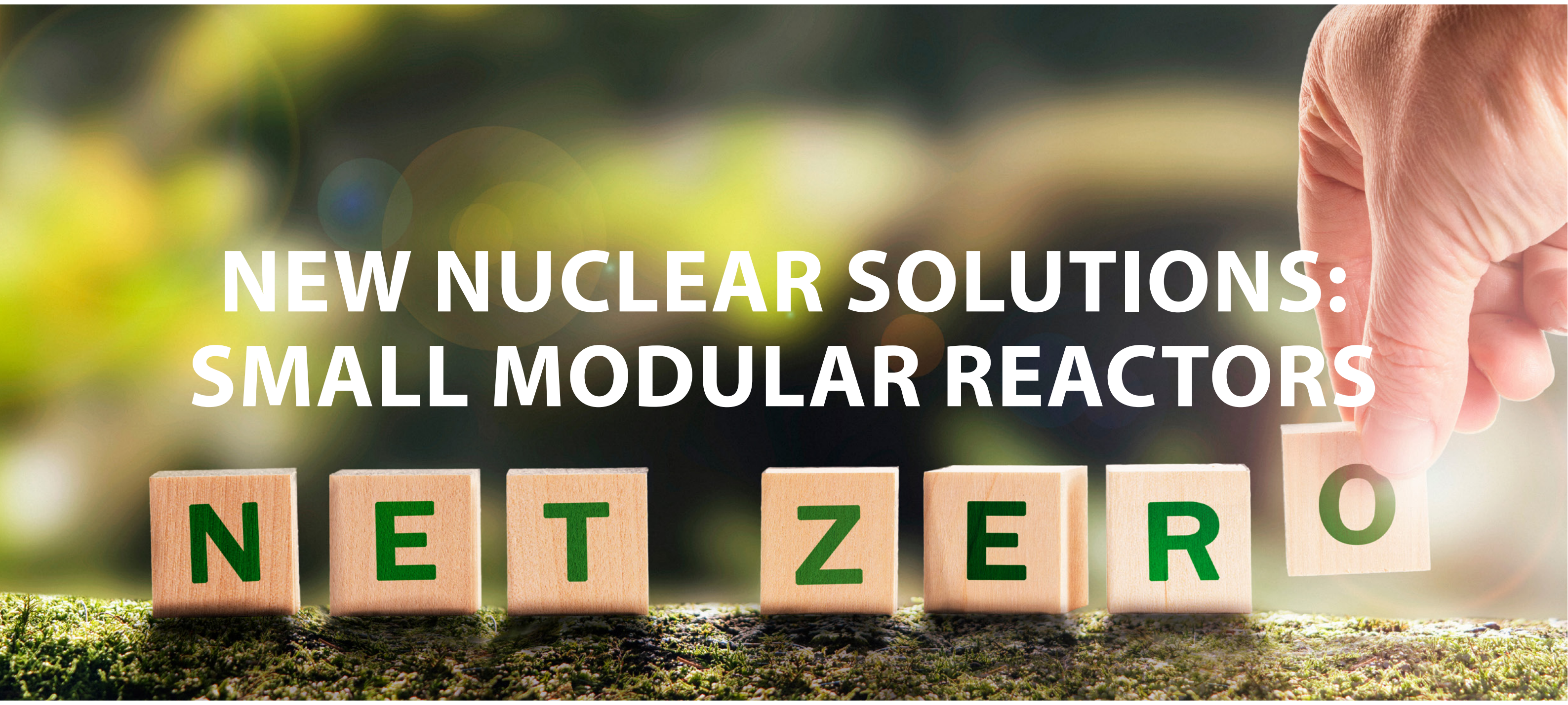
nucleareurope
Supporting a sustainable future



NEW NUCLEAR SOLUTIONS: SMALL MODULAR REACTORS

NUCLEAR

IS A LOW-CARBON ENERGY SOURCE

ENSURES SECURITY OF SUPPLY

IS ENVIRONMENTALLY, ECONOMICALLY AND SOCIALLY SUSTAINABLE

EU NUCLEAR INDUSTRY IN NUMBERS

ACCOUNTS FOR **25%** OF ELECTRICITY

ALMOST **50%** OF LOW-CARBON ELECTRICITY

SUPPORTS AROUND **1Mn** JOBS

TURNOVER OF **100bn** PER YEAR

October 2022

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Executive Summary

The world is currently facing an energy and climate emergency. Extending the lifetime of the existing nuclear fleet will help achieve the EU 2030 targets. New nuclear projects – both large reactors and Small Modular Reactors (SMRs) – will contribute to the 2050 net-zero goals. The entire energy sector is facing structural changes under the current geopolitical context. Uncertainties with regards to oil and gas supplies to Europe might lead the European Union (EU) institutions and Member States to reconsider the share of nuclear power in the European energy mix, both under the medium (2030) and longer term (2050) scenarios. These uncertainties, combined with the impact of the EU Emissions Trading System and the variable nature of renewable energy sources, have triggered a massive increase in energy prices. Furthermore, some countries have resorted to re-opening dirty fossil-powered power plants.

