Chapter 4

Small Modular Reactor Advantages and Opportunities

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Chapter 4

Small Modular Reactor Advantages and Opportunities

In June 2020, the International Framework for Nuclear Energy Cooperation (IFNEC) held a series of webinars on small modular reactors (SMRs) to share information and discuss five issues: market perspectives, financing, licensing, the activities of vendors, and synergy with other energy sources. This webinar series showed the strong interest of many countries in SMRs and identified issues to be solved for its worldwide deployment. The webinars were held on 2, 9, 16, 23, and 30 June via Zoom meetings.

In July 2020, the Organisation for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA, 2020) published a report titled 'Unlocking Reductions in the Construction Costs of Nuclear (REDCOST)', which identified NNP construction project cost reduction opportunities. Some parts of the report also mentioned SMRs. In April 2021, OECD/NEA published another report focusing on SMRs (OECD/NEA, 2021). This report analysed the opportunities and challenges of SMRs from various viewpoints.

It is important to understand the advantages of SMRs and the conditions to deploy them, and these international discussions give this research meaningful information. Therefore, this chapter summarises the salient features of SMRs as observed from IFNEC webinars and the OECD/NEA report.

1. IFNEC Webinar 1: National Market Perspectives Regarding SMR Market Development

Keynote speech 1

- Electricity is becoming more and more important. Not only solar and wind energy but also nuclear energy is important to securely provide electricity. Although conventional nuclear energy faces the challenge of high costs, SMRs can possibly resolve this problem.

Keynote speech 2

•China considers nuclear to be a reliable energy and places importance on SMRs, which contribute to small grids in remote areas. Recently, research on a 200 MW high-temperature gas-cooled reactor (HTGR) has been started, and research on a 100 MW pressurised water reactor (PWR) is planned.

•SMRs are important for a low-carbon future. International cooperation on technical standards and regulation systems is crucial.

Panel discussions

•Power generation in Jordan mostly consists of gas. It is a problem to import large amounts of fossil fuels. Our target is to diversify and increase domestic and low-carbon energy resources. Moreover, the planned power generation capacity will not catch up with the growing demand. That is why Jordan is trying to introduce nuclear energy.

•A small reactor (about 400 MW) is considered a realistic option because a large reactor needs 1,000 MW in demand. When a nuclear reactor is installed, it is important not only for it to be cost-competitive compared to natural gas and renewable energy but also for it to be installed by 2030. In choosing a technique, we focus on pressurised water reactors, light water reactors, and high-temperature gas-cooled reactors and exclude liquid metal reactors and molten salt reactors. The scale of the investment is limited considering Jordan's gross domestic product (GDP), and there may be a financial risk.

•To meet the growing demand, Kenya plans to introduce nuclear energy after 2035. The Kenya Nuclear Power Program (NuPEA) was started in 2010, with planned land acquisition and site characterisation and a research reactor project in 2020. Large reactors are planned to be installed first, followed gradually by SMRs. To implement the plan, it is important to reduce costs.

•Poland plans to install its first nuclear reactor based on advanced technology by 2033 and construct another five by 2043, which means 6–9 GW capacity.

•Although the priority of Poland's plan is large reactors, we understand the potential benefits of SMRs like HTGRs, especially for heat generation and co-generation. We consider

SMRs to be a contributor to climate change mitigation. To replace fossil fuels for industrial heat production, the HTGR project was started. Industry interest in SMRs is also growing.

•CO_2 prices have largely influenced oil demand. Despite the domestic oil shale resources, oil shale power generation decreased by 60% in Estonia. Intermittent capacities will be replaced.

•Amongst various reactors, GE HITACHI BWRX-300 is the most promising SMR.

•The European Union (EU) plans to achieve carbon neutrality by 2050. Considering the phasing out of fossil fuels and limitations on renewable expansion, the SMR market potential will be very large if the LCOE reaches €35 or US$35/MWh. Public acceptance of SMRs as an alternative for fossil fuels is growing.

•In 2020, various studies for SMRs (site screening, construction time, licensing models, hydrogen) were planned.

Q&A

Q: What do you think about nuclear energy or SMRs although there is strong opposition to nuclear and approval for renewable energy? What is the biggest problem for new construction?

A: Financial difficulties (high costs compared to natural gas and renewable energy), licensing, the lack of operational experience, insufficient demand growth, etc.

A: Market growth is key for SMR development. We must understand the real industry: what reactor is the most practical or which vendor has updated skills. US SMR projects are especially important because vendors in the US try to install commercial SMR.

Q: What is different in current nuclear energy from the 1960s and 1970s?

A: Small, economical, and safe products are being commercialised. If SMR technologies vendors succeed, SMRs can be introduced in any location without the need for a large environment. A different approach is needed for SMRs, especially in regulation and waste disposal.

Q: Although EU does not have a positive attitude towards nuclear now, why do you think there is potential for 300 SMRs?

A: Since energy consumption is decreasing due to COVID-19, energy investment returns are becoming more important. Renewable energy cannot produce high-temperature heat, and suitable sites are limited. The solar and wind market is getting saturated. However, SMRs can be constructed near industrial buildings and provide electrolysis and constant heat generation.

Q: Jordan is interested in SMRs but doesn't have enough research or development. How do they deploy SMRs?

A: Jordan directly approaches vendors or regulators to conduct skills and regulation processes smoothly. We send people to regulation agencies or nuclear committees in the vendor countries.

Q: How do people say about the problem of spent fuels?

A: There are some discussions on the concept of a common multinational repository. There is strong opposition to domestic repositories. A common repository should be pushed internationally.

