Elia - Nuclear Deployment Options for Belgium - Technical Summary

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Elia Transmission Belgium

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W.005273 - Elia - Support on nuclear siting in Belgium

Nuclear Deployment Options for Belgium - Technical Summary for Stakeholder Consultation

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1. Introduction

This document gives a practical summary of nuclear deployment options in Belgium, prepared to support Elia's public consultation. It's built on Tractebel's technical work, which provides the assumptions and parameters used in Elia's scenario modelling. The aim is to clarify how nuclear technologies could fit into the future energy mix, and to show that the scenarios are backed by solid engineering and siting analysis. All key inputs (including deployment schedules, cost figures, site selection criteria, and grid connection aspects) come directly from Tractebel's detailed study (Ref. [1]); they are based on Tractebel's best knowledge at the time of writing and are therefore not binding.

2. Overview of Technologies

In this section a simplified overview of nuclear technologies considered for Belgium's energy mix is provided, distinguishing between Large Nuclear Power Plants (NPPs) and Small Modular Reactors (SMRs). The study evaluates both types of technologies in detail, presenting their respective advantages, limitations, and technical characteristics. It highlights how each option contributes differently to the energy system, with large NPPs offering scale and stability to the grid, and SMRs providing modularity, flexibility and serving the need for industrial heat. These differences are explored to support informed scenario development.

2.1. Large Nuclear Power Plants

Large NPPs are conventional, gigawatt-scale reactors designed for centralized electricity generation. These technologies have a long construction history and are considered proven and mature, with a long operating history in Europe and globally. Their deployment is typically state-led and involves extensive planning and regulatory coordination. Large NPPs are well-suited for base-load operation and contribute significantly to grid stability through inertia and frequency regulation. Technologies considered include:

- **EPR (French design by Électricité de France (EDF)/Framatome)**: High-capacity reactor (~1650 MWe), active safety systems, limited modular construction.
- **AP1000 (American design by Westinghouse)**: ~1150 MWe, passive safety systems, extensive modular construction.

NOTE: The **APR1400 (Korean design by KHNP/KEPCO)** would be well suited as well but KHNP appears to have withdrawn from the European market.

Key characteristics:

- Built in pairs ("twinning") or sets of three (“tripletting”) to reduce costs and improve efficiency.
- Require **large sites** (>100 hectares) near major water sources (see Section 4).
- Proven **load-following** and **island operation** capabilities (see Section 3).
- **Safety Concept:** Active safety systems require power and operator action to function, while passive safety systems rely on natural forces (gravity, convection) to ensure reactor safety.
- Construction record:
  - **EDF - EPR & EPR2**
    - EPR units built: China (2), Finland (1), France (1); under construction in UK (4).
    - EDF developing EPR2 for France: 6 units planned on 3 sites, with potential for 8 more.
  - **Westinghouse - AP1000**
    - AP1000 units: China (4 in operation, 8 under construction, 4 more planned), US (2 in operation, 2 partially built).
    - New projects planned in Poland (3 units) and potential revival in the US (e.g., Texas, V.C. Summer).
  - **KHNP - APR1400 / EU-APR**
    - APR1400 deployed in Korea and UAE (Barakah: 4 units built in 8 years).
    - EU-APR selected in Czech Republic: up to 4 units on 2 sites.
  - First-Of-A-Kind (FOAK) projects in China (EPR and AP1000 reactors) completed in **~9 years**[1]. Recent projects in France (EPR), Finland (EPR), US (AP1000), and UK (EPR) have experienced typical growing pains of FOAK designs resulting in significant schedule and cost challenges. Lessons learned should drive cost and schedule improvements.
  - New strategy: build units in pairs for cost efficiency (e.g., Sizewell C, Hinkley Point, EPR2 rollout).

2.2. Small Modular Reactors

SMRs are compact nuclear reactors designed for flexible deployment, including industrial integration and decentralized power generation.

Tractebel has developed in the last years an integrated vision of an ecosystem including all energy solutions (renewables, hydrogen, electrification, interconnections). For the different SMR technologies, a **blended fleet** approach is adopted. Since no single SMR technology can address alone all Belgian energy challenges, at least three pillars must be developed, focusing on different advantages of the technologies under development.