SMRs can provide a solution to some of these problems. By design, SMRs integrate higher modularisation, standardisation and factory-based construction in order to maximise economies of series production.

SMRs have the potential to offer a slew of benefits to the Member States and in the communities where they are deployed, including helping to tackle climate change, ensuring security of energy supply, energy market and grid stability, and the potential for industrial development and job creation.

Over the coming years, the focus will be on light water SMRs given that they are a proven technology used in hundreds of reactors worldwide. Nevertheless, several other promising technologies will become available in the near future. These include high temperature gas-cooled reactors, fast spectrum liquid metal reactors, molten salt reactors or fast neutron reactors, among others.

Numerous countries in Europe have shown interest in SMRs, with some of them having already signed agreements with suppliers in view of their deployment. The French and Belgian governments, for example, are also investing into SMR technologies.

Whilst SMRs look very promising on a number of aspects, their deployment is not without challenges, requiring carefully planned and well implemented solutions. Promoting the creation and development of a harmonised 'domestic' SMR European program (including foreign technology) is key. The EU should build its own capacity in order to become a leading actor in the future SMR market and create industrial and economic value at a European scale. Facilitating access to financial resources throughout the design development phase will be key to ensuring a timely development of SMRs. Technical challenges, relating to both design and widespread deployment, including supply-chain development, licensing procedures, investment frameworks, and nuclear fuel cycle adaptation must also be addressed.

Introduction

nucleareurope supports the development and deployment of Small Modular Reactor (SMR) technologies, encouraging projects developed by the European nuclear industry which can complement the new and existing fleet of nuclear reactors. This will contribute to Europe's decarbonization goals while providing opportunities for new applications such as industrial heat, district heating, and hydrogen production.

This paper provides information on the potential of SMR technologies for interested stakeholders and policymakers.

Context

Climate change

The world is currently facing an energy and climate emergency. Extending the lifetime of the existing nuclear fleet will help achieve the EU 2030 target[1]. New nuclear projects – both large reactors and SMRs – will contribute to the 2050 net-zero goals. According to Ember's European Electricity Review, the long-term, structural decline of nuclear power in the EU has slowed power sector decarbonisation. Some of the growth in renewable output is needed to replace lost nuclear output, slowing down the replacement of fossil fuels[2]. This leads to a situation whereby emissions are not falling fast enough because fossil fuels are not being replaced rapidly enough with clean power.

While the European Commission foresees a limited share of nuclear in 2050 (between 10 and 15% of the EU electricity mix, source: EC long term strategy 2050)[3], according to the updated version of the Compass Lexecon[4] report, keeping around 20% of nuclear in the mix will make it easier to achieve the climate targets and bring other benefits such as lower customer costs and security of supply. The report puts forward several scenarios (Fig.1) based on the share of nuclear in the 2050 decarbonised energy mix. When comparing the high and low scenarios, it demonstrates the various benefits of a high share of nuclear.

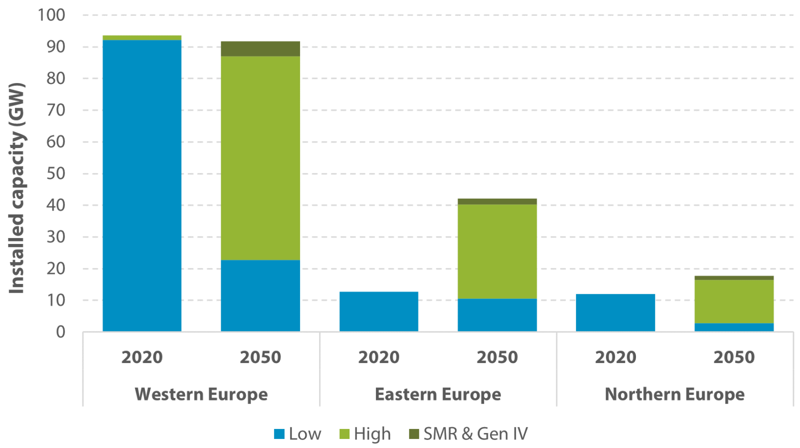

Fig.1 - nucleareurope's nuclear installed capacity outlooks (GW) - EU-27+UK

Under the high nuclear scenario, installed nuclear power capacity will be around 152 GW (EU27+UK) in 2050, 27GW of which would be produced by SMR and Gen IV reactors. The SMR figure is based on information received from nucleareurope members in January 2021. Taking into account recent developments in terms of electricity prices and security of energy supply concerns, these figures can be considered conservative and could be much higher as Europe tries to steer away from its dependence on foreign fossil fuels.