A: It is important to communicate with stakeholders and the public in order to resolve the problem.

A: There is not much of a problem technically about the disposal of LWRs, but many challenges about social relations.

2. IFNEC Webinar 2: SMR Financing

Introduction

•Through the discussion today, we want to share the experts' attitudes on SMR finance and explore the areas in which to make great efforts in a full-spec conference. We have a hypothesis that SMR finance may be somewhere in between conventional independent power producer (IPP) finance and nuclear finance at a large scale. Whilst IPP finance has already been packaged as a commodity, nuclear finance is at an evolving stage that has many risks, such as policy, supply chain, and construction time risks.

•Can SMR finance follow the same path of renewable energy? To answer this, we should clarify what challenges we can overcome using the experience of conventional IPP finance, and what are the common challenges for finance for SMRs and large reactors and the unique challenges for SMR finance.

Public–private risk-sharing: Its contribution to lowering financing costs and enabling nuclear new builds

•Nuclear energy is a proven low-carbon source with many benefits. However, new construction of NPPs has significant risks because 80% of the costs are capital costs. Each dimension (i.e. design and development, construction, operation, decommissioning) has risks that different stakeholders owe, and they need to share the optimised risks.

•Although the category of SMRs vary from micro-reactors to 300 MW and above, most advanced projects are still large, especially multi-module plants.

•SMRs are different from large nuclear reactors in that they are easy to invest in, and some financial risks will be shifted to the vendors due to the dedicated factory assembly lines.

•Two major risks are construction risk and market risk. One of the solutions for construction risk is the regulated asset base (RAB) model, which imposes some costs on consumers as a substitute for significant financial costs. Consequently, overall costs can become lower because the risk uncertainty over long constructions is reduced. On the market risks, price volatility is challenging with capital-intensive nuclear. Regarding the various risks including these, governments play a direct role. It is also important to communicate with consumers.

Financing an SMR project: Considerations from the financial community

•Although finance is often the greatest challenge for nuclear power projects, SMRs can represent a paradigm shift.

•It is crucial for finance that the structure behind the project makes sense. It is important to answer such questions as how to trade electricity, who is the final owner for the plant, the possibility for refinancing, and policy support for clean energy.

•According to the IAEA, the time frame for research reactors is 50% less than large reactors. Although no specific milestone approach for SMRs has been reported, the time frame can be shorter, like for research reactors.

•Nuclear is basically proven technology, but newcomer countries do not have experience. There are still challenges, such as the market conditions, regulatory risk, long construction periods, high construction costs, and public acceptance. The challenges for SMRs are the FOAK risk and the need for enough volume of business and support in the early stages. If you realistically plan to introduce SMRs, government support is essential.

Financing experience of the Taishan NPP Project

•The Taishan Project planned to construct six EPRs. Two of them with a capacity of 1,750 MW have been in commercial operation since 2018 and 2019, respectively.

•Third-generation NPPs have significant risks in the form of construction costs, constructional duration, project abandonment, over-budgeting, and consumption and electricity tariffs. The project has overcome these risks because (1) significant economic growth leads to high energy demand, (2) the government has supported nuclear energy development, (3) the investors have powerful economic strength and experiences, (4) the excellent project management team has controlled the project, and (5) the credit structure for debt financing is designed well.

Government support in the design, development, financing, and deployment of SMRs: The UK experience

•According to the Expert Finance Working Group (EFWG) of the UK government, current SMR deployment lacks private sector investment. They analysed the cause and concluded that the UK could be well placed to develop FOAK small reactor projects with less than £2.5 billion by 2030.

- It is essential that governments mobilise finance in order to realise FOAK projects.
- The EFWG suggested possible financial models. One of them is a CfD/PPA model based on project finance where the government plays the role of investor. This method provides high reliability of the investment, catalysation of private finance, and help for FOAK projects. Another CfD/PPA model with governmental guarantee attracts debt and affects the weighted average cost of capital positively, but it would have a serious impact on the balance sheet if the government sets an improper guarantee rate.
- The regulated asset base model (RAB) is considered to be best suited for small and large nuclear projects. Since the Thames Tideway Tunnel project succeeded with RAB, various classes of investors or financers can be interested.

Q&A

Q: Can the Taishan project be an SMR demonstration platform?

A: The Taishan project uses a third-generation reactor, which is different from an SMR. An SMR is new technology and has a high risk. If SMRs are realised on a large scale, they may be cost-competitive.

Q: If a first SMR project succeeds, can following projects become common and practical, like renewable energy and IPPs?

A: Whilst IPP is a business model for technologies whose markets have already been established, nuclear has problems in the liberalised market. It is necessary to take account of the total cost, schedule, and nuclear benefits and the future power generation mix and decide finance.

A: SMRs will acquire finance from the private sector in the future. If made in a factory, it can be a similar technology. The government should give significant support.

A: It is necessary for the SMR supply chain to strengthen with enough investment.

A: Until SMRs becomes profitable, guarantees or subsidies are necessary from the government. If so, SMRs will become like IPPs and attract more private investors.

Comments on questions from the audience

C: 'Whether BOO or BOT is desirable for nuclear projects?' No. Nuclear is so complex that even the worldwide company TVO could not get sufficient money and the OL3 project was cancelled. To mitigate the risk, TVO had worked with the vendor for 2 years until the bid for their next reactor. They cooperated on design improvements and asked technological questions.

