

# FRAMEWORK CONDITIONS FOR SMALL MODULAR REACTORS IN EURATOM MEMBER STATES

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## EXECUTIVE SUMMARY

Small Modular Reactors (SMRs) are nuclear reactors with electric outputs up to 300 MWe, promoted as a flexible, potentially cost-effective complement to traditional large reactors. This study provides a critical analysis of framework conditions for SMR deployment in Euratom Member States, structured around six key topics.

The Umweltbundesamt GmbH conducted this study on behalf of the Federal Ministry of Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management. The goal was to support the current discussions regarding the deployment of SMRs within Europe with science-based facts.

The study begins with estimated market potential in Europe, covering the regulatory landscape and current development status. The analysis then examines required industrial capacity and supply chain constraints, with particular focus on the nuclear fuel cycle. Next, it assesses interest levels from energy utilities, energy-intensive industries, and supply chain companies. The study evaluates the necessity of exports for SMR profitability, alongside global market competition. It compares SMR market competitiveness against other energy technologies. Finally, it explores trends and causes of cost escalation in SMR development.

### Market Potential

Studies show a large uncertainty in projected SMR capacity in the EU, which depends strongly on national policies and industrial priorities. Most projections indicate that deployment would remain limited, potentially corresponding to only several tens of units by mid-century. While the launch of the European SMR Industrial Alliance in 2024 reflects interest by some Member States and parts of the nuclear industry and aims to enable first European SMRs in the early 2030s, these initiatives primarily indicate a willingness to build an ecosystem rather than concrete deployment.

It remains highly uncertain whether SMRs will play a significant role in the European energy mix. Member States with large nuclear fleets, such as France, are focusing on the construction of conventional large nuclear power plants, while others only consider SMRs as a secondary option. Poland, as a nuclear newcomer, is planning three large reactors, with SMRs potentially deployed at a later stage. Czechia has already signed contracts for new large units, while Slovakia and Hungary consider SMRs but are prioritizing large reactor projects.

Nuclear regulation remains a sovereign responsibility of each Member State, leading to significant differences in rulesets, codes, standards, and administrative rules. While EU-level legislative frameworks exist, detailed regulations and licensing processes are country-specific. These differences are particularly relevant for SMRs, as national requirements may necessitate design adjustments, complicating licensing and undermining the potential for standardization and series production. Harmonization is especially challenging at the level of technical standards, which have developed over time within national contexts.

SMRs are also associated with significant uncertainties regarding their commercial viability. Although they are proposed for a range of applications, including electricity generation, district heating, and industrial process heat, no design has yet demonstrated in practice that it can meet European safety requirements, achieve cost competitiveness, and be deployed at scale.

Timeline considerations further limit their potential contribution. Typical construction times for light-water SMRs are estimated at 3.4 to 6 years, without accounting for FOAK-specific delays. Experience from recent projects suggests that initial timelines may increase significantly, with delays of more than seven years. Applied to the EU context, this implies that first commercial SMRs are unlikely to become operational before the early 2040s, even under optimistic assumptions. Demonstration projects may occur earlier, but deployment would only follow later.

Based on these time estimates, it seems unlikely that SMRs will play a significant role in the transition from fossil fuels to low-carbon fuels in Europe. Any deployment strategy will be “too little, too late” for the Euratom Member States to reach their climate goals, even in an optimistic scenario.

Despite the relatively large number of SMR designs discussed in Europe, all remain at early stages of development, mostly in pre-licensing. Several countries are engaged in pre-licensing activities with different vendors, but progress towards implementation remains limited. As of 2025, no SMR in the EU has been granted a construction license or is under construction, and only one EU-based design has entered the licensing process.

### **Industrial Capacity, Supply Chain and Fuel Cycle**

To date, there is no proven industrial capacity in Europe to manufacture and assemble SMR units at the scale often envisaged. Existing nuclear manufacturing capabilities are geared towards large light water reactor components such as pressure vessels, steam generators, turbine

systems, and I&C, as well as lifetime extension projects. At the same time, the ability to manufacture safety-relevant nuclear components has declined significantly since the 1980s due to the limited number of new construction projects. As a result, the high-volume, modular production lines required for SMRs would need to be developed largely from scratch, under conditions of technological, regulatory, and geopolitical uncertainty.

In principle, serial SMR deployment would require a dedicated industrial ecosystem, including at least one module fabrication facility, a network of specialized suppliers, and transport infrastructure capable of handling oversized nuclear-grade components. Such a system would only be economically viable with sustained production volumes of many tens of units per year over several decades. However, these volumes remain speculative, as they are not supported by firm orders or concrete project pipelines. European institutions themselves acknowledge that a competitive SMR supply chain still needs to be established and that current capabilities remain fragmented across national industries and regulatory frameworks.

Experience from traditional nuclear projects indicates that the development, licensing, and industrialization of new reactor designs in Europe typically takes well over a decade. Given that many SMR concepts are still facing unresolved technical, regulatory, and economic questions, it appears unlikely that deployment targets for the early 2030s can be met. Furthermore, the diversity of SMR designs implies differing manufacturing requirements, making it difficult to define standardized production processes or reliably estimate timelines and capacity needs.

The feasibility of accelerated SMR deployment is further constrained by material, manufacturing, and institutional bottlenecks. Large-scale rollout would require significant quantities of nuclear-grade materials and specialized components, which are already limited in supply for existing reactor projects. In addition, long-term availability of skilled workforce and sustained regulatory oversight would be necessary, further limiting the speed and scale at which SMRs could be deployed in Euratom Member States.

Constraints in the nuclear fuel cycle represent an additional structural challenge. On the front end, natural uranium supply in the EU is almost non-existent, and utilities rely entirely on imports. The supply is also highly concentrated, with a small number of countries accounting for the majority of deliveries, creating dependencies on external suppliers and exposure to geopolitical risks and global logistics chains.

Current fuel-fabrication plants are optimised for standard LWR fuel assemblies and not for the diverse fuel types required by SMRs, where each new physical-chemical form and architecture demands distinct manufacturing processes and technologies. While light-water SMRs using conventional low-enriched uranium could theoretically leverage existing conversion and enrichment capacities, they still require new fabrication lines and licensing for each design. As 60% of SMR designs rely on fuel forms not yet available at commercial scale, substantial additional capital and time is required to establish fabrication infrastructure and qualification processes, without the guarantee of sufficient deployment volumes to justify the investment.

On the back end, SMR deployment would either add to existing inventories of spent light water reactor fuel or introduce new types of radioactive waste with different characteristics. These would need to be managed within already slow and complex repository programs. The diversity of fuel types would further complicate transport, storage, and conditioning, increasing both technical complexity and costs.

Because fuel cycle infrastructure is typically design-specific, early adoption of particular SMR technologies would lock countries into long-term supply chains and dependencies. This reduces flexibility, especially if selected designs later prove uneconomic. Rather than relying on the relatively standardized global fuel market for large reactors, SMRs could lead to a fragmented landscape of specialized fuel cycles, each associated with distinct technical challenges and geopolitical risks, while continuing to depend on imported uranium.

### **Interest from energy providers, industries, and supply chain companies**

Various examples indicate that interest in SMRs among traditional nuclear utilities remains limited, with several operators continuing to prioritise traditional large nuclear power plants. Many utilities adopt a cautious approach, as key uncertainties regarding costs, licensing, and project delivery remain unresolved.

At the same time, there is growing interest from energy-intensive industries such as steel, chemicals, refining, heavy manufacturing, and more recently data centres, which view SMRs as a potential source of low-carbon heat and electricity. However, light water SMR designs are unlikely to provide the high temperatures required for core industrial processes in sectors such as cement, steel, chemicals, aluminium, and refining. These sectors are among the largest contributors to greenhouse gas emissions in the EU, making this limitation particularly relevant. While high-temperature SMR concepts could theoretically address some of

these needs, their availability remains uncertain and they would still not cover all industrial applications. As a result, SMRs in industrial settings would likely be limited to electricity supply, placing them in direct competition with other generation technologies.

The increasing electricity demand from data centres, driven in part by the expansion of AI applications, has recently positioned this sector as a potential market for SMRs. This has led to a number of early-stage partnerships between SMR developers and data centre operators in Europe. However, these initiatives remain exploratory and depend on reactor designs that have not yet been demonstrated or licensed.

So far, private sector engagement in SMR commercialisation has been limited. One reason is the absence of mature, market-ready SMR designs that could be procured and deployed with predictable costs and timelines. In addition, nuclear power plants differ significantly from conventional industrial energy systems, such as gas-fired plants, particularly in terms of safety, security, regulatory oversight, liability, non-proliferation requirements, and waste management. These factors introduce additional complexity and risk, which need to be addressed before private industrial actors are likely to commit.

Supply chain companies currently appear to be the strongest proponents of SMRs, partly due to limited business opportunities in the existing nuclear market. However, even within this group, there is a clear expectation that substantial public support would be required to mitigate financial risks before significant investments in SMR-related manufacturing capacity are undertaken.

### **Export necessity for SMR profitability**

Export-dependent profitability is a core feature of current SMR business models in Euratom Member States. SMR concepts aim to replace the traditional economy of scale of large reactors with an 'economy of multiples', targeting cost reductions through serial factory production and learning-by-doing. However, technical and policy assessments consistently show that unit costs only become competitive after a large number of identical units have been deployed.

Economic studies indicate that even optimistic learning rates require many dozens to hundreds of units to reach stable 'nth-of-a-kind' costs. Realistic European demand cannot support such volumes for any single standardized design, even if clustered to replace large plants. As a result, many vendors base their business cases on substantial export markets, involving additional economic and regulatory risk and higher dependence on geopolitical circumstances.

This envisaged export reliance exposes EU stakeholders to significant demand risks. If foreign markets fail to materialise, early projects face high capital costs. Centralised serial production further relocates the value chain: unlike traditional nuclear builds with substantial local construction employment, factory-made SMRs may reduce on-site jobs and regional economic benefits.

No European-designed SMR is yet operational, unlike Russian and Chinese designs. Even if the targeted timeline of a first European SMR deployment in the early 2030s can be achieved, Russian and Chinese units will have years of operating experience, giving them an advantage, as many newcomer countries prefer technologies with reference plants to minimise perceived risk.

This intense global competition from state-backed rivals, combined with the limited domestic demand, high volume thresholds for cost competitiveness, and inherent regulatory as well as geopolitical risks, shows that the Euratom Member States are particularly ill-suited to foster SMR deployment.

### **Cost escalation trends and causes in SMR development**

Nuclear projects (both large and small) have a well-documented history of cost overruns and schedule delays, and SMRs are proving no exception despite promises of simpler construction. A comprehensive study of 180 nuclear projects worldwide found over 92% exceeded budgets, with average cost overruns of 117% (about 1.3 billion USD) and schedule overruns of 64% or 36 months.

Recent SMR experiences confirm this pattern. The NuScale Carbon Free Power Project in the US saw overnight construction costs rise from 3 billion USD for a 600 MW 12-module plant in 2015 to 9.3 billion USD for a downsized 462 MW six-module version by 2023. Operating SMRs in China (Shidao Bay) and Russia (Akademik Lomonosov) also tripled initial cost projections, undermining claims of lower electricity prices, especially for FOAK units burdened by high upfront costs.

Several interrelated factors drive these escalations as projects advance from concept to reality. Early estimates rely on incomplete conceptual designs, leaving technical details and regulatory demands unresolved. Weak supply chains and manufacturing constraints compound the issue.

