7 Market and industry perspectives and the GIF Senior Industry Advisory Panel report

Market issues

Since the creation of the Generation IV International Forum (GIF) in 2000, market conditions have continued to evolve, and they continue to be a common concern among users and developers of Generation IV (Gen-IV) concepts. The role of the GIF Senior Industrial Advisory Panel (SIAP) is to understand core drivers, opportunities and constraints related to the market environment with the objective of identifying the most appropriate advice in terms of GIF activities, in collaboration with the System Steering Committee (SSC) chairs, task forces and working groups, and with the guidance of the members of GIF Policy Group (PG).

Following the conclusions of the 2015 Paris Agreement, numerous countries have initiated major endeavours to reduce CO_2 emissions related to economic activities. Efforts taking place over the past years to decarbonize the electricity sector have largely been concentrated on massive capacity additions of variable renewable energy (VRE) resources, such as wind and solar power. As recently illustrated by the International Energy Agency (IEA, 2019),[1] low-carbon electricity demand is set to increase by 2040, and the mobilization of all low-carbon technologies will be needed in order to meet climate engagements. For instance, according to the IEA "Sustainable Development Scenario", nuclear capacity should increase by 60% compared to today's levels if these engagements are to be met.[2] However, several issues continue to challenge the economic rationale of nuclear energy, ultimately slowing the development of nuclear power.

The cost of VRE resources has been steadily decreasing, enabling a higher penetration of these types' technologies in current electricity systems. This trend, combined with cheap and abundant fossil fuels – particularly in the United States – is undermining the profitability of nuclear projects in terms of the levelized cost of energy (LCOE). At the same time, and partly as a result of the long hiatus in nuclear new build since the 1990s, recent nuclear projects are experiencing difficulties in OECD member countries in relation to being delivered on time and on budget, thus increasing investor risks.

It is important to underline that the eruption of VRE resources is shaping electricity systems, and new opportunities are emerging. Dispatchability attributes are becoming more valuable, in the light of intermittent electricity generation and the absence of large-scale storage solutions. Distributed generation is also gaining momentum. Moreover, decarbonization of energy systems also involves low-carbon heat generation for domestic and industrial processes, or even hydrogen production.

These issues were explored during the Vancouver GIF Workshop on Flexibility, held in May 2019. The event gathered members of the GIF Economic Modelling Working Group (EMWG), SIAP and SSCs, with the objective of assessing the flexibility of the Gen-IV systems. It was a good opportunity for SIAP to share with the GIF community the main findings of the 2018 SIAP charge[3], which has a strong focus on the flexibility of Gen-IV systems and the opportunities associated with hybrid systems. The workshop confirmed that all Gen-IV concepts have significant flexibility features to meet emerging, energy market needs in terms of load following, scalability and heat generation, as well as hydrogen production. Technologies with lower technology readiness levels have the highest potential as they face reduced constraints from the design standpoint. The different options for flexibility may allow Gen-IV systems to better adjust to more uncertain and turbulent energy markets. Integrating flexibility in Gen-IV designs could nevertheless come at a cost and should be fairly compensated through adequate market designs.

In this context, small modular reactors (SMRs) are capturing the attention of the nuclear industry since they potentially offer a more attractive business case in current market conditions. SMRs are nuclear reactors with power output ranging between 10 MWe and 300 MWe, which integrate by design higher modularization, standardization and factory-based construction in order to maximize economies of series (or the series effect). The different modules can then be transported and assembled on-site, leading to predictability and savings in construction times. More recently, vendors have been proposing micro modular

1. *World Energy Outlook* (IEA, 2019), available at: www.iea.org/reports/world-energy-outlook-2019.

2. www.iea.org/topics/tracking-clean-energy-progress.

3. A "Charge" address to SIAP is a technical question or a problem addressed by the Policy Group and the Experts Group to SIAP to get their feedback, vision & recommendations with their industrial point of view. Usually a maximum of one charge per year is addressed to SIAP.