C: SMR has an important role in a clean energy future and meeting electrical demand due to electrification, populational growth, and water shortages. SMR needs to be a volume business before discussing the definition of 'clean energy'. The discussion should focus on how to develop each country's nuclear project rather than the right taxonomy. It is essential to generalise project elements, including technological design so that any country can make a successful nuclear project.

C: I have acknowledged the key issues to follow and consider through the discussions today. Further comprehensive discussion on SMRs will be continued.

C: The discussions today are just a starting point. I have high expectations for the next webinar on SMR licensing.

3. IFNEC Webinar 3: SMR Licensing

Introduction

- The COVI-19 pandemic has proved the need for nuclear because it supplies secure electricity for the medical industry. Nuclear also gives economic, geopolitical, environmental, social, and public health benefits.
- Canada published the SMR roadmap cooperating with many stakeholders. NRCan also announced Canada's SMR action plan.
- No country can introduce SMRs without cooperation. It is important to share the experiences globally.

Opening remarks

•Countries around the world have a strong interest in SMRs, but the assumptions of SMRs are different amongst them. SMRs has various categories, such as light water reactors or fourth-generation reactor, which leads to significant differences in regulation.

•SMRs can be successful if they can get a market everywhere in the world, like aircraft, which is different from conventional reactors that are made for each site specifically. Boeing and Airbus would make products rather for the world market than the domestic market.

•After basic rights become standardised, we should look at the technology not at specific sites to get the worldwide market. We have to licence each individual SMR technology.

•It is important for regulators to work together. Amongst many challenges, I think licensing is most important. It is also important for those countries who are interested in SMRs and do not have NPPs because SMR fits small grids without large reactor regulations. If such newcomers do not get profit, SMRs will not have a global market.

Multilateral cooperation supported by the IAEA

•SMRs have many challenges. Since accidents have no borders, all countries need to work together to get transparency and accountability.

•The nuclear industry, including SMRs, has continued to innovate, so regulatory systems must be developed too. SMRs are significantly different from existing reactors in that they are less dependent on safety systems. That is why they need a regulatory approach for safety. A regulatory framework should be developed reflecting the understanding of risk and performance.

•Through the SMR regulators' forum, we can recognise common issues. The objectives are to collaborate on technological development and deployment, propose changes to national requirements and practices, and provide inputs for the consideration of IAEA in future activities.

•There are three phases in the forum. In phase 2 (2018–2020), a new working group was established and the topics were 'design and safety analysis', 'licensing issues', and 'manufacturing, commissioning, and operation'. The publications are now available online.

•The IAEA has made a safety and licensing framework with a top-down approach applying existing knowledge from general to specific. The IAEA has a planned hierarchy of safety goals combined with a technology-neutral and specific framework.

CNSC perspectives on regulatory collaboration

•The Canadian Nuclear Safety Commission (CNSC) is a Canadian independent nuclear regulator. The CNSC always puts safety first and stays flexible to technological developments. We keep good relationships with vendors.

•Preparing for the changes to the regulatory environment, the CNSC ensures enough workforce with the right skills, and transfers valuable knowledge and experiences from veteran staff to the next generation.

•The CNSC develops collaboration with international nuclear agencies or regulators, especially with the IAEA and NEA. Bilateral cooperation is also developed, including the NRC and ONR. Furthermore, we share experiences and provide guidance on SMRs through engagement with embarking nuclear nations.

•Industry should work to harmonise engineering safety standards with international agencies. SMR development also needs a global supply chain. In conclusion, international collaboration is most important to increase the level of safety with better and quick decisions.

Regulatory infrastructure and collaboration in Indonesia

•Badan Pengawas Tenaga Nuklir (BAPETEN) has long experience as a regulatory agency with 400 personnel, including 270 technical staff. In Indonesia, some proposals for SMRs have already existed, but the government has made no clear decision.

•Regulations are actively updated in accordance with international standards. Although no vendor design reviews are in progress, BAPTEN is conducting open dialogues with applicants. International and bilateral cooperation is developed, such as with the IAEA and CNSC.

•There are many challenges: (1) the assessment and decommissioning of ageing research reactors should be considered; (2) existing regulation is mostly based on LWR, so it must be developed to deal with FOAK; and (3) we should have leadership for regulating safety and for transparent and open information because of the lessons from the Fukushima accident.

CANDU Owners Group SMR activities

•CANDU Owners Group (COG) is a platform of CANDU owners and expands SMRs. They have established an SMR forum under the COG that involves CEOs of various companies to share perspectives and address common challenges. The Canadian Nuclear Industry SMR Secretariat is going to be launched, which inputs into the Action Plan under the SMR roadmap released in 2018.

•Industry has reviewed the existing framework and benchmarks against other guidance. The COG has been collaborating on some areas, such as liability. On security, the COG SMR Security Task Team, consisting of experts from the CANDU community, have issued position papers. The COG has also developed international collaboration. It enables SMR development, but we need to consider the differences in the time frames of each country. Not only regulators but also industrial players (vendors, supply chain, operators) need to collaborate with each other, and organisations should facilitate this.

Discussion

Q: Why is it important to harmonise regulation now?

A: Many countries have declared they will be carbon neutral by 2050. This means that low-carbon technologies need to be commercially introduced in the market by around 2030, 10 years after now. So, there is a period of only 10 years for SMR development to realise this objective.

A: The economies in many countries are severely suffering. They should move forward to a clean energy future and SMRs play an important role.

A: From the long period of regulation, now is the timing for international collaboration. Isolated implementation is not enough.

A: Current challenges for nuclear are the lack of public confidence, regulatory complexity, huge initial costs, and the need for long governmental support. If SMRs can be harmonised quickly, they can solve the problems in 10 years.