Increasing pressure on regulatory authorities add further complexity. While advocates push for streamlined licensing to speed SMR deployment, stringent standards remain essential, particularly for units sited

near populations or industry. Non-LWR designs face heightened scrutiny because their limited operational track record (combined with the relative inexperience of many new entrants and startups) often leads to iterative review cycles, repeated information requests, and evolving regulatory requirements that are expensive and delay progress.

FOAK projects incur substantial initial costs for detailed engineering, prototyping, and new production lines, with private firms typically seeking public subsidies or guaranteed contracts to offset risks. Empirical research on megaprojects highlights frequent optimism bias and strategic misrepresentation in initial projections, including aggressive SMR assumptions on learning curves, timelines, and financing.

Nuclear's large upfront capital and long build times heighten sensitivity to interest rates, inflation, and labour costs. SMRs aim to reduce this through shorter schedules and modularity, but empirical delays erode that advantage, perpetuating the sector's systemic performance challenges.

### **Competitiveness of SMRs vs. other Energy Technologies**

SMRs currently lack cost competitiveness against the cheapest energy sources like wind and solar, and even struggle to match large nuclear, gas, or coal when realistic project risks are factored in. They largely repackage traditional nuclear cost and schedule challenges into smaller units, relying on overly optimistic learning curves, substantial public support, and export volumes that may never materialise.

Comparative studies for Europe show SMRs with significantly higher unit costs and levelized costs of electricity (LCOE) than large reactors. Recent analyses indicate average capital costs per kW around 41% higher for SMRs, with an LCOE of about 85€/MWh. In comparison, large plants benefit from economies of scale, spreading fixed costs over much greater output than a 300 MW SMR unit.

Proponents claim factory fabrication and standardization will enable SMRs to 'learn down' costs through serial production, but this requires a large, stable order book that does not yet exist in any market. SMRs are often promoted as fossil fuel replacements, but even with carbon pricing, they would need additional political measures for viability. The European Commission views both fossil gas and nuclear as transition technologies, positioning SMRs in direct competition with gas in key segments.

Renewables are projected to see sharp LCOE declines (e.g., -55% for solar PV and -12% for onshore wind by 2050), while new nuclear cost

curves remain flat. While SMR advocates highlight renewables' grid integration costs (€10-25/MWh), these remain lower than nuclear's system costs (€20-50/MWh), especially with SMRs' FOAK premiums and financing burdens.

Beyond LCOE, SMRs face high investor risks requiring public guarantees, concessional finance, and long-term contracts. By contrast, wind and solar rely on standard project finance without deep sovereign backing, due to their lower technological and construction risks.

When a technology demands such exceptional risk mitigation yet fails to deliver costs comparable to low-carbon alternatives, SMRs cannot be considered competitive under normal market conditions.

The discussed limitations and difficulties demonstrate that framework conditions for SMRs in Euratom Member States are far from optimal, rendering the prerequisites particularly ill-suited for driving their deployment. Prioritizing this technology therefore carries the risk of being exceedingly inefficient and expensive.

# 1 INTRODUCTION

Small Modular Reactors (SMRs)<sup>1</sup> are nuclear reactors with electric outputs of up to 300 MWe (IAEA, 2023), often advertised as a more flexible and potentially cost-effective complement to traditional large reactors. Advocates of SMRs stress their potential role in meeting climate targets and in decarbonizing the industry in a relatively cheap and competitive way.

The European Commission in a Communication proposes SMRs as “one of Europe’s next major industrial development projects” (European Commission, 2026), and a possible technology to meet EU policy objectives such as “industrial competitiveness and decarbonisation, as well as strategic independence and security of energy supply” (European Commission, 2026).

A detailed analysis is needed to address the complex area of potential SMR deployment in Euratom Member States and therefore this study discusses the framework conditions for SMRs in Euratom Member States, focusing on six key topics:

- estimated market potential for SMRs in Europe, reflecting the regulatory framework and the current development status;
- required industrial capacity and supply chain limitations with a focus on the fuel cycle;
- level of interest from energy utilities, energy-intensive industries, and supply chain companies;
- export necessity for the profitability of SMRs, and analysis of the competition on the global market;
- trends and causes of cost escalation in SMR development; and
- market competitiveness of SMRs relative to other energy technologies.

The Umweltbundesamt GmbH conducted this study on behalf of the Federal Ministry of Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management. The goal was to support the current discussions regarding the deployment of SMRs within Europe with science-based facts.

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<sup>1</sup> Other sources use ‘Small and medium-sized or modular reactors’ (IAEA, n.d.) as long form for SMR.

## 2 MARKET POTENTIAL FOR SMRS IN EURATOM MEMBER STATES

### 2.1 Scale of Potential Deployment

The maximum projected market potential for a possible deployment of SMRs in Euratom member states appears to be significant, but the estimations are only a fraction of the projected global SMR market. A recent EY-Parthenon industry analysis estimates that 400–700 SMR units of 150 MWe each could be deployed worldwide by 2050, resulting in a total SMR capacity of 60–100 GWe. However, only roughly 17% of this total capacity (about 10–17 GWe) is anticipated to be in Europe. EY Parthenon highlights, that those ‘two scenarios are, however, based on the condition that the challenges to deployment have been overcome (financing, industrialization, etc.). (EY Parthenon, 2024).

On the other hand, the International Energy Agency (IEA) assumes an SMR deployment with a global capacity of up to 40 GWe until 2050 under current policy settings, while the capacity could be tripled with pro-nuclear policies and streamlined regulations (International Energy Agency, 2025). The European Commission projects that SMRs and AMRs might add about 17 (current projection scenario) to 53 GWe (boosted development scenario) in the EU by mid-century (European Commission, 2025).

The mentioned studies show a large uncertainty of the projected SMR capacity in the EU, which strongly depends on the national policies and industry focus. However, the deployment could remain limited, potentially corresponding to only several tens of units until mid-century.

Independent academic reviews also indicate that Europe’s share of the global SMR rollout would be limited, especially when compared to more advanced projects in countries like the US or China (Black, Shropshire, & Araújo, 2021; Van Hee, De Jaeger, Bauwens, Valkiers, & Laes, 2024). For example, the EY Parthenon study estimates that China and the US together are going to account for about half of the world SMR deployment potential by 2035, whereas the UK (associated Euratom member state) has the highest SMR potential in Europe, followed by other Euratom Member States, such as France, Belgium, Czechia, Sweden, etc. (EY Parthenon, 2024).

Historically, the projections and scenarios on the development of installed nuclear capacity and the deployment of new nuclear reactors were massively overestimated (Muellner, et al., 2021). Nuclear industry has a long tradition of overpromising and underdelivering. The track record of nuclear raises questions if the expected capacities will be anywhere near today's scenarios. This is especially true as the crucial obstacles (uncertainties in development, low technology readiness level, financing, etc... ) are far from being resolved.

## 2.2 SMR Ambitions in EU Member States

The European Commission has not set specific SMR capacity targets to date, but it assumes SMRs could play a role in replacing retiring coal plants and complementing renewables (European Commission, 2023; European Parliament, 2023). Interest by some Member States and parts of the nuclear industry also resulted in the launch of the European SMR Industrial Alliance in 2024, aiming to enable the first European SMRs in the early 2030s (World Nuclear News, 2024a; Nuclear Europe, 2024). This alliance and related initiatives show the willingness of some actors to create an ecosystem for SMRs.

In its Communication from March 2026 the European Commission proposes SMRs as “one of Europe’s next major industrial development projects” (European Commission, 2026), and a possible technology to meet EU policy objectives such as “industrial competitiveness and decarbonisation, as well as strategic independence and security of energy supply” (European Commission, 2026).

While Member States with large nuclear fleets such as France are focusing on the planned construction of traditional large NPPs (Euronews, 2026), others do vaguely consider the SMR option, though not as a priority. Poland as nuclear newcomer plans the construction of three traditional large NPPs (World Nuclear Association, 2026a), SMRs might be deployed at a later stage (World Nuclear News, 2025d). Czechia is interested in SMRs (World Nuclear News, 2025c), but the contracts for new traditional large reactors have already been signed (World Nuclear Association, 2025b). Slovakia considers SMRs (World Nuclear News, 2026a), but a large reactor seems to be more realistic (Enerdata, 2025b). Hungary has also recently expressed interest in SMRs (World Nuclear News, 2025h), but the construction of two large reactors has recently started (World Nuclear News, 2026b).

Still, actual deployment depends on several factors. There are plenty of different SMR designs in different stages of their development. There is no operational SMR in the EU. There is no SMR under construction in the EU. There is no SMR in the EU which was granted a construction licence.

## 2.3 Regulatory framework

The nuclear regulatory regime, its ruleset, codes and standards and other administrative rules like fire protection differ from Member State to Member State. Further nuclear policies of the member states also vary widely (from nuclear friendly countries like France, Czechia, or Finland to ones that are opposed to new nuclear fission like Germany or Austria).

### 2.3.1 EU Level

Authorization of nuclear installations is the sovereign responsibility of the state, in which the nuclear installation is to be built. On the EU level there are certain legislative frameworks that each member state must comply with.

All nuclear licensing processes need to be in line with the EU legislative framework. The primary legislation is the Treaty establishing the European Atomic Energy Community (EURATOM Treaty, 1957; consolidated 2016/C 203/01).

Key directives which are relevant for nuclear installations are:

- Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment, as amended by Directive 2014/52/EU, <https://eur-lex.europa.eu/eli/dir/2011/92/oj/eng>
- Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment, <https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex:32001L0042>
- Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, <https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A31992L0043>
- Directive 2000/60/EC establishing a framework for Community action in the field of water policy. <https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex:32000L0060>

- Directive 2014/87/Euratom amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0087>
- Directive 2011/70/Euratom establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste, and <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32011L0070>
- Directive 2013/59/Euratom protection against ionising radiation <https://eur-lex.europa.eu/eli/dir/2013/59/oj/eng>
- Directive 2006/117/Euratom on the supervision and control of shipments of radioactive waste and spent fuel <https://eur-lex.europa.eu/eli/dir/2006/117/oj/eng>

It should be noted that these EU Directives are often transposed into national law in different ways, with national legislation remaining the primary legal authority.

### **2.3.2 Regulatory (nuclear) frameworks in selected Member States**

Regulations, nuclear codes, and industrial standards vary significantly across countries. As authorizing and regulating nuclear installations falls under each state's sovereign responsibility, EU Member States maintain multiple layers of legislation and regulations tailored to their nuclear facilities. Codes and standards are typically country specific as well.

To illustrate the variety of levels of nuclear regulations, codes and standards affecting nuclear installations in a national system, Germany is depicted below as an example. (Bundesministerium für Umwelt, Klimaschutz, Naturschutz und nukleare Sicherheit, n.d.):

Federal legislators:

- Basic Law (generally binding)
- Atomic Energy Act, Radiation Protection Act, Site Selection Act (generally binding)

Federal Government, Federal Council:

- Legal ordinances (generally binding)
- General administrative regulations (binding for authorities)

Federal Government, State Authorities:

- Announcements by the Federal Ministry for the Environment (binding through incorporation into the licence or through supervisory measures in individual cases):
- Safety requirements for nuclear power plants
- Guidelines and recommendations

Advisory bodies and Nuclear Safety Standards Commission (KTA):

- Reactor Safety Commission (RSK), Commission on Radiological Protection (SSK) and Nuclear Waste Management Commission (ESK) guidelines (binding through incorporation into the licence or through supervisory measures in individual cases)
- RSK, SSK and ESK recommendations (binding through incorporation into the licence or through supervisory measures in individual cases)
- KTA rules (binding through incorporation into the licence or through supervisory measures in individual cases)

Industry:

- Technical specifications for components and systems (binding through incorporation into the licence or through supervisory measures in individual cases)
- Organisational and operating manuals (binding through incorporation into the licence or through supervisory measures in individual cases)

An in depth-overview of each Member States nuclear regulations including the technical codes and standards is not part of this analysis. Nevertheless, an overview of some legislations and regulations for selected Member States are listed below.

