Chapter 3

Small Modular Reactor Advantages and Opportunities

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Chapter 3

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As interest in SMRs grows in the world, more and more people and organisations are having discussions or publishing reports to evaluate their benefits and feasibility. Some countries have already begun the pre-licensing phase of safety regulation. It is interesting that not all of them have favourable conclusions regarding SMRs. Such discussions would be meaningful for Asian countries that are considering deploying nuclear energy. Therefore, this chapter summarise such international discussions, reports, and a letter related to SMRs conducted or written in recent years.

1. NEA-IFNEC Webinar: The Financing of SMRs

On 18 May 2021, International Framework for Nuclear Energy Cooperation (IFNEC), an international framework for promotion of civilian nuclear energy cooperation, and OECD/NEA held an online webinar focusing on issues related to the financing of SMR projects. Below is a summary of the webinar.

1.1. Session 1 – Presentation of the NEA SMR Report

- SMRs are smaller in physical size and electrical output than conventional reactors. SMRs can be mass-produced at factories and transported to the construction site, which can improve economic efficiency. Relatively large-scale SMRs are suitable for replacing coal-fired power plants, and micro-reactors are applicable to off-grid areas.
- Load-following SMRs can coexist with variable renewable energy. They can also be used to desalinate seawater and produce hydrogen.
- Nevertheless, SMRs are facing many challenges. Significant progress has been made in terms of technology, but public trust and regulatory readiness remain problems.
- Decreasing the size of a project would reduce the risks and make it more attractive to financial institutions.

- To make SMR projects more feasible, we need to harmonise the international regulatory framework. Cooperation in global value chains would also be needed.

1.2. Session 2 – SMR Financing – Customers' perspective

- Coal-fired power plants have been shut down one after another in Europe, and some countries are closing nuclear power plants. Such countries are importing electricity, and electricity prices are supported by subsidies from the government.
- The carbon price is expected to keep rising in Europe. Therefore, the deployment of SMRs is an essential step. SMRs are important to meet the decarbonisation targets of each country.
- Funding should be secured step-by-step in parallel with the procurement process. It would also be important to have the government actively involved in communicating with local communities to help their decision-making.
- Kenya has published a roadmap to introduce nuclear power within 50 years. It seems that the economic competitiveness of SMRs is not so high today, but the Kenyan government sees SMRs as an important option given the potential for shorter construction time, lower maintenance costs, and utilisation other than electricity production. It is also paying attention to the combination of SMRs and renewable energy.

1.3. Session 3 – SMR Financing – Vendors' perspective

- X-energy's Xe-100 is a true game-changer. It can contribute to desalination, the petrochemical industry, district heating, and hydrogen production. It can also help renewable power generation through its load-following operation. Three major initiatives are underway: a programme led by the US Department of Defense, that led by Ontario Power Generation (OPG), and the Advanced Reactor Demonstration Program (ARDP) led by the US DOE. X-energy is a candidate for these programmes.
- There are emerging markets, including desalination and hydrogen production, as well as a distributed power market. These markets usually separate ownership, management, and operations to reduce the risk, so financing is likely to be complex.

State support of low-carbon power sources and a carbon tax would be meaningful.

- SMRs would be a game changer from a financial perspective because of their shorter construction period and small project size. It is important to expand the markets and secure policy support for SMRs. As financial policies, there are science and technology funds developed by national and local governments, as well as policy guidance for the early stages of R&D. We need to guarantee both the safety and the interests of our investors. Therefore, a flexible regulatory scheme is needed.

1.4. Session 4 – Panel discussion

- It was very difficult for X-energy to build a relationship of trust with investors under the COVID-19 pandemic. It was also difficult to quantify the risk related to regulatory requirements in each country.
- In China, the government funds almost all investment for R&D and it also provides tax credit. It will probably offer power purchase agreements at a fixed price. Despite this, it cannot be said that SMR projects will be successfully carried out without fail.
- One of the important issues in financing SMRs is government guarantees. There are also some social problems, such as the case with thermal power plants, which have already faced opposition from local communities. In some countries, the construction of thermal power plants has been stopped by lawsuits even though the projects had entered their final phase.

