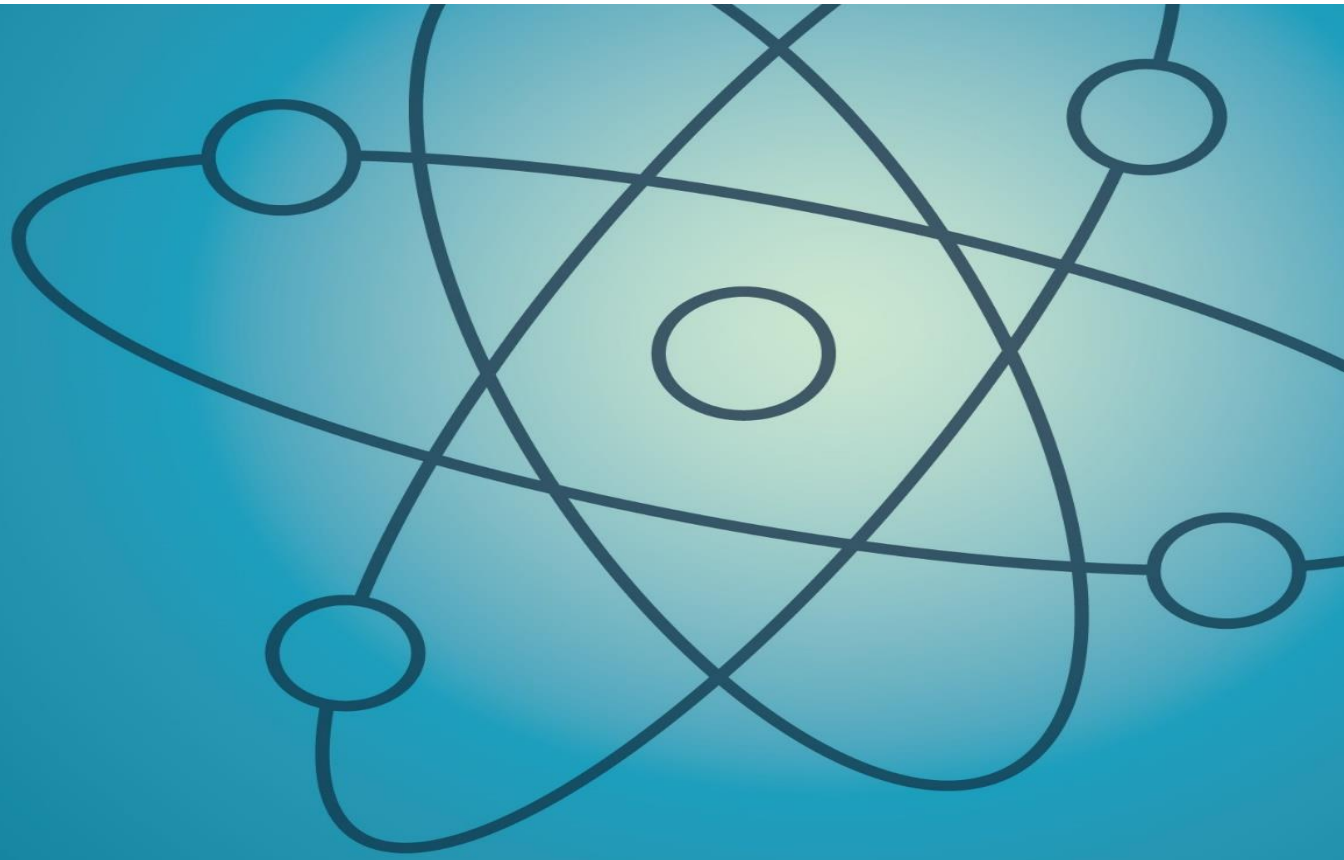
European SMR pre-Partnership

WORKSHOP
14 October 2022



With the support of :

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Context:
First EU Workshop on Small Modular Reactors (SMRs) - 29 June 2021

- **Organised by the European Commission's DG ENER in response to the call of the European nuclear industry;**
- **110 participants from 22 Member States;**
- **A "vision paper" of industry stakeholders widely endorsed by the participants;**
- **Including a <u>proposal for a 'European SMRs Partnership'.</u>**
  - **collaboration scheme involving industrial stakeholders, research & technological organisations, interested customers (i.e. utilities and even Member States), as well as European policy-makers and regulators**

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European SMR pre-Partnership – Steering Committee

General objectives

- **Identify enabling conditions and constraints** towards safe design, construction and operation of SMRs in Europe in the next decade and beyond in compliance with the EU legislative framework in general and to the Euratom legislative framework in particular.

Specific objectives

- Develop the necessary industrial supply chain in Europe
- Encourage the implementation of common (harmonized) licensing process across the EU
- Establish a strategic research agenda :
  - LWR, as a mature technology to be deployed in 2030.
  - Advanced SMR (Gen IV) design have to be matured by 2035 for long term prospect

- **Composition:** nucleareurope (chairing), SNETP, ENSREG, EC + chairs of 5 WS
- **Secretariat:** EC, nucleareurope, SNETP
- **Meetings:** Kick-off 17 March 2022; 4 meetings so far (last one 13 October)

WS1 – Market analysis

Objectives:

- Identify future needs of the EU energy/power market (electricity, industrial and residential heat, hydrogen), market size and global competitiveness in a context of high RES deployment,;
- Assess SMRs as technology to replace coal and gas plants, help decarbonize assets/processes such as hydrogen production, district heating, industrial heat processes, and provide load balancing capabilities to Transmission System Operators (TSOs)
- Establish a list of sustainability criteria to highlight SMR technologies added value(SMR/AMR) compared to alternative energy options.