**Czech Republic** (State Office for Nuclear Safety, n.d.)

- Act No. 263/2016 Coll., atomic act
- Decree No. 358/2016 Coll., on requirements for assurance of quality and technical safety and assessment and verification of conformity of selected equipment
- Decree No. 359/2016 Coll., on details of ensuring radiation extraordinary event management
- Decree No. 360/2016 Coll., on radiation situation monitoring
- Decree No. 361/2016 Coll., on security of nuclear installation and nuclear material

- Decree No. 362/2016 Coll., on the conditions for the award of the grant from the state budget in some existing exposure situations
- Decree No. 374/2016 Coll., on the accountancy and control of nuclear materials and reporting of information on them
- Decree No. 375/2016 Coll., on selected items in the nuclear area
- Decree No. 376/2016 Coll., on dual-use items in the nuclear area
- Decree No. 377/2016 Coll., on the requirements for the safe management of radioactive waste and on the decommissioning of nuclear installations or category III or IV workplaces
- Decree No. 378/2016 Coll., on siting of a nuclear installation
- Decree No. 379/2016 Coll., concerning the approval of some products in the field of peaceful use of nuclear energy and ionising radiation and the carriage of radioactive or fissile material
- Decree No. 408/2016 Coll., on management system requirements
- Decree No. 409/2016 Coll., on activities especially important from nuclear safety and radiation protection viewpoint, special professional qualification and training of persons ensuring radiation protection of the registrant
- Decree No. 422/2016 Coll., on radiation protection and security of a radioactive source
- Decree No. 21/2017 Coll., on assuring nuclear safety of a nuclear installation
- Decree No. 162/2017 Coll., on the requirements for safety assessment according to the atomic act
- Decree No. 329/2017 Coll., on the requirements for nuclear installation design
- Act No. 18/1997 Coll., on Peaceful Utilisation of Nuclear Energy and Ionising Radiation (the Atomic Act) and on Amendments and Alterations to Some Acts – regulating solely the area of civil liability for nuclear damage.

**France** (Nuclear Energy Agency, n.d. b)

- Act No. 2006-686 of 13 June 2006 on Transparency and Security in the Nuclear Field
- Environmental Code, Legislative Part, Article L.125-10 to L.125-40 [French], Articles L. 542-1 to L. 542-14 [French] and Articles L. 591-1 to L. 597-46
- Public Health Code, Legislative Part, Articles L. 1333-1 to L. 1333-32
- Defence Code, Legislative Part, Articles L. 1333-1 to L. 1333-20

- Labour Code, Legislative Part, Articles L. 4451-1 and L. 4451-4
- Energy Code, Legislative Part, Articles L. 311-5 to L. 311-9 and Articles L.336-1 to L. 336-10
- Act No. 2006-686 of 13 June 2006 on Transparency and Security in the Nuclear Field

#### Regulations

- Environmental Code, Regulatory Part, Articles R. 592-1 to R. 596-17 Articles R. 542-1 to D. 542-96 and Articles R. 125-49 to R. 125-87
- Public Health Code, Regulatory Part, Articles R. 1333-1 to R. 1333-175
- Defence Code, Regulatory Part, Articles R. 1333-1 to D. 1333-79
- Labour Code, Regulatory Part, Articles R. 4451-1 to R. 4451-135
- Energy Code, Regulatory Part, Articles R. 311-1 to R. 311-11-1 and Articles R. 336-1 to R. 336-44
- Decree No. 2007-243 of 23 February 2007 on the securing of the financing of nuclear charges
- Decree No. 2007-1557 of 2 November 2007 concerning basic nuclear installations and the supervision of the transport of radioactive materials with respect to nuclear safety
- Decree No. 2008-209 of 3 March 2008 on the procedure applicable for the management of foreign spent fuel and radioactive waste
- Decree No. 2016-333 of 21 March 2016 implementing Article L. 597-28 of the Environmental Code and relating to third party liability in the field of nuclear energy
- Ministerial order of 7 February 2012 laying down general rules for the basic nuclear installations

#### **Finland** (Nuclear Energy Agency, n.d. a)

##### Primary nuclear legislation

- 1988 Finnish Nuclear Energy Act (990/1987)
- 1972 Nuclear Liability Act (484/1972)
- 2018 Radiation Protection Act (859/2018)
- 1983 Act on the Radiation and Nuclear Safety Authority (1069/1983)
- 1994 Act on Transportation of Dangerous Goods (719/1994)
- 1996 Act on the Control of Exports of Dual-Use goods (562/2016)

### Secondary nuclear legislation

- 1988 Nuclear Energy Decree (161/1988)
- 2018 Decree on Ionising Radiation (1034/2018)
- 1997 Decree on the Radiation and Nuclear Safety Authority of Finland (618/1997)

### **Spain** (Nuclear Energy Agency, n.d. c)

#### Primary nuclear legislation

- Law 25/1964, of 29 April, on Nuclear Energy
- Law 15/1980, of 22 April, creating the Nuclear Safety Council

#### Secondary nuclear legislation

- Sixth additional provision of Law 54/1997, of 27 November, on the Electricity Sector
- Law 12/2011, of 27 May, on third party liability for nuclear damage or damage caused by radioactive materials
- Law 21/2013, of 9 December, on Environmental Assessment

#### Royal Decrees

- Royal Decree 1836/1999, of 3 December, approving the Regulation on Nuclear and Radioactive Facilities
- Royal Decree 1029/2022, of 20 December, approving the Regulation on Sanitary Protection against Risk arising from Exposure to Ionising Radiations
- Royal Decree 1308/2011, of 26 September, on physical protection of installations, radioactive materials and radioactive sources
- Royal Decree 102/2014, of 21 February, on the responsible and safe management of spent fuel and radioactive waste
- Royal Decree 1400/2018, of 23 November, approving the Regulation on Nuclear safety in nuclear facilities

Furthermore, the process of obtaining a license varies considerably. In countries like France, the licensing system does not include any type of design certification before the construction licensing step. In Romania, a design certification process is in place and a vendor can apply for a design license of a new technology, which was never built in the country of origin (Nuclear Europe, n.d.).

The European SMR pre-Partnership – Workstream 2 – Licencing (Nuclear Europe, n.d.) summarizes the licensing process relevant for SMRs such

as, in some countries, projects must begin with a formal decision in principle that triggers the licensing process, and this stage may conclude with a general or preliminary opinion or a formal statement from the national regulator. In other countries, a pre-licensing phase is carried out only if requested by the applicant. In most cases, only the prospective licensee, that is the organisation that will carry the primary responsibility for the facility is allowed to apply for such a pre-licensing step. Even where pre-licensing is not explicitly defined in legislation, a de facto pre-licensing phase often takes place. This early phase allows the regulator to identify and discuss safety issues and provides the future licensee with initial feedback, improving predictability for the subsequent construction licensing stage.

Besides variations in nuclear licensing processes, codes, and standards across countries, civil regulations, such as fire protection and building codes also differ significantly, sometimes even within a single nation. In most European countries, national governments establish fire regulations, whereas in Germany, responsibility lies with the federal states (Länder).

Some examples of national approaches (RIBAJ, 2017; MYDEK, 2024):

- In Spain, fire protection standard compliance for buildings can be approved by either local authorities or certified private contractors, both at the design stage and for the completed structure.
- In France, fire safety installations in public and high-rise buildings are verified by safety commissions at various project stages.
- In Germany, fire safety follows prescriptive rules for most buildings, while industrial facilities adopt a more performance-based approach.
- In Italy, national fire safety rules apply; construction cannot begin without prior approval from the local fire brigade authority.
- In Finland, national fire regulations govern, with local authorities handling construction control in consultation with the fire service; additionally, the fire authority conducts an inspection before operations commence.
- In Czechia, Act No. 133/1985 Coll., the Fire Protection Act, establishes the legal framework for fire prevention, response, and state oversight in Czech Republic. State Fire Supervision conducts inspections, approves plans, and imposes measures (Database of Information Obligations, n.d.).

For the second ENSREG Topical Peer Review (TPR) “Fire protection” was the selected topic. The Peer Review Summary Report concluded that, *“National regulatory frameworks for fire protection in nuclear installations vary significantly across countries and facility types. Many countries adopt specific nuclear safety requirements to protect structures and components critical to nuclear safety, while others rely on conventional fire safety focusing on protection of people and property. Fire protection responsibilities are often shared between several authorities: nuclear safety authorities and national conventional fire safety bodies (fire rescue services, building authorities, labour inspectorates, etc).”* (European Nuclear Safety Regulators Group , 2025)

Those civil codes are essential for potentially mass-produced nuclear installations, because national and regional differences might impact the design and make adjustments necessary, which were initially not planned and might impact the licensing and construction phase.

Challenges in harmonizing regulations arise specifically at the lower-level rulesets, regulations and technical standards and specification. Those developed over time and are often specific to a country, its nuclear installations and its industry.

## 2.4 Potential applications in Europe

Within the potential European market, SMRs claim to be used in different areas including electricity generation, district heating, and thermal and electrical energy for industrial processes (Serin, Glückler, Pasquet, & Vaglio-Gaudard, 2025). SMR proponents claim that SMRs could be used for process heat and hydrogen production for chemical and steel industries and for remote regions or islands where grid reinforcement is difficult (IAEA, 2024b; Ahmed & Rahman, 2023). However, Europe’s robust grid infrastructure makes off-grid remote power less relevant than it is in other regions of the world (E3G, 2025).

For all those claimed use cases, the different SMR designs have not yet shown, in practice, that they are able to commercialize a design, comply with the safety standards set by the Euratom Member States, and that their product is financially competitive. Additionally, not all proposed SMR designs are valid options for providing industrial process heat as different industries require different temperatures, which possibly cannot be reached by SMRs (see section 0).

SMRs are also often envisaged as a tool for reaching the climate targets of the EU. However, it is unclear whether this technology can fulfil these expectations. The EU plans to reduce its net greenhouse gas emissions by 90% by 2040 in order to reach climate neutrality in 2050 (European Commission - Climate Action, n.d.). However, typical construction times for LW-SMRs are estimated to be between 3.4 and 6 years (Asuega, Limb, & Quinn, 2023), without taking into account FOAK-specific delays. Other analyses (Softwareseni, 2025) estimate a realistic timeline for SMR construction in the US as following:

- Design certification: 3-5 years
- Construction permit: 2-3 years
- Construction: 3-5 years (claimed timeline; unproven for FOAK)
- Commissioning: 1-2 years of testing

This would result in an overall duration of 9-15 years from design certification to operation. If similar conditions are assumed for the EU, first SMR units would be in operation in 2035 the earliest. However, most European SMR designs are currently still in early pre-licensing phases (see section 2.5), which further delays any design decisions and thus the whole timeline.

Additionally, assumptions regarding construction times need to be doubted for FOAKs. As shown in Table 1, real-world experience demonstrates significant delays for SMR designs worldwide, compared to their initial timeline estimation at the construction start (Schissel & Wamsted, 2024; IAEA PRIS, 2026).