Give the current geopolitical context, the entire energy sector is facing structural changes including the need to stop burning fossil fuels and to find alternative fuel sources as some become unreliable. Therefore, these recent

[1] European Commission – 2030 Climate Target Plan
[2] Ember European Electricity Review
[3] Impact Assessment Report of the revised Renewable Energy Directive (SWD/2021/621 final)
[4] Compass Lexecon - Pathways to 2050: Role of nuclear in a low-carbon Europe - 2021 updated results

estimates and scenarios must be taken with a pinch of salt. The first half of 2022 saw an unpredictable sequence of events which turned current energy policies upside down due to supply chain issues and an armed conflict. Uncertainties with regards to oil and gas supplies to Europe may push the EU institutions and Member States to reconsider the share of nuclear power in the European energy mix in both the medium (2030) and longer term (2050).

Security of Energy Supply

The EU is highly dependent on fossil fuel imports (see fig. 2), making the transition towards 2030-2035 very challenging from the long-term security of supply point of view.

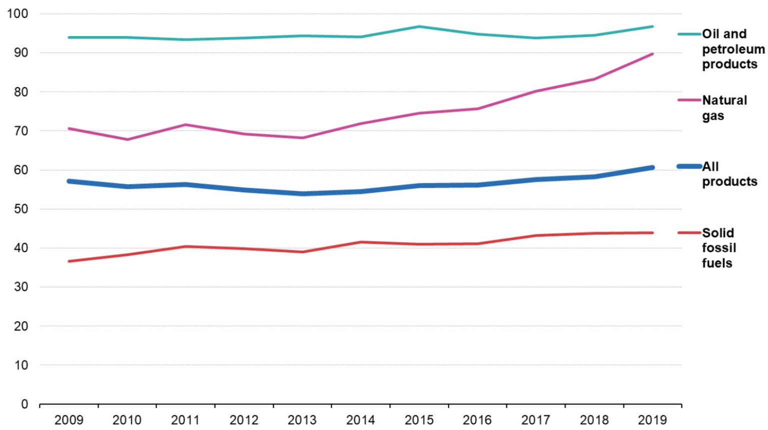

Fig.2 - Energy dependency rate, EU27, 2009-2019[5]

In addition to the import dependence issue, the closure of fossil fuel plants (mainly coal) will also lead to a lack of firm power production capacity.

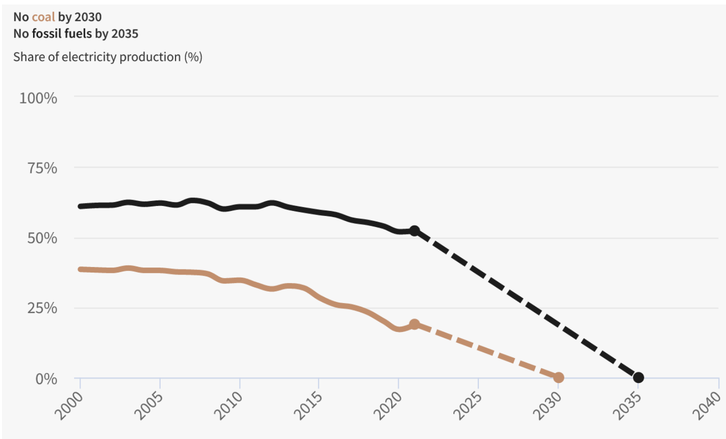

Fig.3 - Share of fossil fueled electricity production (estimates), G7, 2000-2035[6]

Energy prices

The recent energy price escalation is mainly due to the following:

- On the gas and coal side, the enormous quantities of these fuels needed to produce electricity. Fossil power plants need to receive new fuel shipments daily, as opposed to nuclear power plants which are refuelled every 12 to 24 months on average. This makes power production from fossil fuels highly dependent on the market price of coal and natural gas, which in turn are dependent on external events such as pandemics and armed conflicts like the one currently on the EU's doorstep.

[5] Eurostat
[6] Ember

- As far as CO_2 prices are concerned, fluctuations in the EU ETS (Emissions Trading Scheme) market have a considerable impact on energy costs and this impact will only rise as the deadline for "Net Zero" approaches. Since the beginning of 2021 up until May 2022, the CO_2 price rose more than 150%, from €34 to €87 per tonne, reaching at one point a peak of €97.
- Given the intermittency of variable renewable sources (RES), their availability can only be forecast on the short term (contrary to nuclear or fossil-based power production which can be controlled). Counting on non-dispatchable sources usually means having to rely on natural gas to fill in the gaps in order to meet higher demand.

Introduction to SMR technologies

Definition

SMRs, which can produce a large amount of low-carbon electricity, are:

- **Small** – physically a fraction of the size of a conventional nuclear power reactor.
- **Modular** – making it possible for systems and components to be factory-assembled and transported as a unit to a specific location for installation.
- **Reactors** – harnessing nuclear fission to generate heat and produce energy.