2. OECD/NEA Expert Group on Advanced Reactor Systems and Future Energy Market Needs

In December 2021, the OECD/NEA Expert Group on Advanced Reactor Systems and Future Energy Market Needs (ARFEM), which investigates the changing needs of energy markets and the potential role of advanced nuclear reactors, published a report of their study results. Below is a summary of the report.

2.1. Introduction

The needs of energy markets are continuously changing. Low-carbon energy sources can help to unlock hard-to-abate sectors, and various efforts are underway to develop these alternative energy sources.

Currently, various advanced nuclear reactor systems are under development and are capable of offering more flexible options with respect to energy supply. In order to analyse how and to what extent these technologies will be able to address future energy market needs and conditions, and the possible constraints that might arise, the OECD/NEA established ARFEM. ARFEM investigated the current situation and future prospects of energy market needs, as well as the characteristics and prospects for the development of advanced reactor systems. It also identified key factors that would help maximise the potential benefits of advanced reactor systems in future energy markets.

2.2. Future market opportunities and requirements

The need for flexible power operation from power plants is growing as variable renewable sources are increasingly penetrating electricity grids. Future advanced reactor system concepts have different characteristics for flexible operation.

The role of nuclear power in the electricity system may be more diverse in future, depending on the regional characteristics of the system. The development of electric vehicles, demand-side management, and storage technologies could allow conventional plants to operate at high-capacity factors, even with significant variable renewable sources deployment. Advanced reactor systems are also capable of providing firm capacity to ensure manoeuvrability over a wide range of timescales.

The heat sector is another area where advanced reactor systems can make a significant contribution. Lower temperature heat systems can be provided by conventional nuclear reactor systems, and higher temperature heat, under which a large percentage of the current global demand falls, could be provided by generation IV concepts. Also, small modular reactor systems aim to achieve higher deployment flexibility, which allows the reactors to be located closer to regions of demand.

Hydrogen production by advanced nuclear reactor systems could significantly contribute to the reduction of CO_2 emissions in many sectors. All advanced reactor system concepts can produce hydrogen using the existing low-temperature electrolysis technology, and some concepts could supply high-temperature heat, producing hydrogen with even higher efficiency. The role of advanced reactor systems in hydrogen production should be underlined for the potentially significant contribution to the decarbonisation of hard-to-abate sectors. Some national R&D programmes are working on coupling nuclear reactors with hydrogen-producing facilities.

The potential benefits of closed fuel cycle and generation IV systems may prove to be another strong motivation for deploying such systems in the short-to-medium term. For those generation IV systems that can demonstrate high levels of safety, co-location on certain sites may also be a valuable option.

2.3. Policy recommendations

The characteristics and needs of energy markets are becoming more diverse, and the strategies to reach carbon neutrality vary depending on the conditions. However, advanced reactor systems could adapt to such needs. In order to maximise the potential, the NEA is proposing the following policy recommendations:

- The potential of advanced reactor systems as a low-carbon, cost-effective means to support country policies with respect to low-carbon emission targets and variable renewable energy deployment should be recognised.
- Non-electric applications involving advanced reactor systems should be included in policymaking considerations.
- Governments and industry should work together to demonstrate the current capabilities of advanced reactor systems in target markets.
- International collaboration should be promoted to improve the economic viability of advanced reactor system development.
- Public understanding for advanced reactor systems should be continuously fostered.

3. The Socio-Economic Impact of GE Hitachi SMRs

One of the Canadian electric power utilities, Ontario Power Generation (OPG) is seeking to deploy an SMR plant at its Darlington site. Amongst three candidate designs, OPG eventually selected BWRX-300 developed by GE Hitachi Nuclear Energy. Prior to the decision, international consulting firm PricewaterhouseCoopers (PwC) conducted a research project that evaluated the impact that would be brought by the deployment of the BWRX-300 in Ontario. Below is a summary of the report.

3.1. About GE's BWRX-300

The BWRX-300 is a 300 MWe boiling water reactor (BWR). This reactor technology builds on existing BWR technology with a proven track record, which means the BWRX-300 is advantageous in commercial readiness. At the same time, the reactor design is innovative, with dramatic simplification and the elimination of unnecessary systems. The regulatory process for the BWRX-300 has been progressed in North America. The Nuclear Regulatory Commission (NRC) in the US has issued a Final Safety Evaluation Report for three licensing topical reports. In addition, the vendor design review process with the Canadian Nuclear Safety Commission (CNSC) is underway. To date, feedback has been positive, and no barriers have been identified.