Table 1: Construction timelines for SMRs

SMR	Country	Initial construction time estimation	Construction start	Commercial operation	Actual construction time
<b>Shidao Bay</b>	China	4 years	2012	2023	11 years
<b>Akademik Lomonosov</b>	Russia	4 years	2007	2020	13 years

Both examples show a tripling of the initial timeline estimations and delays of more than seven years. Transferred to the situation in the EU (where the nuclear framework conditions might even be worse than in Russia or China), this would mean that the first operational commercial SMRs (demonstrators of prototypes might be available earlier) cannot realistically be expected before 2040, even in the unlikely case of an immediate design choice.

With regard to these timeline estimations, it seems to be very unlikely that SMRs will play a significant role in the transition from fossil fuels in Europe. Any deployment strategy will be “too little, too late” for the Euratom Member States to reach their climate goals, even in an optimistic scenario (Schissel & Wamsted, 2024).

## 2.5 Status of SMR designs in EU Member States

The third edition of the NEA Small Modular Reactor Dashboard (NEA, 2025) lists 74 SMR technologies under development worldwide, including 18 designs from organisations with their headquarters in an EU member state:

Table 2: Status of SMR Designs in EU Member States

Headquarter	Name	Organization	Thermal power [MWth]	Outlet temperature [°C]	Concept	Licensing status
Czechia	Energy Well	Research Centre Rez	20	700	Molten salt	No information
	TEPLATOR	University of West Bohemia	50	180	Water	No information
Denmark	CMSR	Saltfoss Energy	250	650	Molten salt	Pre-licensing
Finland	LDR-50	Steady Energy	50	150	Water	Pre-licensing
France	Blue Capsule	Blue Capsule Technology	150	750	Metal	Pre-licensing
	Cal-30	Gorgé-Calogena	30	110	Water	Pre-licensing
	HEXANA	HEXANA	800	530	Metal	Pre-licensing
	Jimmy HTR	Jimmy	10	550	Gas	License application submitted
	XAMR	NAAREA	80	625	Molten salt	Pre-licensing
	LFR-AS-200	newcleo	480	530	Metal	Pre-licensing
	LFR-AS-30	newcleo	90	530	Metal	Pre-licensing

Headquarter	Name	Organization	Thermal power [MWth]	Outlet temperature [°C]	Concept	Licensing status
	NUWARD SMR	NUWARD	1000	307	Water	No information
	Otrera	Otrera	600	550	Metal	Pre-licensing
	Stellarium	Stellaria Design	1080	750	Molten salt	No information
<b>Netherlands</b>	Thorizon One	Thorizon	250	550	Molten salt	Pre-licensing
<b>Poland</b>	HTGR-POLA	National Center for Nuclear Research	30	750	Gas	No information
<b>Sweden</b>	SEALER One	Blykalla	70	550	Metal	No information
<b>Switzerland</b>	START	Transmutex	600	450	Metal	No information

While the absolute number of European SMR design seems to be impressive, it is important to consider that all mentioned SMR designs are in a very early pre-licensing stage. While several countries are involved in pre-licensing activities with different vendors and designers, only one EU vendor (the High Temperature Reactor Project Jimmy in France) has submitted a license application in April 2024 (ASNR, 2024).

Pre-licensing processes are generally legally non-binding exchanges of information in different stages of the development of a nuclear reactor, and might differ from country to country. Pre-licensing talks and meetings between vendors and regulatory bodies are often undertaken at a very early stage of the design. Additionally, the pre-licensing phase is optional in most countries. It offers some benefits to the vendors, as they can show progress to the shareholders and investors, and get feedback from the regulatory body.

The legally non-binding pre-licensing procedures provide no indication whatsoever that a nuclear reactor project will be commercially available at any point in time. As of 2025, in the EU, no SMR was granted a construction licence, and no SMR is under construction (NEA, 2025).

### **3 INDUSTRIAL CAPACITY, SUPPLY CHAINS AND FUEL CYCLE**

To date, there is no proven industrial capacity to manufacture and assemble dozens of SMR units per year in a standardized way. Existing nuclear manufacturing in Europe focuses on large light-water reactor components such as pressure vessels, steam generators, turbine islands and I&C, as well as lifetime-extension projects. Additionally, the capability to manufacture safety-related components and systems in Europe has been drastically reduced since the 1980s due to the limited amount of new nuclear projects (World Nuclear Association, 2026b). High-volume modular product lines necessary for SMRs would have to be built up basically from zero under high technological, regulatory, and geopolitical uncertainty.

Conceptually, serial SMR deployment in Europe would require at least one dedicated module fabrication plant, multiple specialised supply facilities and qualified logistics for oversized heavy transport of nuclear-grade components. Production volumes in the order of many tens of modules per year over several decades would be needed to justify the required investments for such facilities, which are currently purely speculative rather than grounded in firm orders.

The European Commission explicitly acknowledges that a competitive SMR supply chain would need to be created and that current capabilities are fragmented across various national regulatory and industrial frameworks. The EC Communication and other policy documents emphasize the necessity of building a “highly competitive European industrial supply chain with strong capabilities and sufficient capacity” (European Commission, 2026), requiring a multi-stage process of identifying gaps, mobilising investment, qualifying suppliers, and harmonising standards before any serial production can even start at the first place (European Commission, n.d.).

Experience from large-reactor programmes suggests that developing, licensing, and industrialising a new design in Europe typically spans well over a decade (IAEA, 2024a). Given that several leading SMR concepts still face open design, licensing, and economic questions, it is highly doubtful that the deployment goal of SMRs in Europe in the early 2030s (European Commission, 2026) can be achieved. As different SMR designs also require different manufacturing and supply prerequisites, any assessment of likely timelines or necessary industrial capacities remains highly uncertain.

### 3.1 National vs. international supply chains

Nuclear new-build contracts in Europe remain strongly influenced by national industrial interests, with governments and utilities trying to keep many parts of the supply chain in the hands of domestic suppliers. The recent contract between the Czech Republic and Korea Hydro & Nuclear Power for new large units at Dukovany illustrates how host governments explicitly negotiate dedicated shares for their own construction and manufacturing industries (Prague Stock Exchange, 2025; Government of the Czech Republic, 2024). In such an environment, suppliers might tend to maintain national control over key technologies capabilities, rather than to create open, easily transferable SMR supply chains within Europe, which would be necessary for a rapid transnational deployment.

At the same time, critical parts of the value chain (such as turbine-island manufacturers and I&C providers) are already concentrated in a few international players.

- Arabelle Solutions, for example, positions itself as a specialist in nuclear steam turbine islands for future SMRs, building on French turbine manufacturing know-how (Arabelle Solutions, 2026). The company has been selected as turbine supplier for Hitachi's BWRX-300 SMRs at Darlington (Arabelle Solutions, 2025a) and the TerraPower Natrium project in Wyoming (Arabelle Solutions, 2025b).
- Siemens Energy presents itself as a major German supplier of conventional island components and nuclear-qualified I&C systems with a global project portfolio (Siemens Energy, 2025). Partnership agreements and contracts have been signed with Rolls Royce (World Nuclear News, 2025b) and Oklo (World Nuclear News, 2024b).

While these firms operate internationally, they are unlikely to give away their competitive advantage by a broad technology diffusion to potential rivals within the Euratom Member States.

The sustainability of an accelerated SMR deployment in Europe is thus constrained by material, manufacturing and institutional bottlenecks. Deploying dozens of units in a narrow timeframe requires large quantities of nuclear-grade steels and specialised components that are already scarce for the large reactor industry. In addition, the necessity for continuous regulatory and skilled-workforce support over many decades' further limits how fast and how far SMR deployment in Euratom Member States can realistically grow.

## 3.2 Fuel cycle

The constraints originating from the nuclear fuel cycle are a clear structural weakness for SMR strategies in Euratom Member States, concerning both the front-end and back-end of the fuel cycle.

### 3.2.1 Front-end: mining, conversion, enrichment, fabrication

EU policy papers openly state that uranium production in the EU is almost non-existent. The 2024 annual report of the EURATOM Supply Agency (EURATOM Supply Agency, 2025) shows that none of the uranium delivered to EU utilities originates within the EU. Additionally, the uranium market is very concentrated, as in 2024, only four countries (Canada, Kazakhstan, Russia and Australia) have provided over 84% of the uranium deliveries to EU facilities (EURATOM Supply Agency, 2025). This results in a strong dependency on uranium imports from a few producer regions, together with long global logistics chains that are outside of Europe's control and are impacted by geopolitical issues.

On the other hand, industrial capabilities for conversion, enrichment and fuel fabrication are present in some Euratom Member States but are concentrated in a few sites and operators. Conversion and enrichment facilities in France as well as Urenco centrifuge plants (with European sites in Germany, and the Netherlands) are currently in operation (IAEA - INFCIS, n.d.). Fuel-fabrication plants are optimised for standard LWR fuel assemblies and not for a heterogeneous portfolio of possible new fuel types for SMRs. Each combination of physical-chemical forms and fuel architectures requires different manufacturing processes and technologies, making the whole development process more expensive and time-consuming (NEA, 2025).

For light-water SMRs that use conventional low-enriched uranium, existing conversion and enrichment could theoretically supply fuel, but new fabrication lines and licensing work would be required for each specific design. However, according to the NEA SMR Dashboard, '60% of the SMR designs rely on fuel forms that are not currently available at commercial scale' (NEA, 2025). For these designs, additional capital and time is needed to build up a commercially available fuel-fabrication infrastructure and to establish complex qualification processes, without any guarantee that volumes required to justify those investments will ever be reached.

### **3.2.2 HALEU and advanced SMR concepts**

Many advanced SMR concepts proposed for Europe rely on high-assay low-enriched uranium (HALEU, between 5 and 19.75% U-235), which is not part of the traditional LWR fuel market. At present, only Russia and China have the infrastructure to produce HALEU at scale (World Nuclear Association, 2026c), which would cause a significant vulnerability for any large-scale deployment of HALEU-fuelled reactors in the EU.

The NEA SMR dashboard has identified that more than half of the SMR designs worldwide require uranium enrichment above 5%. Only four of them have established binding contracts with fuel supply chain companies capable of HALEU production (NEA, 2025). As HALEU is needed also for research reactors and medical isotope production, the demands of a possible advanced SMR design in Europe would be in a direct competition for a scarce and politically sensitive resource.

The difficulties regarding the HALEU supply chain have also been recognised by the SMR industry in the US. Multiple SMR developers have acknowledged that a 'domestic supply chain for HALEU does not exist' and 'HALEU manufacturing sites have to be built from scratch' (Reuters Events Nuclear, 2026). In addition, different reactor designs require separate fuel fabrication plants because of the unique requirements of the design (Reuters Events Nuclear, 2026).

The situation regarding HALEU in Europe is very similar to the US. Euratom's Supply Agency has therefore launched working groups to study how HALEU can be secured, including options for rebuilding European enrichment and fuel-metal production capabilities. While Urenco and some national initiatives signal willingness to produce HALEU in Europe, it is also clear that at current demand levels, large new infrastructure investments are not yet justified.

### **3.2.3 Back-end: spent fuel, reprocessing, waste**

SMRs do not avoid the back-end of the fuel cycle; they rather multiply it across many more units, designs and sites. France is the only Euratom Member State to operate commercial reprocessing (IAEA - INFCIS, n.d.), and spent fuel from most reactors has to be stored for long periods, waiting for national repository decisions.