Responsability: nucleareurope

Chair: Tractebel

Contributors:

- nucleareurope-SMR-task force: Tractebel, Engie, Fortum, Rolls-Royce, EDF, Orano, Vattenfall, SCK-CEN, CEA, Nuclearelectrica.
- Kick-off meeting: 14 January 2022

WS1 – Market analysis

Main ongoing activities:

- Task 1 : Literature analysis conducted to address 1) the EU market size/needs, 2) technical-economic capabilities of SMRs, 3) market potential for SMR development
  - First draft report done and commented, Complete report expected in November
- Task 2 : Surveys to assess appetite from:
  - Industrial users → no answers received yet
  - National Fora → 4 answers received
  - Member States → 3 answers received
  - TSOs → in preparation.
- Task 3 : Establish a list of sustainability criteria. Report that assesses SMR technologies vs. alternative energy solutions in light of this criteria
  - List of sustainability criteria completed
  - First draft report expected in November, Complete report by the end of the year

WS1 – Market analysis

Key insights gained at this stage:

- European market needs for low-carbon energy are huge (may appear unbelievable) → there is room for everyone (nuclear and renewables)
- What will drive success for SMRs is delivery on time and on budget
- Beyond that step, market upscale is the real challenge and needs to be at least on par with nuclear deployment pace in 1970s and 1980s
- Still a lack of knowledge of SMRs from Industrial users (probably the reason for absence of answers to the survey) → nuclear industry needs to open towards the outside and demystify SMR technology
- Security of supply, energy sovereignty cited several times in the surveys as a driver toward SMRs by national for a and member states
- National policies cited several times as the main hurdle

WS2 – Licencing

- ENSREG (European Nuclear Safety Regulators Group)
- WS2 on SMR licensing
  - Objectives
  - Activities
- SMRs new designs – what are we talking about?
- What harmonisation needs to be done for SMRs ?
  - A. Safety requirements
  - B. Authorisation or licensing process
- Conclusion
- Q/A

- **European Nuclear Safety Regulators Group (ENSREG)**
- **Independent expert advisory group to the Commission created in 2007**
- **Senior officials from national regulatory authorities and the Commission**
- **Plays a key role in:**
  - **The preparation of new EU legislation**
  - **Nuclear "Stress Tests" in Europe and abroad and their follow-up**
  - **EU "Topical Peer Reviews"**
  - **Preparatory steps of the European SMR pre-Partnership**

WS2 – Licencing

Objective:

- **Identify the elements for establishing a European pre-licensing process based on commonly accepted safety assessments from different ENSREG members interested in the licensing of the same SMR design**

Responsibility: ENSREG - Chair: ASN

Contributors: 17 experts from 14 countries' nuclear safety authorities from: AT, DE, HU, LT, FI, SE, IT, FR, RO, SK, NL, ES, CZ and PO + industry representative: ENISS

Main ongoing activities:

- Establish a clear state of play of activities in other fora (IAEA, SMR Regulatory Forum, NEA Committees, WENRA, ENISS, CORDEL, etc.) in relation to SMR licensing ☑
- Develop a common understanding on NPPs licensing processes in different EU countries interested in SMR licensing (main milestones, etc.) ☑
- Collaboration ongoing with WS5 on three topics: Human Factors, Severe Accidents, Passive Systems. ☑
- Collaboration starting with WS4 on Codes & Standards. ☑

Conclusion

Goal: To have an efficient preparation for license application in different EU countries

1. **Engage early dialogue between designers - licensees and regulators on main elements of the design options**
2. **Promote cooperation of "interested" regulators to carry out a joint safety pre-assessment on a mature design**
3. **Review in advance key elements of the licensing process and "Safety Case" of the "interested" countries to avoid blocking points at a later stage**

1) SMRs new designs – what are we talking about?

New SMR designs are based on technologies that have existed for many years (not for commercial use, but for research reactors (molten salts, HTRs, etc.) or in the naval sector (PWRs, lead reactors))

However, considered as innovative reactors because of:

- **technological** innovations
- **intellectual** innovations

Most regulations are goal oriented

- **no means specified**
- **licensees can choose the most appropriate provision**

An innovation must be not only attractive but has to be a proven technology

- **this takes time: time for R&D, experiments, studies, qualification**

CHALLENGE

Engage early dialogue on innovations between regulators and innovation's support (licensee, vendors, start-up)

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2) What harmonisation needs to be done for SMRs?

Industry calls for harmonization

There is a need to distinguish harmonisation of

A. Safety requirements
B. Authorisation or licensing process

A. Safety requirements

- Established in different frameworks (IAEA, WENRA) and built on the experience of what is already implemented (mainly derived from water reactors)

  No need really for requirements harmonization now, nor for C&S

- <u>It is rather how to demonstrate compliance with the requirements that needs to be worked on</u>

2) What harmonisation needs to be done for SMRs?

Cooperation between regulators on the pre-assessment of SMRs is an opportunity

- to share regulators' approach
- it brings robustness to the assessment: it may lead (or not) to common positions. The common positions or dissensus (and why) are made clear to the licensees and provides predictability

It requires a <u>mature design</u>, a <u>similar time frame</u> for regulators reviews and therefore a cooperation of licensees as well.

CHALLENGE

Promote cooperation of interested regulators to carry out a joint pre-assessment on a mature design

3) What harmonisation needs to be done for SMRs?

B. Authorisation or licensing process

- Cooperation carried out in some frameworks (EU, IAEA, NEA, etc.): should contribute to a certain convergence in the pre-licensing or licensing processes

➡ At this stage, it cannot lead to international certification or reciprocal recognition of the authorisations issued by the safety authorities

CHALLENGE

Review in advance key elements of the licensing process and "Safety Case" of the "interested" countries to avoid blocking points at a later stage

NB: Authorisation remains the sovereign responsibility of states

Conclusion

Goal: To have an efficient preparation for license application in different EU countries

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WS4 - Supply chain adaptation: goals & objectives

Goals:

- Identify the key features of an SMR supply Chain (vs. current practice)
- Analyze the existing gaps and the main hurdles to overcome
- Identify which ones are largely technology-independent and define roadmaps to address them
- Identify recommendations to systematically address technology-dependent hurdles from various partnerships

WS4 – Supply chain adaptation

Objectives:

