FACULTY OF ENGINEERING
AND ARCHITECTURE

THE ROLE OF SMALL MODULAR REACTORS IN THE BELGIAN INDUSTRIAL ENERGY TRANSITION

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This work received the financial support from SCK CEN under the LFR-SMR research activities.

EXECUTIVE SUMMARY

Small Modular Reactors (SMRs) are nuclear reactors characterized by small nominal capacity – typically under 300 MW(e) – with components that could be factory-fabricated and transported to the desired site for modular installation. A few SMR prototypes already entered operation globally or are under construction, and over 80 SMR designs are in different development stages. Belgium, through the EAGLES international consortium, is concentrating on the lead-cooled fast reactor (LFR) with a stepwise approach from a technical demonstrator to global commercialization.

This white paper analyses the potential for the deployment of SMRs in the Belgian industry. This focus stems from the fact that the industrial energy demand in Belgium accounts for over 25% of the final energy consumption, and nearly 60% of this is coming from fossil fuels. While current large-scale nuclear power plants are devoted mostly to the electricity generation, SMRs can be designed to offer a range of energy products (e.g. electricity, steam, process heat, hydrogen and other molecules). This possibility aligns with the needs of energy-intensive industries, where a significant portion of the heat demand is in the temperature range above 400ºC.

SMRs can be integrated into existing industrial sites but they can also be considered in the development of future industrial parks. The SMRs compact footprint is a good fit for industrial sites with little available space, and the SMRs operational flexibility can be tailored to the end user requirements. However, the SMR deployment in industrial areas requires careful planning regarding e.g. emergency zones, cooling systems, and logistics.

Industrial stakeholders may engage with SMRs either as nuclear operators or through "energy-as-a-service" models. While the "energy-as-a-service" model has been the traditional choice, either option had benefits and burdens in terms of needed competences and flexibility. The SMRs approach to modular deployment aims at reducing total investment costs and ease the conditions for financing.

Along with technical considerations, public acceptance is also a factor in the successful deployment of SMRs. A sustained stakeholder engagement should emphasize the SMRs opportunities in terms of e.g. resource efficiency and climate-change goals. At the same time, an honest dialogue should also address concerns linked to e.g. nuclear safety, waste, and costs.

The current interest in the SMRs development seem justified, and the SMRs can play an important role in the energy transition of the Belgian nuclear industry. However, a set of challenges remains before a broad deployment of SMRs. Building from the considerations in this white paper, future efforts should focus on specific case studies to expand our nuclear power reactors park with sizeable solutions, including SMRs.

1 GLOBAL DEVELOPMENT IN SMALL MODULAR REACTORS

Small Modular Reactors (SMRs) are **nuclear reactors** with a power output typically **under 300 MW(e)**, designed with components that could be factory-fabricated and transported to the desired site for **modular installation**[1].

According to the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA)[2], more than 80 SMR designs are at different development stages world-wide, and a handful of prototypes entered commercial operation or are under construction. SMR developments follow different reactor technologies such as water-cooled, gas cooled, liquid metal cooled, and molten salt designs. A global overview of the SMRs development is shown in Figure 1. The interest in SMRs is spread globally and many SMR vendors propose a very ambitious timeline for commercialization in the 2030s or sooner.

Belgium is also at the forefront of the international SMR developments, focusing on the Lead-cooled Fast Reactor (LFR) technology. The Belgian nuclear research centre SCK CEN has a long-standing experience in designing lead-based nuclear reactors under the MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) project[3].

Building on the existing expertise, SCK CEN formed an international consortium with RATEN, ENEA, and Ansaldo Nucleare with the aim of developing a **lead-cooled SMR** (LFR-SMR). The plan of the consortium is to build the LEANDREA technology demonstrator in Belgium to focus on fuel and materials testing, the construction of the ALFRED LFR-SMR in Romania to serve as a scale-up toward commercial deployment, and finally the commercialization of the 350 MW(e) EAGLES-300 LFR-SMR[4].

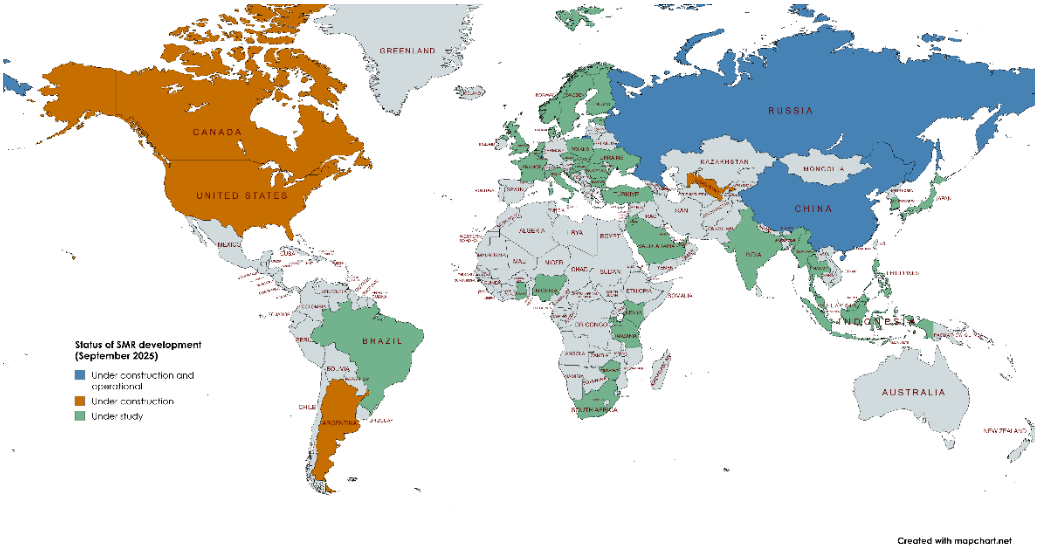

Figure 1: Status of SMR global development as of September 2025.