Closed-fuel-cycle concepts around some advanced SMR designs are reflected in EU strategy documents (European Commission, 2026), but always in a long-term research context. Additionally, while fuel reprocessing and 'closed-fuel-cycle' reduces the amount, it does not lead to a

complete avoidance of high-level radioactive waste, and the necessity for final repositories remains in place (National Academies of Sciences, Engineering, and Medicine, 2022).

In practical terms, any SMR fleet deployed in the next decades in Euratom Member States will add to national inventories of spent LWR-type fuel or create new waste with unfamiliar characteristics, which needs to be integrated into already slowly progressing repository programmes. The different types of fuel further complicate transport, storage and conditioning, leading to increased costs for regulators and operators.

### **3.2.4 Strategic autonomy vs. lock-in**

European Commission's strategy papers present SMRs as a way to 'strengthen EU's energy security and autonomy by reducing reliance on fossil fuels' and to 'ensure the sustainability of the nuclear fuel cycle in the longer term' (European Commission, 2026). However, the same document states that the 'development of fuel cycle capacities, including new fuel production and, in some cases, additional reprocessing capacity, needs to proceed in parallel with reactor design activities' (European Commission, 2026). This parallel development means that any difficulties regarding fuel-cycle investments can significantly delay or even block the corresponding reactor projects.

As both front-end and back-end investments are design-specific, early choices for a dedicated SMR concept would effectively lock Euratom Member States into long-term fuel-cycle dependencies that cannot easily be escaped, even if the chosen design later turns out to be uneconomic. SMRs therefore shift Europe from dependence on a standardised global LWR fuel market to a patchwork of fragmented specialised fuel chains, each with its own technical risks and geopolitical exposure, while still depending on import of natural uranium.

## 4 INTEREST FROM ENERGY PROVIDERS, INDUSTRIES, AND SUPPLY CHAIN COMPANIES

### 4.1 Electricity Utility Interest

Some European electric utilities and energy providers have shown interest in SMRs:

- Électricité de France (EDF) has promoted its NUWARD SMR project, but it remains in the early design and licensing phase (World Nuclear News, 2025g). EDF has already reworked its SMR strategy after difficulties with earlier concepts (Balkan Green Energy News, 2024). Additionally, the French Energy Strategy considers SMRs as R&D and prototype projects, but it does not include any concrete SMR deployment as commercial reactors in the national energy mix (French Government, 2024).
- ČEZ (Czechia) plans at least one SMR unit at the Temelín site by the mid-2030s (NucNet, 2022), with Czech strategy documents envisaging at least one SMR in the national mix by 2040 (Ministry of the Environment of the Czech Republic, 2025). In October 2024, Rolls-Royce signed a cooperation agreement with ČEZ to prepare site studies and a possible future SMR fleet (Rolls Royce, 2024). In parallel, ČEZ is currently also planning to construct two traditional large NPPs at Dukovany (CEZ Group, n.d.).
- Fortum (Finland) has completed a feasibility study, which keeps SMRs on the table only as a ‘future option’, signalling that the company is not rushing into investment decisions and still sees major regulatory, economic and schedule risks (Fortum, 2025). Fortum has also signed a framework agreement with Steady Energy, which is focused on R&D cooperation and early projects for district heating (Europawire, 2026).
- Vattenfall (Sweden) has highlighted SMRs as one possible route for new reactors at Ringhals and has shortlisted GE Hitachi’s BWRX-300 and Rolls-Royce SMR designs (European Nuclear Society, 2024). However, also the option to construct traditional large NPPs was not excluded.
- Nuclearelectrica (Romania) is pushing an SMR project with NuScale at the former coal site Doicești (Nuclearelectrica, 2024), with the plan to deploy Europe’s first SMR by 2028 (European Nuclear Society, 2022). However, the project is an early-stage, high-risk

venture where long-term economics, construction timelines and public acceptance seem to remain highly uncertain.

These examples show that only a few traditional nuclear electricity providers are interested in SMRs, while several are leaning more towards traditional large NPPs. Many utilities remain cautious until costs and licensing potential are more certain.

## 4.2 Industrial Interest

There is growing interest from energy-intensive industries (such as steel, chemicals, refining, and heavy manufacturing, as well as more recently from data centres) that see SMRs as a potential option for generating heat and power without direct carbon emissions (World Nuclear Association, 2024). In the EU, this interest has led to various partnerships and memoranda of understanding (MoU).

- Advanced-reactor start-up Newcleo (France) and steel-equipment supplier Danieli (Italy) signed a Memorandum of Understanding to study using Newcleo's reactors for 'green steel' production (Interesting Engineering, 2025), but this remains at concept stage, with no proven SMR design, no licensed plant and no demonstration that nuclear-powered steel can compete with renewables-based processes.
- SMR developer Hexana (France) and engineering firm Tractebel (Belgium) launched a nuclear cogeneration task force, targeting hard to abate sectors like cement, steel and chemicals (World Nuclear News, 2025f). The initiative is mostly limited to lobbying, as no industrial site has committed to host an SMR, and the economic and regulatory feasibility of such co-located plants remains unclear.
- Poland's Orlen Synthos Green Energy is promoting a large fleet of GE-Hitachi BWRX-300 SMR units near energy-intensive industrial sites like Anwil (chemicals) and Synthos' own plants (World Nuclear News, 2025d; Orlen Synthos Green Energy, 2025a). The first unit at Włocławek is still in the permitting phase (Enerdata, 2025a), and the technology is not yet commercially operating anywhere.
- In February 2022, the Polish state-owned copper mining company KGHM signed an agreement for the deployment of NuScale SMRs to replace KGHM's existing coal-fired plants by 2029 (KGHM Polska Miedź, 2022). The Ministry of Climate and Environment of Poland issued the basic decision for the construction in July 2023 (KGHM Polska Miedź, 2023). Since then, NuScale redesigned their SMR

project, resulting in a cancellation of its planned FOAK project in the US. KGHM is meanwhile focusing on investments in energy efficiency and renewable energies like PV and wind, as they are available on the market (KGHM Polska Miedź, 2024).

- The French pulp and paper industry explicitly envisions SMRs as possibility to decarbonise certain industrial processes, as mentioned in the summary report of the Sectoral Transition Plan for the French Pulp and Paper Industry (Mangeart, et al., 2025). However, SMRs are seen as a ‘technology that has not currently reached maturity’, with a potential deployment in 2030 or later, requiring that open questions regarding ‘industrial safety, fuel availability and management, and the certification of sites’ have been clarified.

#### 4.2.1 Drivers of Industrial Interest

SMR vendors present their reactors as a solution that can do what large conventional nuclear has often failed to deliver: they promise electricity at competitive prices, projects built on time and on budget, and designs that can be integrated even into smaller or weaker grids. They highlight the reduced physical footprint of SMRs compared to large plants, arguing that this would result in an easier siting process. Additionally, the possibility of SMRs to supply not only power but also high-value process heat is often highlighted (EY Parthenon, 2024).

At the marketing level, SMRs are framed as 24/7 reliable, low-carbon energy sources that can back up variable renewables, support security of supply and contribute to deep decarbonisation of both power and heat (EY Parthenon, 2024), even though these claims are largely based on design intentions and forward-looking cost assumptions rather than a long track record of commercial operation.

These promises make SMRs interesting for industries like steel and chemicals, which face EU decarbonization and cost competitiveness pressure. The European Industrial Alliance on SMRs explicitly aims to ‘establish ways to inform and engage potential industrial users of SMRs such as energy-intensive industries, hydrogen producers, etc.’ (European Commission, n.d.). According to the Commission, SMRs could ‘contribute to the decarbonisation of hard-to-abate sectors such as transport, chemical and steel industry, and district heating’ (European Commission, 2023). Such statements might raise interest in SMR technologies, but energy intensive industries are likely to choose the most cost-competitive ready-to-deploy solution available on the market, which might not necessarily be SMRs.

The supply of high-value process heat is of special interest, as different actors inter alia argue for the construction of SMR at industrial sites in order to use process heat of the reactors. The EC communication (European Commission, 2026) notes:

*“A variety of end uses, beyond electricity production*

*[...] While the first SMR projects worldwide focus on electricity production, SMR technologies are likely to maximise their potential when targeting hybrid or off-grid applications and heat production for hard-to-abate industrial and residential purposes rather than competing only in the established EU electricity market. [...] By delivering low-carbon electricity and heat, SMRs can directly support the decarbonisation of hard-to-abate sectors at the heart of EU's industrial base including chemicals, steel, refineries, maritime transport, defence, and district heating [...]*

*Use case on chemical industries*

*Affordable, low-carbon electricity and high temperature industrial heat (steam) are key for many chemical manufacturing facilities.”* (European Commission, 2026)

In order to assess the potential of industrial heat for some so called hard-to-abate sectors the typical temperature levels are listed in Table 3. Placing SMRs at industrial sites only adds added value if the temperature can be used by the industries located on the sites.

Table 3: Hard-to-abate sectors and typical temperature levels

<b>Sector</b>	<b>Typical Process Heat Levels (Range)</b>	<b>Key Processes</b>	<b>BREF References</b>
<b>Cement</b>	900–1.450°C	Clinker calcination, kilns	Production of Cement, Lime and Magnesium Oxide (Schorcht, Kourti, Scalet, Roudier, & Sancho, 2013)
<b>Steel</b>	800–1.600°C, 1.200–1.500°C	Blast furnace, Electric Arc Furnace	Iron and Steel Production (Remus, Aguado-Monsonet, Roudier, & Sancho, 2013)

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Interest from Energy Providers, Industries, and Supply Chain Companies

<b>Sector</b>	<b>Typical Process Heat Levels (Range)</b>	<b>Key Processes</b>	<b>BREF References</b>
<b>Chemicals</b>	200–500°C, up to 1.000°C	Distillation, Steam cracking, Steam Reforming	Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers (IPPC Bureau at the Institute for Prospective Technological Studies, 2007), Production of Large Volume Organic Chemicals (Brinkmann, et al., 2017)
<b>Aluminium</b>	900–1.000°C	Electrolysis (Hall-Héroult process)	Non-ferrous Metals Industries (Cusano, et al., 2017)
<b>Refining</b>	300–700°C	Hydrotreating, Fluid Catalytic Cracking, Hydrocracking	Refining of Mineral Oil and Gas (Barthe, Chaugny, Roudier, & Sancho, 2015)

Core outlet temperatures of LWR SMRs are around 300°C. Table 3 shows that the relevant temperature levels reached by SMRs are far below what is needed by the displayed sectors.

A more detailed overview of the sector's key processes is given in Table 4.