SMRs are defined today as nuclear reactors with a power output of between 10 megawatt electric (MWe) and 300 MWe. However, some technologies fall outside of this definition. For example, the Rolls Royce SMR which features 470 MWe in installed capacity per module.

By design, SMRs integrate higher modularisation, standardisation and factory-based construction in order to maximise economies of scale (or the "scale effect"). The different modules can then be transported and deployed onsite, leading to better predictability and construction time savings. This also enables the creation of new business models for energy production and a larger value chain. Although very versatile, it can be assumed that the first SMR deployed will probably aim to replace current fossil-based electricity generation capacity and continue providing the grid stability required in a system characterised by a high share of renewables.

Worldwide, there are currently over 70 SMR designs under development based on different technologies[7].

New features of SMRs

What do SMR technologies bring to the table?

- Financing: thanks to their modularization, SMRs are expected to benefit from the scale effect and shorter deployment times. Moreover, given that each unit requires a lower level of investment and that initial units will already be able to generate revenues whilst follow-up ones are under construction (even if in a different location), the investment risks associated to SMRs are expected to be significantly lower (for example, lower interest rates on CAPEX loans). SMRs are also expected to open the door to a much wider range of customers (industries and new utilities) and equity shareholders (investors) given the relatively low initial capital investment.
- Design: SMRs generally allow for easier application of passive safety systems and longer coping times, and consequently their design is simpler than that of large reactors.

[7] IAEA (2020), Advances in Small Modular Reactor Technology Developments

- Load following + integration with RES: SMRs, like large scale nuclear plants, can easily follow demand and compensate for fluctuations in the availability of variable renewables. Their small size (and thus low inertia) facilitates this as it provides flexibility, making it easier to shut them down and start them back up again.
- Electricity + heat: several SMRs are being designed to produce both electricity and heat for industrial applications or district heating.

Public Opinion

Several factors may facilitate public acceptance of these reactors:

- Their integrated modular design allows for factory assembly, shortening construction and deployment times.
- Lower power output means smaller plants and thus a smaller footprint. This could mean that communities become more open to having a nuclear installation nearby.
- Their size also enables the use of additional passive safety systems, allowing them to cool down in case of an accident without the need of external power supply which could be welcomed by the public. This also allows for reduced emergency planning zones as the level of releases would be much lower.
- The fact that SMRs are a suitable replacement for polluting coal plants (around the same size, using brown field sites, enabling workforce reconversion, etc.) brings advantages for local communities.

Benefits to society

Climate targets

SMRs produce low-carbon electricity and will contribute to a faster decarbonisation of the electricity grid. Thanks to the "co-generation mode" which is being implemented in several SMR designs, they will be able to produce not just low-carbon electricity but also heat. This can help decarbonise various industry sectors such as steel manufacturing and hydrogen production. Hydrogen generated through high temperature electrolysis or thermochemical splitting are two of the most promising solutions and they can both take advantage of the co-generation capabilities of SMRs.

Security of supply

Nuclear energy, including SMRs, presents several advantages when it comes to energy security:

- It has a high energy density compared to other stable energy sources. 1 uranium fuel pellet, weighing just 7g, produces as much energy as 1 tonne of coal, 500 m^3 of natural gas and 477 litres of oil. This means that much greater amounts of energy can be stored and transport costs can be reduced.
- High capacity factor. Current large nuclear power plants have a capacity factor of around 93%, meaning that they are able to produce electricity at full power 93% of the time (stopping on average every 12 to 24 months to refuel). Some SMR technologies under development foresee even higher capacity factors. By comparison, wind power has a capacity factor of around 35% and solar PV around 25% in Southern Europe and 12% in Northern Europe. In addition, because nuclear power is not weather dependent it can produce electricity regardless of whether it is windy or sunny. Moreover, it is resilient in the event of extreme weather conditions as it can withstand very high and low temperatures as well as climatological events such as storms.
- Uranium can be found almost everywhere. As of 1 January 2019, the worldwide annual consumption of uranium was around 59 thousand tonnes. There are currently 59 countries with uranium reserves, and more than 17 million tonnes of recoverable uranium reserves have been identified worldwide. Based on constant demand, these reserves are expected to last for almost 300 years. Virtually every country in the world has uranium deposits, although in some instances extraction is not economically viable.
- Some SMRs would use fuel more efficiently and thus require less of it. In addition, advanced SMRs may require less frequent refuelling, every 3 to 7 years, compared to between 1 and 2 years for Pressurised Water Reactors (PWR) and Boiling Water Reactors (BWR) plants. Some SMRs are even designed to operate for up to 30 years without refuelling.

