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Non-Electrical Products of Nuclear Energy: Opportunities and Challenges

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Introduction

Today, nuclear energy is used almost exclusively for electricity generation. Entering new markets by offering other products, such as heat or hydrogen, would provide opportunities but also create challenges for the nuclear industry and for governments of countries receptive to using nuclear energy. Globally, non-electrical products could more than double the size of the market for energy services accessible to nuclear energy. However, when assessing this potential, it is important for policy makers and industry to consider economic as well as technical characteristics, the development lead times, the infrastructure requirements and socio-political issues.

Experience to date

Nuclear power plants currently provide some 16% of world electricity consumption and in OECD countries the share of nuclear electricity approaches 25% [1]. Since electricity represents less than one-third of final energy consumption in the world, supplying only electricity limits the potential contribution of nuclear energy to global energy supply.

Energy consumption is increasing and within this the share of electricity is increasing also, owing to its attractiveness to the customer. However, other energy services are needed that could be supplied by nuclear energy. Heat and transportation are the two, additional major services that people will continue to use extensively in the coming decades. Technically, the heat produced by nuclear reactors could be used to provide energy products other than electricity, including district and process heat, potable water, motive power and hydrogen as a fuel for transport use.

While non-electrical applications of nuclear energy have been considered since the very beginning of its development, they have not been deployed so far on an industrial scale for civilian purposes in any country.

For district heating and process heat, the technical feasibility of using nuclear energy systems has been demonstrated. A few nuclear power plants are – or have been – providing heat to consumers, but the scale is not significant and the experience in this field is very limited. Using nuclear energy more broadly for heating houses or for supplying process heat in some chemical or agro-industrial facilities does not require scientific breakthrough or dramatic technical innovation.

The feasibility of nuclear propulsion for transportation has been demonstrated, but mainly for non-civil applications; there is very limited relevant experience regarding industrial deployment.

It has been demonstrated that nuclear power plants can be used for desalination but the water produced has been used only on the site of the plant in most cases and not for large public consumption. However, coupling distillation or reverse osmosis plants to a nuclear reactor and producing desalinated water for the domestic, industrial or agriculture sectors is not a demanding technical challenge.

In principle, nuclear energy systems could produce hydrogen by steam reforming, electrolysis or even thermochemical processes. However, the technical and economic feasibility of this application remains to be demonstrated.

The application of nuclear technology

The range of non-electrical products that could be provided by nuclear energy systems depends largely on the temperature of the heat they can deliver. High temperature is not required for all non-electrical applications, but increases in coolant outlet temperature would enlarge the range of potential products from nuclear systems and enhance their efficiency.

Reactors of the current generation can produce heat suitable for district heating, low temperature process heat, and can be used for water desalination. Like any other electricity generating plant, nuclear power plants can produce hydrogen by electrolysis. The advantage of nuclear units for the latter is their high availability factor that would allow the cheap production of hydrogen during off-peak periods.

Liquid metal-cooled fast reactors would extend the range of possible applications to other industries, including the treatment of heavy petroleum products. High temperature gas-cooled reactors could produce hydrogen by steam reforming and thermochemical techniques. Very high temperature reactors, such as those being considered within the Generation IV International Forum (GIF) project, are aiming at temperatures up to and above $1500^{o}C$ and could meet all of society's needs. The GIF roadmap recommends R&D to assess capabilities of various concepts to increase temperatures. However, Generation IV systems are unlikely to be available in commercial markets before 2030-2050 [2].

Furthermore, developing nuclear energy systems for non-electrical applications will also require extensive R&D in the field of balance of plant design and equipment. In most cases, production processes have not yet been tested beyond laboratory scale and in some cases part of the process has not reached the stage of scientific feasibility demonstration. For technical and economic reasons, this field of R&D, which is not trivial, needs to receive as much attention as nuclear reactor concepts in the programmes devoted to innovative nuclear energy system development.