[1] https://www.worldnuclearreport.org/A-Double-First-for-China-as-Taishan-EPR-and-Sanmen-AP1000-Connect-to-the-Grid

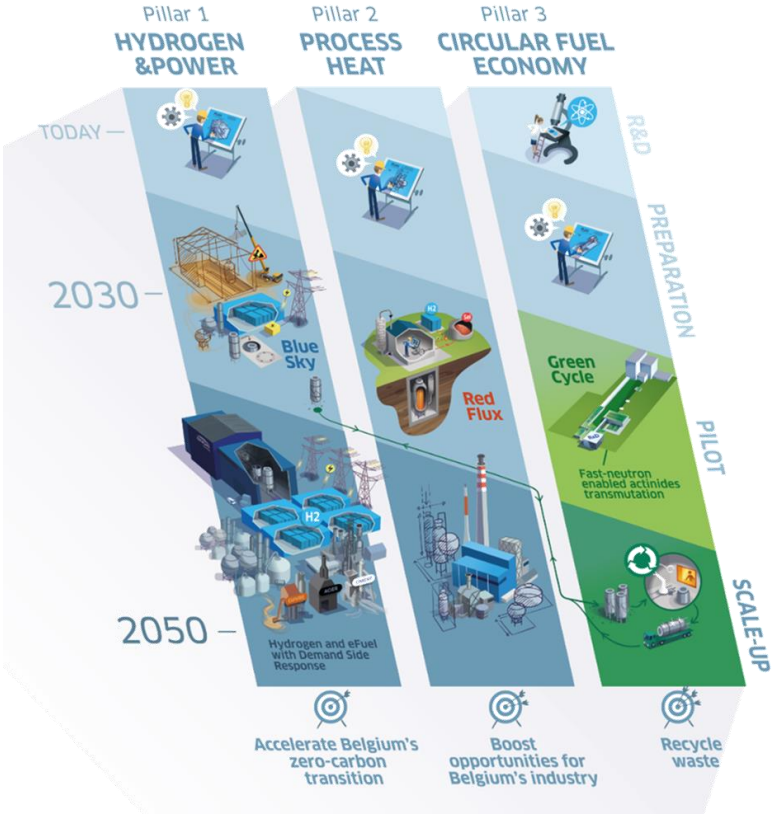

Figure 1: SMR technology development pillars - Source: Tractebel

Concerning **SMRs**, in the present study Tractebel focused its efforts on those technologies with a reasonable chance to be deployed in Belgium within the timeframe of the federal grid development plan (i.e. an estimated grid connection date between 2035 - 2050).

Excluded designs:

- Concepts developed by non-OECD countries.
- Projects that are considered dormant, i.e. no significant progress has been observed in the last two years.
- Designs with a power output below 15 MWe per module were not considered, judging that their impact would be too limited to the Belgian grid for this exercise.

For the purpose of this study, Tractebel divided the SMRs into four **SMR Families:**

- **Electricity-focus**: Focused on electricity generation, with integration of low-temperature applications depending on the design - e.g. BWRX-300, Rolls-Royce SMR, AP-300, Nuward SMR.
- **Versatile Applications**: Designed to supply electricity and high-temperature heat for industrial processes - e.g. XE-100, KP-FHR.
- **Heat Storage Integration**: Include integrated thermal storage to enhance flexibility and grid support - e.g. Natrium, Hexana.
- **Closing the Fuel Cycle**: Advanced reactors designed to recycle nuclear fuel and reduce waste - e.g. EAGLES-300, LFR-AS-200, Thorizon One.

See the full list of SMRs considered in Appendix 1. While prudency dictates to rely on only a fraction of those designs to actually make their way to successful deployment, there are enough candidates and demonstration projects in each family to support the view that the blended fleet approach will actually come through.