Energy market stability

With a flat, dispatchable output and essentially fixed costs, SMRs can provide price stability to customers (for example through PPA), avoiding high power market volatility. For nuclear energy the variable costs represent a small share of production costs, and the marginal impact of fluctuations in uranium prices provides stability in terms of final power prices.

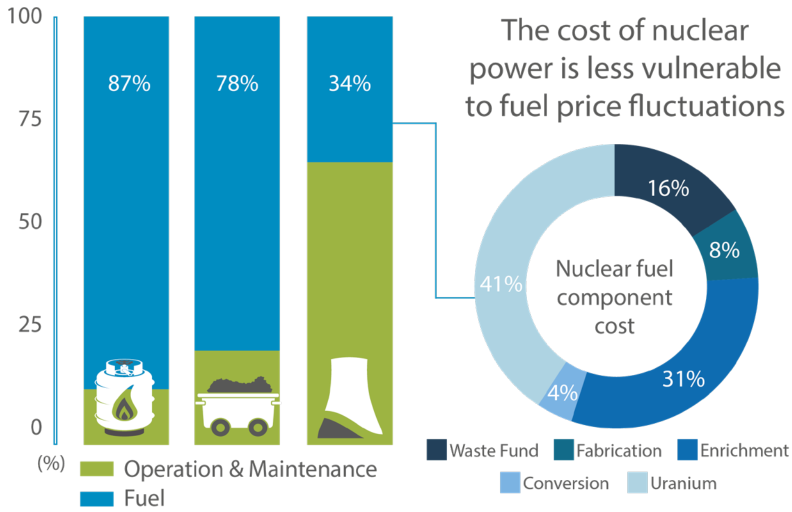

Fig.4 - Breakdown of operating costs for nuclear, coal and gas generation[7]

SMRs can also provide grid stability, as they are able to respond to the Transmission System Operator's needs by providing flexibility, back up capacity and ancillary services. SMRs provide a dispatchable source of energy which complements the massive deployment of variable renewables and responds to the specific needs of the new grid configuration.

Industrialisation

SMRs have the potential to create a very impactful industrial and economic value at a European scale. Deployment of these technologies will go hand in hand with maintaining and further developing the industrial supply chain. Existing available qualified suppliers will be able to provide nuclear specific components. In addition, it may be possible to procure components from other industries that can be adapted to SMRs thanks to their simplified design.

In this respect, the nucleareurope "Quality assurance guideline for procuring high-quality industrial grade items aimed at supporting safety functions in nuclear facilities" report presents a methodology that licensees can use to ease acceptance of non-nuclear equipment. Specialised industrial facilities will be constructed for the manufacturing of SMR elements and the assembly of fully equipped modules before being shipped to the deployment site. Even in non-nuclear countries a considerable percentage of SMR investments could be provided by domestic manufacturers and civil construction companies.

European integration of innovation and research

The development of SMRs will strengthen the links between Research Technological Organisations, universities and R&D centres all over Europe. Research into not only the reactors themselves but also their coupling with hydrogen generation and heat production for industrial purposes will reinforce current European synergies. Beyond research, the opportunities for cooperation between technology developers, suppliers, manufacturers, operators and regulators are immense.

Jobs potential

Several tens of thousands of highly skilled jobs could be created as the SMR market expands, from R&D, fabrication and deployment to operation and maintenance. The reconversion of the existing operating personnel, mainly from coal power plants, might be also a possibility. Likewise, education and training opportunities for highly qualified personnel, like PhD positions or high-level technicians, will be created.

[7] World Nuclear Association, Nuclear Energy Institute (2017) Nuclear Power Economics and Project Structuring

Technology developments

Several different SMR technologies are under development. The list is not exhaustive. The technologies presented here are either those that can be considered as the most mature or which present interesting features that are worth mentioning.

Pressurised Water Reactors

PWRs are cooled by ordinary water and present a low technological risk, as many reactors currently operating worldwide are based on this technology. Some Pressurised Water SMRs are essentially a smaller version of current large reactors and use features that have been in operation for many years in nuclear vessels and submarines. As such, they are a proven technology. Notable examples include VOYGR (NuScale Power, US, which is expected to generate power in 2029), NUWARD™ (EDF, France - early 2030s) and Rolls Royce SMR (UK - early 2030s).

Boiling Water Reactors

Like PWRs, BWRs are also cooled by light water and present a low technological risk, since a large fraction of today's NPP fleet is of this type. The most notable example of this technology is the GE Hitachi BWRX-300 (US) which is expected to be generating power by 2028 in Canada. The US and some countries in Europe have also shown interest in this technology.

Advanced modular reactors are a technology which has yet to be tested on an industrial scale unlike light-water reactors (PWR and BWR). They present their own advantages and challenges. This chapter covers some of the most mature technologies and it is non-exhaustive.