Q: What can the nuclear industry apply from other sectors? How can the IAEA help us to increase international collaboration?

A: Compared with the aviation industry, SMRs have several problems. They need not only to be certificated by the regulatory bodies, but they also need to be standardised as an industrial product. To acquire a global system, there are two international agreements needed on the cooperation of vendors and technological neutrality. International organisations, including the IAEA, should lead the discussions for a global SMR roadmap.

A: Looking at the COVID-19 pandemic, nuclear can learn many lessons from the identification of a vaccine, which is needed for safety and the quick sharing of information.

A: We have also started to look at other industries and will discuss regulatory activities in common with other regulators. I think countries deeply interested in SMRs should lead the cooperation in regulations and the IAEA should support them. Too many countries should not be involved at first because of the differing time frames.

A: More international workshops are needed, such as an SMR security paper workshop. This should start from a few countries and progress to many countries.

Questions from audience: (1) How do we harmonise regulation in many types of design? (2) How is SMR licensing different from GW-scale reactors? (3) Pursuing perfect harmonisation, will business progress be later?

A: (3) If the regulatory mechanism or international policy framework develop by about 15%–20% of the level of those of the aviation industry, nuclear could be a business. (1) After 3–5 years in selection, regulators will do good work. We have to care about time because much time is needed for licensing after that selection.

A: (2) SMRs and large-scale reactors have many common characteristics, but there are many differences, too. In particular, there are differences in the security measures and the liability of operators. Another challenge is for the vendor to get investment due to many designs for SMRs. Government should back up and make clear policy for clean energy, including SMRs.

A: (1) Countries differ significantly in the extent to which they introduce IAEA safety standards. It is important to consider to what extent regulatory issues are harmonised. (2) SMR licensing should be developed basically from conventional reactors. However, it is most important to consider the risks of SMR facilities. (3) I do not think so. There are common views for safety between countries that have developed their own safety principles. Identifying such common views would make national reviews in other countries more efficient.

C: A bilateral approach is more efficient and a quicker way to go on harmonisation. The CNSC has a similar opinion to the US NRC. Not only an international approach but also a bilateral approach is important.

C: Especially for embarking countries, harmonisation and standardisation are really important. Regulatory bodies have to reinforce independence and technical competency. International agencies maintain much information, and documents of specific projects can be useful for many countries.

C: Today's summary: (1) there are only 10 years to move forward; (2) it is essential to build a global market and somebody should take leadership; and (3) to establish a low-carbon framework, regulations need to be developed.

4. IFNEC Webinar 4: SMR Vendor Forum

Introduction

- The IFNEC develops cooperation in peaceful nuclear use. We collaborate with many governmental representatives.

BWRX-300: Innovative, cost-competitive, and ready for deployment

•General Electric has pursued new nuclear technologies for decades. We focused on the large light water reactor, but we will focus on SMRs.

•To achieve decarbonisation, nuclear is getting more important. The key is cost competitiveness. BWRX-300 is designed to reduce the overall cost and is capable of load following and is ideal for industrial applications and electricity generation. The building volume is reduced by about 90% from the economic simplified boiling water reactor (ESBWR) due to loss-of-coolant accident mitigation. BWRX-300 is really cost competitive.

•Canada and the US have been prepared for licensing. In addition, many countries and companies have strong interest. Research to reduce operation costs using AI is progressing with partners, including universities. BWRX-300 is ready for near-term deployment with industrial partners, affordable design, licensing, supply chains, and after-market services.

Chinese high-temperature reactor programme

•China considers the high-temperature reactor (HTR) to be important as a supplement to PWRs replacing coal-fired power. It is expected to produce hydrogen and as co-generation. Research was started in the 1970s and commercial plants have been constructed since 2014.

•HTR-PM is being demonstrated in Shangdong. The technology is based on HTR-10 and the two reactors and two steam generators are connected with one turbine. This enables cost efficiency and high temperatures. The HTR-PM project started construction in 2012 and is almost all completed. Critical and power operations are scheduled for 2021.

•The main achievements are the standard nuclear steam supplying system (NSSS) module with a full scale-testing and licensing framework. The project has brought many facility developments, a useful supply chain, fuel fabrication capacity, and so on. Whilst HTR-PM can be constructed in bulk, an improved version of HTR-PM600 is also being developed.

The IMSR power plant – a resilient and cost-competitive clean energy alternative

•Terrestrial Energy is developing the IMSR in order to solve cost problems. The first commercial IMSR plant is to be constructed within 10 years. We have already completed CNSC Vendor Design Review Phase 1, and we are now in Phase 2.

•Conventional nuclear power has the ‘problems of 10’ (US$10 billion/GW, over 10 years of construction, and over 10 cents/kilowatt hour LCOE) and is highly complex.

•Modularity and reduced size alone are not cost effective, but IMSR is dispatchable and low-cost because research has continued over 60 years and the private sector has innovated focusing on the market.

•Nuclear has two opportunities. One is the replacement of the ageing Western fleet, and another is further deployment in replacing coal and natural gas. These can make the nuclear cost competitive.

Moltex: An overview and update

•Moltex has three features: (1) elimination of the meltdown risk, (2) recycling of its fuel and reducing radioactive waste, and (3) thermal energy storage.

•Thermal storage is much cheaper than electricity storage. Moltex uses spent CANDU fuel, which reduces the amount of waste.

•Moltex has partnered with New Brunswick to build a first reactor taking account of the local supply chain. The project finalised the CNSC Phase 1 Vendor Design Review and is preparing for Phase 2.

