydrogen production using heat and electricity from the HTGRs. These papers covered modeling & analysis, experimental study & developmental work, bench scale & engineering demonstration loop and national projects and experiences. A few papers concerned with electrolytic and hybrid processes utilizing heat and electricity from water cooled reactor, super critical water cooled reactor and fast breeder reactor. One paper highlighted the role of high temperature reactors in synthetic fuel production. Technical details of existing high temperature reactors and the ones under consideration or development were presented along with the details of various proposed applications. The economic and financial aspects were also considered in some cases.

The theme of the conference that it is possible to do much more than produce electricity from nuclear reactors was convincing and broadly expressed. The case for nuclear heat for synthetic fuels was strongly made and the possibilities reviewed were directed toward real problems, e.g. supplying water, making synfuels and ameliorating the GHG-climate crisis.

Coal gasification/liquefaction as a relatively cleaner fossil fuel source is an area of active interest. Production of synfuels and other hydrocarbons using nuclear heat is another area of greater promise. CO_2 can be used as feedstock together with water, nuclear heat and electricity for producing synthetic hydrocarbons, which may be better energy carrier than hydrogen. This can also act as CO_2 sink reducing its emission to the environment. Preliminary estimates indicate that synfuels could be produced at prices comparable or even lower than fossil fuels. Further work on integrated nuclear-chemical complex is desirable to gain vital experience in this area.

Most of the work on hydrogen production has concentrated on high-temperature processes such as high temperature steam electrolysis (HTE) and the sulphur–iodine (SI) and calcium-bromine cycles. These processes require higher temperatures (>750^{o}C). Advanced reactors such as the very high temperature gas cooled reactor (VHTGR) can generate heat at these temperatures, but will require several years before they are commercially deployed. There are estimates that for SI or even for HTE process, the hydrogen cost can be brought to \$2/kg levels, if O_2 credit is also taken in to account. If the natural gas price ranges between \$6–8 /MMBTU and CO_2 sequestering costs are also included, hydrogen by steam methane reforming (SMR) would cost more than nuclear hydrogen.

A greater appreciation is emerging of the economic and financial aspects of hydrogen production. It was particularly noted that the ability to switch between two possible product streams — e.g. electricity and hydrogen; heating and desalination may further improve economics.

Several papers reported on interesting new experimental results and momentum toward and enthusiasm for experimental demonstrations was clearly evident. This is appropriate since, for example, materials issues as we go to higher temperatures with aggressive chemicals are not fully solved.

Training is seen as a key topic for spreading nuclear to new countries and new markets. For the non-electric applications, the wealth of work done in the 70s and 80s in Europe, especially in Germany, should be recaptured while this is still possible, even to the extent of involving retirees. It is well known how General Atomics draw on the experience of people from the earlier “hydrogen age” who are still employed. This was noted as hugely valuable to current work. However, much of the European work has no new generation of specialists to maintain knowledge of previous work.

Technical Session 5
NUCLEAR SEAWATER DESALINATION AND OTHER APPLICATIONS

Chairpersons: **P.K. Tewari** (India)
S. Nisan (France)

The session covered in all fourteen papers from eight countries and three international organizations. Presentations included two regional and three national studies. Two specific studies were presented on applications other than desalination namely oil shale sands and ethanol production.

In the first part of the session, the nuclear desalination activities of IAEA Member States both with past and existing nuclear desalination systems were summarized by IAEA. Currently, a number of Member States are involved in techno-economic site- specific studies while some are pursuing nuclear desalination demonstration projects.

The role of Arab Atomic Energy Agency (AAEA) in promoting nuclear desalination in Member Arab states was outlined by its representative. AAEA is now coordinating a project to define and develop steps for deploying nuclear desalination systems. Nine Arab countries are participating in the project which involves working groups dealing with:

- Specifications and characteristics of a virtual site
- Safety and licensing
- Desalination technologies and coupling schemes
- Techno-economic feasibility studies

In the subsequent presentation, the history of nuclear desalination activities in the Arab World was presented, first giving the balance of water and energy demands and of the available resources. The presenter gave several arguments in favour of nuclear desalination systems, based on the probable use of Small and Medium-sized Reactors (SMRS). The paper concluded by discussing the various reasons and socio-economic factors, which could lead to broader pan-Arab collaboration.

The next presentation from IDA, discussed the market drivers for power and desalination. Tremendous increases have been reported in power and water demands worldwide. The primary conditions to meet these demands in a sustainable manner would be to first meet the challenges regarding further cost reductions, environmental sustainability and public acceptance of nuclear desalination systems. In future, the single most important requisite for desalination market expansion would be the privatization of the desalination market.