Energy strategy considerations

There are a number of alternatives to nuclear energy for supplying products such as heat or hydrogen, but nuclear energy appears particularly attractive from a long-term sustainable development perspective. The advantages of nuclear energy include technical maturity, security of supply, reduction of carbon dioxide emissions and ample fuel resources.

In the past, the main reason for launching nuclear power programmes has been, in most countries, to ensure or enhance security of energy supply. Alleviating dependency on imported fossil fuels, especially hydrocarbons, by the development of indigenous energy sources remains one of the major objectives of energy policies in many OECD countries. Non-electrical products of nuclear energy have the potential to improve national energy independence by increasing significantly the share of nuclear energy in total primary energy supply.

The environmental benefits of nuclear energy, in particular its role in alleviating the risk of global climate change, could be a strong incentive for the development of its non-electrical applications. The operation of nuclear reactors does not emit greenhouse gases; even taking into account their entire fuel chain, nuclear energy systems are virtually carbon free. Developing non-electrical applications of nuclear energy could be a key element in national climate change policies of the countries wishing to rely on the nuclear option for meeting their commitments under the Kyoto Protocol [3].

However, the advantage of nuclear energy in alleviating the risk of climate change will not favour market penetration of nuclear energy products – or, for that matter, of nuclear electricity – as long as energy policies internalising the value of carbon are not implemented. National policies on climate change vary from country to country but very little has been done so far to credit nuclear energy systems for their contribution to reducing greenhouse gas emissions.

Nuclear resources

A broad development of non-electrical products from nuclear energy would significantly increase the requirements for nuclear fuel. Statistical data on uranium resources and supply show that uranium resources available for production today would last less than a century at present consumption rate [4]. However, confidence apparently exists that nuclear fuel resources extend way beyond known uranium resources and that adequate supply of nuclear fuel is unlikely to become an issue provided timely measures will be taken to enlarge the resource base and enhance the efficiency of nuclear energy systems.

More uranium, and thorium, can probably be discovered and exploited when sufficient exploration and development effort is undertaken in proper time. Also, improved mining, milling and other extraction technologies are likely to become available. In addition, advanced reactors and fuel cycles, more efficient in recovering the energy content of the fuel, can increase by an order of magnitude or more the amount of energy eventually extracted from natural ore. Therefore, in all probability, security of nuclear fuel supply could be ensured in the long term, even if the demand for non-electrical products of nuclear energy grows significantly.

Market issues

In considering the deployment of nuclear energy for non-electrical applications, challenges and difficulties should not be overlooked. In particular, it should be acknowledged that a scientific potential is not a technical reality and that competition will drive the choice of energy sources for each application and may eliminate nuclear energy from some markets. Depending on the product considered, the range of challenges facing nuclear energy includes building the necessary infrastructures for district heating and eventually for hydrogen distribution, internalising the value of clean air and establishing a market for desalinated water.

Assessing "realistic" future demand for energy products other than electricity is not an easy task. Even for heat demand, statistical data available are by far less exhaustive and robust than is the case for electricity. Furthermore, as far as district heating is concerned, heat distribution infrastructure and human settlement evolution are key driving factors that are difficult to predict.

Today, hydrogen is used for a few industrial processes, mainly in the petroleum sector. If and when hydrogen becomes a commonly used energy carrier in the transportation sector, for example through the use of fuel cells, the demand for hydrogen could be enormous. Nuclear-derived hydrogen is the most promising solution for a sustainable energy future, but hydrogen production by nuclear reactors requires considerable research and development, demonstration at the industrial level and eventually the implementation of adequate infrastructures. Ongoing R&D programmes on innovative Generation IV nuclear energy systems are placing some emphasis on products other than electricity, in particular hydrogen production by thermochemical process.

On the other hand, the design and implementation of hydrogen storage facilities and transportation and distribution networks have not been given a high priority in national energy programmes. The development of markets for hydrogen, from nuclear energy or other sources, will not occur as long as the infrastructures are not in place. Policy decisions and large investments are needed to build the source-to-service chain that will allow hydrogen to become a commonly used energy carrier. The transition to a hydrogen economy is a major step in energy policy that will require governmental support as well as efforts from the industry.