NuScale Power SMR overview and update

•NuScale was formed to complete the design and commercialising of the NuScale Power Module SMR. The first plant in the UAMPS Carbon Free Power Project is expected to be in operation by around 2027.

•Compared to large PWRs, the cost is significantly reduced due to the lack of a cooling system. In the advanced design, combining 12 modules enables the production of up to 720 MW. Even if a power outage occurs, safety can be maintained because the plant can shut down automatically and modules are cooled in a pool.

•Design certification application (DCA) was completed in 2016 and the NRC technical review Phase 4 was completed in 2019. We also applied for CNSC VDR Phase 1 and 2.

•Following FOAK of the 720 MW reactor, the 'nth-of-a-kind' cost is estimated at about US$2.5 billion (US$3,672/kilowatt).

Rosatom RITM series SMRs

•ROSATOM can offer a whole supply chain for nuclear. ROSATOM has already experienced over 20 small reactors, so SMR is not new. We also completed the first floating NPP (two 77 MW reactors) in the world in 2019, and it was fully commissioned.

•The RITM series uses proven PWR technology and can be transported by train and has a reduced size. RITM is prepared for many applications.

•The first kind of land-based NPP in Russia is planned, with an estimated 3–4 years of construction. The RITM series has a safety concept. The site licence is to be obtained in 2023, and it is to be commissioned in 2027.

Rolls-Royce SMR in a decarbonised economy

•We started the SMR project 3 years ago. It focuses on energy costs not only electricity but also heat. Huge financing costs make the LCOE high. The electricity market price is uncertain, which is difficult to estimate.

•We make great efforts for reducing capital costs, the construction period, and risk. For example, we reduce the size and power output and modularise whole plants. Most methods of decarbonisation require more clean electricity and SMRs play an important role.

SMART development with validated technologies

SMART is a 110 MW reactor. Not only steam but also sea water can be used to produce fresh water.

SMART has passive safety systems in preparation for an emergency. The performance and safety of SMART are evaluated by a comprehensive technology validation programme.

There is a SMART business model. The Korea Atomic Energy Research Institute and King Abdullah City for Atomic and Renewable Energy of Saudi Arabia are joint SMART technology owners. They plan to introduce FOAK SMART first in Saudi Arabia and newcomer countries. They are ready to develop optimal business model with each other for better finance, project structure, and long-term operation.

Xe-100 technology overview

•X-Energy is developing both advanced reactors and fuel.

•Reactors: They are safe and proven by technology. The fourth-generation reactor, now used, is the nearest to market. The licence approval is on track from the US and Canada.

•Fuels: Our product TRISO-X is the most robust nuclear fuel on Earth.

•Xe-100 is a fourth-generation HTGR design based on proven technology. The safe design requires no power or operator action to ensure that the fuel is not damaged. Within the next 5–6 years, it can be deployed as a cost-competitive, low-risk, and carbon-free energy source.

•X-Energy has also worked on the safety shutdown. The Reactivity Control and Shutdown System offers suitable management.

Discussion

Q: What kind of collaboration can be seen for SMR development worldwide?

A: I believe there is immense potential for collaboration. The US and Canada have collaborated on licensing. Cooperation on regulatory guidelines is a good example. Another possible collaboration is in the supply chain, which requires an international view.

A: Whilst vendors compete in the market, they can cooperate in the supply chain and licensing. This enables new SMR technology to develop and be deployed globally.

A: It is important to cooperate with the host country. Vendors should fully cooperate with the local industry when implementing a project. Another example of good collaboration is Rosatom, GE, and Framatome.

Q: How are SMRs to be applied to heavy industry requiring very high temperatures as a low-carbon option?

A: Although the current design produces about 750 degrees, it can be changed immediately to produce 900 degrees. With 870 degrees, the sulphur-iodine (SI) process can produce hydrogen.

Q: Hydrogen production can supply super high temperatures. Our SMR technology can be cost competitive in heat produced almost all by combustion.

A: SMRs can produce high-temperature heat. Our research shows that a great deal of hydrogen can be produced effectively at 860 degrees.

A: We also focus on the same approach. We replace the steam generator with a heat exchanger and combine this with an air combustion system. This can also produce a very high temperature and reduce harmful gas emissions.

Q: How can regulators who are specialised in light water reactor regulation transform to other reactors' regulation?

A: The US NRC has changed the design criteria with the DOE's support. This can be applied to advanced reactors, especially for HTGR. I was surprised at NuScale's activity in highly supporting regulators.

5.IFNEC Webinar 5: Energy Synergy and Hybrid System

Opening remarks

•Today's programme focuses on clean energy synergy between nuclear and renewable energy. The 'Nuclear Innovation: Clean Energy Future' (NICE Future) initiative established under the Clean Energy Ministerial considers it important.

Slovenia: Experience with operating 99% CO_2 free generation fleet of nuclear and hydro

•Gen group has three pillars of business, which are electricity production, development and investments (new hydro power plants), and trading and sales.

•Two-thirds of electricity generation in Slovenia are low-carbon sources. Gen group has generated 350 MW in nuclear electricity as baseload power, which accounts for 50% of nuclear in Slovenia.

•We can get synergy from the coordinated operation of Krsko and hydro power plants on the Sava River by adjusting production hours relative to electricity price fluctuations and managing high and low river flows.

Argentina: Energy transitions and the role of nuclear energy

•Most countries generate electricity mainly from fossil fuels. France and Argentina have very little amounts of fossil fuel electricity, exceptionally.