[1] IAEA, 2024. Small Modular Reactors: Advances in SMR Developments.

[2] NEA, 2025. The NEA Small Modular Reactor Dashboard: Third Edition

[3] MYRRHA project website, 2025.

[4] SCK CEN, 2025. Leading nuclear European organizations unite to develop EAGLES-300 next-generation lead-cooled Small Modular Reactor.

More information on the SMRs development status in different countries (listed in alphabetical order) can be found in the links below.

- Operational: China, Russia
- Under construction: Argentina, Canada, China, Russia, United States of America, Uzbekistan
- Under study: Belgium, Brazil, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Ghana, Hungary, India, Indonesia, Italy, Japan, Jordan, Kenya, the Netherlands, Nigeria, Norway, Malaysia, Myanmar, Philippines, Poland, Romania, Rwanda, Saudi Arabia, Slovakia, South Africa, South Korea, Sweden, Tanzania, Thailand, Turkey, Ukraine, United Arab Emirates, United Kingdom, Zimbabwe

It is important to clarify that **SMRs are not a specific nuclear reactor technology** but rather represent a shift in paradigm compared to large-scale nuclear power plants (NPPs). While the economies of scale principle drove the increase of the nominal capacity of large-scale NPPs (up to 1650 MW(e)), SMRs rely on the economies of numbers to reduce the overall costs. This different approach is also reflected in the envisaged construction plan, transitioning from large on-site works for large-scale NPPs to factory-assembly lines for SMRs.

The global interest in the SMRs development is motivated with the **potential** for SMRs to respond to specific energy needs and to fit in the current and future economic conditions. The standardization of components aligns well with the assembly line production envisaged for the SMRs. The modular design of the SMRs should lead to shorter construction times and make them more suitable for flexible power generation depending on the user demand. The reduced nominal capacity of the SMRs should result in a lower total investment cost, easing also the burden on the project financing. With the deployment of a dedicated SMR, an industry actor becomes largely independent from the energy price volatility.

However, significant **challenges** still lie ahead of SMRs commercial deployment. For example, most of the SMR designs are First-of-a-Kind where long-term reliability and economic competitiveness must be demonstrated. Moreover, efforts are still needed to strengthen the supply chain and adapt the current regulatory frameworks. Finally, the broad deployment of SMRs requires the availability of a large pool of specialized workforce.

Despite the significant interest around SMRs, most of the designs are still in the development phase, and both strengths and challenges will have to be evaluated as the projects develop. This white paper focuses on the opportunities of the coupling between SMRs and industrial users in Belgium. The next chapter will describe the industrial energy demand, while the interactions between the SMRs and the industrial process (Chapter 3), the industrial site (Chapter 4), the industrial partner (Chapter 5), and the society (Chapter 6) will be addressed in the rest of the publication. The main conclusion from the analysis will conclude the white paper offering ideas for future research.

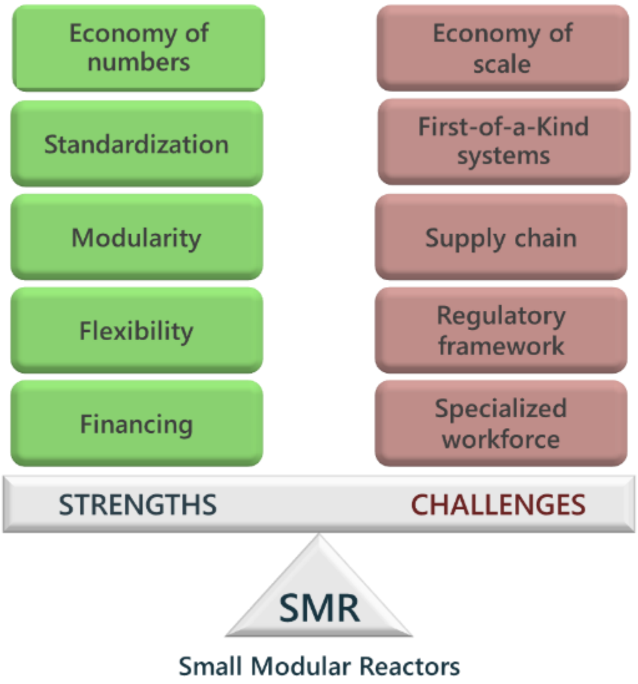

Figure 2: Balance of strengths and challenges related to the SMRs development.

