

TRACTEBEL

ENGIE



The Rise of Nuclear Technologies 2.0

17/03/2021



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INTERNAL



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CONFIDENTIAL

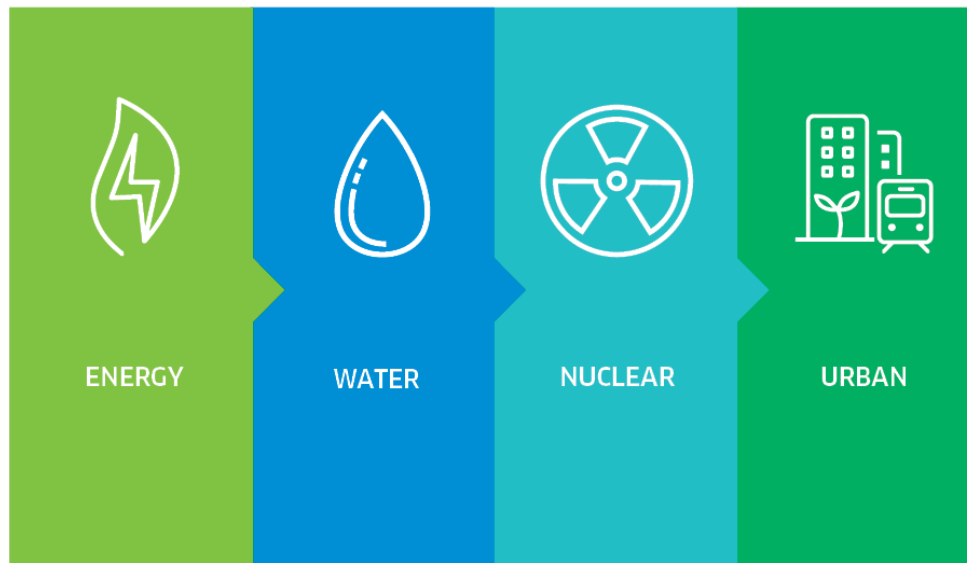
5,000 imaginative experts

Through a network organisation with 7 Entities and 4 Business Lines

ENTITIES

- 1 Asia-Pacific
- 2 Belgium & Central South Europe
- 3 France, Africa & China
- 4 Germany, Eurasia & Turkey
- 5 Latin America
- 6 Middle East & India
- 7 Research & Innovative Solutions

BUSINESS LINES



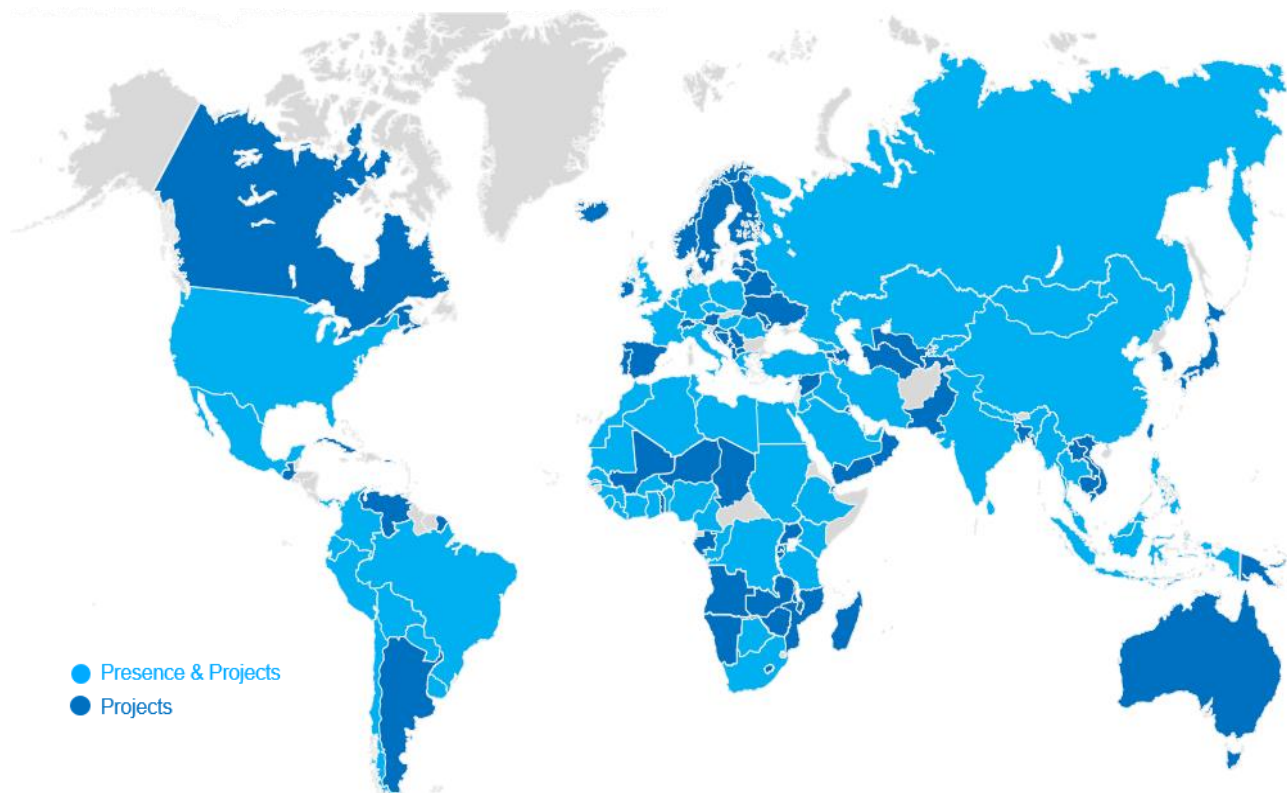
Offering you an A-Z value proposition

combining strategy, design, engineering and project management



2019

Key figures



671 M€

turnover



5,000

employees

+70

presence in more
than 70 countries

>160

projects in over
160 countries

0,6

High safety standard :
frequency rate 0,6

To deep-dive the question of SMRs

Tractebel White Paper

1. Chapter 1: The vibrant international race for Advanced Nuclear

- SMR design context explanation
- International trends synthesis

2. Chapter 2: Beyond Baseload electricity production

- Insights from in-depth master plan electric study (Europe)

3. Chapter 3: European Heat Market

- Main heat-intensive industrial sectors characterization
- 100+ identified and screened theoretically compatible sites (Europe)

4. Chapter 4: Low-carbon Hydrogen for eMolecules

- Market drivers for synthetic fuels (eFuel)
- Insight from industrial project prefeasibility (100MW scalable to 1GW)



<https://tractebel-engie.com/files/attachments/.3456/Tractebel-The-rise-of-nuclear-technology-2-0.pdf>

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1. SMR Technologies Overview

21st century context and drive

International dynamics

Water type SMR overview

Molten-Salt type SMR overview

High-Temperature-Gas type MMR overview

Recent industry milestones

2. Tractebel Market Study

Heat Market Study

Tomorrow's European Grid Alternatives



Small Modular Reactors bring sensible answers to crucial questions

Inherently safe

- Eliminate the risk of severe accident by making them physically impossible
- **Passively** cool down the reactor even in the most adverse conditions thanks to natural phenomena
- Reach safe state without human intervention
- Eliminate the need for evacuation of population

A catalyst for the zero-carbon transition

- Foster the penetration of intermittent renewables thanks to **built-in flexibility**
- Better size compatibility with market demand for non-electric usage: district heating, **hydrogen** production, desalination...
- Alternative coolant & higher temperature to enable far-reaching application : **industrial heat** & GWh-scale **energy storage**