High Temperature Gas-Cooled Reactors

By using graphite as a moderator and gas, such as helium or carbon dioxide, as a coolant, these reactors can reach temperatures of up to 1000°C making them a good choice in terms of generating heat for industrial purposes. The fuel used for these reactors can be in the form of TRISO (tristructural-isotropic) particles which are less than a millimetre in diameter. Each particle has a kernel of uranium enriched up to 20% which is surrounded by layers of carbon and silicon carbide, making them resistant to temperatures of up to 1600°C. The only commercially-scalable HTR project currently in operation is the Chinese HTR-PM, although there are others under development.

Fast Spectrum - Molten Salt Reactors (FS-MSR)

FS-MSRs are a very promising concept that would be capable of burning highly radioactive waste (e.g. actinides and plutonium) coming from spent nuclear fuel. This type of reactor applies a circular economy approach to the nuclear fuel cycle as it aims to limit the use of natural resources (uranium), maximise energy production from all fissile materials contained in the fuel, reduce the resulting waste footprint and produce valuable isotopes for other applications. Although already used in some research reactors, this kind of technology is still in its early stages of development for industrial purposes.

Pressurized water SMRs will be able to take advantage of the well-established fuel supply chain in Europe but this is not the case for advanced technologies like high-temperature gas-cooled reactors (HTGR) and some lead-cooled fast reactors (LFR). These designs use HALEU (High Assay low Enriched Uranium) which is enriched by up to 20% while current LWRs use 3 to 5% uranium enrichment. The availability of HALEU is essential for those advanced reactors. However, this fuel is not currently produced in any Western country so security of supply may be at risk as the US fabricated fuel stockpile is depleted, and the reliability of Russian imports can no longer be considered a given.

For such non-LWR SMR technologies, spent fuel reprocessing and waste management solutions must be developed to enable new fuel types, and thus boost both the circular economy of nuclear and improve social acceptance. The same applies to logistics and transport solutions.

For Fast Spectrum - Molten Salt Reactors (FS-MSR) which use chloride salt, recycling of the salt could be explored. Some value to MSR developers can also be brought thanks, most notably, to specific equipment design and manufacturing, implementation of remote maintenance concepts, gas and waste treatment devices and installation.

At a later stage, securing the availability of HALEU will be critical to the success of advanced SMR deployment in Europe. This will require the intervention of political actors both to secure uranium supplies and to upgrade infrastructure, logistics and regulations. The EU should anticipate and develop domestic production, building on its unique expertise and know-how as recommended by the Euratom Supply Agency Working Group on HALEU (2022).

Projects and expectations in Europe

There is clearly a lot of interest in SMR deployment across Europe and a number of agreements and memoranda of understanding have been signed over the past few months. Many initiatives are quite recent and show a rapidly growing interest in this technology. This is due to the geostrategic situation and the realization that the use of RES alone will not solve the decarbonisation challenges ahead of us.

Below is a non-exhaustive list of countries interested in SMRs:

Belgium:

- Belgium's SCK-CEN nuclear research centre has received a budget of €100 million from the federal government to conduct research into SMRs (May 2022).

Bulgaria:

- US-based Fluor Corporation has signed a memorandum of understanding with Bulgarian Energy Holding relating to the potential construction of SMRs in Bulgaria (November 2021).

Czech Republic:

- According to a memorandum signed by the utility ČEZ, the South Bohemian government, and the UJV Rez research organisation, SMRs are expected to be developed at the Temelín nuclear power plant (under the name of South Bohemia Nuclear Park). ČEZ has already signed memorandums of cooperation in the field of SMRs with NuScale, GE-Hitachi, Rolls-Royce SMR, EDF, Korea Hydro and Nuclear Power, and Holtec.

Denmark:

- Samsung Heavy Industries (a South Korean multinational shipbuilding company) and Seaborg (a Denmark-based reactor technology company) have signed a partnership agreement to develop floating nuclear power plants using Seaborg's compact molten salt reactor (CMSR, April 2022).

Estonia:

- Fermi Energia has said it will accept tenders from three SMR developers: GE Hitachi, NuScale and Rolls -Royce SMR. The company said bids with comprehensive technical documentation needed to estimate the construction cost are expected by December 2022, and the technology selection will take place in February 2023. (September 2022)
- Estonian energy company Fermi Energia has been developing, since 2019, an SMR deployment project in Estonia. The government has created a formal Nuclear energy working group which is due to deliver a report by the end of 2023 with the goal of developing Estonia's commitment to a nuclear energy program. Fermi Energia has close to 1300 Estonian shareholders, and some other minority shareholders including Vattenfall AB (Sweden) and Tractebel Engineering (Belgium). (April 2022)
- GE Hitachi Nuclear Energy (GEH) has entered into a teaming agreement with Estonia's Fermi Energia to support the potential deployment of its BWRX-300 small modular reactor in the country.