Key characteristics:

- Modular and scalable, with capacities typically between 100-300 MWe[2] per unit. SMRs are designed to be installed in clusters of multiple units (variable per design).
- Can be deployed on industrial sites (15-40 ha), closer to demand (see Section 4).
- Load-following and island operation capabilities vary by design.
- **Safety concept:** Depending on the design it can include passive or hybrid safety systems.
- **Deployment status:** The market for SMRs is still at its dawn, with several demonstration projects either operational or under construction, together with a few FOAK reactors that are supposed to be followed by a large number of projects in the international market. Construction projects are especially advanced in North America, while the European projects are still in a pre-construction stage (FOAK announced dates available in Appendix 2). Most of European designs are either supported by the European Industrial Alliance on SMR, by France 2030 or other national program (e.g. UK SMR).

European Industrial Alliance on SMR

The European Industrial Alliance on Small Modular Reactors (SMRs) was launched in February 2024 by the European Commission to accelerate the development, demonstration, and deployment of SMRs in Europe by the mid-2030s. The Alliance brings together industry stakeholders to promote safe, low-carbon nuclear technologies and rebuild the European supply chain for nuclear power. It operates through dedicated working groups and supports selected SMR projects, aiming to enhance energy security and sustainability across the EU.[3]

The designs approved by this alliance are:

- **EU-SMR-LFR project (EAGLES-300)** (Ansaldo Nucleare, SCK-CEN, ENEA, RATEN)
- **CityHeat project** (Calogena, Steady Energy)
- **Project Quantum** (Last Energy)
- **European LFR AS Project** (newcleo)
- **Nuward** (EDF)
- **European BWRX-300 SMR** (OSGE)
- **Rolls-Royce SMR** (Rolls-Royce SMR Ltd)
- **NuScale VOYGR™ SMR** (RoPower Nuclear S.A)
- **Thorizon One project** (Thorizon).

[2] There are some SMR designs that can produce more than 300 MWe but are exceptions.

[3] European Industrial Alliance on SMRs: https://single-market-economy.ec.europa.eu/industry/industrial-alliances/european-industrial-alliance-small-modular-reactors_en

3. Characteristics with respect to the grid

Grid integration is a key consideration for nuclear technologies, particularly in a system with increasing shares of variable renewable energy. Both large NPPs and SMRs offer valuable capabilities that support grid stability and flexibility. The study covered:

- **Loss Of Offsite Power (LOOP) requirement**: Scenarios where a facility loses its external electrical supply from the grid. The reactor must demonstrate it capability to safely shut down or maintain critical functions during a LOOP event.
- **Load following capability**: Ability to adjust output to match demand or compensate for renewable energy variability.
- **Island Mode capability**: According to European Utility Requirements organization for LWR NPPs (EUR) (Chapter 2.7 - Grid Requirements), the reactor should be capable of stable island operation at reduced power, supplying its own internal auxiliary loads, for a specified period.
- **Power Ramp-up/down**: Capability of increasing and decreasing the power output.
- **Cogeneration:** Simultaneous production of electricity and useful heat. This process can achieve higher overall efficiency, as the heat generated during electricity production is not wasted but used for other purposes, such as district heating, industrial processes, desalination or hydrogen production.
- **Edge-of-grid and off-grid (SMRs only):** Fully off-grid SMRs means completely isolated from the grid, edge-of-grid SMR is referring to SMRs which are connected to the grid, but at locations at the periphery of the main grid, where grid infrastructure is weaker, less redundant, or more prone to reliability issues.
- **Scheduled and Unscheduled Maintenance:** The unavailability of the production unit due to maintenance activities impacts the production. This is key metric for assessing the reliability of power generation.

Large NPPs contribute to grid inertia and frequency regulation due to their large rotating masses and stable output. Their ability to operate in island mode and follow load within defined parameters makes them suitable for base-load operation with limited flexibility.

SMRs, by contrast, offer enhanced operational flexibility. Many designs support fast ramping and load-following, making them well-suited to complement intermittent renewables. Their siting near industrial clusters or grid edges can reduce transmission needs and improve local grid resilience.

Full list of features comparison is presented in Section 5. These characteristics must be considered in dispatch modelling and grid planning tools to ensure reliable and efficient system operation.

4. Siting Considerations

Siting is a critical factor in the deployment of nuclear technologies. While **specific locations are confidential at this stage**, general principles can be outlined to guide stakeholder understanding.

4.1. Large Nuclear Power Plants

Large NPPs require large plots of land (typically >100 hectares for a pair of reactors) and proximity to major water sources for cooling. These sites must also meet stringent safety, environmental, and grid connectivity criteria. Due to their scale and infrastructure needs, suitable locations are limited and often pre-identified through national planning processes.