3.2. Economic footprint of the GE SMR

PwC assessed the direct, indirect, and induced economic footprint of development, manufacturing, and operations of GE's SMR with the OPG. According to their assumptions, CA$2.0 billion would be spent for GE's first-of-a-kind SMR over seven years in the manufacturing and construction phase. After that, operation of the SMR at the Darlington site would bring annual spending of CA$35.0 million over the project lifetime. This spending would increase GDP by CA$1.3 billion, labour income by CA$1.1 billion, and tax revenue by CA$460 million and would sustain 1,712 jobs per year over seven years of the construction phase. As for the operating phase, GDP would be increased by $1 billion, labour income would be increased by CA$768 million, and tax revenue would be increased by CA$303 million, and 197 jobs would be sustained per year over 60 years.

If another BWRX-300 plant is constructed in Ontario or in other provinces of Canada or is exported to other countries, it would bring further economic impact as shown in Table 3.1.

Table 3.1. Estimated Economic Impact of the BWRX-300

Scenario	Economic footprint (excluding operating impacts)
Future Ontario reactors: per-reactor benefits of subsequent SMRs that GE will install alongside partners in Ontario	CA$1.1 billion in GDP, CA$728 million in labour income, CA$312 million in tax revenue, and sustain 1,951 jobs per year over four years
Future Canadian reactors outside of Ontario: per-reactor benefits of subsequent SMRs that GE will install alongside partners elsewhere in Canada	CA$1.1 billion in GDP, CA$730 million in labour income, CA$313 million in tax revenue, and sustain 1,956 jobs per year over four years
Export activity: per-reactor benefits to Canada of GE's BWRX-300 SMRs installed internationally	CA$98 million in GDP, CA$110 million in labour income, CA$46 million in tax revenue, and sustain 217 jobs per year over four years

Source: PwC (2021).

3.3. Broader benefits

The benefits of deployment of the BWRX-300 go beyond the economic footprint above. There would also be various additional benefits. First, the deployment of the SMR would help Canada to fulfil its climate change commitments. GE, especially, is taking action to reach net zero emissions for its operations by 2030. Second, GE is committing to diversification and inclusion. It is trying to increase the representation of women and other marginalised groups in the nuclear sector. Third, GE emphasises engagement with indigenous communities as part of the SMR deployment, including creating opportunities for employment. Fourth, the deployment of the BWRX-300 would bring skill development for employees that will enhance safety and technical excellence and increase the technical skills of workers in Ontario and Canada. Finally, technical excellence will enhance the concentration of engineering talent and know-how in Ontario and Canada.

4. Nuclear Power and Small Modular Reactors in Indonesia

In 2017, the Nautilus Institute for Security and Sustainability, a public policy think tank studying various issues related to security, energy, and climate change, etc. published a report that evaluates the possibility of SMR deployment in Indonesia. The following is a summary of the report.

4.1. Indonesian Interest in SMRs

Since the late 1970s, the Indonesian Atomic Energy Agency (BATAN) has been trying to convince the government of the need to embark on a nuclear power programme. However, since state-owned companies are not in a position to make large-scale investments, it is not possible to build nuclear power plants in Indonesia for the time being. Therefore, a possible breakthrough for construction is the introduction of small reactors of Generation IV nuclear power, with the goals of low power generation costs that can compete with thermal power, high safety without major accidents, less waste, and nuclear proliferation prevention. On the other hand, the technological innovation of SMRs itself has not progressed as much as expected. Whilst SMRs that satisfy the three requirements of safety, non-proliferation, and reduction of nuclear waste are being developed, the lack of SMRs with price advantages has become a bottleneck in the construction of new nuclear power plants.

4.2. Public opinion and opposition to nuclear power

Since the 2010s, based on BATAN surveys of public attitudes, it has become clear that nearly 60% of the public generally supports nuclear power plants, whilst 40% do not. In particular, the 2011 survey confirmed that disapproval exceeded support, which is believed to be due to the Fukushima nuclear power plant accident. In response, BATAN actively undertook activities designed to increase public support for nuclear power.