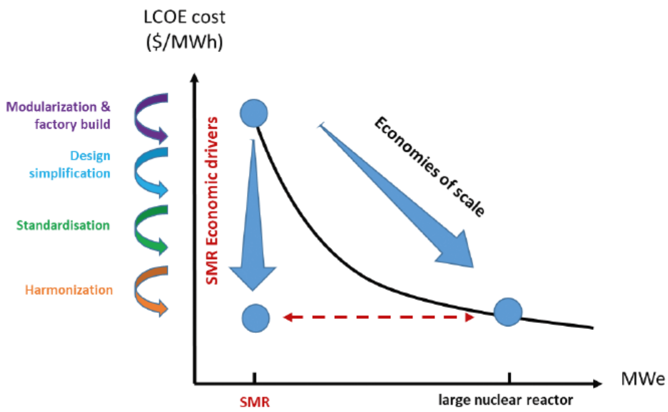
reactors (MMRs), with power outputs of lower than 10 MWe. Such reactors are capable of semi-autonomous operation and can take advantage of higher levels of transportability compared to the larger SMRs.

Among other factors, the series effect plays a central role in the economic competitiveness of SMRs. In fact, the small size of this type of reactor introduces a considerable economic penalty in terms of the LCOE (i.e. diseconomies of scale). The cumulative effect of modularization, simplification, standardization and harmonization may be driving the series effect, which is necessary to compensate for the penalty in relation to economies of scale, and could potentially improve the overall economic performance of SMRs. This effect is illustrated in Figure SIAP-1. Moreover, once established, the series effect could trigger increased confidence from financial institutions, thus leading to lower financing costs, which today represents a significant share of nuclear LCOE. Additional cost reductions could be unlocked with the introduction of new technologies.

The potential of the economic drivers of SMRs is supported by past experience in other industries (e.g. aviation). Additional empirical evidence is nevertheless needed for the SMR technology. Through this process, access to a global market that would enable the large-scale deployment of SMRs will be essential. It is worth noting that an Nth-of-a-kind cost level for an SMR can be achieved with significantly less cumulative installed power, and thus less upfront investment.

Beyond LCOE issues, the value proposition of SMRs also includes unique features such as access to off-grid/remote areas and non-electric applications. From a financial perspective, SMRs may represent an attractive investment, principally because of the lower overall capital outlay compared to large reactors. This lower capital outlay implies that private investors will face lower capital risk, which could make SMRs a more affordable option. It would, in turn, attract new sources of financing and lower the cost of capital. The ability to add modules incrementally provides additional financial flexibility, especially under sudden market shifts. Moreover, the shorter construction period allows revenues to be available sooner in capital projects. Shorter construction times will also work synergistically with other factors, namely serial production and smaller capital expenditure, to ultimately bring the financial cost of SMRs to a level that is much more in line with other major industrial projects.

According to the International Atomic Energy Agency (IAEA),[4] there are around 72 SMR concepts under development, with varying technology and licensing readiness levels. Among these concepts, around 50% are Gen-IV concepts, also called



Source: NEA (2020), *Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders*, OECD Publishing, Paris.

Figure SIAP-1. SMR economic drivers that help compensate for diseconomies of scale

advanced small modular reactors (ASMRs). The HTR-PM, a 200 MWe model of gas-cooled high-temperature reactor, is under commissioning in China, with cold functional tests completed in unit 1 in October 2020. Even if most of these projects are endorsed, to some extent, by the governments of GIF member countries, involvement of the private sector has been increasing substantially.

Countries such as Canada, the United Kingdom and the United States have made significant progress in the development of policies and licensing frameworks to accelerate the time to market for SMRs.

In Canada, one ASMR vendor (i.e. Global First Power, with its 5 MWe HTGR MMR concept) is in the licensing process to build, own and operate a first demonstration unit at the Canadian National Laboratories (CNL) site in Chalk River by 2026. The Canadian government is investing CAD 20 million (USD 15 million) to accelerate the development of Terrestrial Energy's Integral molten salt reactor.