Tractebel has identified only two sites of sufficient size and suitable characteristics for hosting pairs of reactors. Securing (i.e. reserving) these sites for implementing the country's future energy plan will be a prerogative of the Belgian government and is a prerequisite for the large reactor scenarios discussed in Ref. [1].

4.2. Small Modular Reactors

SMRs offer greater flexibility in siting. They can be deployed on **industrial sites** ranging typically from 15 to 40 hectares, often closer to demand centres. This allows integration into existing industrial clusters, reducing transmission needs and enabling cogeneration applications. Key siting criteria include:

- Proximity to industrial heat demand or data centres.
- Access to cooling water (air-cooled designs are less common in early deployment).
- Grid connection capacity and resilience.
- Favorable topography and geotechnical conditions.
- Compatibility with land use planning and environmental constraints.

Siting assessments typically follow international guidelines (e.g. IAEA SSG-35) and involve multi-criteria screening using GIS (Geographic Information Systems) tools. These evaluations consider exclusion zones (e.g. floodplains, protected areas) and discretionary factors (e.g. infrastructure proximity, population density).

While detailed maps and candidate sites are confidential, the methodology ensures that selected locations align with safety, technical, and strategic priorities, while complying with the recommendations made by the IAEA.

Tractebel has identified a list of 7 to 8 potential areas located nearby industrial clusters. The selection of sites and the development of projects in these areas will require close coordination between public and private stakeholders, supported by consistent government involvement throughout the project lifecycle.

Besides the industrial focus, multi-unit SMRs of gigawatt scale may also compete with large reactors for the production of electricity and would require the same type of site attributes (area, access to cooling water, grid connection, etc.) as large reactors.

5. Key Features comparison

This section outlines the key technical features that both Large Nuclear Power Plants and Small Modular Reactors benefit from. These characteristics are essential to understanding their performance, safety, and integration into the energy system. While some features are shared, others vary significantly depending on the technology type, influencing their suitability for different deployment scenarios:

Feature	Large NPPs	SMRs
Example Technologies	EPR, AP1000	BWRX-300, Nuward, XE-100, Natrium, EAGLES-300, Hexana, LFR-AS-200, Thorizon One, Rolls Royce SMR. Full list in Appendix 1.
Power Output	~1150-1650 MWe	~20-350 MWe per module
Safety Concept	Active or passive	Passive or hybrid
Construction Model	Fleet (twinning/tripletting)	Modular, scalable, clusters
Availability Factor	90%	90-95%
Load-following	Yes (optional)	Yes (design dependent)
Island Operation	Yes (EUR compliant)	Yes (varies by design)
Ramping up/down	EUR compliant Design dependent Ramp up/down : up to 5%/min Step up/down : up to 10%/min Between 25% and 100% power	Very design dependent Up to ±7%/min With possible temporary boost of ±17%/min
Cogeneration	Not considered (but District Heating is possible)	Yes, except for power-only designs.
Off-grid & End-of-Grid	No	Yes, depending on the design
Siting Requirement	>100 ha near water (for a pair of reactors)	15-40 ha (for 600 MWe) industrial sites

6. Realistic Deployment Timelines

6.1. Large Nuclear Power Plants

- Based on the current industry track record, deployment of a first unit would reasonably be achieved by **2042** - provided that a program is initiated by the end of 2026.
- Based on the critical path under current regulatory framework and stakeholder environment, and should enabling conditions be met (technological readiness, regulatory alignment, stakeholder commitment, and timely decision-making), then deployment could be envisaged as early as **2039**.

- **Key Enablers:**
  - Fleet Approach: Building 2 reactors (or 3) per site lowers costs and improves logistical efficiency. Vendors usually prefer this setup.
  - Government Support: Strong political backing and public tenders help attract vendors.
  - Vendor Experience: EPR and AP1000 are proven technologies with active projects in Europe and worldwide.
  - Streamlined Licensing: Using existing safety reviews from trusted regulators speeds up approval.
  - Available Sites: Options exist, with sufficient grid and water access, but need to be secured.
  - Grid Benefits: Large NPPs help stabilize the grid with steady power and frequency control.
- **Key constraints:**
  - Financing, from feasibility phase to final investment decision.
  - Long permitting procedures, including public consultations and zoning changes.
  - Site characterization and preparation (~5-7 years).
  - Licensing and design adaptation (~6-7 years), in parallel stream with siting activities.
  - Construction and commissioning (~7-9 years).