•Renewable energy, such as hydroelectricity and nuclear, are complementary relationships. Their mix can be the solution for energy transition.

•In Argentina, whilst energy demand is concentrated in or around the centre of the country, wind is concentrated in the south and solar is concentrated in the north. Renewable power generation units are far from the demand area, so Argentina has three NPPs in the centre of the country. Moreover, we are planning the SMR 'CAREM25', which is a PWR with 32 MW capacity and 100 MW core thermal power.

Integrated energy systems: Moving from models to reality with near-term nuclear-hydrogen demonstration projects

•The future energy system needs to be reliable, effective, affordable, and low-carbon. Nuclear can offer not only heat and electricity but also hydrogen. Right-sized reactors offer new options for various community sizes and demand. For example, SMRs can meet community demand and advanced reactors can supply heat at high temperatures.

•The Idaho National Laboratory (INL) has developed a graded approach to identify, design, and evaluate hybrid system architectures. They consider resource, technology, economic, and market potential.

•We have an integrated energy systems demonstration project: hydrogen production via electrolysis. Hydrogen enables energy storage and industrial use. Moreover, NPPs become cost-effective due to the second source of revenue from hydrogen. In our recent analysis, SMRs are cheaper to produce, compress, and deliver hydrogen. The LWR-H2 project is now being demonstrated in Exelon and Davis Besse.

European research and initiatives on hybrid systems, including co-generation

•Nuclear is needed to operate flexibly and to contribute to hybrid energy systems, such as in combination with renewable energy and applications for other industries than electricity.

•The EU Renewable Energy Directive endeavours to increase the share of renewable energy in the heating and cooling sector by 1.3% per year, which includes waste heat from nuclear.

•The HTGR system researched in the EU can make fertiliser, which is highly dependent on natural gas, low-carbon.

•In the future, hybrid energy systems need to develop not only in terms of innovation but also society (public acceptance), regulation (licensing and standardisation), policy, and deployment.

The role of advanced reactor systems in meeting future market needs

•The role of electricity is increasing and, consequently, demand-side management and storage are attracting much attention. Non-electrical sectors also need decarbonisation. Although the technologies are uncertain, they are becoming more important for frequency response, profile operation, and load following.

•The problem of spent fuel is significantly difficult, and advanced reactors need to manage the problem.

•Nuclear also provides heat that is being used in desalination and district heating. Nuclear can contribute to the generation of high temperature heat and hydrogen.

Implementation strategies of resilient nuclear-renewable hybrid energy systems

- •Coupling electric power with thermal power enables effective energy use. Combining hydrogen provides more options, mainly in storage. Many models have been developed to produce multi-output with multiple resources.
- •A micro modular reactor (MMR) for the NPP outage model is proposed. If an NPP does not work normally, it will be disconnected from the consumer side.
- •As another model, the SMR is used in marine ships. Hybrid energy systems with SMR and renewable energy on ships is being considered.

Q&A

Q: How should we address the clean energy system in the discussion of taxonomy where nuclear is excluded by the European Commission?

A: Nuclear new builds need sustainable funds for investors. Whilst the EU has consulted about taxonomy, nuclear is not excluded nor included. Foratom emphasises that nuclear is a clean and affordable energy option that can generate power regardless of the weather.

A: It is important for decision makers in many countries to share the value or practice of nuclear and consider the solution for complex problems. Opportunities are needed across various organisations, such as NICE Future.

C: In Europe, each country has a different opinion on nuclear. International agencies such as the IEA say that both nuclear and renewable energy is important to mitigate climate change and for energy security and the Sustainable Development Goals.

Q: This webinar has discussed the nuclear-renewable hybrid system. From the standpoint of renewable energy, what does the system mean?

A: Although renewable energy itself cannot provide steam or high temperature heat, a hybrid system can do it, which makes other industrial processes low-carbon.

A: Renewable energy can seize new opportunities, including business or scalability by combining with SMR or MMR.

A: We believe the combination of renewable and nuclear is suitable for the future. Nuclear can help renewable energy, which is variable and unstable. We want the renewable community to share nuclear's value.

A: There might be no competition between renewable and nuclear energy. Even after much more renewable energy is deployed, nuclear will also be needed to achieve climate goals.