1. Identify specific needs for SMR manufacturing
2. Identify tier1/ tier 2 supply chains in Europe and their adequacy to the needs
3. Standardisation: how, and how far, to promote it
4. Modularity, Quality insurance & Reliability: possible synergies with other industrial sectors
5. How to maximise new tools and methods in SMR manufacturing
6. Possible use of non-nuclear,high quality components
7. Robustness of the future supply chain

WS4 – Supply chain adaptation

1. Identify specific needs for SMR manufacturing

   - *Key features to support series effects*
   - *Factory fabrication (at which extent?)*
   - *Lead times*
   - *…..*

   interaction with several vendors

2. Identify tier1/ tier 2 supply chains in Europe and their adequacy to the needs

   - *EU based*
   - *Wide-range cathegorization*

   survey among national industrial member fora

WS4 – Supply chain adaptation

3. Standardisation: how, and how far, to promote it

   - New codes and standards required?
   - Transnational application/ licensing aspects

   Review of IAEA works / interaction with WS 2

4. Modularity, Quality insurance & Reliability

   - How can we learn from other industrial sectors?
   - Which potential barriers in terms of quality requirements ?

   Interviews with experts

5. How to maximise new tools and methods in SMR manufacturing

   - How to improve series production through advanced manufacturing ?
   - How to qualify new manufacturing techniques for nuclear application?

   Interviews, review of existing literature from other sectors

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WS4 – Supply chain adaptation

6. Possible use of non-nuclear,high quality components

- Path towards simplification and cost reduction?

Review of JRC works on the subject

7. Robustness of the future supply chain

- More components per installed power: capability issues?
- Dedicated factory management issues
- Staffing considerations for SMR design, manufacturing & operations

WS5 – objectives: develop a R&D&I roadmap for European SMR development

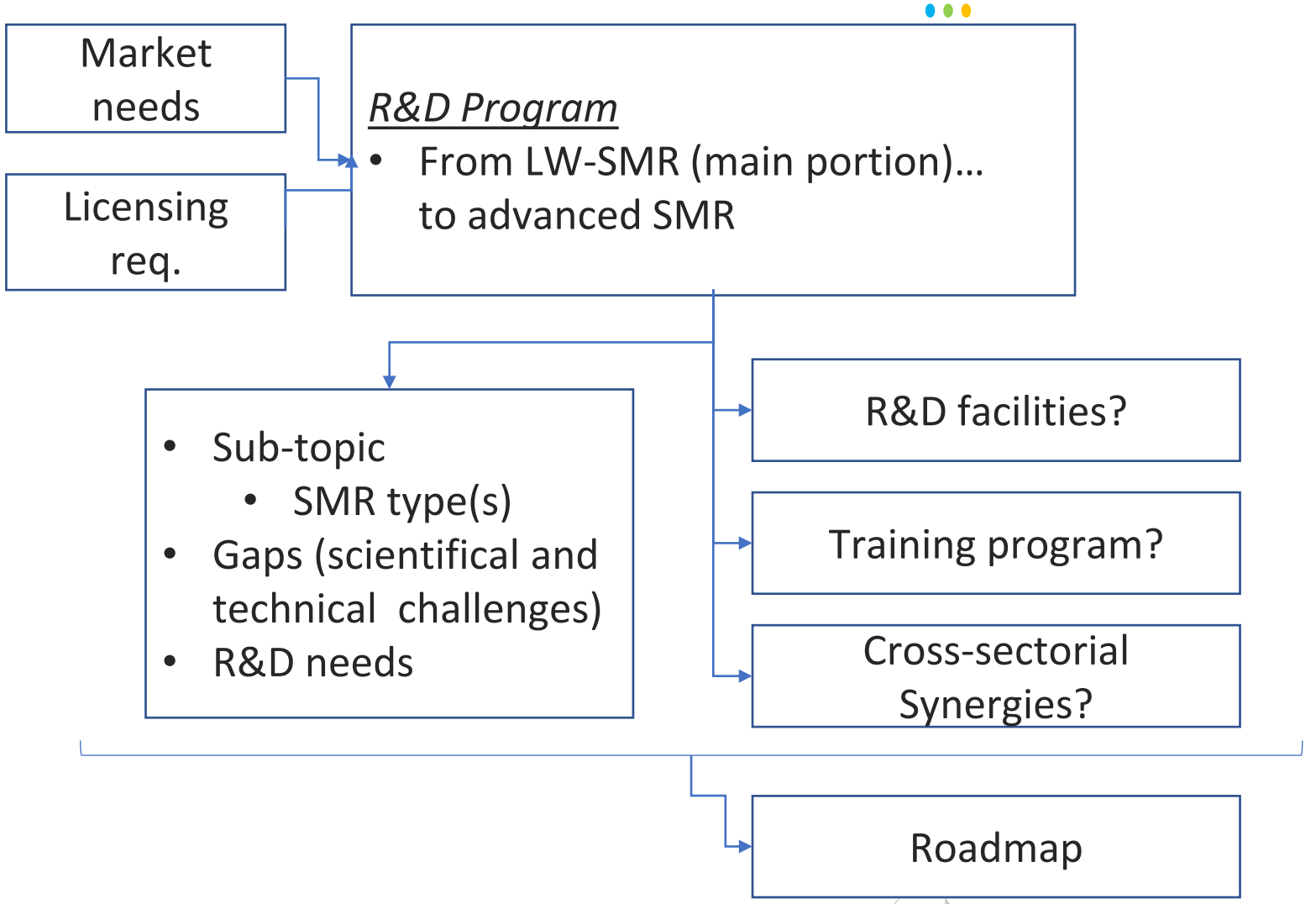
Objectives: building a R&D&I roadmap, in line with market needs and regulatory requirements, and promoting its realization