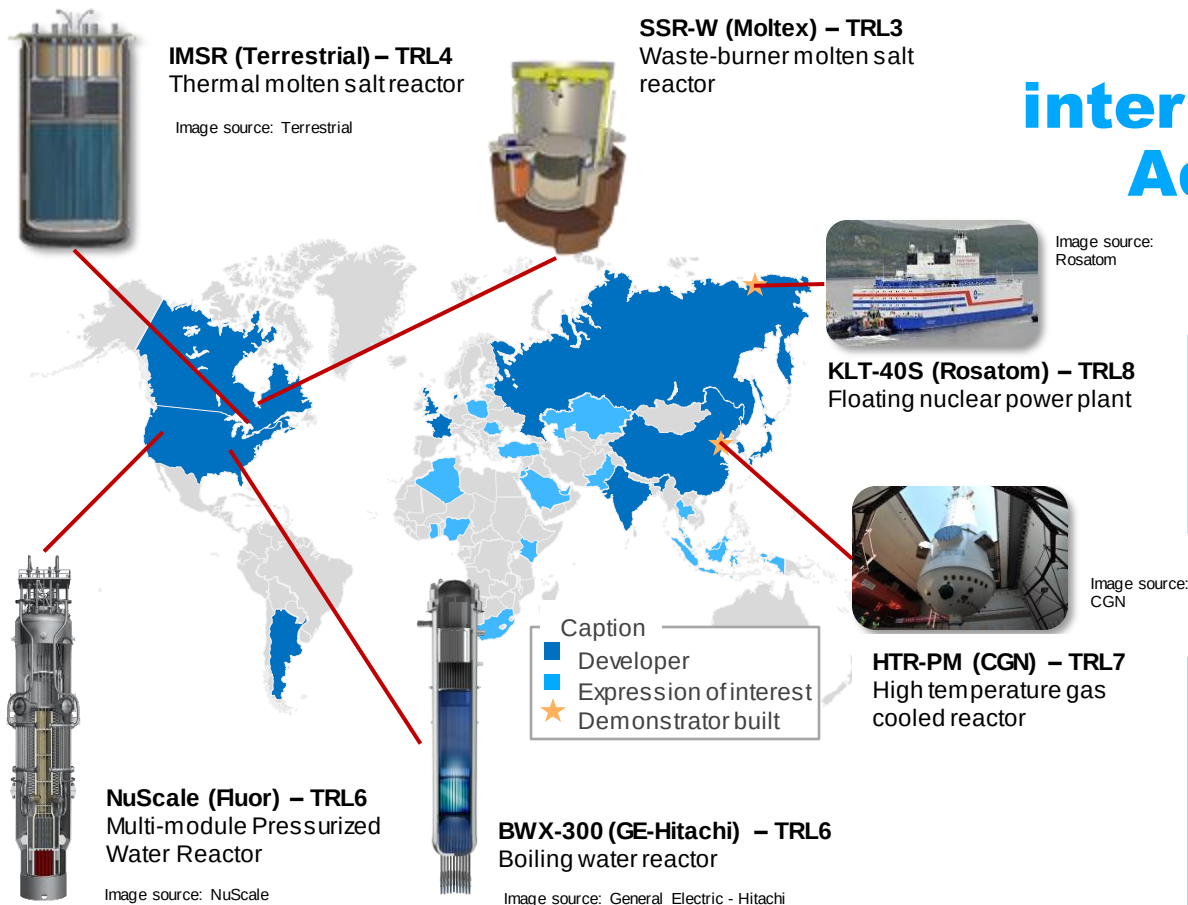
Investment-grade new build projects

- Alleviate the financial burden of ultra-large infrastructure projects by refocusing on smaller projects
- Offset scale economy by mass production of **standardized** and **simplified** design
- Streamline delivery process

Turning wastes into watts

- Deepen overall sector sustainability with advanced fuel cycles
- Reduce nuclear waste by extracting more energy from same quantity of uranium
- Cut down lifetime of nuclear waste by **burning long-lived radioisotopes** in Advanced fast-neutron reactors
- Provide an alternative route for the radioactive waste produced in the current fleet

The vibrant international race for Advanced Nuclear

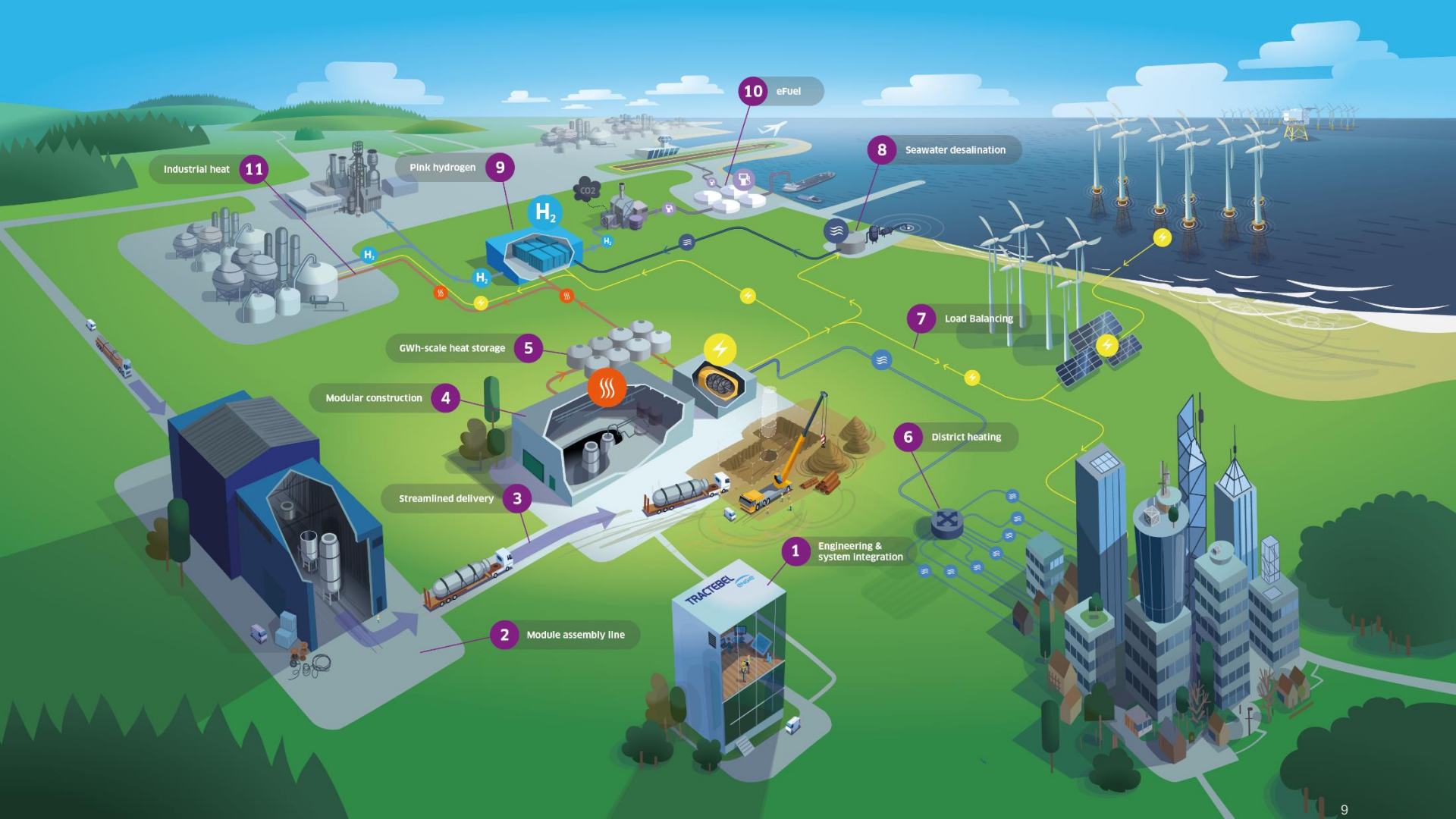


Key figures

- +70 concepts of SMR under development
- +6 Technologies
- 10 countries leading development
- 2 demonstrators built

Our approach to date

- Assessed most **promising technologies**
- Engaged with vendors
- Engaged with utilities and key industry conglomerate
- Investigated promising 'new' uses of nuclear energy



NuScale Power (USA)

FLUOR



At a glance

Small modular reactors (SMRs) are commonly defined as nuclear reactors of 300MWe equivalent or less, designed with modular factory fabrication, pursuing economies of series production and short construction times.

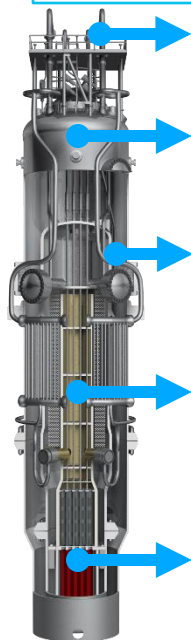


Image source: NuScale

Steam line

Transport the steam toward its **desired applications**: turbine for electric generation or heat network for co-generation applications

Containment Vessel

Prevent the release of radioactive materials and protect from external interaction

Reactor Pressure Vessel

Ensure the **integrity** of the primary circuit

Warm coolant rising channel

Guide the **natural circulation** of the expanding cooling water through the heat exchanger to produce steam.