The availability of adequate quantities of water for direct human consumption and for irrigation is raising concern in many developing and industrialised countries. In 2002, the Johannesburg World Summit identified water resource management as a key problem for sustainable development. However, there is a large gap between social needs and "economic" demand. While in many developing countries a large share of the population has little or no access to potable water, the people needing water cannot afford to pay for it under present – and foreseeable – economic conditions. Establishing a sizeable market for desalinated water will require the improvement of economic conditions in developing countries.

In electricity markets, nuclear energy is competing with fossil fuels and renewable sources. Similarly, the viability of the nuclear option for supplying energy products other than electricity depends on the availability, acceptability and competitiveness of alternatives. Fossil fuels are readily available at present and, for some applications, cheaper than nuclear energy. Their acceptability may become questionable, owing to the increasing public awareness of atmospheric pollution and concerns about climate change, but gas and even coal are unlikely to be abandoned soon. Renewable energy sources are too expensive today to be a serious market competitor in the absence of policy measures to support their development. However, rapid progress is being made that may change drastically the technical and economic performance of renewable energy systems within a few decades.

Some words of caution

Considering the potential requirements and technical capabilities of nuclear energy systems, their non-electrical applications seem rather promising. Moving from dreams 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. Technical problems might be easier to address than social issues, but one should not underestimate their importance nor the lead times necessary to design and deploy new technologies.

The safety implications of coupling a nuclear power reactor to high-temperature industrial processes or hydrogen production facilities necessitate in-depth studies. In particular, for building nuclear energy systems close to chemical facilities or, in the case of district heating, in densely populated areas, a convincing demonstration that the safety system performance practically excludes the risk of off-site impacts in case of accident will be required.

Some non-electrical applications, such as district heating, require small size units adapted to local heat demand, because long-distance heat transport is inefficient technically and economically. The feed-back from experience on several decades of nuclear power plant development has demonstrated the importance of size and scale effect for capital cost reduction. In order to be competitive for heat supply and other non-electrical applications, small nuclear energy systems will need to be cheap and very safe.

Public acceptance is a major issue for nuclear energy, in particular when considering applications such as district heating, which require a large number of small and medium size units located near human settlements. Public perception of small size nuclear units relying on passive safety systems relative to large power plants and large fuel cycle facilities will be a critical issue.

Electricity remains the core business

Nuclear energy has proven to be a reliable, safe and economic electricity generation source. Based upon several decades of commercial experience, nuclear energy systems can continue to supply electricity and this is the most promising near-term market for nuclear reactors. Maintaining and enlarging nuclear electricity market shares in various countries is the best, and may be the only, way to promote non-electrical applications of nuclear energy in the long term.

Broadening the scope of nuclear energy applications is a relevant objective in a long-term perspective. It is an ambitious task that complements, but does not substitute for, enhancing the performance of nuclear power plants used for electricity generation. The latter is mainly the responsibility of industry; the former is mainly of strategic interest to governments.

Concluding remarks

If non-electrical products of nuclear energy were to penetrate markets on a significant scale, the role of nuclear energy in supply systems could change dramatically, from a marginal player to a main contributor. However, such an achievement will materialise only if considerable technical, economic, social and political challenges are overcome and this will require long lead times, up to several decades for some applications.

The development of non-electrical applications of nuclear energy requires extensive research and development programmes covering nuclear reactor and fuel cycle technologies as well as balance of plant and distribution networks for some products, in particular hydrogen. Recognising the long lead times involved before commercial deployment, this evolution will take place only with considerable governmental support, at least in the first phase.

International collaboration can enhance the overall effectiveness of R&D efforts that will be undertaken in various countries, creating synergies between different projects and avoiding duplication of work. Pulling together resources and infrastructures as well as know-how and manpower will facilitate reaching ambitious objectives. International organisations, such as the Nuclear Energy Agency, can provide a framework for joint projects to assist member countries in planning and implementing comprehensive R&D programmes covering concept specific issues and cross-cutting topics.

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