Large-scale NPPs and SMRs: economies of scale vs. economies of numbers

- ***Economies of scale*** *refer to the cost advantages achieved by increasing the nominal plant capacity, leading to a lower cost per unit power or per unit of energy generated. This is possible by spreading the fixed construction and operation costs over a larger nominal capacity.*

- ***Economies of numbers*** *refer to the cost advantages achieved by the mass production of components. This is possible by the optimization of the production process, as well as the design standardization and simplification. These characteristics may also lead to a reduction in operational costs.*

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2 INDUSTRIAL ENERGY DEMAND

Belgium's industrial sector is the largest **total energy** consumer in the country and in 2024 accounted for over 25% of the final energy consumption (Figure 3). The total industrial energy demand was estimated at approximately 9.5 Mtoe, split across various forms of energy use.

Analysing the total energy demand from different sectors (Figure 4, data for 2023), the chemical sector accounts for 32.3% of the demand, followed by the iron and steel sector with 20.1%, and the food, beverages and tobacco sector with 14.7%.

For these subsectors, the energy mix used to satisfy the demand largely relies on fossil fuels:

- Chemical: natural gas (33.3%), electricity (32.5%), and oil products (28.4%)
- Iron and steel: solid fossil fuel (66.9%), natural gas (18.5%), and electricity (14.2%)
- Food, drinks, and tobacco: natural gas (58%) and electricity (31.3%)

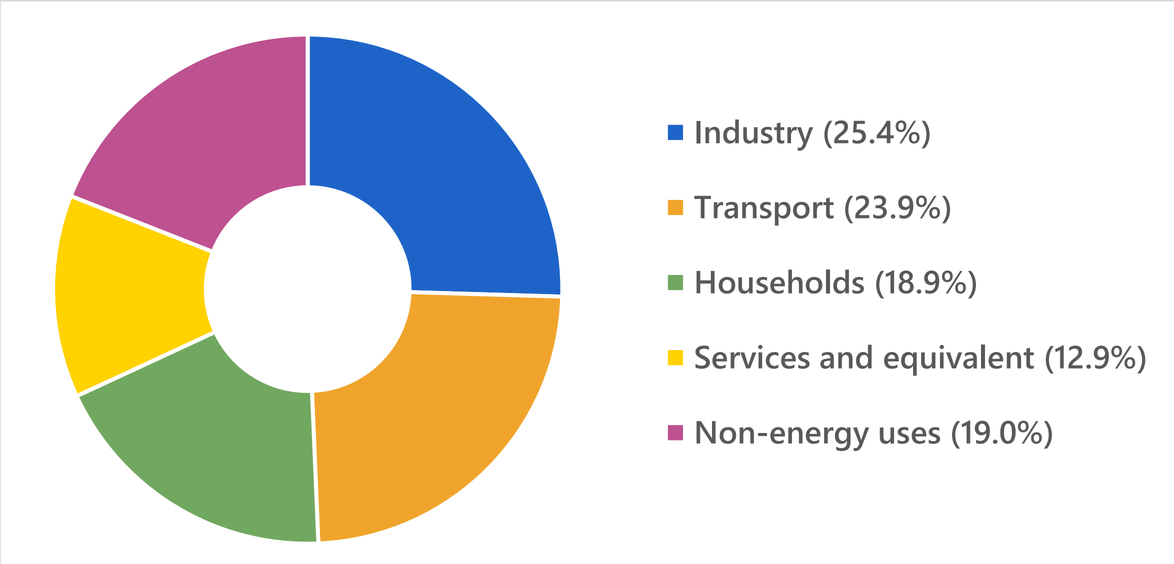

Figure 3: Total final energy consumption in Belgium. 2024 data from FPS Economy[1].

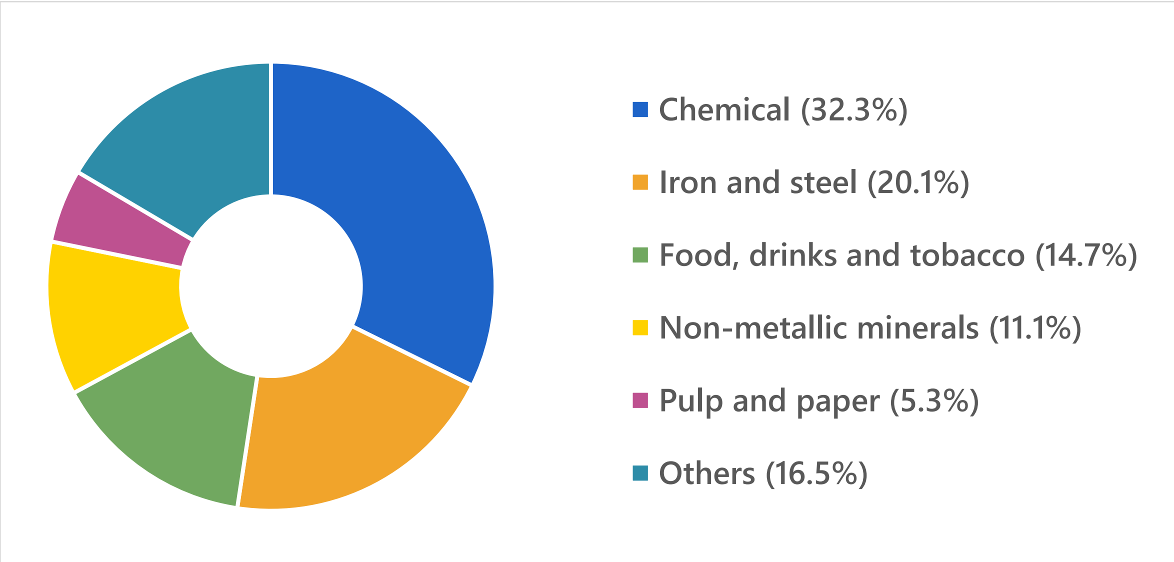

Figure 4: Total final energy consumption per industry sector. 2023 data from FPS Economy

[1] FPS Economy - Belgian Energy Data Overview. Edition June 2025.