Nuclear Core

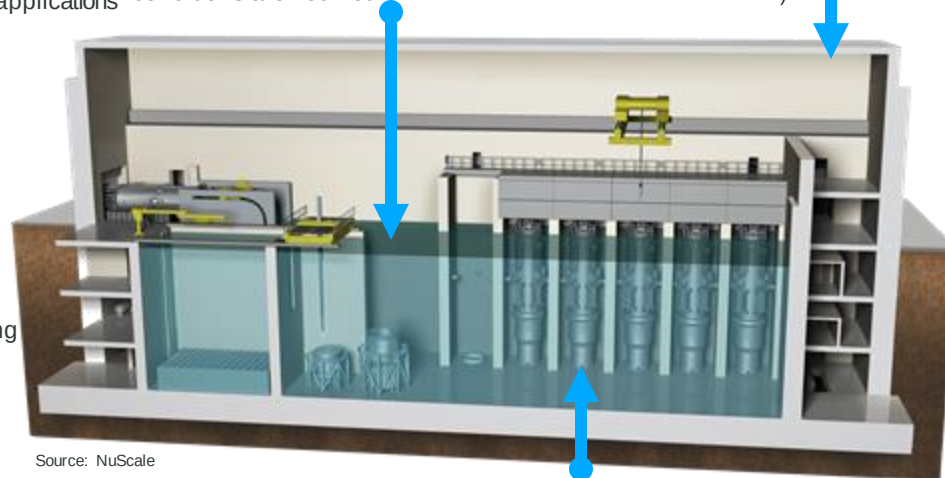
Contain the uranium assemblies within which **nuclear reactions** occur liberating a large amount of CO₂-free heat

Water pool

Provide an ultimate **heat sink** that passively cools down the reactor and maintains it into a safe state for **unlimited period** when normal operation conditions are not met.

Reactor building

Prevent the release of radioactive material into the environment in adverse conditions. Protect the reactors from **external interactions** (natural disaster, industrial hazards...)

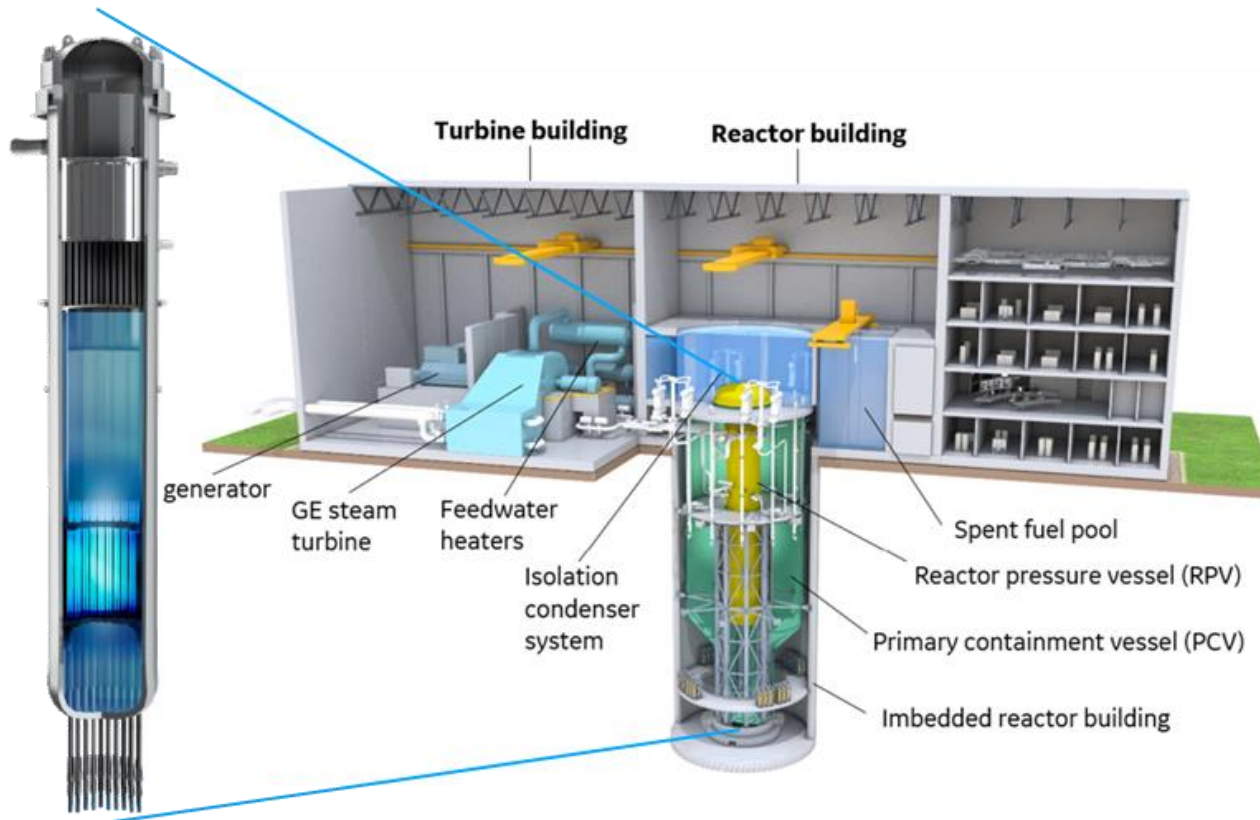


Source: NuScale

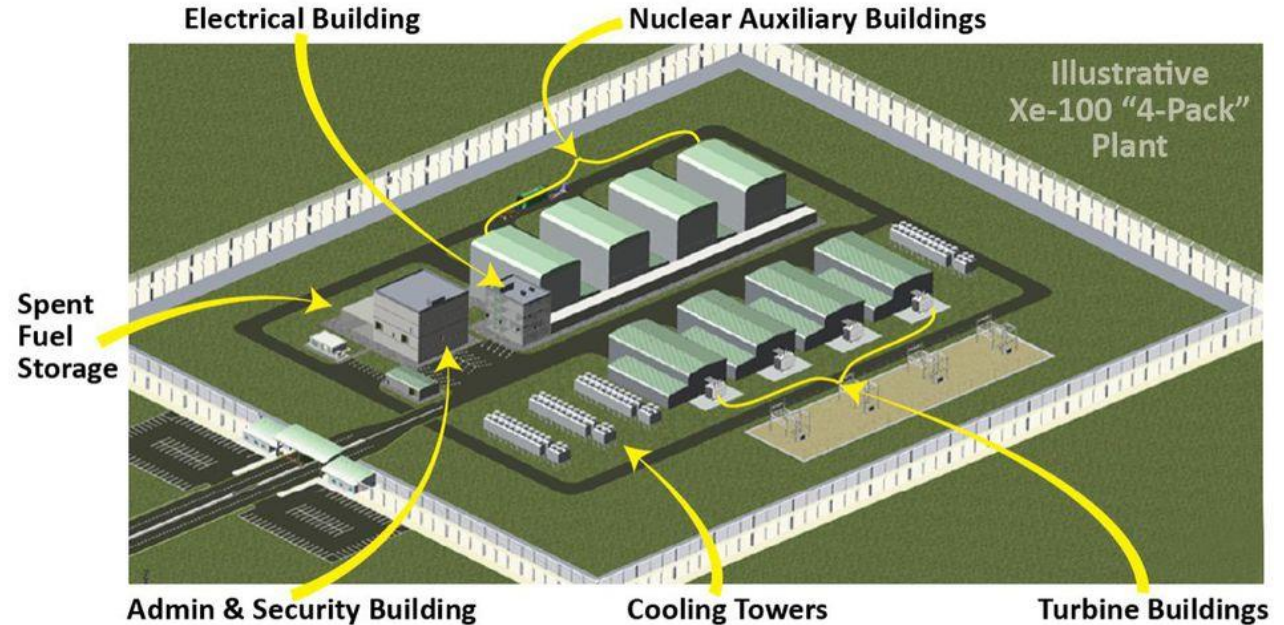
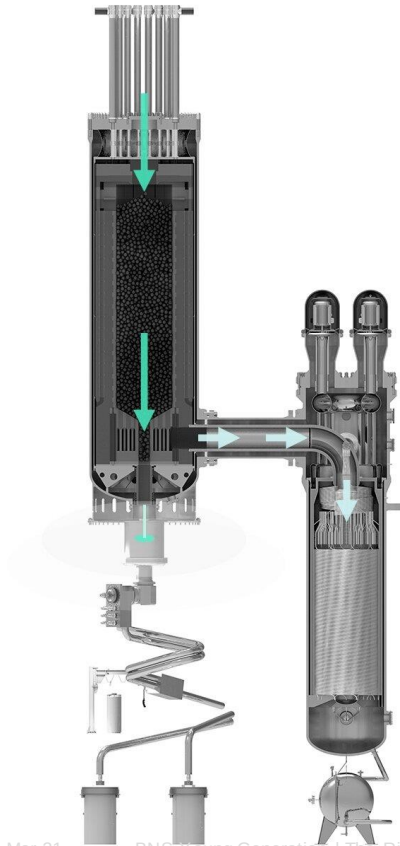
NuScale Power Modules (23m x Ø4.5m)