Some facts and figures for nuclear desalination systems for the development of the Sinai region were presented in the next paper. A paper on the development of a small sized MVC plant development for a remote island site in Indonesia was then presented.

In the following paper, the first results of a demonstration nuclear desalination system based on the utilization of a PBMR to be constructed at Koeberg site in South Africa around 2012 were presented.

Another paper from Indonesia explained why the nuclear desalination system comprising two SMART reactor units coupled to MED, were considered necessary for the Madura Island. This presentation included analysis of complex factors such as the introduction of a sophisticated nuclear desalination system in a relatively undeveloped area with little qualified manpower and deep rooted rural background.

In the last paper of the first part of the session, representative from Argentina discussed the contents of an eventual safety report for a nuclear desalination system, the safety approach that should be used to meet the double safety objective of desalted water free from any radioactivity without any impact on the operation and safety of the coupled nuclear reactor. It was shown, how the incorporation of certain engineered features could meet these objectives.

In the second part of the session the US representative from Idaho National Laboratory gave a presentation on the use of generation IV power conversion systems in the context of the hydrogen initiative. The paper outlined various methods by which nuclear reactors could provide the energy for the production of transportation fuels while the carbon source for these fuels is extracted from the atmosphere using biomass.

It was shown that this approach could be a sustainable method for the continued use of hydrogen fuels. High temperature electrolysis is proving to be a flexible product of H_2 and/or synthesis gas. At the moment there is no clear economic advantage of one particular method of hydrogen production over the other.

In the second paper from Argonne National Laboratory USA, the future of desalination in the US, were presented for the water stressed regions are California, Texas and Florida. In this context, two objectives have been identified:

- A short- term objective aiming to achieve a 20% improvement in costs and energy efficiency.
- A long- term objective to achieve up to 80 % improvements, to be realized around 2030.

It was shown how optimized hybrid systems using RO and MED could lead to considerable flexibility of water quality for various applications. It was observed that the costs of such hybrid systems could be of the same order as that of a stand- alone RO system.

In the next presentation some interesting facts and figures about water demands and use in Yemen were presented. In this country, 90% of the available water is used for agriculture.

A paper from Canada presented the work on extraction of oil from oil sands in the Alberta region, using the SAGD process. This process is very energy intensive. At present, natural gas-fired plants are used as energy source, which could be replaced by nuclear reactors producing steam and electricity or dedicated reactors producing only high temperature steam.

The last presentation of the session was from Germany on the fuel ethanol production using nuclear plants. A typical example is the production of ethanol from corn. Other biomass forms could be sugar or starch and cellulose, from which sugar with enzymes would be produced to enable ethanol production. The processes are energy intensive and could use massive quantities of steam, ideally provided by nuclear reactors. The ultimate requirement of the market is measured in hundreds of Giga Watts of nuclear heat.

3. PANEL DISCUSSION

Panelists: **M. Ogawa, M. Petri, A. Eltayeb, S.J. Herring, S.M. Ghurbal, H Al Thani, I. Othman**

Rapportier: **R.S. Faibish**

The panel consisted equally of members from developing countries and OECD countries. It was noted that representatives from the developing countries (Libya, Sudan, Syria, and the UAE) focused on one big issue that is their countries are witnessing increasing power and water demands in the present and coming years due to increasing population, industrialization and economic development. These countries are considering the introduction of nuclear power and desalination for their future energy and water security in the near and long terms. The OECD countries were represented by panelists from the US and Japan. They shared the information on the other promising heat applications of nuclear power. The focus of the panel was to highlight the challenges to the introduction of nuclear power and its use for non-electric applications particularly in the developing countries and suggest solutions/ actions.

General Issues

For nuclear desalination to be attractive in any given country, 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. Both are present for example in China, the Republic of Korea and, even more so, in India and Pakistan. These regions already account for almost half the world's population and thus represent potential long- term market for nuclear desalination. The market will expand further to the extent that regions with high projected water needs, such as the Middle East and North Africa, increase their nuclear expertise and capabilities. Many of the countries in these regions already have large-scale desalination plants based on fossil sources.

Most of the countries, suffering from scarcity of water, are generally not the holders of nuclear technology, do not generally have nuclear power plants, and do not have a nuclear power infrastructure. The utilization of nuclear energy in these countries will require infrastructure building and institutional arrangements for such things as financing, liability, safeguards, safety, and security and will also require addressing the acquisition of fresh fuel and the management of spent fuel.