Focusing on the **heat demand** from the industrial sector, data from 2009 (Figure 5) reveal that the chemical sector is the main user (35%), followed by the iron and steel industry (25%) and non-metallic minerals products (15%). The same data also provides information on the type of heat required from the industry sector. Significant differences can be seen on the temperature needed for the industrial processes (Figure 6). Heat at temperature above 400ºC is mainly used in the iron and steel sector, for non-metallic mineral products, and for reactions such as cracking and reforming in the chemical industry.

Various industrial actors in Belgium are actively pursuing energy efficiency and industrial decarbonization strategies, including electrification, waste heat recovery, and the use of hydrogen. In this framework, SMRs can also play a role for example in the delivery of high-temperature process heat and in the electrification of certain processes.

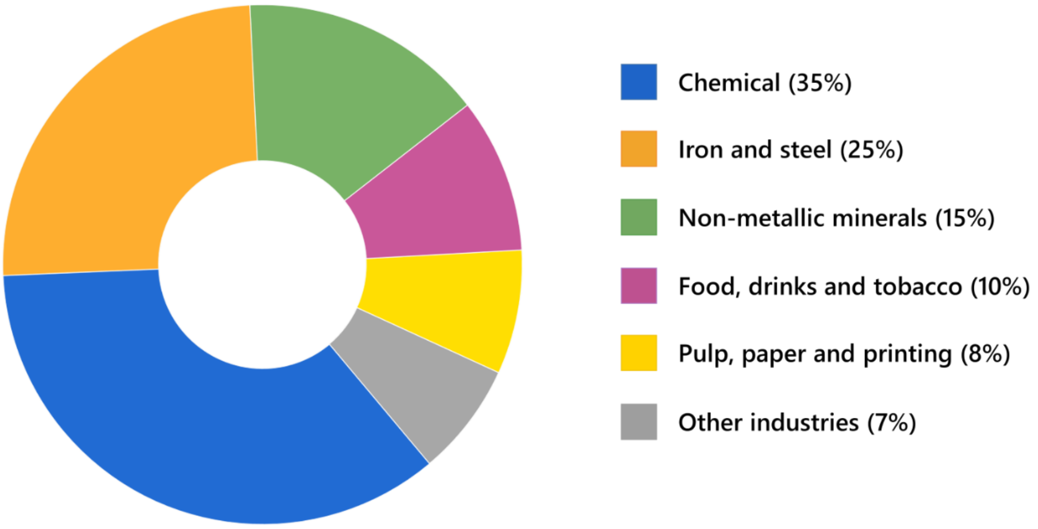

Figure 5: Industrial heat demand in Belgium by sector. 2009 data from Joint Research Centre.

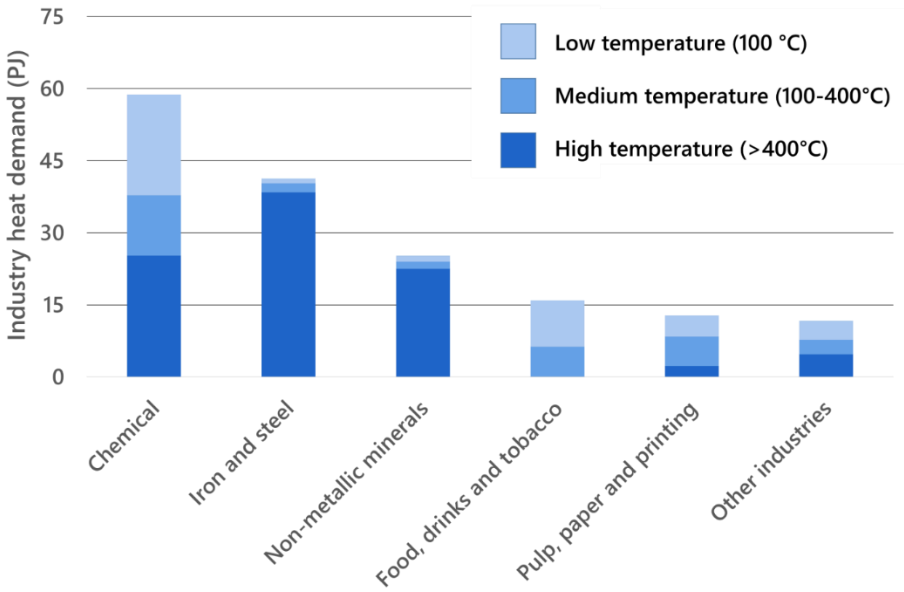

Figure 6: Industrial heat demand in Belgium by temperature range. 2009 data from Joint Research Centre.

3 SMRS AS INDUSTRY ENERGY PROVIDER

The interest driving the SMRs development is also linked to the variety of energy outputs that the SMRs can provide to the end user. In addition, the SMRs reduced capacity can be optimized for the end user needs. This co-production approach can improve efficiency and economic viability by maximizing the use of heat generated from the reactor. Examples of the different product streams from a SMR are depicted in Figure 7.