- **Total timeline**: from ~13-15 years in the critical path scenario, to ~15-17 years considering past industry track record.
  - **Dependencies**: Political decision, vendor engagement, owner-operator readiness, regulatory alignment, and availability of suitable sites (>100 ha).

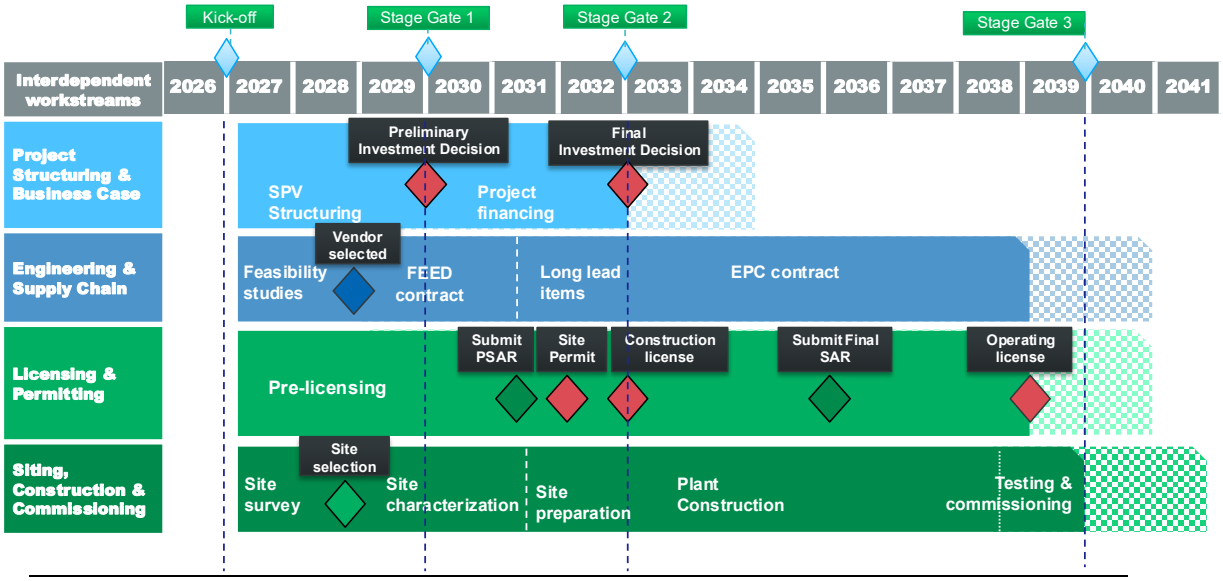

Figure 2: A perspective into Large NPPs deployment: ~13-15 in the critical path scenario, to ~15-17 years considering industry track record - Source: Tractebel

6.2. Small Modular Reactors

- Based on the current industry track record, deployment of a first unit would reasonably be achieved by **2037** - provided that a program is initiated by the start of 2026.
- Based on the critical path under current regulatory framework and stakeholder environment, and should enabling conditions be met (technological readiness, regulatory alignment, stakeholder commitment, and timely decision-making), then deployment could be envisaged as early as **2035**.

- **Key enablers:**
  - Shorter construction times (4-7 years for FOAK, 3-5 years for Next-Of-A-Kind (NOAK)).
  - Potential for private-led initiatives with faster decision-making.
  - Modular construction and smaller site requirements (15-40 ha).
  - Industrial partnerships and targeted use cases (e.g. cogeneration, data centers).
  - Belgian supply chain readiness: current Belgian industry experience (e.g.: recent construction of Combined Cycle Gas Turbines) is closer to building SMRs than large reactors.

- **Key Constraints:**
  - Technology readiness level (TRL) varies by SMR family.
  - Licensing familiarity and fuel supply chain development still evolving.
  - Regulatory engagement with Nuclear Regulator needed early.