As a greenhouse-gas-free alternative, the U.S., Japan, and other nations are exploring ways to produce hydrogen from water by means of electrolytic, thermochemical, and hybrid processes. Most of the work has concentrated on high-temperature processes such as high-temperature steam electrolysis and the sulfur–iodine and calcium-bromine cycles. These processes require higher temperatures (>750^{o}C) than can be achieved by water-cooled reactors. Advanced reactors such as the very high temperature gas cooled reactor (VHTGR) can generate heat at these temperatures, but will require many years for commercial deployment. Meanwhile research work on hydrogen storage, distribution and its use in FCVs is continuing. Another important high temperature application of nuclear power is in the production of synthetic fuels and other hydrocarbons in a nuclear-chemical complex, as an alternate clean fuel source.

Nuclear power production is now a mature technology. Its role in combined heat and power application such as mentioned above is significant indeed. Unfortunately, existing nuclear power plants have been branded as “cash cows” for most utilities worldwide. A remarkable change in the view of the capital markets in the last few years on nuclear being not that capital intensive is quite encouraging. Economic competitiveness appears to be no more an issue. A large number of reactors are now planned in many developing countries due to their increasing energy demand as a result of high economic growth, but which have meagre fossil fuel resources.

However lack of confidence in the political stability, nuclear regulatory policies and financial aspects in many countries interested in nuclear technology has been a negative factor. To overcome this, partnership of utilities/ large industrials will be welcome. The role of governments in recognizing the social benefits and in reducing various risks is also desirable.

Nuclear heat applications including desalination have been considered for long time, but not much has succeeded. Effective and practical measures to climate change/ green house gas reduction need to be taken, taking advantage of it being a clean energy source. Nuclear technology and its related institutions should advance and address to the real world as other technologies and environmental institutions do. Practical application would be possible based on exchange of experiences and further international collaboration.

Specific issues

Specific issues were raised by the panelists from the developing countries especially from Middle East and North Africa for the introduction of nuclear power/ desalination or other heat applications in their regions. These are as follows;

Although, no nuclear reactors have been so far utilized for electricity production in the Middle East region, dual use and other applications of nuclear reactors have been now suggested. As energy source, oil and gas reserves in the Middle East make more than 70% of world resources this may be one of the reasons for not giving priority to nuclear energy as an option. The socio-economic aspects of nuclear applications are favourable when compared and judged against conventional, non-nuclear competitors on cost, reliability, safety, simplicity and sustainability. When considering these applications, nuclear energy has priority not only in energy supply, but also in health, industry and agriculture.

Developing countries need skilled and trained human recourses to operate nuclear installations. In this respect the IAEA can support capacity building and enhance the knowledge in non -electrical applications. The IAEA support may include but not limited to energy options, health and safety risks of alternatives energy systems, local, regional and global environmental issues. In conclusion, it is time to benefit from nuclear power in the region of the Middle East and start serious joint nuclear projects. The Middle East countries got all reasons for success in achieving these objectives.

Seawater desalination is the sustainable solution for the supply of potable water. In view of the impact of conventional fuel prices, its depleting nature and the concern over the global warming, using nuclear energy for seawater desalination gained wide interest and is being considered as an appropriate solution including in North African countries. Countries, which are enjoying good wealth from oil revenue, need to consider the energy mix plan in their national strategy in order to maintain socio-economic development.

The need for introduction of nuclear power technology for seawater desalination and electricity generation in developing countries faces some challenges. Among these challenges that can generally be envisaged are:

– The public perception (negative due to safety concern),
– Political will (both sides, vendor and recipient countries),
– Infrastructure requirement for nuclear power project such as, regulatory bodies, qualified manpower, grid size, basic supporting industry etc. The IAEA role in training, guidance, etc is desirable.
– Financial barrier.
– International community concern about safety and proliferation.

In fact these challenges differ from one country to another depending on its economic situation, available infrastructure and others.