- Define R&D&I program consistent with market needs and licensing requirements for SMRs development,
  - Share a common view on the roadmap to clear technical/scientifical hurdles and necessary R&D to demonstrate the safety and performance of SMR features.
    Paving the way to LW SMR deployment to achieve timely the Net Zero by 2050 objective, by demonstrating the maturity and competitiveness of SMR with a first commercial operation in the 2030s.
  - … and from LW SMRs to advanced SMR (AMR / Gen IV) in the longer term, for nuclear sustainability (raw materials uranium, limiting the impact of long-life waste)
- identify the needed facilities to execute this program
- set up a coherent training and education program

Responsibility: SNETP

Contributors: (~60 p.) JRC, EDF, CEA, IRSN, GRS, Framatome, SCK.CEN, VTT, Engie/Tractebel, UJV Rez, ENEA, Ansaldo Nucleare, NCBJ, NRG, Ecole des Mines, CIEMAT, NINE, NC2I, Becker Technologies, …

R&D&I proposed roadmap is structured according to 7 technical topics



- General
1. Core/fuel
2. NSSS Integrated vessel and its internals
3. Passive systems
4. Severe Accidents
5. Modularity
6. Human Factors and autonomy
7. Uses beyond electricity

WS5 needs will be more accurate when technologies of specific interest will be selected

Topic	Leader	A: LW-SMR vs. B: AMR	Sample of key subtopics
0. General	S. Takenouti (EDF), V. Tulkki (VTT)+ SNETP (Scientific com.)	Overall consistency	Aspects not covered by other topics?
1. Core/Fuel	E. Hanus (CEA) + 12 contributors	Different issues: A then B (HTGR; others Gen 4)	**Adaptations to regular LWR fuel** (shorter fissile length, burnable poisons, InCore instrumentation) *Irradiation of control rods / fuel with burnable poison*
2. NSSS Vessel	O. Martin (JRC) + 7 contributors	Common for advanced manufacturing. A (iPWR specific) then B	**Advanced manufacturing** methods; adaptation of In-Service Inspection requirements/means; Specific components development
3. Passive systems	F. Mascari (ENEA) + 8 contributors	Common	Study of the **coupling between reactor coolant system and (small) containment** **Reliability evaluation** (methodologies robustness vs. different transient scenarios and conditions, assessment of functional failure related to the T-H phenomena and associated uncertainties) Facilities to expand the experimental database for code validation for PCCS, SACO, etc.

WS5 needs will be more accurate when technologies of specific interest will be selected

Topic	Leader	A: LW-SMR vs. B: AMR	Sample of key subtopics
4. Severe Accidents	P. Dejardin (ENGIE) + 13 contributors	Different issues: A then B	Postulated SA scenarios, **numeric tools and methods** for deterministic and probabilistic analyses Specific modeling of phenomena in small containments
5. Modularity	M. Marconi (Ansaldo) + 8 contributors	Common	Codes, connecting solutions/qualification Methodologies for the modularization: full integrated Building Information Model addressing modules (tools and methods, including digital twins)
6. Human Factors	S. Couix (EDF) + 4 contributors	Common	Virtual or real-size surrogate MCR for 2 reactors or more (**Multi unit operation in a single control room**) Organization and procedures for passive systems, hybridization
7. Uses beyond electricity	V. Tulkki (VTT) + 7 contributors	Common	*Follow-up TANDEM project, waiting for WS1 (**markets**) inputs* Capability of hybrid systems to enhance the load follow capabilities

WS5 roadmap initiated focusing on the first needs, but to be complemented with other stakeholders insights…

Objectives: building a R&D&I roadmap, in line with market needs and regulatory requirements, and promoting its realization

- Preparation of the involvements of reactor designers/vendors is key
  - Discussions within WS5 on the possible first R&D actions for LW-SMR LW Designs / AMR technologies selection is needed to further develop the roadmap : biggest part of specific needs depend on the actual designs of interest (e.g. validation of NSSS components), and the generic needs would be more accurate when a few designs (LW-SMR) or technologies (AMR) of interest are selected (e.g. for materials)
- Interfaces with other workstreams
  - WS1 markets: to confirm R&D is consistent with the market needs
  - WS2 licensing: Have a clear view on the level of harmonization (on the licensing process, on safety objectives) among European Regulatory Bodies, in order to facilitate the design development of innovative reactors, that could in the end meet national regulatory requirements.

    Be in position to propose robust SMR designs, where a unique design would fit to accommodate the variety of national regulatory expectations or interpretations.

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Take aways for the R&D&I workstream

Objectives: build a comprehensive and credible R&D&I roadmap to secure an on-time deployment of SMR in Europe

- Identification and prioritization of the relevant R&D work needed to enable SMR deployment, considering market needs and regulators expectations.

- Make it possible to pool resources for common R&D needs among SMR designs, e.g. enhancing the experimental database for accuracy of numerical simulation