Like many countries around the world, Indonesia is in the midst of a heated debate over the pros and cons of nuclear power. Civil society organisations have played an important role in this debate. The main organisations opposing nuclear are the Indonesian Anti-Nuclear Community (Masyarakat Anti Nuklir Indonesia, MANUSIA), the Indonesian Forum for Environment (Wahana Lingkungan Hidup Indonesia, WALHI), Greenpeace, and Nahdlatul Ulama (especially in the Central Java sector).

4.3. SMR proposals

In addition to a general interest in SMRs, the Indonesian nuclear establishment has studied some SMR possibilities in much greater detail.

- Gorontalo floating small NPP proposal

The oldest nuclear proposal directly relevant to SMR technology stems from the mid-2000s when the Russian nuclear supplier Rosatom proposed a small Russian floating nuclear power plant to supply electricity to Gorontalo Province, Sulawesi. Floating nuclear power plants are modelled after the reactors used to power a small fleet of nuclear-powered icebreakers operated by Russia for decades. The government, on the other hand, has expressed its opposition to the construction of floating nuclear power plants and believes that they should be built on land.

In May 2015, the provincial government of Sulawesi urged the central government of Indonesia to build a nuclear power plant, as the region was experiencing power shortages. However, such motivation for building a nuclear power plant disappeared because they decided to build a 100-MW (four 25 MW plants) gas-fired power plant in Pohuwatu in the same province.

- Madura desalination small NPP proposal

In October 2001, under the framework of the Interregional Technical Cooperation Project of the IAEA, BATAN signed an agreement with Korea Atomic Energy Research Institute to undertake a joint study, entitled 'A Preliminary Economic Feasibility Assessment of Nuclear Desalination in Madura Island'. The institute has been developing an SMR called the System-Integrated Modular Advanced Reactor since 1996. However, no progress can be seen since they conducted seismic and economic surveys.

- West Kalimantan NPP proposal

Another region that has been identified by BATAN as a potential site for SMRs is West Kalimantan, in part because of the paucity of grid infrastructure in the area. This plan seemed to be supported by the provincial government. Based on this, the Nuclear Power Plant Development Coordination Team was formed. Considering the long-term electricity demand in the West Kalimantan region, they argued that if a nuclear plant were to be built at all, then it would necessarily have to be an SMR, which is not the same as asserting that a SMR should be built.

4.4. Electricity landscape and comparison of costs

Domestic forecasts of the future Indonesian energy mix by 2050 seek to increase the share of new and renewable energy. The fuel mix in the power sector is projected to be dominated by coal and gas-fired power plants. The total new and renewable energy target for Indonesia's energy is set at 31% by 2050. According to the same projections, nuclear power plants are 'estimated to enter the Java-Bali electricity system in 2030 with a capacity of 2 GW' and this is projected to 'increase up to 6 GW in 2050' (BPPT, 2015). Moreover, the National Development Planning Agency has incorporated plans for nuclear energy into the National Mid-Term Development Plan 2015-2019, and nuclear energy is also included in the most recent Government Work Plan. On the other hand, in the long-term scenario, there is currently no prospect that new SMR construction will be promoted.

The Nautilus Institute shows a study that compares the power generation costs of solar PV, a conventional large-scale NPP, and an SMR. As a result, PV has the lowest cost of power generation at US$73.25/MWh, followed by the large-scale NPP at US$183.63/MWh, and the SMR at US$222.15/MWh.

4.5. Conclusion

There are two bottlenecks to realising the construction of SMRs in Indonesia. First, it is difficult to improve the political environment for contributions to the expansion of the nuclear industries. Since the 1970s, attempts to establish a nuclear power plant have failed to convince government leaders, and no obvious progress has been made thus far. In addition to this, it has been pointed out that there is not enough public consensus on nuclear energy. Secondly, the cost of SMRs is high compared to conventional large-scale nuclear reactors and solar power generation, which has become more competitively priced in recent years. For these reasons, it is unlikely that the installation of SMRs in Indonesia will be large enough to contribute to the improvement of power generation.

5. NRC letter: Denial of the Aurora combined operating licence application

In the US, NuScale's SMR has successfully received the standard design approval from the US Nuclear Regulatory Commission (NRC). However, Oklo's micro-reactor, named Aurora, was refused in the pre-licensing process. Below is a summary of NRC's letter declaring the denial of the review of Aurora. It is important to learn from the NRC's letter why Oklo's proposal was refused and what the issues were in the regulatory discussions.