Table 4: Key processes of the hard-to-abate sectors

<b>Sector</b>	<b>Typical Process Heat Levels (Range)</b>	<b>Key Processes</b>	<b>BREF References</b>
<b>Cement</b>	1.300–1.450°C	Clinker sintering	Production of Cement, Lime and Magnesium Oxide (Schorcht, Kourti, Scalet, Roudier, & Sancho, 2013)
<b>Steel</b>	1.500–1.600°C	Blast furnace	Iron and Steel Production (Remus, Aguado-Monsonet, Roudier, & Sancho, 2013)

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<b>Sector</b>	<b>Typical Process Heat Levels (Range)</b>	<b>Key Processes</b>	<b>BREF References</b>
<b>Steel</b>	1.200–1.500°C	Electric arc furnace	Iron and Steel Production (Remus, Aguado-Monsonet, Roudier, & Sancho, 2013)
<b>Chemicals</b>	800–900°C	Steam Cracking	Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers (IPPC Bureau at the Institute for Prospective Technological Studies, 2007)
<b>Chemicals</b>	800–1.000°C	Steam Reforming	Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers (IPPC Bureau at the Institute for Prospective Technological Studies, 2007)
<b>Aluminium</b>	940–980°C	Electrolysis	Non-ferrous Metals Industries (Cusano, et al., 2017)
<b>Refining</b>	500–650°C	Fluid Catalytic Cracking	Refining of Mineral Oil and Gas (Barthe, Chaugny, Roudier, & Sancho, 2015)
<b>Refining</b>	350–450°C	Hydrocracking	Refining of Mineral Oil and Gas (Barthe, Chaugny, Roudier, & Sancho, 2015)

LWR SMR designs that might be available in the 2030s or later cannot provide the required temperatures for relevant processes in the sectors Cement, Steel, Chemicals, Aluminium, Refining. This is crucial as these sectors are contributing significantly to GHG emissions in the European Union.

High-temperature SMRs, which might or might not be available at a later stage, could produce temperatures relevant for certain processes, but not all of them. This would lead to SMRs only selling electricity for industrial consumers and therefore questioning the siting of SMRs at industrial sites, while additionally putting them in direct competition with other electricity sources.

Another directive (Directive (EU) 2023/2413 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652), known as RED III, promotes the use of renewable energy for electrification and direct use and renewable fuels of non-biological origin inter alia in decarbonization of steel and chemical industries.

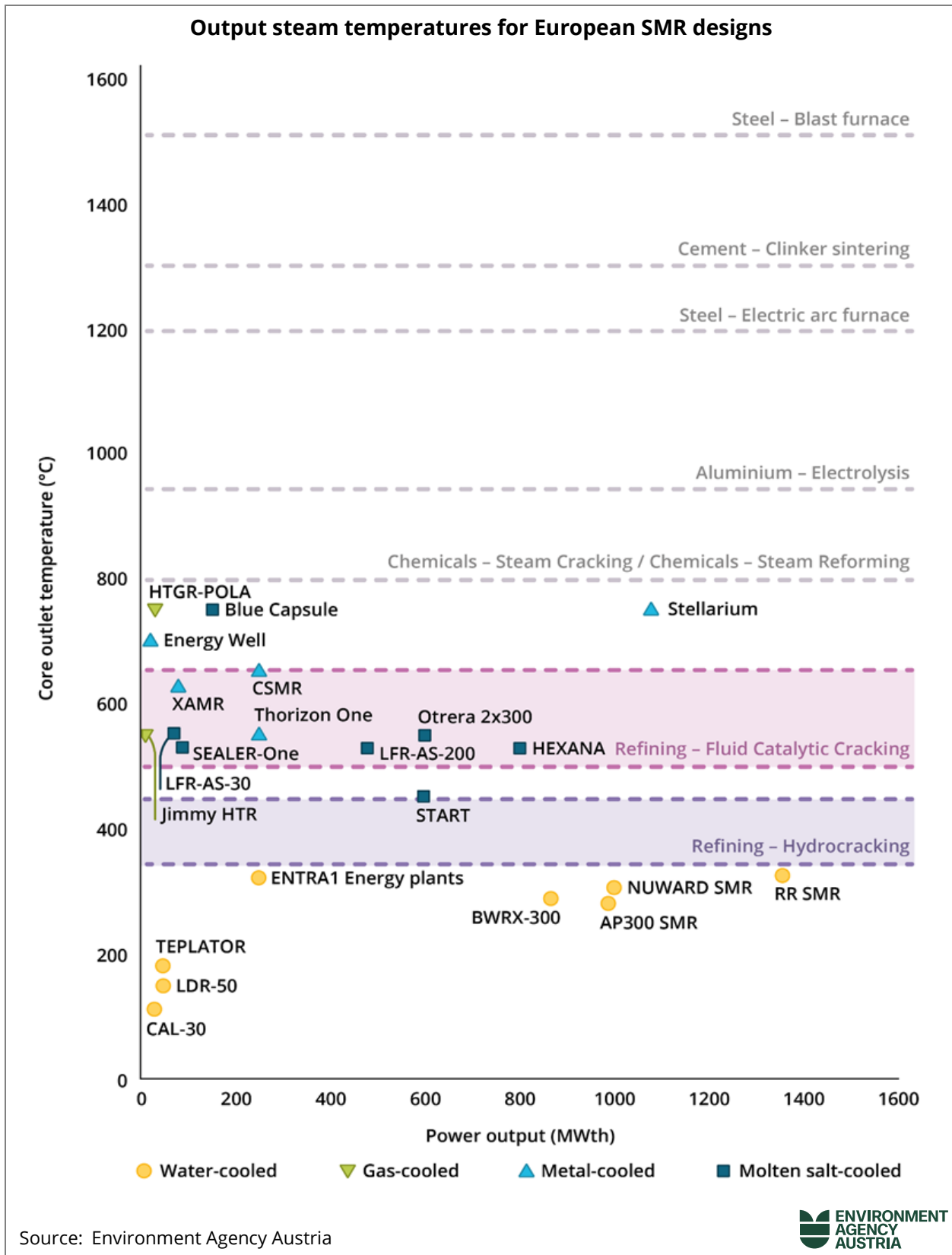
Due to the needed timely investments in low carbon technologies to achieve the EU climate targets industries might not be willing to wait for SMR technologies to become commercially available in the mid-2030s, because this might be already too late and too risky for several private companies.

Figure 1 shows the core outlet steam temperatures of EU SMR designs and compares them with the typical process heat requirements of key industrial processes in the cement, steel, chemicals, aluminium, and refining sectors. The temperatures shown are the reactor core outlet temperatures. The effective temperatures available for industrial heat applications would be lower, although these are not indicated for the SMR designs.

For hydrocracking and fluid catalytic cracking, the full temperature ranges are displayed in Figure 1. For clinker sintering, blast furnace and electric arc furnace operations, steam cracking, steam reforming, and electrolysis, only the lower bound of the respective temperature requirements is shown.

The comparison indicates that water-cooled SMR designs do not reach the temperature levels required for key industrial processes. SMR concepts using alternative coolants such as gas, liquid metal, or molten salt may be capable of supplying industrial heat for certain processes. However, even these advanced reactor technologies mostly cannot achieve the temperature thresholds required for the most demanding processes in hard-to-abate sectors, such as steam cracking, steam reforming, aluminium electrolysis, steel production via blast furnaces or electric arc furnaces, and cement clinker sintering.

Figure 1: Output steam temperatures for European SMR designs



#### **4.2.2 SMRs and Data Centres**

In recent years, with the increased usage of AI applications, data centres have been emerging as major potential electricity consumers, making them a tempting but controversial target market for SMR proponents.

A European Commission study estimated that data centres in EU member states consumed 76.8 TWh in 2018 and are expected to reach 98.5 TWh by 2030, increasing their share of EU electricity demand from 2.7% to about 3.2% on current trajectories (European Commission, 2018). More recent analyses that include European data centre clusters suggest an even steeper growth of up to 150%. Ember projects that the electricity demand of European data centres rises from 96 TWh in 2024 to 168 TWh in 2030 and 236 TWh in 2035, implying that data centres could reach around 4–6% of total European electricity demand within the next decade (Ember, 2025).

This expected increase in electricity demand have led to several early-stage partnerships between SMR vendors and data-centre players in Europe. All of them are still exploratory and depend on unproven reactor projects.

Westinghouse and data-centre operator DATA4 signed an MoU to explore using the AP300 SMR to power a future DATA4 campus in Europe (Westinghouse, 2025), with the AP300 selected as the technology of choice for a feasibility evaluation, rather than a firm build decision.

Swedish SMR developer Blykalla, cloud company evroc and research site operator Studsvik signed an MoU to assess co-locating SMRs and a hyperscale AI data centre at the Studsvik nuclear site, explicitly limited to examining technical and commercial viability, community acceptance and possible PPA structures, with no commitment to build (World Nuclear News, 2025e).

Data-centre company Equinix agreed with Dutch developer ULC Energy to secure future Rolls-Royce SMR capacity for Dutch data centres (Equinix, 2025). The deal concerns potential future electrical output from SMRs that are still in licensing and design phases, so it represents a long-term intent rather than bankable, near-term low-carbon supply.

#### **4.2.3 Contrasting Interest of Utilities and Industry**

While both some utilities and some industrial players are interested in the deployment of SMRs, their motivations and acceptance criteria can differ. Electric utilities primarily evaluate SMRs as power generation

assets, resulting in a focus on economic viability compared to other generation options and public acceptance (Van Hee, De Jaeger, Bauwens, Valkiers, & Laes, 2024). Many utilities have been hesitant to commit to first-of-a-kind SMRs without support of the government, given the mixed economics of nuclear in liberalized electricity markets (Black, Shropshire, & Araújo, 2021; Van Hee, Peremans, & Nimmegeers, 2024).

Industrial companies, on the other hand, might be in general more willing to consider SMRs as part of their decarbonization strategy. Projections by EY Parthenon, based on the assumption that all challenges to deployment have been overcome, assume that by 2050 up to 50% of SMR deployments could be on industrial sites, rather than feeding general power grids (EY Parthenon, 2024).

However, until today private companies have made no meaningful progress towards SMR commercialisation. This might be because the current market lacks mature, commercially deployable SMR designs ready for procurement and construction. Additionally, there are significant differences in operating for example a conventional gas-fired powerplant compared to a nuclear power plant. Questions about costs, safety, security, liability, non-proliferation, waste treatment and final disposal need to be answered in order to increase the interest of private industrial companies.

### **4.3 Interest from supply chain companies**

Several supply chain companies are active participants in the European Industrial Alliance on SMR (European Industrial Alliance on Small Modular Reactors, 2025). As the number of operating nuclear installations in Europe is decreasing and the construction of traditional large NPPs is limited, supply chain companies are looking for new business opportunities. Small modular reactors, which are promised to be produced in larger numbers, might seem attractive for those companies. However, as long as there is only a limited number of entities interested in buying SMRs, there is no real business case for supply chain companies. Therefore, this situation has resulted in strong advocacy efforts by industry stakeholders (European Industrial Alliance on Small Modular Reactors, 2025) for subsidies and investments from the public, in the hope that economically viable interest in SMRs will emerge in the near future – which is currently not the case.

Supply chain companies seem to be the strongest proponents of SMRs due to their current lack in business opportunities. Nevertheless, it

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seems that those companies are only willing to invest if the financial risk is covered by the public.

## 5 EXPORT NECESSITY FOR SMR PROFITABILITY

Export-dependent profitability is a structural feature of current SMR business models in Euratom Member States. This reliance on large export volumes creates economic, regulatory and geopolitical vulnerabilities that are often underplayed in current pro-nuclear EU policy debates.

### 5.1 Volume thresholds and domestic limits in Europe

SMR concepts seek to replace the traditional economy of scale of large reactors with an ‘economy of multiples’ with the goal of cost reductions through serial factory production and learning-by-doing. Technical and policy assessments consistently conclude that SMR unit costs are only expected to approach competitiveness after a large number of identical units have been produced and deployed (Locatelli, Bingham, & Mancini, 2014).

Recent studies on large nuclear reactors also highlight how uncertain such proposed learning effects are. An assessment of the AP1000 projects at Vogtle estimates that lifetime LCOE for the next two units at the same site would still range around 78–97 USD/MWh with substantial federal support, and 112–142 USD/MWh unsubsidised (Shirvan, 2024). This shows how strongly projections of cost reductions depend on optimistic assumptions about learning, schedule performance and policy support, and thus also calls into question similar claims made for SMRs.