- Network of R&D facilities across EU

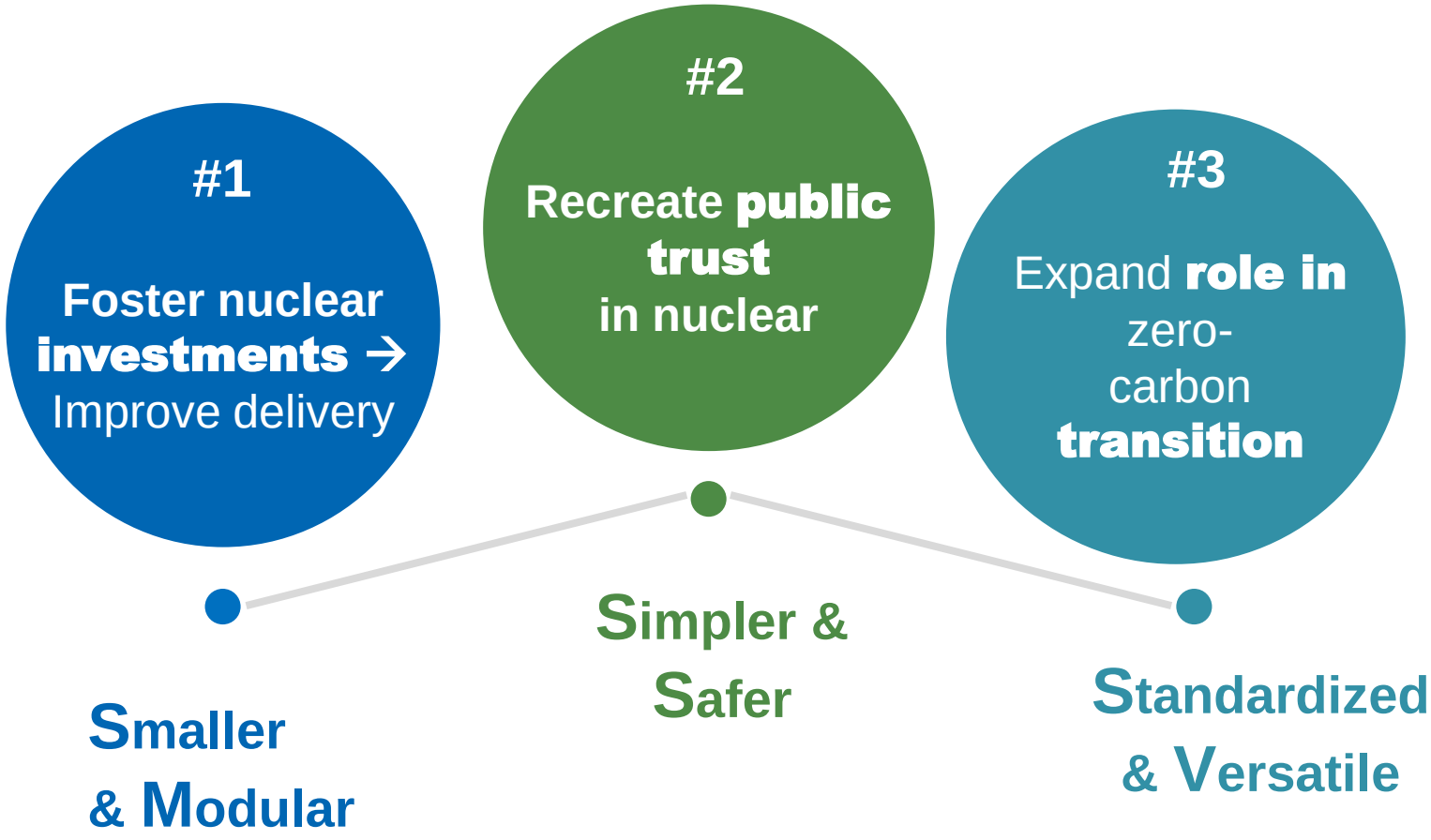
Panel discussion

Overview of the LWR SMR designs considered in Europe – Anicet Touré, ENGIE-Tractebel

Discussion with LWR SMR designers:

- Nuward - Sandro Baldi
- Rolls-Royce SMR - Sophie Macfarlane-Smith
- GE-Hitachi - Fredrik Vitaback

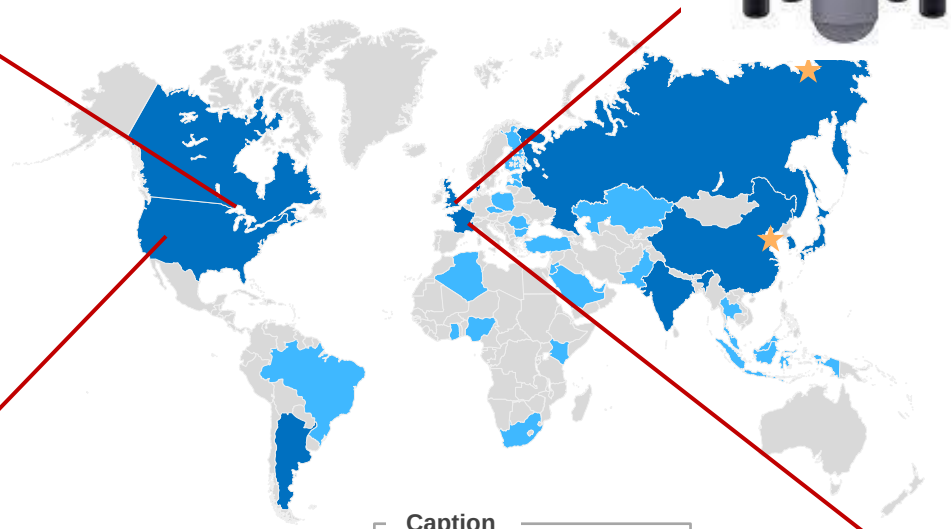
What drives the industry towards SMRs

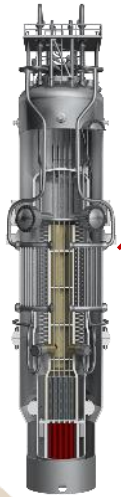


The first wave of SMRs will be Light Water Reactors

BWRX-300 (GE-Hitachi)
Single-Module BWR
300MW
Expected COD:
- 2028, Darlington, CANADA
- ca. 2029, Clinch River, USA

RR SMR (Rolls-Royce)
Single-Module PWR
470MW
Expected COD: ca. 2030, UK





NuScale VOYGR (Fluor)
Multi-module PWR
6x 77MW
Expected COD: 2029, Idaho Falls, USA

Nuward (EDF)
Multi-module PWR
2x 170MW
Expected COD: ca. 2034, FRANCE

Key characteristics of LW-SMR

- +70 years industry and operating experience
- Existing supply chain
- Mature regulatory landscape
- 1 design approval granted by US NRC
- 10+ companies actively developing a LW-SMR design
- 10+ deployments announced in Europe and North America < 2035

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The market need is there!