Supply steam **independently** from the other power modules

BWRX-300 – General Electric - Hitachi

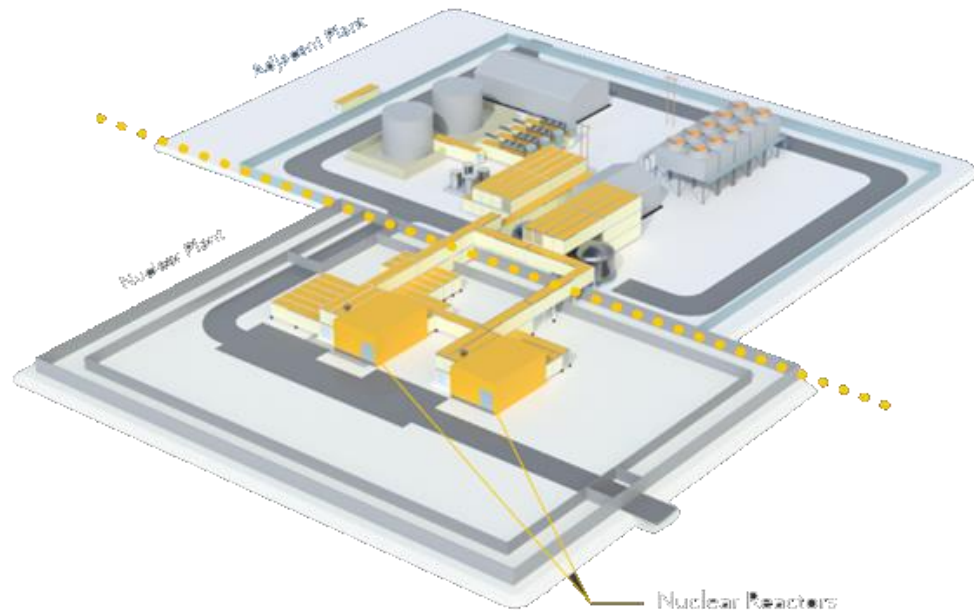
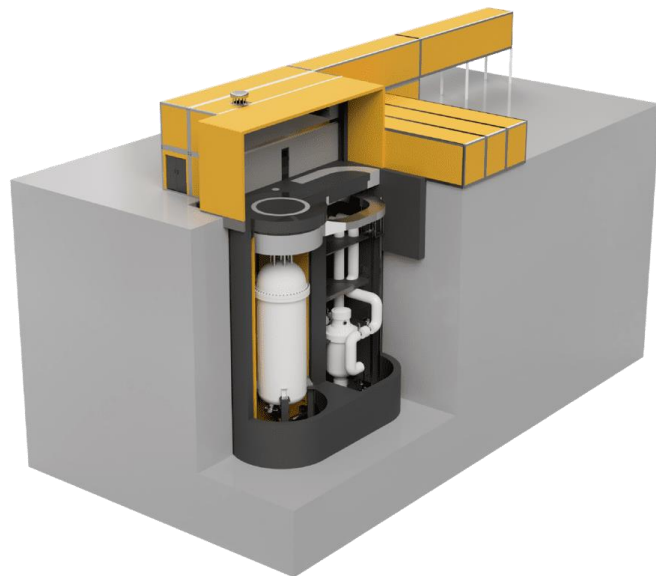


Xe-100 – X-energy



- **Secure:** underground reactor layout is possible
- **Scalable:** allows for build-out based on power demand
- **Small:** can be built on 10 acres of land and allows for grid independence
- **Safe:** smaller EPZ allows for building close to existing infrastructure

MMR – Ultra Safe Nuclear Corp.



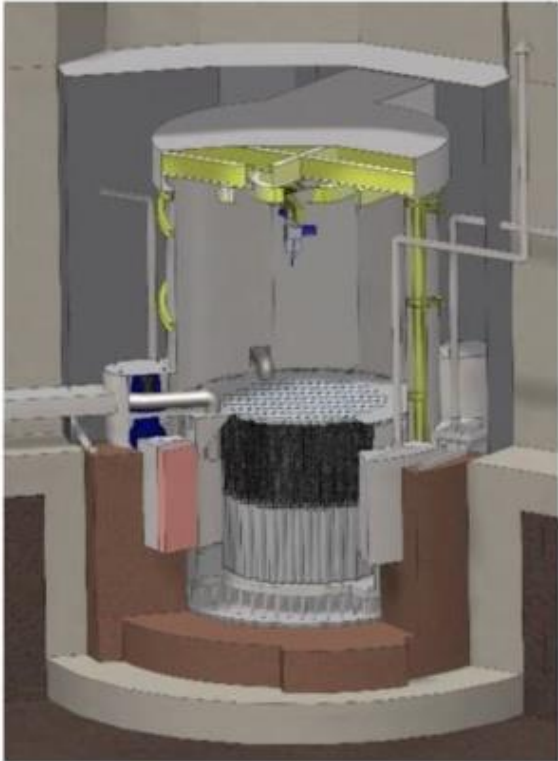
Site Area

5 acres

Assembly Time

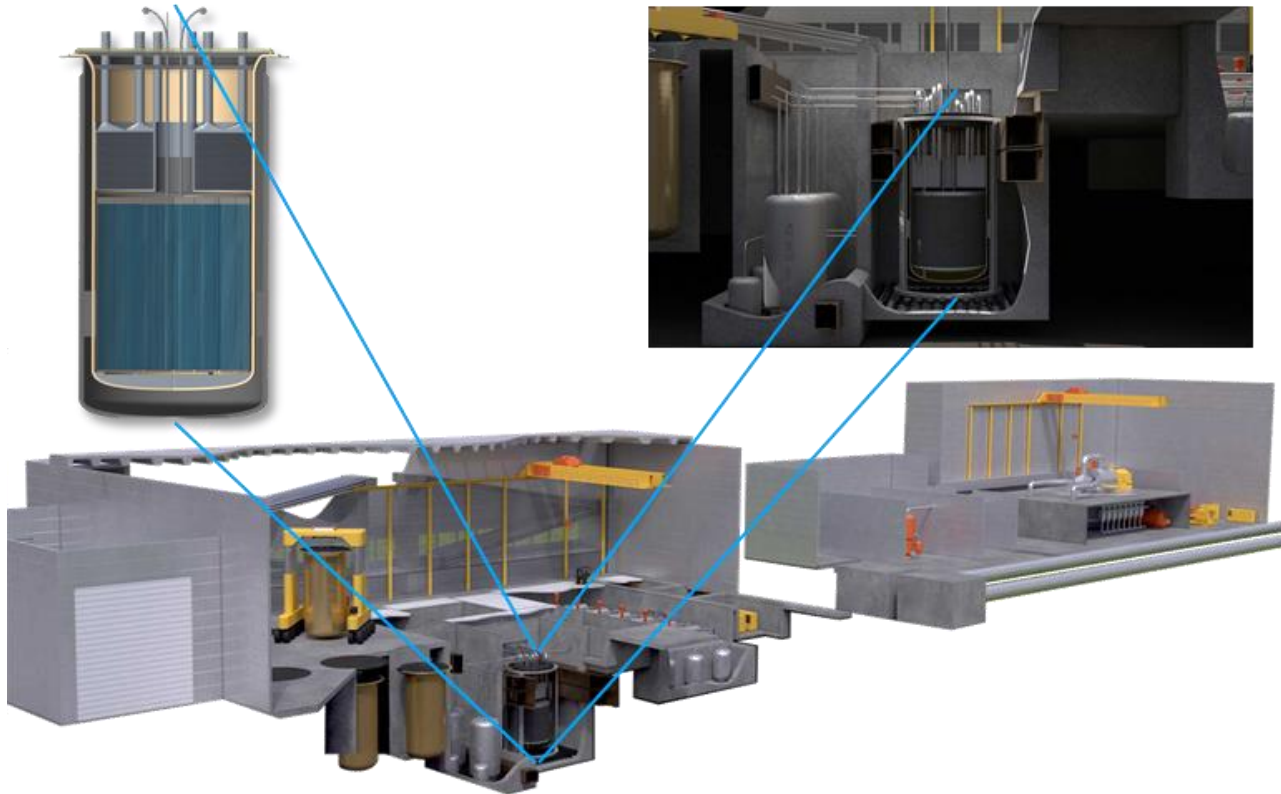
Months

SSR-W – MOLTEX Energy (UK)