In the United Kingdom, phase 1 of advanced modular reactor (AMR) feasibility and development (F&D) has provided eight AMR organizations with funding of up to GBP 4 million (USD 5.5 million) to undertake a series of feasibility studies with contracts worth up to GBP 0.3 million (USD 0.4 million). Tokamak Energy, Westinghouse and U-Battery were selected to receive up to GBP 10m to undertake development activities for phase 2 of the project. Going forward, the Prime Minister's recent "Green Industrial Revolution" program announced up to GBP 385 million (USD 528 million) in an advanced nuclear fund to further invest in the next generation of nuclear technology. It includes funding of up to GBP 215 million (USD 295 million) for SMRs and up to GBP 170 million (USD 233 million) for AMRs. The

4. *Advances in Small Modular Reactor Technology Developments* (IAEA, 2020), available at: https://aris.iaea.org/Publications/SMR_Book_2020.pdf.

objective is to build a first AMR demonstrator by the early 2030s. In parallel, government will invest up to an additional GBP 40 million to develop the regulatory frameworks and support UK supply chains so as to help bring these technologies to market. Plans are also underway to open the generic design assessment process for SMR vendors in 2021 and to further the work on a comprehensive siting assessment and strategy.

In the United States, the advanced MMR design from Oklo is under review by the US Nuclear Regulatory Commission (NRC) and carries a site permit from the US Department of Energy to build a demonstration at the Idaho National Laboratory. In addition, under the "Advanced Reactor Demonstration Program", the Xe-100 and Natrium ASMRs received USD 80 million each in October 2020 to accelerate their development. Five additional SMR developers have received smaller grants in the (investment) "risk reduction" category.

Several challenges will nevertheless need to be overcome in order to achieve large-scale commercialization. The current, wide variety of ASMRs represents both an opportunity and a challenge. In the near term, the role of the first demonstrators will be crucial, not only to trigger the subsequent investments necessary to build a module factory, but also to downselect the most performant concepts.

In addition to the need to reduce cost, industry is also facing the challenge of further improving safety as a result of new and demanding regulations. The IAEA's new design extension conditions require consideration of extreme events, which were previously beyond-design basis. To cope with these combined challenges, new system engineering and risk-informed, performance-based design approaches are being considered. Additional efforts will be required to revisit current licensing frameworks, which rely extensively on the experience developed with Gen-III/III+ and Gen-II light water reactors. At the same time, enabling policy frameworks and international collaboration will continue to be key factors in the timely deployment of new reactor concepts. Avoiding diversion of sensitive materials and ensuring physical protection will also be key in fostering the large-scale deployment of SMRs. In December 2019, the Canadian Nuclear Safety Commission (CNSC) and the US NRC selected Terrestrial Energy's integral molten salt reactor (IMSR) for the first joint technical review of an advanced, non-light water nuclear reactor.

The COVID-19 pandemic has set in place a new paradigm to rethink the importance of developing more sustainable and resilient energy systems, while boosting economic recovery. Given the lack of maturity of most SMR concepts, having this technology included in recovery packages around the world may not bring the near-term employment and emission reduction effects currently being sought by governments. However, these efforts could help to bring the new technologies needed to decarbonize advanced economies into existence by 2050, along with the long-term benefits associated with sustainable and resilient energy systems and the development of new industries and markets.

Senior Industry Advisory Panel report

SIAP 2020 charge and response

ASMRs are gaining recognition from both governments and the private sector. Over the years, GIF has created a significant knowledge base of Gen-IV systems and a unique global network of experts that could help accelerate the commercialization of the ASMR technology. In 2019, SIAP explored how interactions with the private sector could take place. The main outcomes that arose from this exploration include:

- due diligence in relation to ASMR concepts is needed;
- intellectual property rights could hinder collaboration, especially at high technology readiness levels;
- the need to go beyond technology-specific R&D, focusing on cross-cutting initiatives and support for research on processes and methods.

Furthermore, some ASMR designs may not be fully aligned with GIF goals, and the conditions for interaction with the private sector should be carefully defined. The GIF February 2020 workshop was a good opportunity to let the industry know that GIF is reviewing its activities and would like to create a perennial collaboration framework with the nuclear industry, and particularly with ASMR vendors.

The private sector's expectations of GIF, reflected in the 2020 SIAP Charge, cover four main areas:

- public and governmental recognition and acceptance;
- research and data structuring;
- technology acceptance and multinational pre-licensing;
- the global Gen-IV research infrastructure.