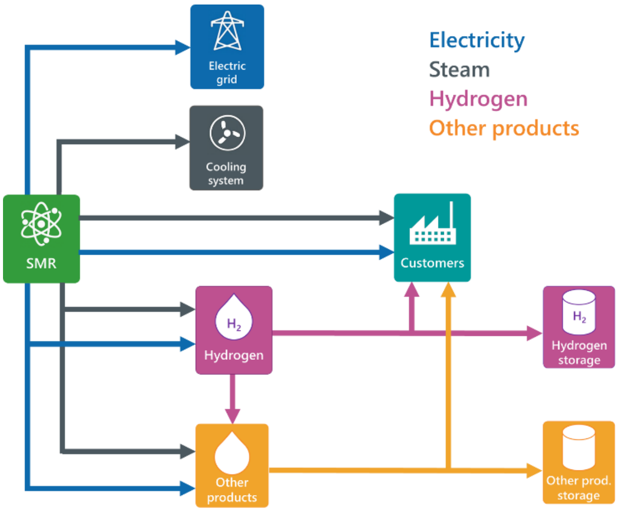

Figure 7: Schematic view of potential product streams from a SMR.

Following the examples of large-scale NPPs, SMRs can be a reliable source of low-carbon **electricity** supporting the increasing demand due to e.g. electrification. Due to the reduced capacity, SMRs seem to fit the case of small grids, remote areas, or off-grid operations.

At the same time, non-water cooled SMRs (such as lead-cooled, sodium-cooled, gas-cooled, or molten salt reactors) can also offer valuable thermal energy in the form of **steam** due to the higher operating temperature compared to water-cooled SMRs. For example LFR-SMR prototypes are envisaged to offer steam at a temperature around 400°C, and even higher temperatures are targeted by very-high temperature gas reactors. This thermal output can be used as process heat in sectors such as chemicals, iron and steel, and non-metallic minerals as shown in Figure 6. On the other hand, low-temperature heat can also be used for seawater desalination or for non-energy intensive industries[1].

The operating temperature of the non-water cooled SMRs can open the way to the production of **hydrogen** through electrolysis processes. For this, electricity and heat from the SMR can be used as input to an electrolyser cell (e.g. solid oxide). Such nuclear-produced hydrogen (also called pink hydrogen) can be used in a variety of industrial processes[2].

The availability of hydrogen allows the further upstream to **other products** such as ammonia and synthetic hydrocarbons[3]. In the case of ammonia production, the pink hydrogen can be combined with electricity and steam from the SMR in a Haber-Bosch process. Ammonia and synthetic hydrocarbons produced with pink hydrogen can serve as low-carbon fuels or feedstocks for fertilizers.

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[1] IAEA, 2022. Advances in Small Modular Reactor Technology Developments.

[2] Nuclear Energy Agency (NEA), 2022. The Role of Nuclear Power in the Hydrogen Economy.

[3] IAEA, 2013. Hydrogen Production Using Nuclear Energy.

4 SMRS AND THE INDUSTRIAL PROCESSES

Since most of the SMRs are still in the development phase, the design can be tailored to supply either single outputs, such as electricity, or multiple outputs simultaneously (co-generation), including electricity, steam, hydrogen, and other molecules.

The choice of the SMR type to be deployed will be the outcome of a multicriteria analysis, where also the industry type and requirements will be factors. However, the SMR flexibility to provide multiple products combined with stable long-term operations aligns well with the requirements of industrial users, especially when decarbonization and reliability are key drivers.

Two general scenarios can be envisaged for the SMR deployment:

- For **existing industrial processes**, it is likely that the SMRs will be adapted to integrate in existing systems. The type of products from the SMRs, as well as nominal capacity and number of units will be determined by the current and planned operations of the industrial users. It is anticipated that the level of retrofitting of the industrial process is rather limited, as the industrial processes have been already optimized for operation.
- For **conceptual industrial processes**, the process design can be optimized considering the full potential of the SMRs. A multicriteria analysis can be used to optimize both the industrial process and the SMR configuration, to maximize the benefits of the co-location in terms of SMR output and industrial production.

One additional aspect to consider for coupling SMRs with industrial processes is the possibility of having very low levels of radioactive contamination in the product delivered to the user (e.g. steam). For most of the SMR designs, the inclusion of an intermediate circuit between the primary reactor coolant and the user side provides an additional barrier to radioactive contamination. Regulatory frameworks must be considered together with industrial safety standards to determine the compatibility of the SMRs with the industrial process. While the same consideration stands also for large-scale NPPs, this eventuality is rather limited since such reactors are mainly operated for electricity production.

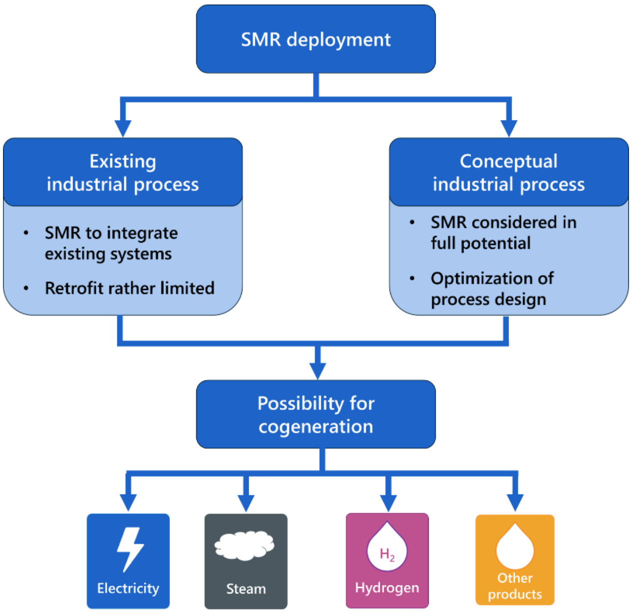

Figure 8: Schematic view of SMRs deployed in industrial processes.