Electricity

1600 TWh/y
EU Low carbon electricity production to be deployed by 2040

80GW
European Nuclear capacity to be replaced by 2050 (end of life)

Hydrogen

>20 Mt H_2/y
REPowerEU Market Estimate for 2030

1000 TWh/y
Equivalent additional clean electricity demand

>125 GW
Equivalent nuclear capacity

Industrial heat

~1250 TWh_{th}/y
Iron – Steel, Non-metallic minerals and chemicals heat demand in EU26

> 45% market
Heat < 400°C

District heat

~500 TWh_{th}/y
Current district heat demand in EU26

> 2/3 fossil- fueled
Assets to be retired and replaced in the coming two decades

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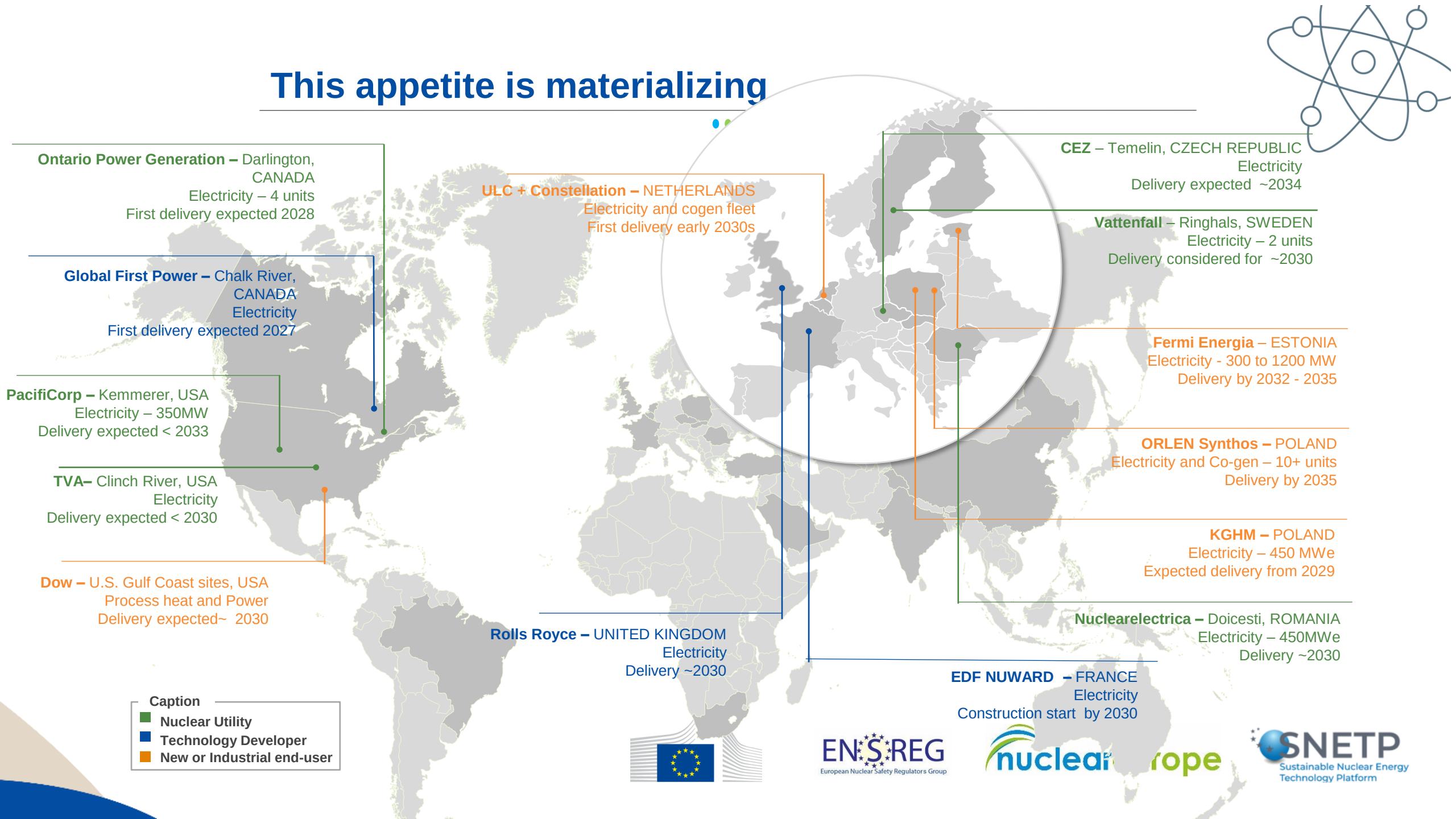
This appetite is materializing



Ontario Power Generation – Darlington, CANADA
Electricity – 4 units
First delivery expected 2028

Global First Power – Chalk River, CANADA
Electricity
First delivery expected 2027

PacifiCorp – Kemmerer, USA
Electricity – 350MW
Delivery expected < 2033

TVA– Clinch River, USA
Electricity
Delivery expected < 2030

Dow – U.S. Gulf Coast sites, USA
Process heat and Power
Delivery expected~ 2030

ULC + Constellation – NETHERLANDS
Electricity and cogen fleet
First delivery early 2030s

Rolls Royce – UNITED KINGDOM
Electricity
Delivery ~2030

CEZ – Temelin, CZECH REPUBLIC
Electricity
Delivery expected ~2034

Vattenfall – Ringhals, SWEDEN
Electricity – 2 units
Delivery considered for ~2030

Fermi Energia – ESTONIA
Electricity - 300 to 1200 MW
Delivery by 2032 - 2035

ORLEN Synthos – POLAND
Electricity and Co-gen – 10+ units
Delivery by 2035

KGHM – POLAND
Electricity – 450 MWe
Expected delivery from 2029

Nuclearelectrica – Doicesti, ROMANIA
Electricity – 450MWe
Delivery ~2030

EDF NUWARD – FRANCE
Electricity
Construction start by 2030

Caption
- **Nuclear Utility**
- **Technology Developer**
- **New or Industrial end-user**

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Overview of AMR designs considered in Europe – Sylvain Takenouti, EDF

Discussion with AMRs designers:

- NAAREA - Jean-Luc Alexandre
- Newcleo - Michele Battistin
- U-Battery Limited - Peter Bradley