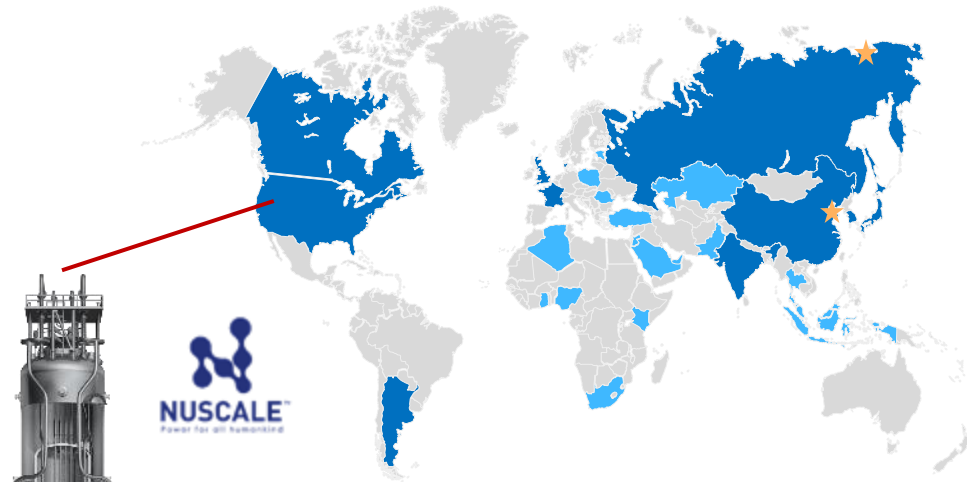


IMSR – Terrestrial Energy

TERRESTRIAL
ENERGY



The first SMR to receive US regulator design approval



At a glance

Quickly identified as the leading pressurized-water SMR in the West, Nuscale is a modular and scalable design that typically features 12 modules of 60MW in a single reactor pool.

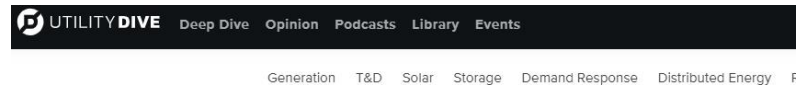
It has unique and innovative passive safety features resilient to severe accidents without relying on external power, operator action or additional water inventory for the decay heat removal for an extended period of over 30 days.

It has recently overcome one of the key milestone by becoming the first-ever SMR to be approved by a Western regulator (USA).

The first-of-its-kind is set to be operational in the US around 2026.



Image source:
NuScale



BRIEF

NuScale small modular reactor design becomes first to get NRC safety approval



Countries on the move with SMR deployment plan

Rolls-Royce plans 16 mini-nuclear plants for UK

By Justin Rowlett
Chief environment correspondent

5 days ago

Climate change

Rolls-Royce and ČEZ to explore SMR deployment

09 November 2020

British engineering company Rolls-Royce and Czech utility ČEZ have signed a Memorandum of Understanding to explore the potential for small modular reactors in the Czech Republic. Rolls-Royce is leading the UK SMR Consortium, which also includes Assystem, Atkins, BAM Nuttall, Jacobs, Laing O'Rourke, National Nuclear Laboratory, Nuclear Advanced Manufacturing Research Centre and TWI. ČEZ has already entered into similar agreements with NuScale and GE Hitachi.

Dutch minister presents report on new nuclear

28 September 2020

The Netherlands is considering the expansion of nuclear power in its energy mix, according to a letter Minister for Economic Affairs and Climate Policy Eric Wiebes submitted to the Dutch parliament last week, together with a report by consultants Enco. The cabinet will now prepare a motion requesting that the country holds a market consultation to assess commercial interest in nuclear new build.



The Borssele nuclear power plant (Image: EPJ)

Company begins SMR discussions with Polish regulator

29 October 2020

Share

Synthos Green Energy (SGE) has entered discussions with the Polish nuclear regulator about a potential GE Hitachi Nuclear Energy (GEH) BWRX-300 small modular reactor (SMR) project. SGE is seeking a general opinion from the regulator, Państwowa Agencja Atomistyki (PAA), which it described as the first step of the procedure before the regulatory process for the planned construction of a nuclear power plant in Poland.



GEH's impression of a BWRX-300 plant site (Image: GEH)

OPG plans SMR construction at Darlington

16 November 2020

Share

Ontario Power Generation (OPG) has announced it is resuming planning activities for building new nuclear generating capacity at its Darlington site in Ontario. However, it is now considering the construction of a small modular reactor (SMR) rather than a large conventional reactor, as previously envisaged.



The Darlington site currently houses four 881 MWe Candu pressurised heavy water reactors (Image: OPG)

At a glance

Seen in the news:

- **UK:** gov seemingly on the verge of announcing plans for multiple Rolls-Royce SMRs
- **Poland:** Synthos starting official discussions with Polish regulator on SMRs (Tractebel likely involved)
- **Canada:** OPG officially moving on with the Darlington site for its first-of-a-kind on-grid SMR
- **Czech:** CEZ signed an MOU with Rolls-Royce and other SMR vendors to explore deployment in Czech
- **Netherlands starts officially considering new nuclear**

Technical successes show progressing TRL

Rosatom plans first land-based SMR for Russian Far East

11 November 2020



Rosatom plans to build a nuclear power plant equipped with an RITM-200 small modular reactor in the village of Ust-Kuyga, in Yakutia, which is in Far Eastern Russia. The land-based small nuclear plant will be able to supply electricity to isolated power systems or remote areas and consumers.



Cold tests completed at first HTR-PM reactor

20 October 2020



China National Nuclear Corporation (CNNC) has announced completion of cold functional tests at the first reactor of the demonstration high-temperature gas-cooled reactor plant (HTR-PM) in Shandong province. Cold testing of the second unit at the plant has now begun. A further 18 such HTR-PM units are proposed for the same site in Shidaowan.



NuScale announces SMR power uprate

11 November 2020



NuScale Power has announced a 25% increase in power output for its NuScale Power Module small modular reactor, which it says will lead to significant cost savings. It has also announced options for smaller four-module and six-module plant sizes in addition to its flagship 12-module plant.



French-developed SMR design unveiled

17 September 2019



A new small modular reactor (SMR) design has been announced by the French Alternative Energies and Atomic Energy Commission (CEA), EDF, Naval Group and TechnicAtome. The Nuward - with a capacity of 300-400 MWe - has been jointly developed using France's experience in pressurised water reactors (PWRs).



Irradiation testing of IMSR moderator graphite begins

13 November 2020



Terrestrial Energy and Nuclear Research and Consultancy Group (NRG) have started a graphite irradiation testing programme at the High Flux Reactor (HFR) in the Netherlands. This work is part of broader programme underway for confirmatory testing of components and systems in the Integral Molten Salt Reactor (IMSR).



At a glance

Seen in the news:

- Chinese first SMR progresses on commissioning
- Russian derive land-based SMR from floating technology
- Canadian makes significant progress with R&D (Laborelec likely to be part of it)
- Nuscale announces power uprate that will improve economics
- French SMR officially unveiled

North-American Investments in SMR Deployment

USA lifts nuclear finance ban

24 July 2020



The USA has lifted its legacy prohibition on funding nuclear energy projects overseas. The US International Development Finance Corporation (DFC) changed its *Environmental and Social Policy and Procedures* following a 30-day public consultation period.



US government backs NuScale projects at home and abroad

19 October 2020



The US Department of Energy has approved a cost-share award of more than USD1 billion for the construction of the first NuScale small modular reactor power plant in the USA. Meanwhile, the US International Development Finance Corporation has signed a Letter of Intent to support NuScale in the development of nuclear generating capacity in South Africa.