6.OECD/NEA Report: REDCOST

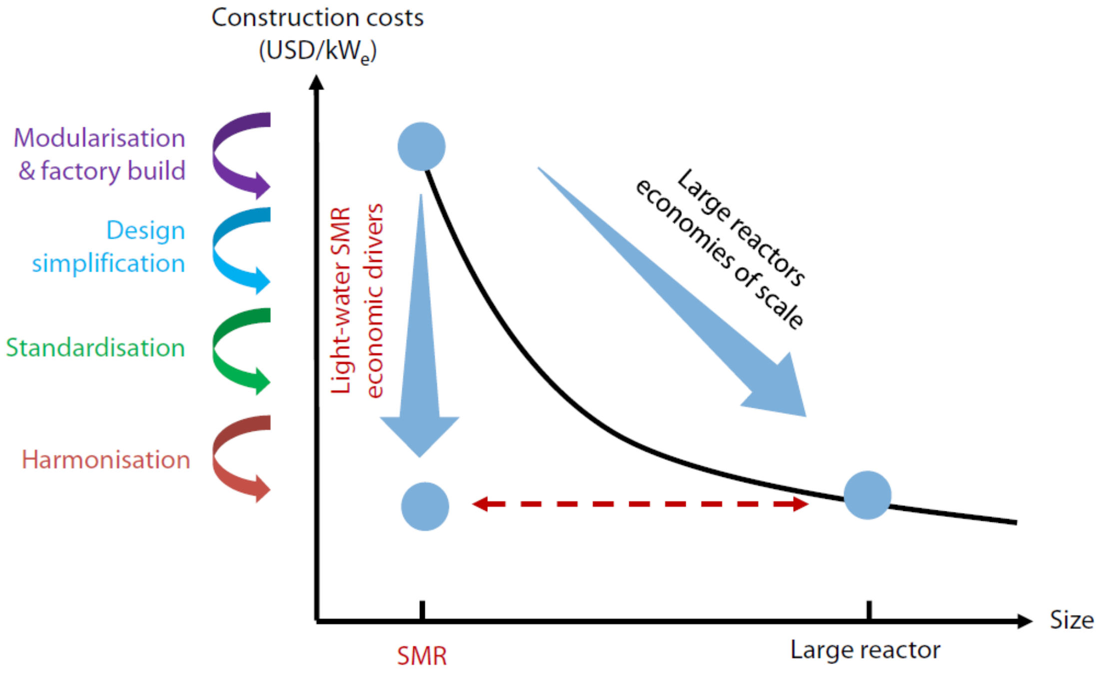
The NEA report titled, *Unlocking Reductions in the Construction Costs of Nuclear*, also known as the REDCOST report, includes some analysis on SMRs. Here is a summary of the explanation of SMRs in the NEA report:

SMRs have cost reduction potential in the long term (beyond 2030). Especially by their design, they may take greater advantage of specific cost-cutting strategies (i.e. the series effect, simplification, modularisation, etc.) to improve the economic performance of new nuclear installations. It is essential for success that governments support the timely development of demonstration projects, the licensing framework required to foster market deployment, and the talent development of highly technological expertise needed in nuclear power. At the same time, the harmonisation of codes and standards and licensing regimes may provide more cost reduction opportunities for conventional reactors, and such commercial drivers are also effective for SMRs.

The small nuclear cores will also solve technical limitations due to the size of Generation III reactors through simplification, modularisation, and standardisation. They enable enhanced passive or gravity-driven mechanisms, integral designs with all the components of the nuclear steam supplying system into a single vessel, and reduced inventories. SMR features allow below-grade siting, providing more protection from natural or man-made hazards, but these innovations may also introduce new safety issues to be assessed in more detail.

Whilst SMRs have many benefits, they have a major economic drawback because they cannot benefit from economies of scale due to their smaller size. However, their economic performance can be improved through series production and higher learning rates thanks to simplification, standardisation, modularisation, and harmonisation (Figure 4.1). These factors will be relatively more important to balance diseconomies of scale, so the cost reduction factors will not carry the same weight as other nuclear technologies. The potential of these strategies to reduce costs has been well documented in other industries, such as shipbuilding and the aircraft industry.

Figure 4.1. SMR Economic Drivers That Help Compensate for Diseconomies of Scale



SMR = small modular reactor.
Source: OECD/NEA (2020).

For timely deployment, SMRs will also require new licensing regimes. Current licensing frameworks typically rely on an extensive experience base with large single-unit LWRs, but LWR SMRs incorporate non-traditional components such as helical coil steam generators, internal control rod drive mechanisms, or new in-vessel instrumentation for which operational experience is limited. Plus, Generation IV SMRs will include features that have never been tested before. The lack of experience with these novel designs poses challenges in demonstrating and approving their safety case. Moreover, the introduction of alternative fuels and/or coolants (i.e. Generation IV SMRs) will translate into greater deviations from previous regulatory paradigms and may require more flexible licensing approaches.