- **Total timeline**: from ~9-11 years in the critical path scenario, to ~11-13 years considering past industry track record, depending on technology maturity and stakeholder alignment.

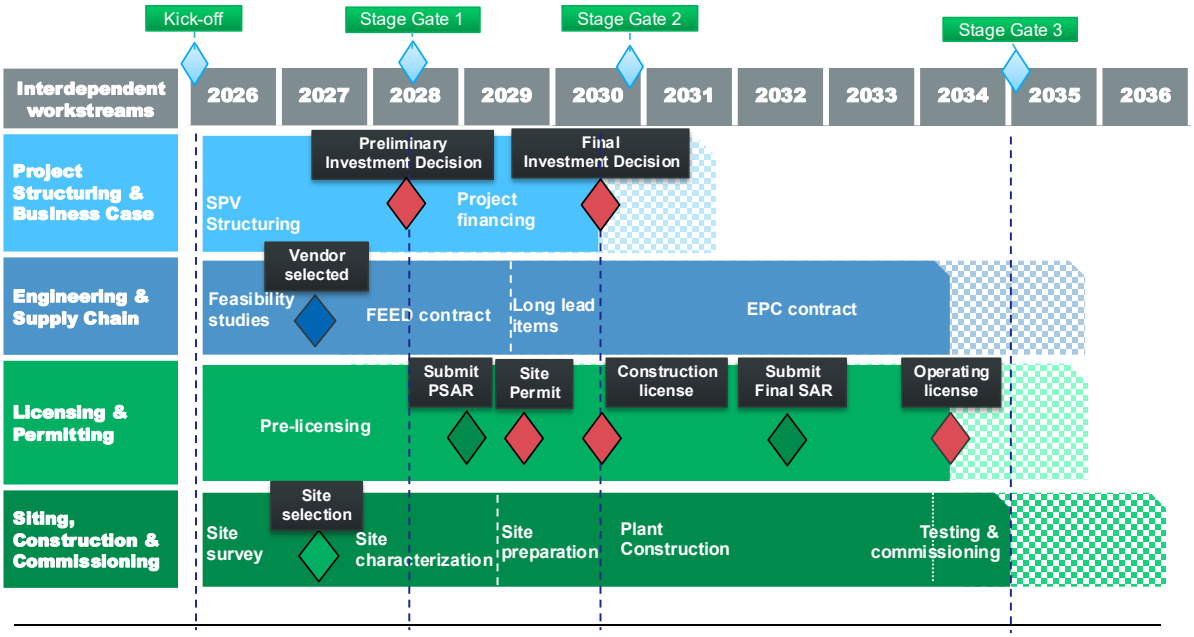

Figure 3: A perspective into SMRs deployment: ~9-11 years in the critical path scenario, ~11-13 years considering industry track record - Source: Tractebel

7. Marginal Price of Nuclear

The marginal price of nuclear energy reflects the operating costs associated with electricity generation, excluding capital expenditures and fixed operational costs. These costs are crucial inputs for economic dispatch models, as they help determine when nuclear power plants are likely to operate, taking into account the other constraints outlined in this report.

7.1. Large Nuclear Power Plants

The estimated marginal price, based on variable operating expenditures only, results in **€11/MWh.** Note that this figure mainly includes the cost of fuel.

This value assumes a load factor of 90% and benefit from economies of scale when multiple units are built on the same site.

7.2. Small Modular Reactors

There are currently no operational SMRs from which to derive proven marginal price figures. The values discussed in this study are estimations based on current designs and expected fuel and variable operational costs. The expected marginal costs for SMRs vary depending on the reactor family and configuration, with estimated differences compared to large NPPs **ranging from +5-30% for power-only SMRs, +0-30% for versatile applications, +0-50% for heat storage designs, and up to around +100% for advanced reactors designed to close the fuel cycle**.

While this last reactor family may initially entail higher marginal costs, their economics can be positively influenced by the valorization of plutonium within the fuel cycle, allowing part of the fuel cost to be offset and improving overall resource efficiency over time.

These ranges illustrate the expected cost competitiveness of SMRs relative to large NPPs, based on design maturity and scale.