Canadian government invests in SMR technology

16 October 2020



The Canadian government is investing CAD20 million (USD15 million) of federal funds to accelerate development of Terrestrial Energy's Integral Molten Salt Reactor (IMSR) power plant. Small modular reactors (SMRs) are expected to play a key role in the country's efforts to achieve net-zero greenhouse gas emissions by 2050 and in providing economic benefits as it emerges from the COVID-19 pandemic.



At a glance

Seen in the news:

- US lifts prohibition on funding nuclear projects abroad to compete with China and Russia... and starts leveraging it to deploy domestic SMR technologies
- Canada moves on to become international SMR hub with significant funding awards

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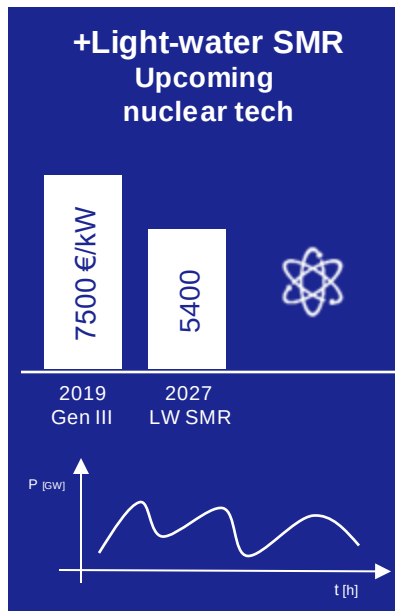
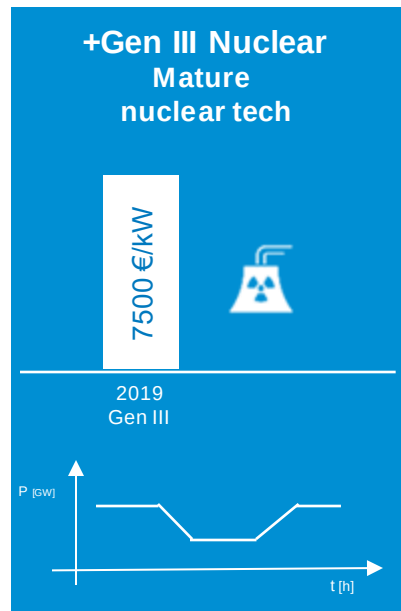
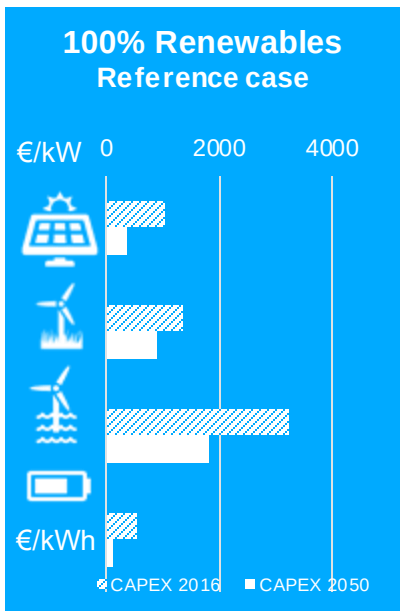
2. Tractebel Market Study