A few definitions

- **SMR: reactors that produce electricity of up to 300 MWe per module (according to IAEA)**
- **AMR (Advanced Modular Reactors) definition is not standardized**
  - SMRs whose designs include innovations which are often comparable to Generation 4 reactors (typically cooled by molten salt, sodium, lead, gas, supercritical water, and not by light water)
  - Gen4 particular embarks sustainability features (limiting raw materials, impact of long-life waste, …)
- **MMR (Micro Modular Reactors) : reactors that produce electricity or heat of 1 up to 20 MWe per module**

- ***Whereas LW-SMR, relying on a mature technology, are expected to be deployed in the 2030s, AMRs / Gen IV designs need to be matured by 2035 for long term prospect***

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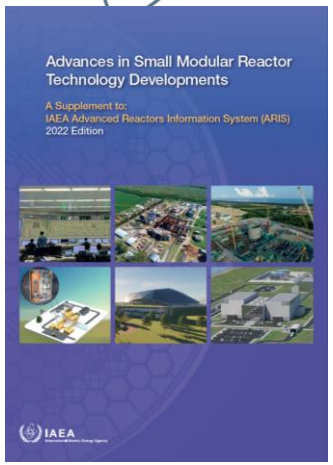
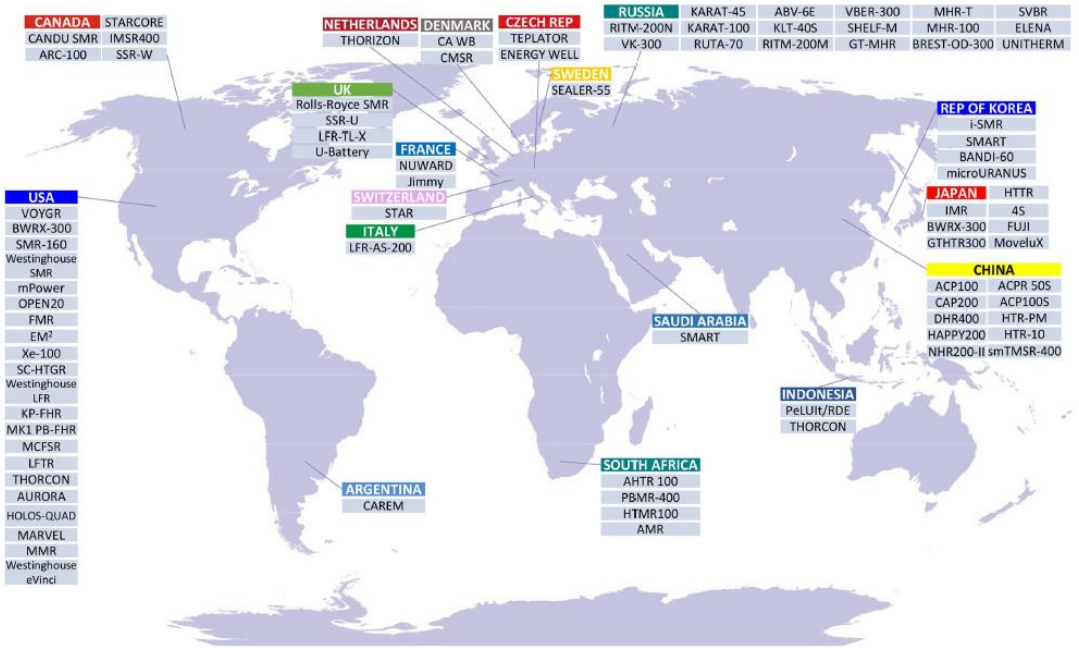
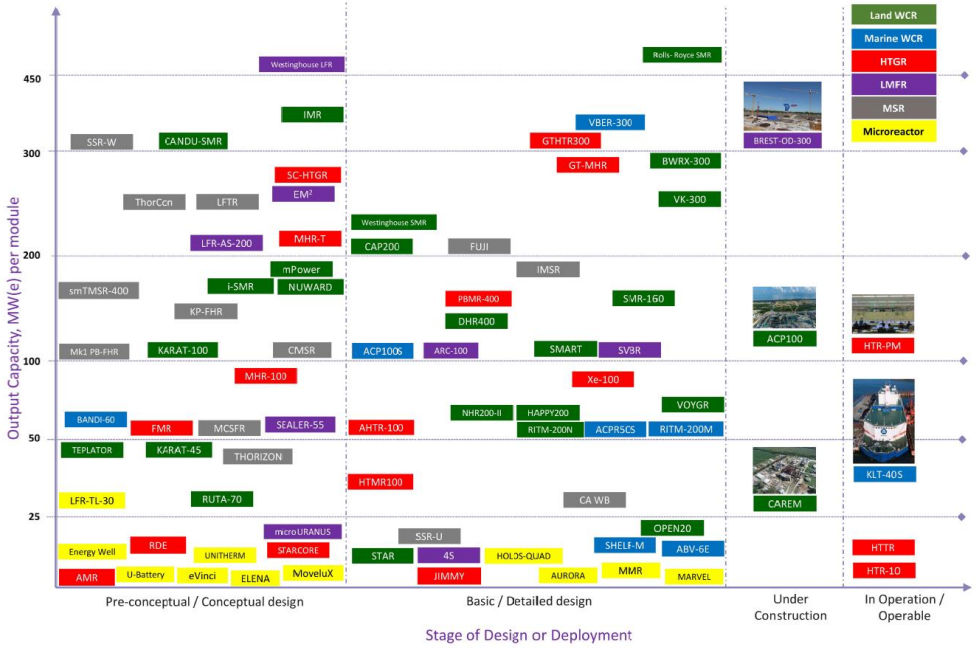
The AMR ecosystem is teeming in the recent years

- ca. 90 designs of SMRs identified in the 2022 IAEA SMR booklet
  - Whereas the SMR ecosystem seem now to stabilized, AMR including MMR is still teeming