8. Conclusions

This summary provides a technically grounded overview of nuclear deployment options for Belgium's 2050 energy mix. It highlights the realistic timelines, cost competitiveness, siting flexibility, and grid integration potential of both large NPPs and SMRs.

Large reactors offer proven technology and scale, while SMRs bring modularity and industrial synergies. Together, they form complementary pathways that can support decarbonization, energy security, and system flexibility.

These insights support Elia's scenario development and stakeholder engagement, ensuring that nuclear options are transparently and robustly considered in Belgium's long-term energy planning.

9. References

[1] Input for Elia's long-term scenarios - ELIANUC_4NT_0905739_000_00_NTE (CONFIDENTIAL).

10. Abbreviations and Acronyms

AP1000 - Westinghouse Pressurized Water Reactor design
APR - Korean Pressurized Water Reactor design
EDF - Électricité de France
EPR - European Pressurized Reactor
EUR - European Utility Requirements
FOAK - First-Of-A-Kind
GIS - Geographic Information Systems
GW - Gigawatt
HTGR - High Temperature Gas-cooled Reactor
IAEA - International Atomic Energy Agency
KEPCO - Korea Electric Power Corporation
KHNP - Korea Hydro & Nuclear Power
NOAK - Next-Of-A-Kind
LFR - Lead-cooled Fast Reactor
LOOP - Loss of Offsite Power
MSR - Molten Salt Reactor
MW - Megawatt
MWe - Megawatt electric
NPP - Nuclear Power Plant
PWR - Pressurized Water Reactor
SFR - Sodium-cooled Fast Reactor
SMR - Small Modular Reactor
SSG-35 - IAEA Safety Standard for Site Survey and Site Selection
TRL - Technology Readiness Level

Appendix 1: SMRs evaluated

Model	Company	Technology	Country	SMR Family
BWRX-300	GEH	BWR	USA	Electricity-focus
AP-300	Westinghouse	PWR	USA	Electricity-focus
RR SMR	Rolls-Royce	PWR	UK	Electricity-focus
VOYGR	Nuscale	iPWR	USA	Electricity-focus
SMR-300	Holtec	PWR	USA	Electricity-focus
PWR-20	Last Energy	iPWR	USA	Electricity-focus
iSMR	KHNP	iPWR	Korea	Electricity-focus
Nuward SMR	Nuward EDF	PWR	France	Electricity-focus
XE-100	X-Energy	HTGR	USA	Versatile App.
KP-FHR	Kairos Power	MSR	USA	Versatile App.
SEALER	Blykalla	LFR	Sweden	Versatile App.
Aurora	Oklo	SFR	USA	Versatile App.
ARC-100	ARC Clean Tech	SFR	USA/Canada	Versatile App.
Otrera ONE	Otrera	SFR	France	Versatile App.
Blue Capsule	Blue Capsule	SFR	France	Versatile App.
Natrium	Terrapower	SFR	USA	Heat Storage
Hexana	Hexana	SFR	France	Heat Storage
IMSR	Terrestrial Energy	MSR	Canada/USA	Heat Storage
EAGLES-300	EAGLES consortium (SCK CEN, Ansaldo Nucleare, ENEA, RATEN)	LFR	EU	Closing Cycle
LFR-AS-200	newcleo	LFR	France	Closing Cycle
Thorizon One	Thorizon	MSR	Netherlands	Closing Cycle
Stellarium	Stellaria	MSR	France	Closing Cycle

Appendix 2 - SMRs FOAK

Reactor name	FOAK announced COD (year)	FOAK location
BWRX-300	2030	Darlington, Canada
SMR-300	2030	Palisades, US
VOYGR6	2031	Doicesti, Romania
PWR-20	2028	Wales -Llynfi
Rolls-Royce SMR	2034	CZ (Temelin) / UK
ARC-100	2032	Point Lepreau, Canada
Aurora	2030	Idaho National Laboratory
KP-FHR	2035	Oak Ridge (Hermes)
Sealer-55	2033	Nyköping, Sweden
Xe-100	2030	Texas, USA
Natrium	2031	Wyoming, US
LEANDREA	2035	Mol, Belgium
LFR-AS-200	2032	Slovakia, Bohunice

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