Heat Market Study

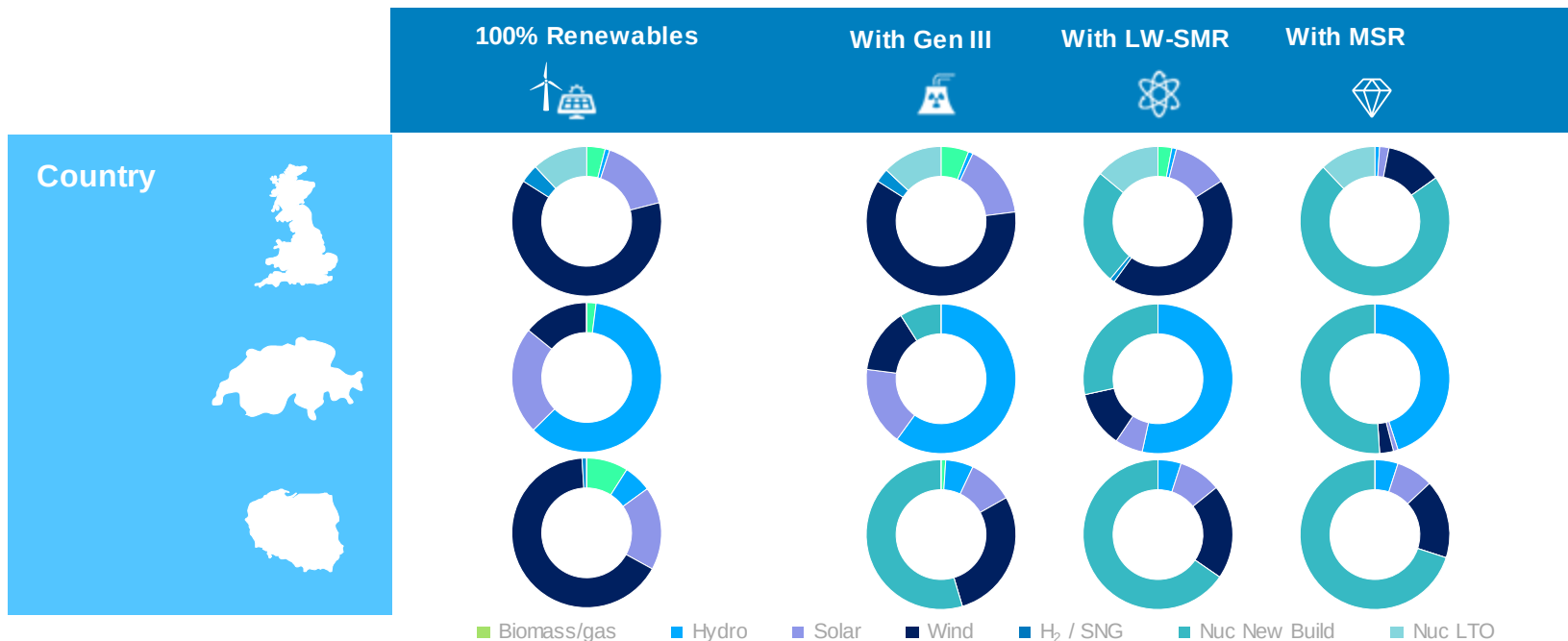
Tomorrow's European Grid Alternatives



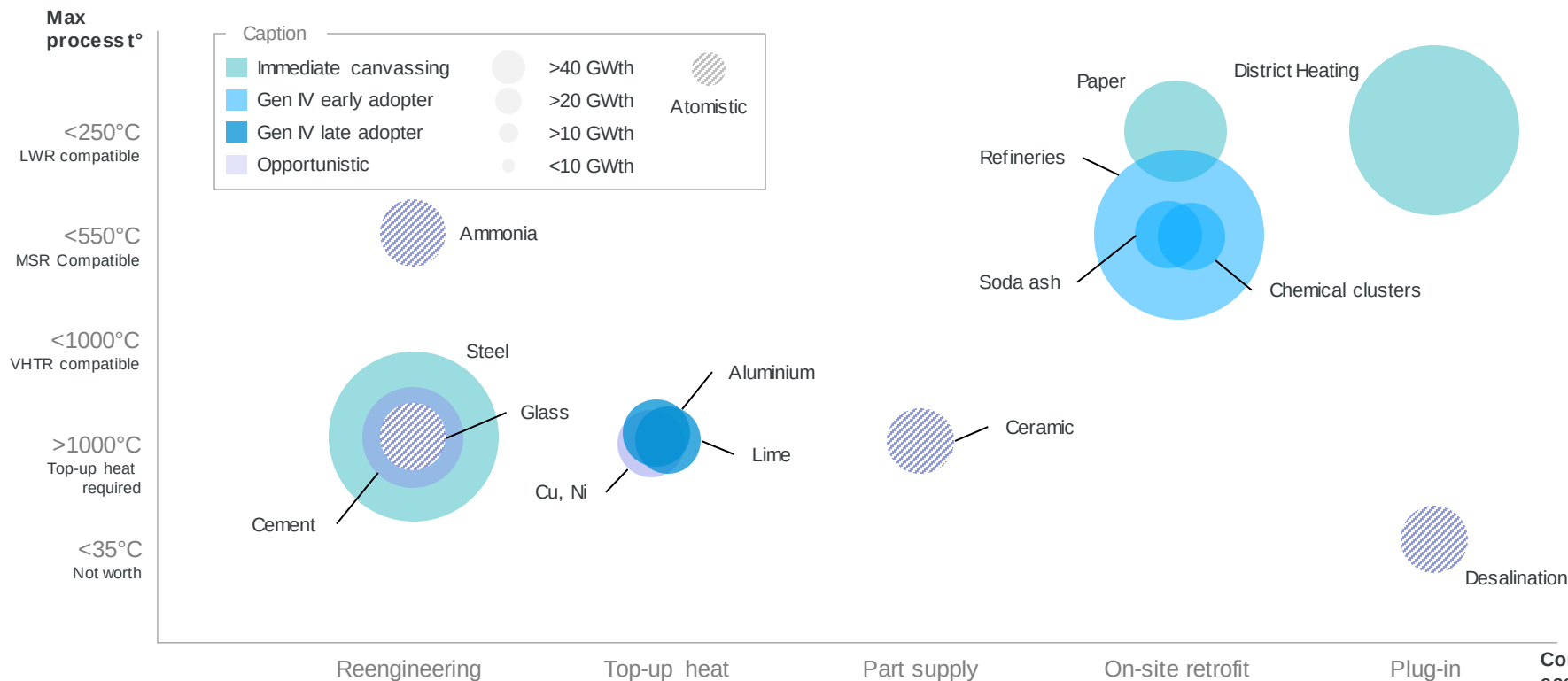
Electricity Master Plan: Scenarios



Electricity Master Plan: Results



Sectorial strategy for European heat market





Engineering a carbon-neutral future





Back-up Slides



Short-term options: light water SMRs



TECHNOLOGY

Integral Pressurized Water Reactor

Boiling Water Reactor

REFERENCE POWER

Up to 12x 77 MWe

300MWe

CAPEX

3.5B\$
4-5000\$/kW

<1B\$
<3000\$/kW

CONSTRUCTION

4.5yrs – factory-built module

4yrs

DISTINGUISHING FEATURES

Triple Crown Safety:
extended grace period > 30days
1mile EPZ

Safety: extended grace period > 7days
Proven technology – Evolved from ESBWR
Cost

LICENSING

Design approved by US NRC

Pre-licensing US and Canada

FOAK

2027 - 2029, Idaho - US

Not yet announced

Mid-term options: high T° reactors

Opening the range of applications



TECHNOLOGY

High-Temperature Gas-cooled Reactor

Micro-Modular Reactor - HTGR

REFERENCE POWER

4x 80 MWe

5 -10 MWe

CAPEX

<1.5B\$ (not confirmed)
~5000\$/kW

50 - 100M\$ (not confirmed)
>10 000\$/kW

CONSTRUCTION

3yrs

1 yr

DISTINGUISHING FEATURES

Walk-away safety & site-boundary EPZ
~ 700°C process heat

Walk-away safety & site-boundary EPZ
> 600°C process heat
No refueling – 20 yrs core lifetime

LICENSING

Application to be submitted to US NRC (2021)

Licensing CNSC

FOAK

2027 - 2030, US DOE site - USA

~2025-2027, Chalk River - Canada

Long-term options: advanced reactors

Closing the fuel cycle



TERRESTRIAL
ENERGY

TECHNOLOGY

Molten Salt Reactor (fast spectrum)

Molten Salt Reactor (thermal spectrum)

REFERENCE POWER

300 MWe

200MWe

CAPEX

<1B\$
3000\$/kW

0.7B\$
<3500\$/kW

CONSTRUCTION

5yrs

4yrs

DISTINGUISHING FEATURES

Waste burner
Walk-away safety & site-boundary EPZ
Load-balancing with **heat storage**

Walk-away safety & site-boundary EPZ
> 500°C process heat
(H₂, petro-chemical, ...)

LICENSING

Pre-licensing CNSC

Pre-licensing CNSC

FOAK

Mid 2030s, New Brunswick - Canada

Early 2030s, Canada (site not selected)

SMR in Biden's political Agenda

[Final-CE4B-Policy-Recommendations.pdf - Google Drive](#)

Proposed Recommendation:

- 1) ***Vision and Leadership: Adopting a whole-of-government approach to nuclear innovation***
- **Establish nuclear-specific staff positions across the Administration to collectively shape and coordinate the U.S. nuclear energy strategy both domestically and internationally**
 - Include a nuclear-specific staff position for any White House climate office to ensure advanced nuclear is included as part of the climate response and set a clear mandate for an environmentally-just, community-centered approach to technology adoption.
 - Reinstate the Obama-era National Security Council position of Director for Nuclear Energy Policy to coordinate the various agencies (primarily the Department of Energy, Department of Commerce, and Department of State) that have jurisdiction over nuclear energy exports.
 - Include a nuclear-specific staff policy specialist on the White House National Economic Council to assist in coordination of President-elect Biden's domestic and international economic program.
 - Reinvigorate the Office of Science and Technology Policy to advise the Biden Administration with a view to integrated strategies including advanced reactors.
- **Re-establish the U.S. government as the first funder and customer of U.S. advanced nuclear energy to compete with Russian and Chinese state-owned nuclear enterprises**

• Invest in coal and power plant communities through a pilot

Coal-to-SMR program:

- Over 600 coal plants have closed across the U.S. in the last decade, with another 25GW planned to close in the next five years, with many closures expected in Michigan, Ohio, Nevada, and North Carolina.²⁴⁰ While this is great news for carbon emissions, it can be devastating to local economies. However, advanced reactors and SMRs can be an ideal replacement for these retiring coal plants. SMRs can take advantage of existing infrastructure and the local workforce.²⁴¹ Nuclear power plants typically employ more people than a coal or gas plant and pay ~20% more on average than other power sector jobs. And the jobs are guaranteed to stay local.²⁴² We propose developing a pilot program to identify, consult with, and fund amenable communities to study issues of workforce retraining and infrastructure repurposing. This will develop a template for other communities to follow. Such a program should focus on underserved communities and fund remediation efforts to clean up legacy pollution from coal mining and combustion in the decommissioning process. Ultimately this program could be expanded to include natural gas facilities.

Study scope & general methodology

Top-down sectorial analysis

Sectorial characterization through literature review from open-source document:

- **EUROPAIRS** report: End-Users Requirements for Process heat Application with Innovative nuclear Reactor for Sustainable energy Supply
- Best Available Techniques (BAT) Reference Document for the relevant Industries (JRC)

Sectorial strategy & recommendations

The strategy consists of:

1. The prioritization of the industrial sectors to be addressed and,
2. **Technical** recommendations in the form of **studies** to be conducted



Bottom-up geographical analysis & recommendations

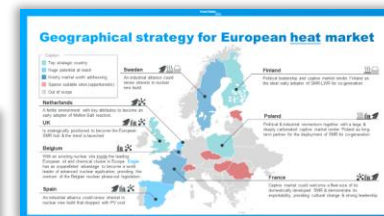
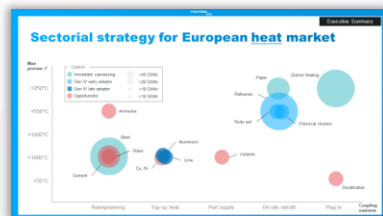
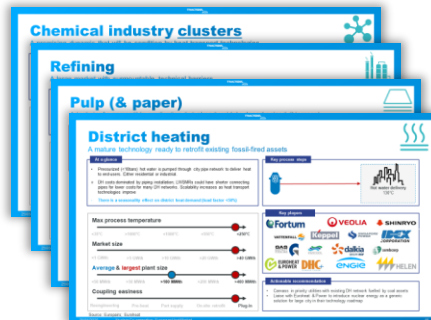
Country-by-country analysis of the potentially suitable industrial sites based mainly based on the **GIS**:

1. HeatRoadmap.eu/Peta4
2. IndustryAbout.com
3. ChemicalPark.eu
4. Endcoal.org/global-coal-plant-tracker
5. Companies website

Geographical strategy

The strategy consists of:

1. The prioritization of the country to be addressed and,
2. **Organizational** recommendations in the form of internal coordination & external **alliance** suggestions