5.1. Overview

The custom combined licence application for the Aurora micro-reactor was denied by US NRC staff. The specific reasons for the denial are based on the following: (1) Oklo repeatedly failed to submit the information needed to complete the Step 1 review of its maximum credible accident (MCA) analysis and safety classification of its structures, systems, and components (SSCs); (2) Oklo's 30 October 2020 responses to NRC staff's requests for additional information (RAI) did not contain sufficient technical information; and (3) the topical reports Oklo submitted to address Step 1 of the review to support a predictable review schedule contained information that was conceptual in nature and did not adequately describe Oklo's methodologies for Aurora's MCA analysis or for the safety classification of the SSCs.

5.2. Two-step process

After providing limited information about its final design to the NRC staff in the pre-application engagement, Oklo submitted a custom combined licence application for one micro-reactor, designated as the Aurora, located at the Idaho National Laboratory, by letter dated 11 March 2020. However, a custom combined licence application must contain complete design information and all site-specific information necessary for the NRC staff to reach safety and environmental findings for licensing and establish a full review schedule. Instead, the NRC staff developed a novel two-step process for the review, and informed Oklo by letter dated 5 June 2020 that the application would be docketed and reviewed under this two-step process. Step 1 intended to obtain from Oklo additional information on key safety and design aspects of the Aurora licensing basis. In establishing the two-step review process, the NRC staff noted their commitment to completing the safety review of the Aurora application within the established generic 36-month NRC schedule for such reviews. To complete Step 1 of the review, the NRC staff engaged with Oklo in numerous public meetings, conducted regulatory audits, and issued RAIs on four key aspects of the application.

The NRC's letter dated 5 June 2020, communicated the need to address four foundational aspects of the Aurora licensing basis during Step 1 of the review: (1) MCA analysis, (2) safety classification of the SSCs, (3) scope of the quality assurance programme, and (4) applicability of regulations.

5.3. Oklo's failure

Of the four issues identified for resolution in Step 1 of the custom combined licence application review, Oklo's MCA analysis and safety classification of SSCs remain open. Oklo proposed a novel approach to determining the spectrum of potential accidents and the safety classification of the SSCs within its design. Oklo was required to explain its novel approaches and the NRC staff would evaluate their reasonableness. Although Oklo has been provided several opportunities to provide the necessary technical information, it has failed to do so.

By letter dated 2 July 2021, Oklo submitted two topical reports that contained insufficient technical information to address the open Step 1 issues for NRC staff review. The NRC staff performed completeness reviews of the topical reports and determined that neither topical report contained sufficient information to initiate detailed technical reviews. Each report contained conceptual information, rather than repeatable methodologies, and each left many issues unresolved and open for future potential applicants referencing the topical reports to address.

The NRC staff identified significant information gaps in the Aurora custom combined licence application in its 5 June 2020 docketing decision and has engaged with Oklo since August 2020 in sustained efforts to provide Oklo with options for providing the information needed on the topics of MCA and the safety classification of the SSCs. The NRC staff used public meetings, audits, RAIs, and conducted two completeness reviews of the topical reports to provide Oklo with clear descriptions of the information Oklo must provide. However, the NRC staff has been unable to obtain the necessary information from Oklo to support the completion of the Step 1 review.

Prior to submitting its custom combined license application for Aurora or its topical reports, Oklo chose to conduct limited pre-application discussions with the NRC staff regarding its

MCA methodology and safety classification of the SSCs. Additionally, the NRC staff reviewed and approved the Oklo Quality Assurance Program Description and the safeguard information protection and handling plan. Oklo covered a broad range of topics in its pre-application engagement with the staff, but the effectiveness and relevance of the pre-application engagement was limited because (1) NRC staff feedback from the pre-application engagement was not incorporated into the Aurora custom combined licence application and (2) Oklo made other changes to the Aurora design and/or design basis after these interactions that limited the applicability of prior discussions to the Aurora custom combined licence application.

5.4. Conclusion

Based on Oklo's failure to provide the NRC with the necessary information on its reactor, as described above, the NRC staff has insufficient information to establish a schedule or conduct a full review of the Aurora custom combined licence application and, therefore, denied the application for failure to supply information.