5 SMRS AND THE INDUSTRIAL SITE

Existing industrial sites are typically characterized by high spatial density, where the available land has been optimized already for production activities. As such, **limited space** is available for deployment of new large-scale installations. This spatial constraint is a favorable condition for the SMRs, whose modest land requirements make them more suitable than large-scale NPPs.

Access to water for reactor **cooling** is generally an important factor to consider during the design of a nuclear power plant. However, due to the small capacity of the SMRs, dry or hybrid cooling systems can mitigate this need. In addition, some of the SMR designs rely on passive systems for reactor cooling both in normal operations and in case of accidents. In case cooling is required, the co-location of SMRs in industrial sites might benefit from existing facilities for the treatment of water for industrial processes.

In the frame of **emergency preparedness and response**, nuclear safety regulations may mandate emergency planning zones around nuclear installations. Such zones depend on the regulatory framework in place but typically range from a few hundred meters to several kilometers[1]. Industrial safety regulations must be considered for the co-location of the SMRs with other industrial hazards such as fire or explosion, and this may also influence the SMR design. Depending on the types of activities occurring in the industrial site, the siting of the SMRs may be restricted due to minimum distances from other high-risk installations.

In addition, logistical planning needs to be accounted for, encompassing the transportation and handling of large-scale components as well as the secure and regulated movement of radioactive materials. Since many SMRs aim at commercial operation before 2030 and claim a 60-year operational lifetime, the long-term vision for the industrial needs must be considered during the planning phase. Integration of SMRs into existing industrial layouts may require reconfiguration of infrastructure or relocation of certain operations to meet both nuclear and industrial safety standards.

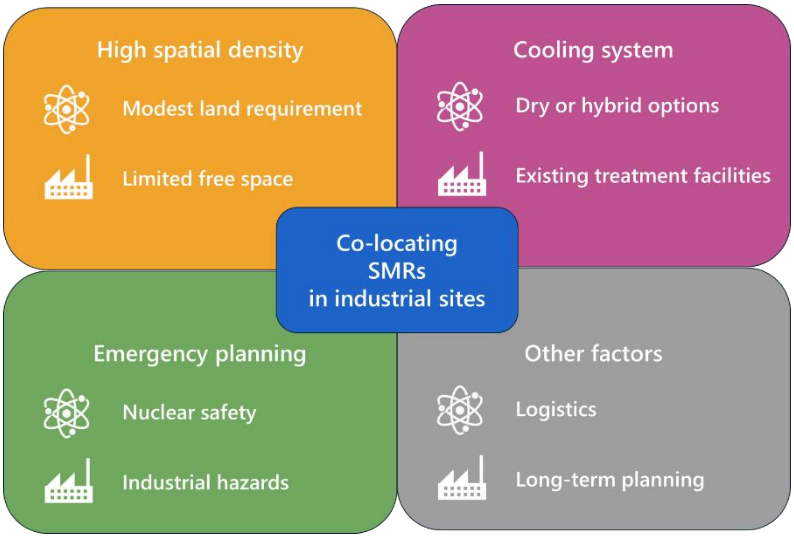

Figure 9: Factors to consider for the co-location of SMRs in industrial sites.

[1] IAEA, 2007. Arrangements for Preparedness for a Nuclear or Radiological Emergency.

6 SMRS AND THE INDUSTRIAL PARTNER

Industrial users engaging with SMR developers have several partnership options. The end users can assume the role of **nuclear operator** taking on licensing, operation, and liability. This option has not been the preferred one in case of large-scale NPPs but SMRs might be better positioned to allow end users to become nuclear operators because of the possibility for off-grid operations. This approach will enable the end user to be independent from the grid in the use of the SMRs and tailor the SMR operation to the specific industrial production requirement. However, interested actors will have to acquire specific knowledge and competences related to licensing and operation of a nuclear facility.

An alternative option for the end users is to consider the SMRs as a provider of "**energy-as-a-service**". Following this approach the end users are interested in the reliable supply of energy products (e.g. electricity, steam) to the industrial process. This alleviates the burden of licensing and operation from the end user but does not guarantee the complete flexibility between the SMR operation and industrial production requirement. When opting for the "energy-as-a-service" framework, different contracts can be stipulated among various actors to increase price stability of the service over time. More information is included in the textbox below.

With regards to project **financing**, the modularity approach of the SMR deployment may ease the conditions for financing. First, the lower total capital cost envisaged for an SMR compared to a large-scale NPP may enable more actors in pursuing this development. In addition, after the completion of the first SMR module on a site, the revenues generated from operation may contribute to the financing of subsequent modules.