Open floor discussion
Many points were raised during the open floor discussion wherein the participants took active interest. The challenges and the solutions suggested during this discussion are as follows:

Challenges to the introduction of nuclear power

- System integration/ requirements of nuclear power plants
- Safety/ radiological issues
- Feed stocks: Transport and location
- Region- specific needs
- Building infrastructure
- Initial investments and general financial issues
- Public acceptance
- Political will
- Regulatory institutions and guidance
- Socio-economic and environmental concerns

Some issues on nuclear hydrogen production

- Distribution and storage
- Analysis tools and predictive modelling needs
- Understanding real market needs
- Safety and risk analysis

Suggested solutions/ actions for combined heat and power (CHP) applications

- Share information experiences in nuclear infrastructure planning and building possibly through IAEA
- Educate the public to alleviate concerns also with leadership of IAEA
- Utilize existing and develop additional required analysis tools in planning and implementation of nuclear applications: clearly identify opportunities, markets, customers, suppliers and understand short and long term needs
- Move quickly to demonstration projects of non-electric nuclear energy applications with IAEA leadership
- Engage potential investors/financiers in planning to make things happen (eg World Bank)
- Develop the regulatory infrastructure as soon as possible

IAEA's role

IAEA has reflected the new trend of rising expectation of nuclear power deployment particularly in developing countries, in its programme by putting emphasis on assistance to those countries, which are planning to introduce nuclear power or intend to extend its capacity. These include support to infrastructure building, technical cooperation for new projects on specific request from interested Member States, workshops and conferences. The Agency's increased scope of interest includes activities on non-electric applications of nuclear power. IAEA support covers wide spectrum of areas including infrastructure building, legal & regulatory frame- work, institutional issues, human resource development, site evaluation and others. A number of IAEA workshops in some of these areas were held in 2007 and many documents were published. Some of the relevant documents/ working materials are:

- IAEA-TECDOC-1513, Basic Infrastructure for a Nuclear Power Project.
- IAEA-TECDOC-1522, Potential for Sharing Nuclear Power Infrastructure between countries.
- IAEA-TECDOC-1555, Managing the First Nuclear Power Plant Project.
- IAEA-TECDOC (in preparation), Improving Prospects for Financing Nuclear Power Plants.
- Workshop on Steps for Conducting Assessment of Nuclear Power Plant Technology with Water cooled Reactors
- Workshop on Milestones for Nuclear Power Infrastructure and Issues for Improving Financing of Nuclear Power Projects Development
- Workshop on Common User Criteria for Development and Deployment of Nuclear Power Plants in Developing Countries.

Member States introducing their first nuclear power/ heat application project will benefit from the available information.

4. HTTR WORKSHOP

The workshop organized by JAEA included four technical presentations from the host institution dealing with operation of high temperature engineering test reactor (HTTR), fuel researches in the HTTR project, development and validation of analysis method for reactor performance and safety characteristics of HTGR and study on safety related issues of the cogeneration VHTR.

5. POSTER PRESENTATIONS

Six poster papers were displayed during the conference. These covered topics on economic evaluation of Cuba's nuclear desalination project using IAEA's DEEP programme, performance evaluation of a RO test rig at Atomic Energy Authority, Egypt and an overview of NPPA, Egypt's El Dabba experimental RO facility. A paper from India introduced the prospects of membrane distillation process utilizing low-grade waste heat of nuclear reactors. Mongolia's demand for nuclear power and Algerian programme on nuclear seawater desalination were presented in the other two posters.

6. Visit to HTTR Facilities

The Japan Atomic Energy Agency (JAEA) organized a technical visit, for participants, to the High Temperature Engineering Test Reactor (HTTR). The HTTR is being utilized mainly to demonstrate high-temperature nuclear heat utilization i.e. hydrogen production using high temperature nuclear reactor. The visit was limited to the hydrogen production plant but not to the High Temperature Engineering Test Reactor itself. The demonstration test plan is constructed as a hydrogen production system by steam reforming of methane and coupled to the High-Temperature Engineering Test Reactor (HTTR). The test facility is a 1/30-scale of the HTTR-H2 and simulates key components downstream from an intermediate heat exchanger of the HTTR. The main objective of the simulation tests is the establishment and demonstration of control technology, focusing on the mitigation of a thermal disturbance to the reactor by a steam generator and on the controllability of the pressure difference between the helium and process gases at the reaction tube in a steam reformer.

CHAIRPERSONS OF SESSIONS

Session 1	L. AWERBUCH T. DUJARDIN	IDA OECD/NEA
Session 2	S. SHIOZAWA A. OMOTO	JAEA IAEA
Session 3	L. BREY M. MEGAHED	USA Egypt
Session 4	S.J. HERRING A.I. MILLER	USA Canada
Session 5	P.K. TEWARI S. NISAN	India France
Session 6 Panel Discussion	I. KHAMIS	IAEA
HTTR Workshop	R. HINO	JAEA
Session 7 Conclusion	I. KHAMIS	IAEA

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