France:

- EDF is working on the development of NUWARD™, a pressurized water reactor, with the strong contribution of CEA, Naval Group, TechnicAtome, Tractebel and Framatome. The first unit is expected to be online by the early 2030s. Emmanuel Macron's government has announced an investment in small and advanced nuclear technologies of 1B€ until 2030 including 500m€ for the development of NUWARD™ reactors in France.

Poland:

- NuScale Power has signed a memorandum of understanding to explore the deployment of NuScale's SMR at coal-fired power plant sites in Poland (September 2021).

- Synthos Green Energy has signed agreements with Poland's state-controlled fuels and energy company PKN Orlen and chemicals giant Ciech SA to foster cooperation on the development and commercialisation of SMRs in Poland for industrial use (December 2021).
- Synthos Green Energy has signed a cooperation agreement with Ultra Safe Nuclear Corporation, which is developing the high-temperature gas-cooled Micro Modular Reactor (MMR). USNC and Synthos jointly applied to the Polish Ministry of Development for financing from the IPCEI mechamism (Important Projects of Common Eurean Interest) for projects within the scope of the value chain of hydrogen technologies and systems (November 2020).

Romania:

- NuScale Power and Romanian national nuclear company Nuclearelectrica have signed a teaming agreement to advance the deployment of NuScale's SMR in Romania. US's President Biden has also pledged $14 million for the Front-End Engineering and Design studies (November 2021).

Sweden:

- The Swedish Energy Agency has awarded just over 99 million Swedish krona ($10.6m, €9.4m) in funding to Swedish Modular Reactors AB (a joint venture between utility Uniper Sweden and Stockholm- based reactor developer LeadCold) to support the construction of a demonstration lead-cooled SMR at OKG's Oskarshamn nuclear power plant (February 2022).
- The cleantech start-up company Kärnfull Next has signed an agreement to work with GE Hitachi Nuclear Energy (GEH) on the deployment of its BWRX-300 SMR (March 2022)
- Vattenfall is working actively to find out how different fossil-free energy sources can satisfy the increased demand for electricity. As part of this work, Vattenfall is now initiating a feasibility study looking at the conditions for building at least two small modular reactors (SMRs) adjacent to the Ringhals nuclear power plant (June 2022).

Ukraine:

- NuScale Power and Ukraine's state nuclear generating company Energoatom have signed a memorandum of understanding to explore the deployment of NuScale SMRs in Ukraine (September 2021).

United Kingdom:

- Rolls-Royce SMR is hoping to secure a number of sites for the rollout of a fleet of SMRs including Dungeness in Kent, Wylfa in Anglesey (north Wales), Moorside in West Cumbria and Trawsfynydd in Gwynedd (northwest Wales).

Roadmap and Challenges

Development and commercialisation of SMRs in the coming years will be conditioned by different challenges including their technical readiness, establishment of the supply chain, lead-times, harmonised regulations and licensing, as well as financial costs and requirements. This section outlines the main challenges that need to be addressed.

Technical aspects and market competitiveness

For non-LWR SMR technologies the first major challenge is a technological one: has the R&D addressed in a satisfactory manner all technology gaps in order to enable the construction of a reliable prototype or an important proof of concept test? Failure in the innovation cycle can lead to project failure since it might hinder the ability to attract further capital investments.

In addition, SMR designs should be able to respond to variations in the grid caused by weather-dependent variable renewables and operate with a high degree of manoeuvrability. Technical integration of a power generation plant with energy storage facilities (molten salt buffer tank, etc) will be an opportunity to facilitate flexible grid management.

One of the unique characteristics of SMRs is that they will be based on mass in-factory production versus in-situ building, creating a series effect for the nuclear power value proposition. Ensuring that new projects are carefully planned and that all elements of the project are fully integrated is essential to reduce the risk of project delays. Currently, modular construction can be one of the most important factors to achieve a significant reduction in construction times.

Development of a reliable supply chain

A robust, capable and reliable supply chain is critical for the success of mass-produced SMRs. Manufacturing processes and costs will need to be optimized (including the adaptation to nuclear standards of workshops for mass production of modules) as well as techniques to shorten construction times for reactor deployment. This optimisation and creation of a supply chain takes time and planning, even more in countries with limited experience in producing equipment and installations that comply with nuclear quality and safety requirements.

In addition, the opportunity of including standardised equipment and high quality industrial commercial grade components within SMR designs can greatly contribute to supply chain optimisation and associated processes by reducing regulatory controls and approval times.

Licensing delay risk

Enabling the construction of standardised designs is key to the competitive advantage of mass production. This implies that the same generic design be accepted by all the regulators where such an SMR is expected to be built. Current national regulations and practices in Europe are diverse and can result in country-specific safety and design requirements, thus leading to both important delays and the impossibility for vendors to implement an identical SMR design in different countries.