SMRs for reliable energy prices: different contract options for "energy-as-a-service"

- *A **Power Purchase Agreement** (PPA) is a contract between an energy provider and a customer, where the customer buys energy from the provider at a pre-negotiated price. This scheme is proposed in the agreement between Google and Kairos Power's SMR project in the USA.*

- *A **Contract for Difference** (CfD) is a contract between an energy provider and a customer, with a third party acting as administrator. A price ("strike price") for the energy product (e.g. electricity) is agreed between the two parties. If the market price of the energy product falls below the strike price the provider is compensated by the administrator, whereas the provider returns the difference to the administrator if the market price of the energy product rises above the strike price. This scheme is proposed in the UK for the Hinkley Point C large-scale NPP.*

*In terms of project financing, other mechanisms are available as well. The **Mankala** principle is a co-operative model used for the Olkiluoto 3 NPP, and the **Regulated Asset Base** (RAB) model is a cost-recovery approach proposed for the Sizewell C NPP. **Government loans and guarantees** are also used for other large-scale NPP projects. More information can be found here.*

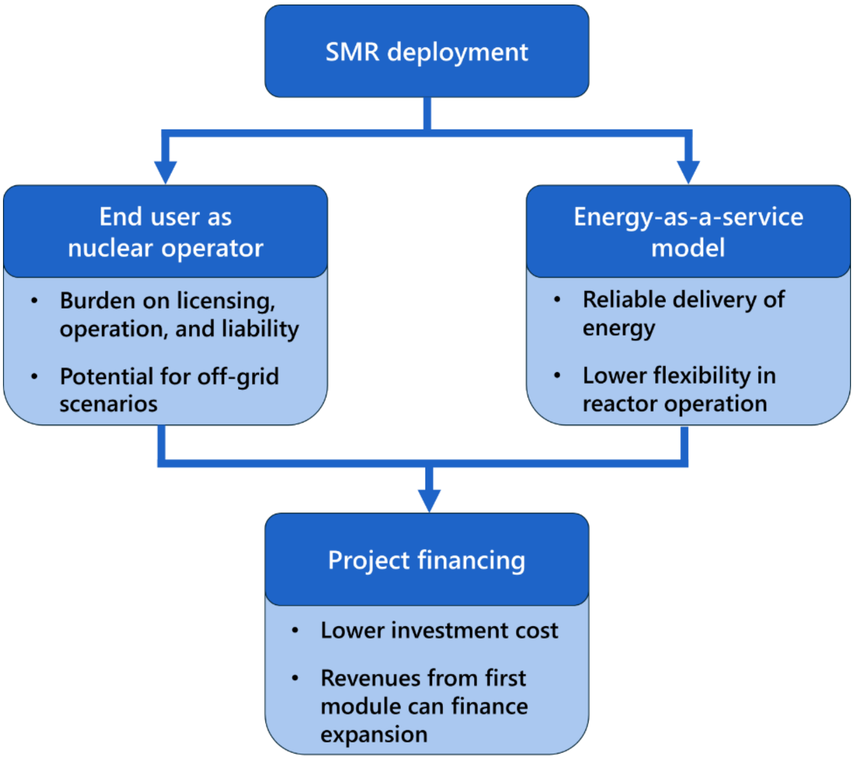

Figure 10: Options for industrial partners in the SMR deployment.

7 SMRS AND THE SOCIETY

Effective engagement with society is a crucial element for the successful implementation of large projects and deserves adequate resources also for the integration of SMRs within the industrial sector. The construction and operation of nuclear facilities generally creates significant public interest, with both positive and negative perspectives from a range of stakeholders.

Over the past years nuclear energy is increasingly recognized for its potential in reducing greenhouse gas emission and enhancing energy security. However, concerns persist in society regarding nuclear safety, waste management and economic performance.

An **evidence-based approach** to stakeholder interaction can be valuable to address these concerns. Open and honest dialogue is necessary to build trust and foster public confidence. While it is obvious that the SMR developer and industrial end user should highlight the benefits of the project, attention should be paid also to potential challenges and uncertainties. This ensures a balanced overview and may stimulate the stakeholders to actively join the development process. The early development stage of many SMR designs provides an excellent opportunity to engage with society.

From the SMR developer side, providing **open access** to data from small-scale demonstrators, safety studies, and clear emergency response plan may substantiate the safety case for SMRs and assure the public of the robustness of contingency measures in case of accidents. However, attention should be paid to the safeguarding of commercially sensitive information. Collaborations with independent actors such as academic and research institutions may also help in addressing misconceptions about SMRs.

From the industrial user side, the transition from fossil-based processes to more environmentally friendly options is appreciated in the context of climate change mitigation. The integration of SMRs within industrial operations can be viewed as an option to reduce the carbon footprint and enhance the **long-term sustainability** of the industrial sector. However, the projected costs associated with most of the SMR designs remain subject to a large uncertainty, primarily due to their First-Of-A-Kind (FOAK) status. This uncertainty may represent a determining factor in the decision-making process of industrial stakeholders. Nevertheless, the potential for increased energy security and greater independence from a volatile energy market may offset the perceived risk associated with such cost uncertainty.

The co-location of SMRs in existing industrial or nuclear sites may involve stakeholders with proven expertise in successfully manage similar projects. This might mitigate public concerns about the SMRs perceived novelty and risks. Public support may be achieved by demonstrating the significant opportunities from the SMRs deployment in terms of efficiency of resources and regional development.