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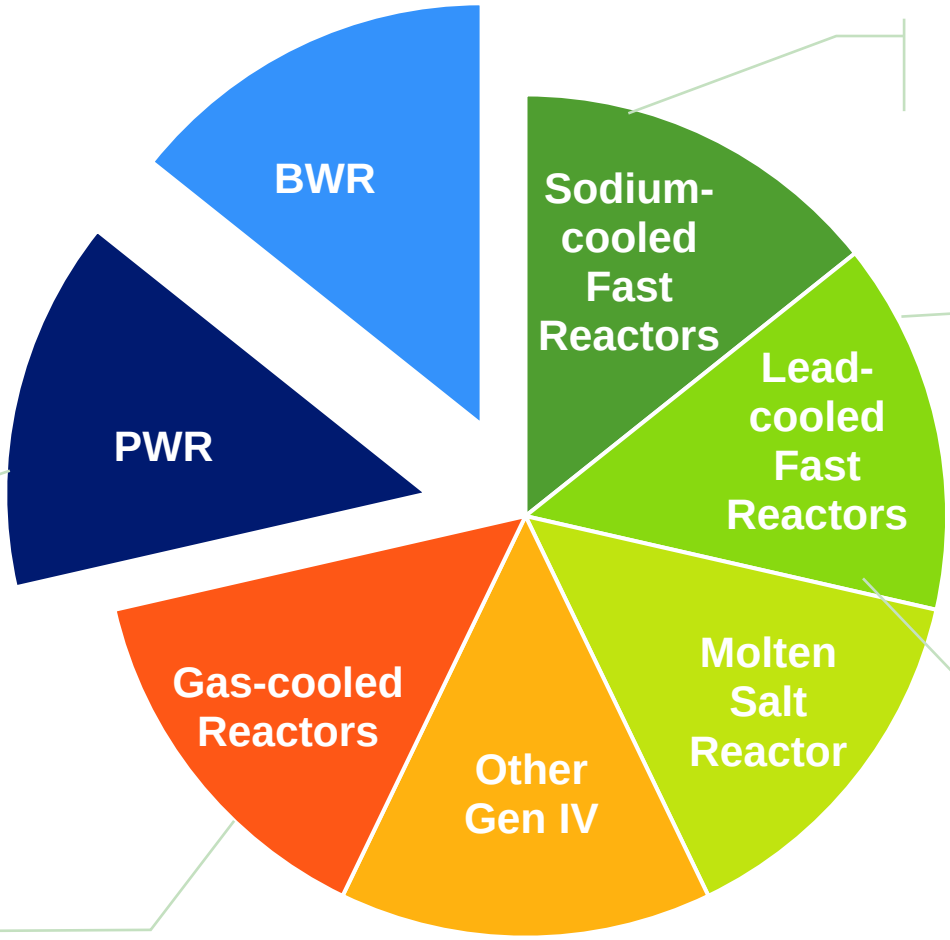
In Europe, a wide and growing variety of players for AMR designs (institutional, industrial, start-ups, etc.)



ANAIS, ATRIUM (CEA, France)

Newcleo (IT, UK, FR)
LeadCold SEALER (SW)
ALFRED / FALCON (RO, IT) ...

ADS
MYRRHA (BE), Transmutex (CH), ...

NAAREA, (FR), Thorizon (NL), Seaborg (DK), EnergyWell (CZ), Moltex (UK), Copenhagen Atomics (DK), ISAC project (FR), ...

Low Temp PWR
LDR (VTT, Finland)
LUTHER (LUT, Finland)

HTGR: U-Battery (UK), Jimmy (FR), EUTHER, GEMINI initiative (PL)...
GFR: ALLEGRO (PL, CZ, ...)

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Overview of the supply chain in Europe – Roberto Adinolfi, Ansaldo Nucleare

The Nuclear Supply Chain in Europe: How to adapt?

Discussion with stakeholders of the supply chain:

- ŠKODA JS - Miloš Mostecký
- Empresarios Agrupados - María Teresa Domínguez
- Walter Tosto - Massimiliano Tacconelli

SMR Business Models: Vendor opinions

- The key feature for SMR competitiveness is «production by series»

- How is this going to affect the future Supply Chain?
  - *Which products for SMRs?*
  - *How many ? (i.e. capacity issues)*
  - *Which changes in the relationship?*

- Answers should start from Vendor opinion on the best way to make SMR succesful in the future EU market (i.e. their «business model»)

Which products for SMRs?

- STANDARDIZATION

  Not only the reactor/plant design shall be standardised, but also component design/procurement/fabrication/factory testing

  ✓Component standardization will bring savings both in costs and in time, which in turn would make fleet deployment achievable and attractive

  ✓Standardization shouldn’t bring to pre-selection of single suppliers: need for more capacity and fair competition towards price reduction

  ✓More stringent specifications/ requirements to be expected from Vendors

Which products for SMRs?

- FACTORY MANUFACTURING

  Improved control of quality and schedule to reduce construction cost

  ✓ focus of the future licensees and the regulatory bodies from the site to the manufacturing facilities

  ✓ Extensive, upgraded factory testing

- LICENSING HARMONIZATION

  Deployment of the same model in several EU countries without redesigning

  ✓ adaptability to different Codes and Standards

Capacity issues

- Smaller unit size can lead to larger number of components for the same amount of power to install (This can be counterbalanced by simpler designs)
- SMR vendors interested to lacalize production to favour series deployment in various Countries
- Interest for use of high quality, non nuclear manufacturers

Which changes in the vendor/supplier relationship

- Vendors need to achieve NOAK cost reduction to make SMR attractive in the future nuclear market
- Supply chain contributes to the largest part of potential NOAK cost reduction
- By making available their NOAK cost savings to Vendors, Suppliers can gain a larger, serial market
- A win-win startegy can be envisaged for SMRs

Overview of the energy intensive users in Europe – Peter Claes, FEBELIEC-IFIEC

Discussion with intensives users:

- KGHM - Maciej Wójcik
- CEMBUREAU - Emmanuel Brutin
- Mytilineos (member of Eurometaux) - Nick Bitsios

Thank you!

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Q&A