Given past experience with several regulators in terms of long approval times for conventional nuclear reactors (which can result in project delays and cost increases) cooperation between regulators and developers is key to ensure that the path to design, construction and operation is as efficient as possible, even more so considering the new and innovative designs and manufacturing processes which some SMRs will introduce.

An initiative related to deployment of SMRs in Europe is currently under preparation, with the goal of establishing a European SMR Partnership. During the pre-Partnership activity, work is underway with regulatory bodies to create conditions that will ease the licensing process of these reactors.

High investment requirements for design development

Nuclear reactor design developments require a lot of resources, both human and financial, across several years. Some private companies might not be able to afford this process, so in order for the first SMRs to be built and fully demonstrated, some form of government support and/or incentives should be put in place to reduce the financial risk of investing in the facilities and people that are needed to develop, manufacture, test and qualify first-of-a-kind (FOAK) components, systems and structures.

Once prototypes are demonstrated, adequate business plans will be critical for the deployment of successive reactors. For these purposes, calculating financing costs during construction and defining suitable indicators to assess the economic performance of an SMR design will be crucial to attract investors. Calculation of these financial parameters should take into account that SMRs might operate in a load-following mode and, consequently, impact the levelized cost of electricity. Energy storage facilities linked to these designs would improve their financial outlook.

Long-term energy market uncertainty

The operation of SMRs will have to be integrated within a fluctuating grid system due to the large deployment of renewable energy which can result in hundreds of megawatts of electricity being added or subtracted within minutes. SMRs should therefore contribute towards grid stability.

Nuclear fuel cycle challenges

As far as the fuel cycle for SMRs is concerned, decisions on front-end as well as back-end management should be taken early on in the development phase. The fuel cycle of future SMRs will need to meet three priorities: safety, non-proliferation and competitiveness.

Policy recommendations

Regulators

A high level of design standardization, an optimized licensing process and the harmonisation of regulations and requirements across Europe is key to allow the economy of scale that will make SMRs very attractive as an energy investment. The aim should be to reduce as much as possible country and site-specific design modifications from licensing to deployment by:

- Creating a joint design assessment and acceptance process for standardised designs.
- Accepting the justifications of equivalence between codes and standards.
- Supporting the development of new European-wide codes and standards.

The recent agreement between the French, Czech and Finnish regulatory authorities to perform a joint early review of NUWARD™ is a practical example of a way towards joint regulatory work.

Policymakers

Countries developing SMRs currently consider them to be of key strategic value, from both a commercial and geopolitical stance. Moreover, existing SMR development programs are being vastly funded by their respective governments either directly or indirectly via the financing of state-owned companies (US, UK, Russia, China, South Korea). That is why promoting the creation and development of a European "domestic" SMR program is key. The EU should build upon its own capacities to become a leading actor in the future SMR market and create industrial and economic value at a European scale. Facilitating access to financial resources throughout the design development phase will be key to ensuring a timely development of the product.

Taking advantage of EU integration:

- Setting up a European SMR Initiative that aims to prepare a roadmap for the deployment of the first SMRs in Europe. This would also contribute to the establishment of an integrated supply chain in Europe which would benefit the economies of several Member States and the economy of the EU as a whole. It would also support initiatives for new R&D collaborative projects (i.e., developing hybrid SMR systems for low-carbon processes such as district, industrial heating, or hydrogen) and future education & training programs needed for SMR deployment. SMRs will become a vehicle for strengthening ties between Research Technological Organizations, universities and industrial R&D centres.
- Analysing the potential recognition of European SMR deployment as an Important Project of Common European Interest (IPCEI), for which the sector seems well suited.
- Integrating an R&D public-private partnership on SMRs within the Euratom programme.
- Encouraging interested Member States to embrace nuclear energy-inclusive and supportive legislation which would encourage the use of nuclear energy to improve their emission reduction obligations and meet climate change objectives.

The European Commission should encourage political support for the development of these technologies, finance integrated projects and prototypes and support the required investment in industrial capacity. SMRs will contribute to the fight against climate change, support the European industry and economy, boost European integration by undertaking joint projects and, above all, reduce Europe's energy dependence on third countries.

Lack of interest and disinvestment in the EU nuclear domain would mean an impoverishment of European industrial and research capacity, resulting in an increased reliance on technological and strategic dependence on foreign countries.

Moreover, a domestic SMR could be exported to both newcomer countries as well as those with existing nuclear capacity. Russia, Asia and North America already have a significant head start when it comes to the export of nuclear technology, mainly due to strong support from their respective governments.

About us

nucleareurope is the Brussels-based trade association for the nuclear energy industry in Europe. The membership of nucleareurope is made up of 15 national nuclear associations and through these associations, nucleareurope represents nearly 3,000 European companies working in the industry and supporting around 1.1 million jobs.

nuclear europe

Avenue des Arts 56
1000 Brussels
tel +32 2 502 45 95
www.nucleareurope.eu