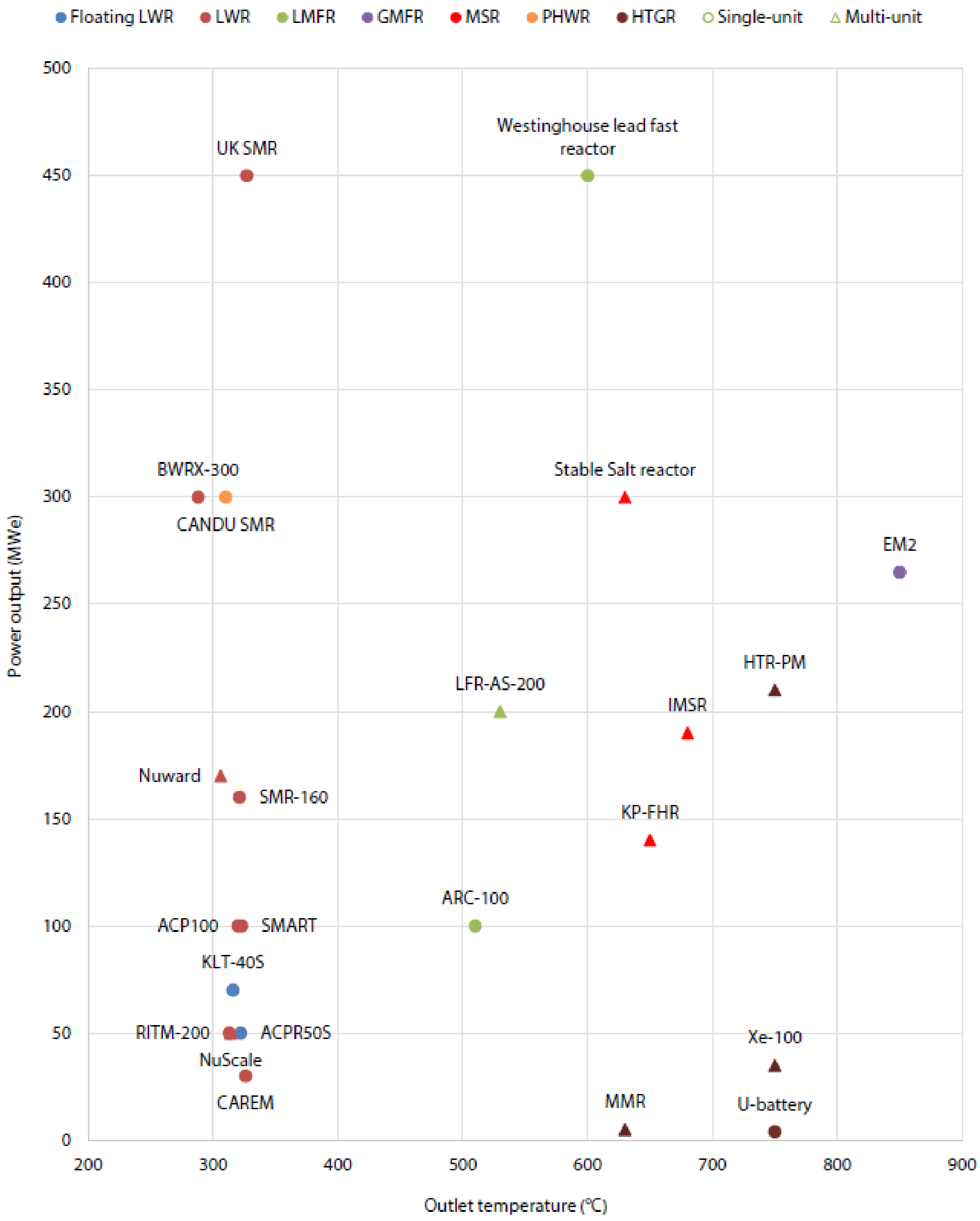
In conclusion, attaining the economic competitiveness of SMRs will require a coordinated effort by the various stakeholders, a dedicated policy and regulatory framework, and, most importantly, a global market. Regulators will, therefore, need to determine how they can work together to devise more streamlined and harmonised regulatory frameworks to create a true global SMR market. It is also imperative to appropriately estimate the size of this market to establish a robust supply chain and sustainable construction know-how that results in competitive capital costs. Beyond the potential cost savings described above, SMRs also offer a different value proposition in terms of financing, ancillary services, and off-grid and non-electric applications that could also improve their economic performance.

7.OECD/NEA Report on Small Modular Reactors

In 2021, the OECD/NEA published another report that focuses on SMRs, which identifies their challenges and opportunities. Here is a summary of the discussions in this report (OECD/NEA, 2021):

According to the IAEA, approximately 70 SMR concepts are currently under development. Whilst the term 'SMR' has been adopted around the world to refer to all small reactor designs, significant differences remain across the major types of SMRs under development (Figure 4.2). Around 50% of the SMR designs under development are variants of light water reactors (LWR-SMRs), and the others correspond to Generation IV reactors (Gen IV SMR) that adopt alternative coolants and advanced fuel, etc. Generation IV-based designs do not have the same levels of operating and regulatory experience as that of LWRs, but they can benefit from an extensive history of past R&D upon which developers and regulators may draw.

Figure 4.2. Selected Reactor Designs as a Function of Power Output, Core Outlet Temperature, and Deployment Configuration



Source: OECD/NEA (2021).

Since SMRs will not benefit from economies of scale, it will be important to ensure 'series construction'. Therefore, SMR designs should be highly modularised, simplified, and standardised so that they will be suitable for mass production in factories. Factory fabrication also contributes to enhanced quality control that can reduce construction risks, foster a ‘series effect’, and enable the introduction of new manufacturing techniques, some of which have already been demonstrated in other industries. At the same time, the smaller size and the prediction of shorter delivery times could reduce upfront investment needs for SMRs compared to larger reactors. Furthermore, SMRs have flexible capabilities which enhance load-following and non-electric applications. These features could bring system-cost benefits and new market opportunities.

As these new technologies were not envisaged when the currently applicable international nuclear conventions were drafted, such conventions would need to be reviewed so that they can be adapted to the innovative SMR concepts. However, the main difficulty with the novel designs is the limited experience base that makes it challenging to demonstrate and approve the safety features of SMRs. In addition, changes to the fuel and/or coolant will translate into greater deviations from previous regulatory paradigms and may require more flexible licensing approaches.

If SMRs are mass-produced in factories, the economic benefits could be significant. This would require, however, a large global market for a single design. Higher levels of regulatory harmonisation will be needed to realise a global market, as well as a reduction in the number of designs.

SMRs have furthermore introduced a series of untested innovations that may lead to additional technology risks. However, as SMRs gain in maturity with the first demonstrators coming online, some of these risks should be mitigated. The supply chain should also be ready to support the emergence of a market for SMRs, ensuring the timely availability of factory-fabrication capabilities, high-assay low-enriched uranium (HALEU), and other innovative fuel production capacities, along with the necessary skills and R&D infrastructure. Additional challenges may arise in terms of public engagement because several concepts of SMRs attempt to minimise evacuation zones and to place the reactors closer to large population centres.

Finally, as a result of the discussions above, this OECD/NEA report identifies four key enablers for SMR deployment: (1) public engagement and international collaboration, (2) the construction of FOAK SMR demonstration units and learning, (3) harmonisation of licensing regimes, (4) development of manufacturing capabilities.