Several economic studies show that even when assuming optimistic learning rates for SMRs, many dozens to hundreds of units are needed before a stable ‘nth-of-a-kind’ cost level is reached (Atkins, 2016). Westinghouse itself has stated that it would need a minimum order of 30–50 SMR units before it would make financial sense to invest in detailed design and modular manufacturing infrastructure (Nuclear Newswire, 2014).

An analysis for the German nuclear safety authority showed that, assuming reasonable scaling factors and learning assumptions, several thousand units of a given SMR design would be required before the costs could undercut that of a large reactor (Pistner, et al., 2021).

Other assessments for other light-water SMR concepts suggested break-even volumes up to hundreds of units, depending on the specific assumptions for the learning rate and other parameter (Noland, Hjelmeland, & Korpas, 2024).

Assuming an average SMR unit capacity of 200 MWe, a conservative order volume of 30-50 SMRs would result in a total capacity of 10-20 GWe, which already exceeds many of the (already optimistic) capacity estimates in Europe as presented in section 2.1. This capacity is needed for financially viable operation of only one SMR design, requiring a very unlikely scenario where all interested European countries agree on one specific SMR design.

In a realistic scenario, such volumes significantly exceed the plausible demand of any single, standardized SMR design in Europe, let alone one Member State. Any plausible national scenarios are constrained by electricity demand, grid integration limits and competing low-carbon options and would therefore not support hundreds or thousands of identical units of one design. Even if several SMRs were clustered to replace a large plant, the total number of units per country would remain far below the required volumes for competitive costs.

## **5.2 Export orientation of SMR vendors**

Due to the limited domestic market capacities, many SMR vendors explicitly assume export markets as a basis for their business cases. Rolls-Royce, for example, has proposed a factory line for its SMR design with a nominal output of around two units per year, and has framed this facility as a platform for exports to Central and Eastern Europe, North America and Asia (Rolls Royce SMR, 2020). To keep such a factory economically utilized over decades, a steady order flow from multiple countries is necessary, which has not materialized to date. Shortfalls or delays in foreign orders would directly translate into higher unit costs for all customers, including EU utilities.

Other examples of light-water SMR programmes entering international memoranda of understanding and export agreements are listed in chapter 3. This obvious trend of trying to gather as many international partners as possible (even in very early design stages) suggests that vendors themselves do not expect they can justify the required upfront investments by domestic demand alone and are therefore focusing on export deals.

### **5.3 Risks and implications of export dependence**

Nuclear industry organisations tend to frame SMR exports as a strategic industrial opportunity, emphasising the need to seize market shares in competition with vendors from the United States, Russia or China (Nuclear Energy Institute, 2021).

The dependence of SMR economics on large export volumes leads to several concerns. First, the need for hundreds or at least several dozen units of a single design to reach competitive costs exposes EU stakeholders to demand risks. If anticipated foreign markets do not materialise, early European projects will almost certainly face high capital costs (Table.Briefings, 2025).

Secondly, efforts to harmonise cross-border licensing risk creating pressure to streamline national safety and security requirements, potentially weakening precaution in favour of regulatory speed (Table.Briefings, 2025).

Finally, tying SMR profitability on global markets makes the nuclear industry in the EU more sensitive to geopolitical tensions, supply-chain disruptions and industrial competition. Any problems in these areas can undermine the necessary economies of series and thus the affordability of SMRs in Europe.

There are additional effects which would need to be systematically addressed in the near future. One of the core ideas of SMRs is the centralised serial production of all components, which significantly relocates the value chain. Today, nuclear power plant projects (like other large infrastructure projects) require a large workforce during the construction period, and therefore directly affect the local economy at the location of the NPP. For SMRs and its factory-produced components, the need for local suppliers as well as the on-site work and thus employment opportunities in the region might be significantly reduced. Detailed studies on deployment effects need to be carried out in order to better understand the potential shift in the value chain.

### **5.4 Competition on the global market**

Due to the aforementioned necessity for SMR vendors to export their designs, the European designs are in direct competition with non-European vendors.

In contrast to Russia and China, no European-designed SMR is yet in operation. The European Industrial Alliance on SMRs targets first SMR deployments by the early 2030s (European Commission, 2023), however it is very uncertain if this target date can be reached.

Even with the existing timeline, a significant demonstration gap occurs: Russian and Chinese SMRs will already have accumulated several years of operational experience before the first European SMR enters into operation. Many potential nuclear newcomer countries prefer technologies with operating reference plants, reducing the perceived technology risk (NEA/OECD, 2024).

#### **5.4.1 Russian Federation**

The Russian state corporation Rosatom has been a dominant player in the export of nuclear reactors in the past decade. It offered the Build-Own-Operate (BOO) model, for example for the Akkuyu NPP in Turkey (World Nuclear Association, 2025a). Rosatom finances, builds, and will own/operate the reactors, selling electricity to the host country under a long-term contract.

A key feature of Rosatom's offer has been state-backed financing and fuel cycle services, including the willingness to take back spent fuel from the customer country. This is attractive to countries without their own waste infrastructure, as Russia effectively relieves them of the burden of spent fuel disposal and thus lowering the entry barriers (Schepers, 2019)

Russia is developing several SMR designs, most prominently the RITM-200 series for land-based applications and the KLT-40S for floating units. The Akademik Lomonosov floating power unit, equipped with two KLT-40S reactors (each 35 MWe and based on nuclear icebreaker reactors), started commercial operation in May 2020 and has generated over one TWh of electricity (World Nuclear News, 2025a).

For SMRs, Rosatom has indicated the offer of similar integrated packages as for large NPPs. The Russian competitive position is thus based on one-stop solutions with full lifecycle support and financing. Indeed, Rosatom's success in securing export orders between 2010 and 2020 is largely attributed to Russia's willingness to finance these projects, as well as to serve markets that Western vendors avoided. (NEA/OECD, 2024; Schepers, 2019)

Russian SMRs could be competitors in third markets, such as Africa and Latin America. For a country considering an SMR deployment, Russia might offer an attractive "hands-off" solution with low immediate costs.

In contrast, European SMR developers typically cannot finance a foreign project by themselves and would need to rely on the host or international investors.

### **5.4.2 China**

China is emerging as a major nuclear exporter and has developed various SMR designs. Two notable Chinese SMRs are the ACP100 “Linglong One”, a 125 MWe PWR under construction on Hainan island (IAEA, 2024b), and the HTR-PM, a high-temperature reactor with a 2x 105 MWe twin unit connected to China’s grid in 2021/2022 (World Nuclear News, 2021).

Chinese state-owned enterprises (CNNC, China General Nuclear Power Group) maintain vertically integrated capabilities including design, manufacturing, construction and operation, possibly resulting in improved cost control and project execution efficiency (Ezell, 2024).

Chinese companies – similar to Rosatom – may be well positioned to serve markets that are challenging for European companies to access. State banks provide financing for overseas projects, often tied to Chinese industrial participation.

### **5.4.3 United States of America**

Vendors from the US have, to date, developed 27 different SMR designs, most notably the AP300 (Westinghouse), the BWRX-300 (Hitachi), Hermes (Kairos Power) and ENTRA1 (NuScale) (NEA, 2025).

The licensing process and approval of new SMR designs in the US is streamlined and heavily accelerated due to political decisions, in addition to heavy federal funding of the development (Energy Network Media Group, 2025). While the focus of the SMR deployment currently lies on the domestic energy market, various cooperations and MoUs between US vendors and foreign countries (e.g. NuScale Power with Romania (POWER, 2026) and Poland (Nuclear Engineering International, 2022); GE Hitachi with Poland (Power Technology, 2019) and Estonia (POWER, 2021); X-energy with the UK (X-Energy, 2025)) confirm that export options are also heavily considered.

The Export-Import Bank of the United States (EXIM) offers long-term buyer financing in the form of direct loans from EXIM and EXIM-guaranteed loans from third party lenders. EXIM works closely with U.S. exporters who are selling nuclear technologies, including traditional

large NPPs and SMRs. Loans can have repayment terms of up to 22 years after the construction of a new NPP (Export-Import Bank of the United States, 2023).

European SMR vendors therefore are in direct competition with non-European countries that possess established export infrastructures, prior operational experience with SMR designs, and substantial state-backed financing. This raises questions about the development of sufficient export markets for European designs.

Combined with the limited domestic demand, high volume thresholds for cost competitiveness, and inherent regulatory as well as geopolitical risks, the Euratom Member States are particularly ill-suited to foster SMR deployment, which should thus not be forcefully advanced.

## 6 COST ESCALATION TRENDS AND CAUSES IN SMR DEVELOPMENT

Nuclear projects (both large and small) have a well-documented history of cost escalations and schedule delays. Although SMRs are intended to be easier to build, recent experiences show that they are not immune to these challenges.

### 6.1 Empirical evidence of SMR cost escalation

Cost escalation in SMRs must be viewed in the broader background of systematically poor cost performance in nuclear construction in general. A large empirical study of 180 nuclear projects worldwide found that more than 92% exceeded their initial budgets, with mean cost overruns of around 117% (equivalent to 1.3 billion USD) and schedule overruns on the order of 64% or 36 months (Gilbert, Sovacool, Johnstone, & Stirling, 2017).

Recent examples of SMR projects indicate that the situation is similar for SMRs. The NuScale Carbon Free Power Project (CFPP) in the United States is the clearest illustration of a cost escalation in a flagship SMR project. Between 2016 and 2023, estimated overnight construction costs raised from roughly 3 billion USD for an initial 12-module plant with 600 MW to 9.3 billion USD for a reduced six-module plant with 462 MW (UtilityDive, 2024). In the same time span, the target power price climbed from about 55 USD/MWh to 89 USD/MWh (E&E News by Politico, 2023). This cost escalation, which is summarised in Table 5, directly led to the cancellation of the project in November 2023 (INSPENET, 2023).

Table 5: Cost escalation for the NuScale Carbon Free Power Project

Year	Capacity	Total cost [USD]	Cost per kW [USD/kW]
2016 (POWER, 2018)	12x 50 MW	3,000,000,000	5,000
2018 (POWER, 2018)	12x 60 MW	3,024,000,000	4,200
2020 (UtilityDive, 2024)	12x 60 MW	6,100,000,000	8,500
2021 (UtilityDive, 2022)	6x 77 MW	5,300,000,000	11,470

Year	Capacity	Total cost [USD]	Cost per kW [USD/kW]
2023 (Institute for Energy Economics and Financial Analysis, 2023)	6x 77 MW	9,300,000,000	20,100

An analysis of the already operating SMRs in China and Russia indicates that also in these countries, SMR projects are not immune to cost overruns. For China’s SMR at Shidao Bay, the initial cost projections were tripled, and the Russian floating SMRs on Akademik Lomonosov are estimated to be 300% more expensive than initially projected (Schissel & Wamsted, 2024).

This example shows that SMRs are not delivering on the lower electricity costs anticipated by advocates, especially not for early projects that must deal with high FOAK costs. This outcome is consistent with broader techno-economic studies (Asuega, Limb, & Quinn, 2023; Stewart & Shirvan, 2022) that find FOAK light-water SMRs are likely to have higher overnight costs compared to large reactors when built by inexperienced vendors and workforces (Stewart & Shirvan, 2022). While the construction time might be reduced (Asuega et al. propose a 90% confidence interval of 3.4-6.0 years for LW-SMRs, compared to 6.9-10.1 years for a larger nuclear plant), and SMRs might benefit from modularisation and simplification, the missing economy of scale results in a net cost increase of \$204/kW (Asuega, Limb, & Quinn, 2023).