Public and governmental recognition and acceptance

If ASMR technology gains public and governmental recognition and acceptance, new policies could emerge to facilitate ASMR industrial development. GIF therefore needs to create a new narrative to explain to policymakers the role that ASMRs could play in the energy transition, and particularly in scenarios with high shares of variable renewables. To increase its policy impact, GIF could actively engage with organizations with high visibility at the policy level – for example the IEA; the Nuclear Innovation: Clean Energy Future (NICE Future) initiative; the IAEA; the Nuclear Energy Agency (NEA) and the World Nuclear Association (WNA) – and contribute to their publications. A recent example is the GIF contribution to a recent report released by the NICE Future initiative on the flexibility of nuclear systems[5]. Overall knowledge dissemination efforts should increase at the same time so as to reach out to universities and industry, attracting the necessary talent and building skills. GIF could also be involved in the knowledge management regional workshops that are organized periodically by the IAEA.

Research and data structuring

Examples already exist in relation to the consolidating and structuring of data to support the qualification of Gen-IV systems. In the United States, a topical report on tri-structural isotropic particle (TRISO) fuel has been elaborated for the US NRC following this approach. This project involved national laboratories, vendors and regulators with the Electric Power Research Institute (EPRI) working as an integrator (see Figure SIAP-2). Most of the data used for the elaboration of this topical report was already in the public domain, but additional efforts were needed in terms of formatting and making it more accessible to regulators and vendors. Similar initiatives are already underway within GIF. The *Gen-IV Materials Handbook* developed under the VHTR materials project arrangement gathers and structures research data that is then used by the American Society of Mechanical Engineers (ASME) to update codes and standards. GIF should communicate more on these examples and propose new initiatives on data structuring and qualification to the member countries. Joint projects could be set up around non-technology-specific materials, components, processes and fuels, such as graphite, liquid-fuel properties, mixed oxide (MOX) fuel or heat exchangers at high temperatures.

Technology acceptance and multinational pre-licensing

The ASMR vendor community could benefit from very early interactions with regulators in order to have an appreciation of their designs and the associated time to market. The GIF Risk and Safety Working Group (RSWG), in collaboration with the NEA Working Group on Safety of Advanced Reactors (WGSAR), could offer this type of service, based on documentation provided by interested vendors on how to comply with design guidelines and the criteria of a given system. These early safety evaluations could then be used to develop harmonized and internationally recognized design criteria and guidelines for Gen-IV systems in collaboration with the IAEA. Some vendors may nevertheless be reluctant to participate in these type of initiatives.

Opportunities in the pre-licensing arena are also important, and GIF should identify pre-licensing safety issues (e.g. licensing of verification codes, experimental data for validation, bounding severe accident cases for ASMRs) and explore the potential for developing a common pre-licensing base for ASMRs. A technology-neutral approach, which properly addresses the necessary adaptations from LWR-based regulations, could be used. Existing initiatives on licensing harmonization, such as the WNA Cooperation in Reactor Design Evaluation and Licensing Working Group (CORDEL) and the NEA Multinational Design Evaluation Programme (MDEP), may provide valuable lessons.

Global Gen-IV research infrastructure

While most of the ongoing research within GIF is focused on developing a mechanistic understanding of the Gen-IV systems, new research opportunities are emerging in relation to design and manufacturing processes and methodologies. Some areas of interest for GIF involve system engineering and risk-informed approaches, as well as the application of digital technologies and advanced manufacturing processes. Moreover, the development of technology readiness levels tailored to advanced reactors remains key to adequately assess which technologies could be adopted by Gen-IV systems.

Based on the success of the February GIF 2020 workshop, GIF should continue to interact periodically with the private sector, organizing dedicated meetings/workshops in order to identify critical research areas and priorities, and match emerging experimental and qualification needs with existing or future R&D infrastructure capabilities.

SIAP intentions for 2021

Since its inception, GIF has been focusing on and supporting the necessary R&D elements to support Gen-IV systems. The recent commercial thrust towards SMR development has awakened more interest in nuclear power in general. The Senior Industry Advisory Panel will continue to advise and support GIF so as to harness this new momentum.

It will stand ready to offer advice on how to interact with the private sector and implement some of the recommendations of the 2020 SIAP charge. SIAP will also continue to provide industrial insight for GIF activities and strengthen its collaboration with the GIF Economic Modelling Working Group (EMWG) to assess cost reduction and safety improvement opportunities arising from new design methodologies for Gen-IV concepts.

Eric Loewen
Chair of the SIAP, with contributions from SIAP members

5. www.nice-future.org/sites/default/files/document/Generation%20IV%20-%20Web%20Page.pdf.