In general, the sustained stakeholder engagement throughout the SMRs development offers a valuable opportunity to build a sense of shared ownership in the energy transition. Although the stakeholders can have sometimes competing interests, an inclusive dialogue to demonstrate the tangible benefits of SMRs may ensure a successful integration of SMRs in the industrial environment.

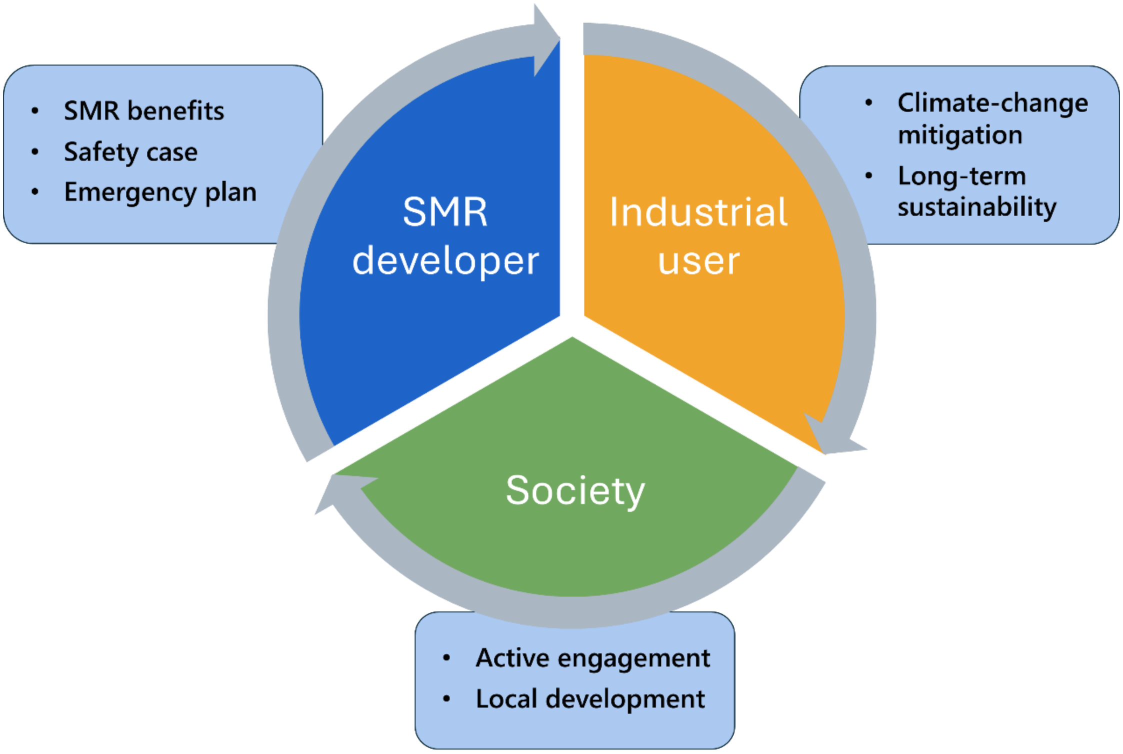

Figure 11: Approach for stakeholder engagement in the SMRs development.

CONCLUSION AND FUTURE WORK

SMRs can play an important role in satisfying the energy requirements of industrial actors. Representing an alternative and complement to large-scale NPPs, SMRs with their reduced nominal capacity, increased flexibility, and possibility for co-generation, seem to be a good fit to the energy demand of several industrial users.

This white paper analyzed the introduction of SMRs in industrial sites, by considering the different energy outputs that the SMR can provide and how they can satisfy the energy requirements of industrial end users. The interplay between the SMR and the industrial process, site, partner, and society was addressed.

From this analysis the SMRs emerge as an interesting option for the energy needs of different industrial end-users, although additional considerations are still needed before a commercial deployment at scale. Adding to the electricity production, with the possibility of co-generation the SMRs can enter the markets for industrial steam, hydrogen and other molecules.

SMRs can be included both in existing industrial sites, as well as in the conceptual planning of future industrial parks. In the first case, it is likely that the SMRs will be adapted to the existing processes, while full optimization can be carried out for developing sites. Factors such as available space, need for cooling system, and emergency planning must be considered during the integration of the SMRs in the industrial site.

When considering an SMR, the industrial actor can become a nuclear operator or view the SMR as an energy provider. The first approach results in responsibilities for licensing, operation, and liability, compensated for by the increased flexibility in operation in a potential off-grid scenario. The second approach focuses on the delivery of specified energy products as a service to the end user. Different types of contracts are possible for either approach, with the view of ensuring long-term stability of prices for the SMR developer and the end user.

The development of SMRs is not happening in a vacuum, but interaction with society is an important aspect leading to successful implementation. An open and honest dialogue with the different stakeholders can increase public engagement and ensure general support for the project.

Future work should focus on the analysis of specific case studies coupling the SMRs to real industrial users. These detailed studies will inform SMR developers as well as industrial users about the SMR potential. In addition, business models can be developed addressing gaps in the economic performance of the SMRs and on the possibilities for project financing.

The next decade will be pivotal for the SMRs development and for the energy transition efforts. Success will require cross-sectorial collaboration, robust policy support, and a clear vision for the role of nuclear energy in a sustainable industry.