## 6.2 Root causes of SMR cost escalation

Several interrelated factors help to explain why SMR cost estimates tend to rise as projects move from the early design phase towards realisation.

### Immature design

Early SMR cost estimates usually rely on conceptual designs, with many technical details and regulatory requirements still undetermined. As designs mature, additional safety features, structural reinforcements, redundancy requirements and site-specific adaptations have to be introduced, increasing both material volumes and engineering effort, and thus also construction costs.

FOAK SMR projects must also translate generic, vendor-side design claims into real sites, real regulators and real grid requirements, which often pushes them towards more complex and costly solutions.

### **Supply-chain weakness and manufacturing constraints**

The challenges of the supply chain for SMR designs are discussed in chapter 3.

### **Regulatory novelty and licensing delays**

There is external pressure on independent nuclear regulatory authorities to streamline the licensing process to allow for faster deployment of nuclear reactors, especially in the context of SMRs (WENRA, 2023). However, there are good reasons to have stringent and strict requirements for nuclear installations. This is especially true for SMRs as they are considered to be constructed closer to populated areas and industrial zones. Non-LWR designs pose substantial regulatory challenges for authorities due to limited to non-existent operational experience with these technologies.

New actors in the field and start-ups that are involved in SMRs pose additional challenges, as they have no experience in the nuclear licensing process. This typically leads to iterative regulatory engagement, additional information requests and evolving requirements, which delays the process and increases the required capital.

### **FOAK engineering burden**

FOAK SMR projects introduce substantial one-time costs for detailed design, prototyping and new manufacturing processes. Because most companies are not willing or not able to take the financial risk, they seek public subsidies or regulated off-take contracts through industry associations and policy advocacy.

In techno-economic studies, these FOAK effects for SMRs are often treated as transitory, assuming substantial cost reductions when more units are built (Noland, Hjelmeland, & Korpas, 2024; Boldon & Sabharwall, 2014). However, empirical evidence suggests that early cost overruns tend to persist, undermining the expectation that learning effects will fully recover them (Eash-Gates, et al., 2020).

### **Systematic optimism bias and strategic misrepresentation**

Empirical work on large infrastructure projects shows that cost underestimation and benefit overestimation are frequently occurring, reflecting optimism bias and, in some cases, strategic misrepresentation to secure political and financial approval (Flyvbjerg, Garbuio, & Lovallo, 2009). Nuclear projects are an example of this pattern, where construction risks,

regulatory uncertainty and financing costs are frequently downplayed (Locatelli, *Why are Megaprojects, Including Nuclear Power Plants, Delivered Overbudget and Late? Reasons and Remedies*, 2018; National Academies of Sciences, Engineering, and Medicine, 2023).

SMR cost projections are often based on aggressive assumptions about learning curves, construction time reductions and financing conditions (Stewart & Shirvan, 2022). The aforementioned cancellation of NuScale's CFPP after repeated cost escalations show the consequences of such misaligned expectations between developers, regulators and potential customers, casting a shadow on other SMR projects (Reuters, 2024).

### **Exposure to macroeconomic and financial conditions**

As nuclear projects typically require large upfront capital and long construction periods, they are highly sensitive to macroeconomic variables such as interest rates, inflation, and labour costs (IAEA, 2018). When schedules cannot be met, prolonged financing periods can substantially increase the levelized cost of electricity (Wealer, Bauer, Göke, von Hirschhausen, & Kemfert, 2019).

SMRs try to mitigate this exposure through theoretically shorter construction times and a staged deployment, but this potential advantage depends on avoiding the delays that are empirically common for recent nuclear builds. The NuScale case once again indicates that when delays and design changes occur, SMRs can experience immense cost pressure from both construction and financing, removing any theoretical benefit from the modular design.

## 7 COMPETITIVENESS OF SMRS VS. OTHER ENERGY TECHNOLOGIES

SMRs are currently not cost-competitive with the cheapest forms of energy generation such as wind and solar, and even struggle to outperform large nuclear, gas and coal when realistic project risks are included. SMRs do not eliminate the cost and schedule challenges of conventional nuclear projects. These challenges persist at a smaller scale, with commercial viability often depending on assumed learning effects, public support, and export volumes that remain uncertain.

A report (Arthur D. Little, 2025) calculates that SMRs would need levelized costs of electricity (LCOE) between 52€/MWh (Sweden) to 119€/MWh (Greece) in order to be competitive under current European market conditions. It remains highly doubtful that current SMR designs can reach this competitiveness threshold across all European countries, as current analyses propose an LCOE of LW-SMRs of 80 to 90 USD/MWh (Asuega, Limb, & Quinn, 2023; Van Hee, Peremans, & Nimmegeers, 2024).

An analysis of Steigerwald et al. even estimates LCOEs between 188 and 991 USD/MWh for 15 different SMR projects, even when most favourable parameter values are used. The study explicitly concludes that 'SMR concepts do not seem to be an economic alternative to existing low-carbon technologies' (Steigerwald, Weibezahn, Slowik, & von Hirschhausen, 2023).

### 7.1 SMRs versus large nuclear

Comparative studies for Europe estimate that SMRs have significantly higher unit costs as well as levelized costs of electricity (LCOE) than large reactors. A recent analysis finds that the average capital costs per kWh is around 41% higher for SMRs than for large nuclear, with an average LCOE of about 85€/MWh for SMRs (Van Hee, Peremans, & Nimmegeers, 2024).

Large nuclear plants benefit from economies of scale: a single large unit spreads high fixed costs over much larger output than a 300 MW SMR. Advocates argue that factory fabrication and standardized designs will allow SMRs to 'learn down' costs through serial production, but this presupposes a large and stable order book, which is not the case in any market to date.

Traditional large NPPs are typically built only where governments or the public absorb a large share of the investment and market risks (NEA/OECD, 2024). As shown above, available evidence also suggests that SMRs are likely to be even less competitive than conventional large reactors in competitive electricity markets, which further discourages private companies from engaging in new nuclear projects and increases the apparent lack of interest.

## 7.2 SMRs versus fossil fuels

SMRs are frequently positioned as an alternative to fossil fuels, which also shows in various plans across Europe to substitute coal plants with SMRs as part of the national decarbonisation strategies (NEA/OECD, 2025). However, even with Europe's established carbon pricing, SMRs are unlikely to deliver economic competitiveness without substantial additional political instruments. Additionally, the European Commission considers fossil gas and nuclear energy as transition technologies (Commission Delegated Regulation (EU) 2022/1214 of 9 March 2022 amending Delegated Regulation (EU) 2021/2139 as regards economic activities in certain energy sectors and Delegated Regulation (EU) 2021/2178 as regards specific public disclosures, 2022). Therefore, SMRs and fossil gas are direct competitors in certain market segments.

Fossil plants, particularly gas combined-cycle (CCGT) units, retain key economic advantages:

- substantially lower upfront capital costs: about 1,000€/kW for CCGT units (Abuzayed, Pollitt, Liebensteiner, & Hochgreb, 2026) vs. more than 4,000€/kW for LW-SMRs (Asuega, Limb, & Quinn, 2023)
- shorter construction timelines: 2–3 years for CCGT projects (Energy Planning, n.d.)<sup>2</sup> vs. theoretically 8–9 years for a FOAK, 4 years for a NOAK (EY Parthenon, 2024)<sup>3</sup>, and
- superior operational flexibility for grid balancing. The high fixed costs for nuclear power require near-constant baseload operation (Nuclear Economics Consulting Group, 2014; NEA, 2009), which is

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<sup>2</sup> Contrary to SMR projects, international CCGT project examples are already existing where the estimated construction time of three years could be reached without significant delays.

<sup>3</sup> Real-world examples of SMRs in Russia (Schneider, The World Nuclear Industry Status Report 2021, 2021) and China (Schneider, 2022) show significantly longer construction times of 12 and 9 years.

precisely the opposite of flexible fossil plants that can ramp up quickly (POWER Magazine, 2025).

Due to these disadvantages and the resulting risks, utilities like Southern and NextEra prioritise renewables over SMRs for fossil replacement (Schissel & Wamsted, 2024), viewing the latter as ‘an opportunity to lose money in smaller batches’ (S&P Global, 2022).

Pursuing SMRs therefore risks locking Europe into costly, slow decarbonisation paths, while accelerated fossil phase-out through renewables and electrification appears to be more viable.

### **7.3 SMRs versus renewables**

Some nuclear proponents are claiming that SMRs would be economically competitive with renewables (Strategy International, 2025). By contrast, the IEA/NEA ‘Projected Costs of Generating Electricity 2020’ report shows that new large onshore wind power plants, hydro power plants (both with reservoirs and river runs) as well as utility-scale solar PV all deliver lower LCOEs than new nuclear power plants. Only the LCOE of offshore wind parks is slightly higher than nuclear power generation. The same is true for construction overnight costs, where new nuclear is attributed with a mean value of 3,370 USD/kWe, which is above the mean overnight construction costs for large onshore wind (1,439 USD/kWe), offshore wind (2,740 USD/kWe), utility-scale solar PV (923 USD/kWe) and hydro (2,778 USD/kWe for large reservoirs and 3,026 USD/kWe for run of river) (IEA/NEA, 2020).

While International cost reviews estimate that the LCOE for renewables will experience a steep cost decline in the upcoming decades (between 2023 and 2050, -55% for solar PV and -12% for onshore wind), the LCOE for new nuclear is expected to remain constant (World Nuclear Industry Status Report, 2025). Even when considering significant LCOE reductions due to learning curves for SMR projects, the costs remain significantly above renewables. Even in an optimistic and unproven scenario of a learning rate of 15%, the LCOE of a 300 MW SMR is calculated as 42 USD/MWh in 2050 (Noland, Hjelmeland, & Korpas, 2024), which is still well above the projected 25 USD/MWh for solar PV and 35 USD/MWh for onshore wind (World Nuclear Industry Status Report, 2025).

Renewables further benefit from shorter construction times and modular deployment at project level, reducing the risk of potential investors

regarding interest rates and cost escalation in a way nuclear projects, including SMRs, have not been able to achieve.

SMR proponents respond that renewables require higher integration investments in grids (International Energy Forum, 2024), but recent analyses show these system costs (€10-25/MWh) remain modest compared to nuclear (€20-50/MWh), particularly when accounting for SMRs' high FOAK premiums and financing costs. Steigerwald et al. conclude that 'none of the tested [SMR] concepts is able to compete economically with existing renewable technologies, not even when taking their variability and necessary system integration costs into account' (Steigerwald, Weibezahn, Slowik, & von Hirschhausen, 2023).

A central competitiveness issue for SMRs is not just the pure LCOE costs, but also the underlying risks an investor must undertake. SMR business models often envisage public guarantees, concessional finance and long-term contracts (Nuclear Business Platform, n.d.; NEA/OECD, 2021). By contrast, wind and solar projects are typically financed on a project-finance basis without the same depth of sovereign guarantees (Germani, 2015), reflecting their lower technological and construction risk.

When the technology requires exceptional risk mitigation measures and nevertheless fails to deliver significantly lower or even comparable costs to other low-carbon options, SMRs cannot be described as competitive under normal market conditions. This assessment holds even if SMRs fit certain narratives of energy security or industrial strategy.

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