Evaluation Criteria

Sectorial analysis

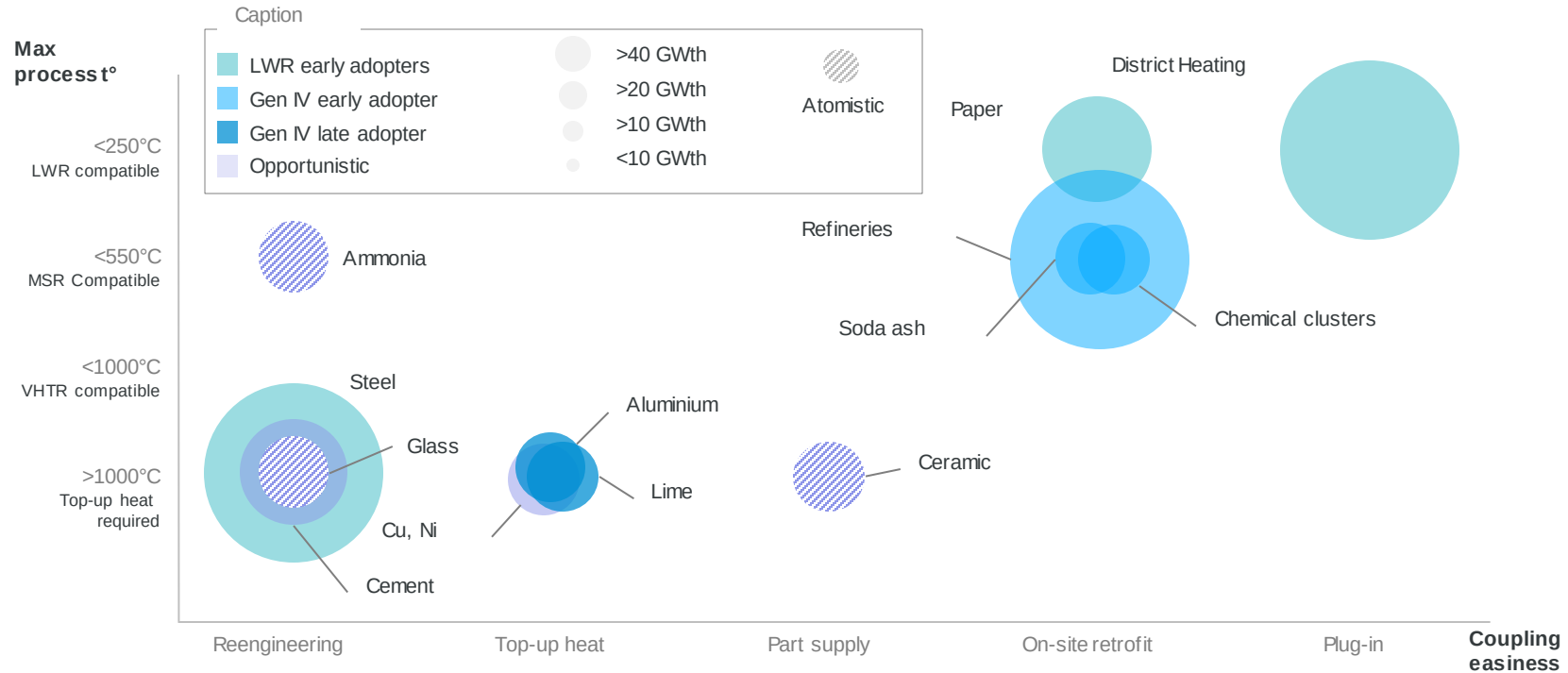
Geographical analysis

	Max process T°	Market size	Average plant size	Coupling easiness	Nuclear industry maturity	Nuclear Appetite	Co-gen potential	Carbon footprint**	Engineering competition
	<250°C LWR* compatible	>40 GWth	>400 MWth	Plug-in retrofit of off-site plant	Tier 1 supply chain	Strong political leadership	>20 GWth	>3t CO ₂ /toe	Very low
	<550°C MSR* Compatible	>20 GWth	>200 MWth	On-site boiler/co-gen retrofit	Several sites	New build program	>10 GWth	>2t CO ₂ /toe	Low
	<1000°C VHTR* compatible	>10 GWth	>100 MWth	Part of process supply	Single site/unit	Strong R&D and public support	> 5GWth	>1t CO ₂ /toe	Medium
	>1000°C Top-up heat required	>5 GWth	>50 MWth	Process pre-heat or top-up heat	Research lab	LTOs* + Phase-out	Sparse application	>0.5t CO ₂ /toe	High
	<35°C Not worth	<1 GWth	<50 MWth	Important effort to re-engineering process	No nuclear	Active opposition	No industry	<0.5t CO ₂ /toe	Very high

*Light Water Reactor (LWR); Molten-Salt Reactor (MSR); Very High Temperature Reactor (VHTR); Long-Term Operation (LTO)

**Carbon intensity of energy carrier in industry

Industrial sectors affinity with SMR-based co-generation



Tractebel's roadmap to becoming leaders of 'SMR as a service'

Consultancy



From multi-métier feasibility studies as our 'produit d'appel' to becoming Project Developers

Utility development program

Owner's Engineering, Business Case, Operational readiness



Vendor development program

Architect's Engineering, R&D, Constructability, Operating procedures



Industrial project creation

Business developer, architect's Engineering, Stakeholder Mgt, R&D...



**Construction,
Installation,
Maintenance**

2020

2023

2027

TRACTEBEL

MSR Technology Developer - **Canada**

Fermi Energia – Estonia

District Heating utility – Finland

Engie Corporate - **Europe**

2018 - 2020

Stage-gated delivery plan

- Definition, structuring and planning of project phases up to Final Investment Decision
- Requirements and hold points for project phase in diverse workstreams

Technology assessment and selection

- Comparison of SMR technologies through technical and business-oriented criteria
- Assessment of suitability based on high-level specifications drafted with utilities (incl. non-electricity uses)

Integration studies in complex ecosystem

- Continental power market modeling
- Feasibility of SMRs integration for district heating and cooling applications in a Northern European city
- Pilot feasibility study for 100MW to 1GW electrolyser coupled to a NPP
- Market survey of the European industrial heat users compatible with SMRs

Site survey and site selection



Proposed work: development of demand-driven case studies on the economics of multi-purpose SMRs. The following application will be looked at:

Energy Vector



Electrons



Hot water



Steam



Solar salts



Hydrogen



eFuel

Attributes

- | | | | | | |
|---|--|---|--|--|--|
| <ul style="list-style-type: none"> • Fungible • Grid (country) • Mature • Room t° | <ul style="list-style-type: none"> • Locally mutualizable • Network (city) • Mature • 60-120°C | <ul style="list-style-type: none"> • Locally mutualizable • Local (industrial site) • Mature for non-nuclear • 150° - 580°C | <ul style="list-style-type: none"> • Local • Local (site) • Mature in CSP • 450° - 650°C | <ul style="list-style-type: none"> • Transportable • Network (region) • Maturing • Room t° - 950°C | <ul style="list-style-type: none"> • Transportable • Trade (world market) • Early pilots • Various |
|---|--|---|--|--|--|

Prospects

- | | | | | | |
|--|---|--|--|---|---|
| <ul style="list-style-type: none"> • Utilities (existing and emerging) • Fossil plants to be retrofitted | <ul style="list-style-type: none"> • Utilities • Cities | <ul style="list-style-type: none"> • Petrochemical clusters • Paper factories • Soda ash plants • Aluminium plants | <ul style="list-style-type: none"> • Industrial sites • High-penetration renewable hybrid system: ports... | <ul style="list-style-type: none"> • Steel mills • Fertilizers plants | <ul style="list-style-type: none"> • CO₂ deposits: limestone industries, ethylene oxide, bioethanol plants... |
|--|---|--|--|---|---|

Proposed Methodology

Suitability requirements

- Operating constraints (availability, reliability, temperature regime...)
- Siting and layout requirements

SMR design screening

- Compatibility with requirements
- Candidate or representative design selection

System integration

- Technical interface management
- Site specific layout influence

Business case demonstration

- Stakeholders structure
- Offtake strategy
- Finance & premium opportunities

Key pre-requisites

- **Industrial partners** for input parameter collection
- Inductive reasoning rather than deductive: generalise from specific case study

Collaboration opportunities

- Pre-project activities: financing schemes, regulations, licensing
- Local industrial partner canvassing (network mutualization)
- Technology developers: technology-related input parameters collection