NEA
NUCLEAR ENERGY AGENCY

Activities supporting the transition of Advanced Reactors from R&D to deployment

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Outline

- **OECD Nuclear Energy Agency**
  - NEA Small Modular Reactor (SMR) Dashboard
- **Generation IV International Forum (GIF)**
  - GIF Task Force on Non-Electric Applications

Global installed nuclear capacity needs to triple by 2050 for Net Zero

Reaching the target of tripling global installed nuclear capacity by 2050 will require a combination of:

1. long-term operation

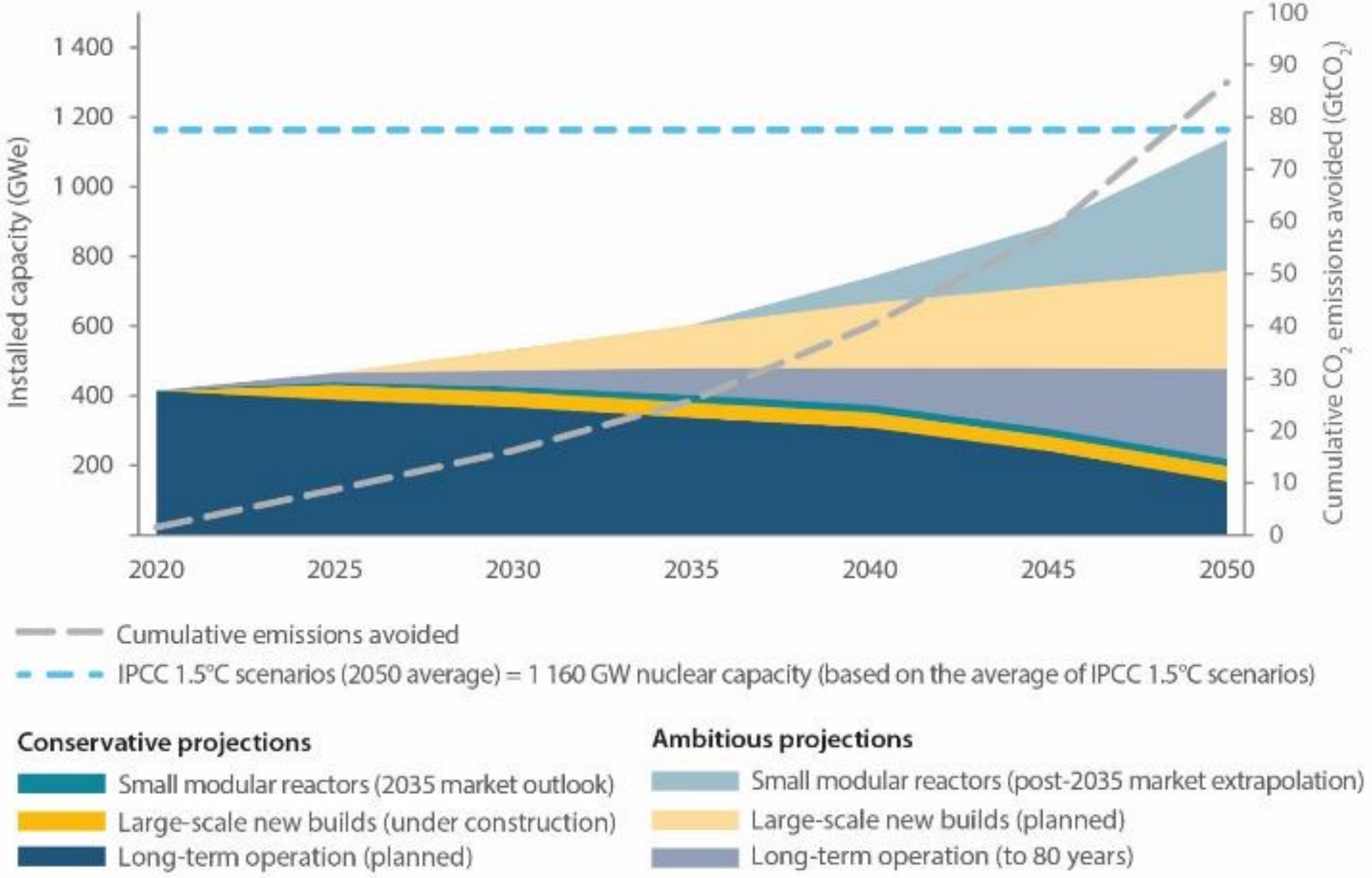
2. large-scale new builds

3. small modular reactors

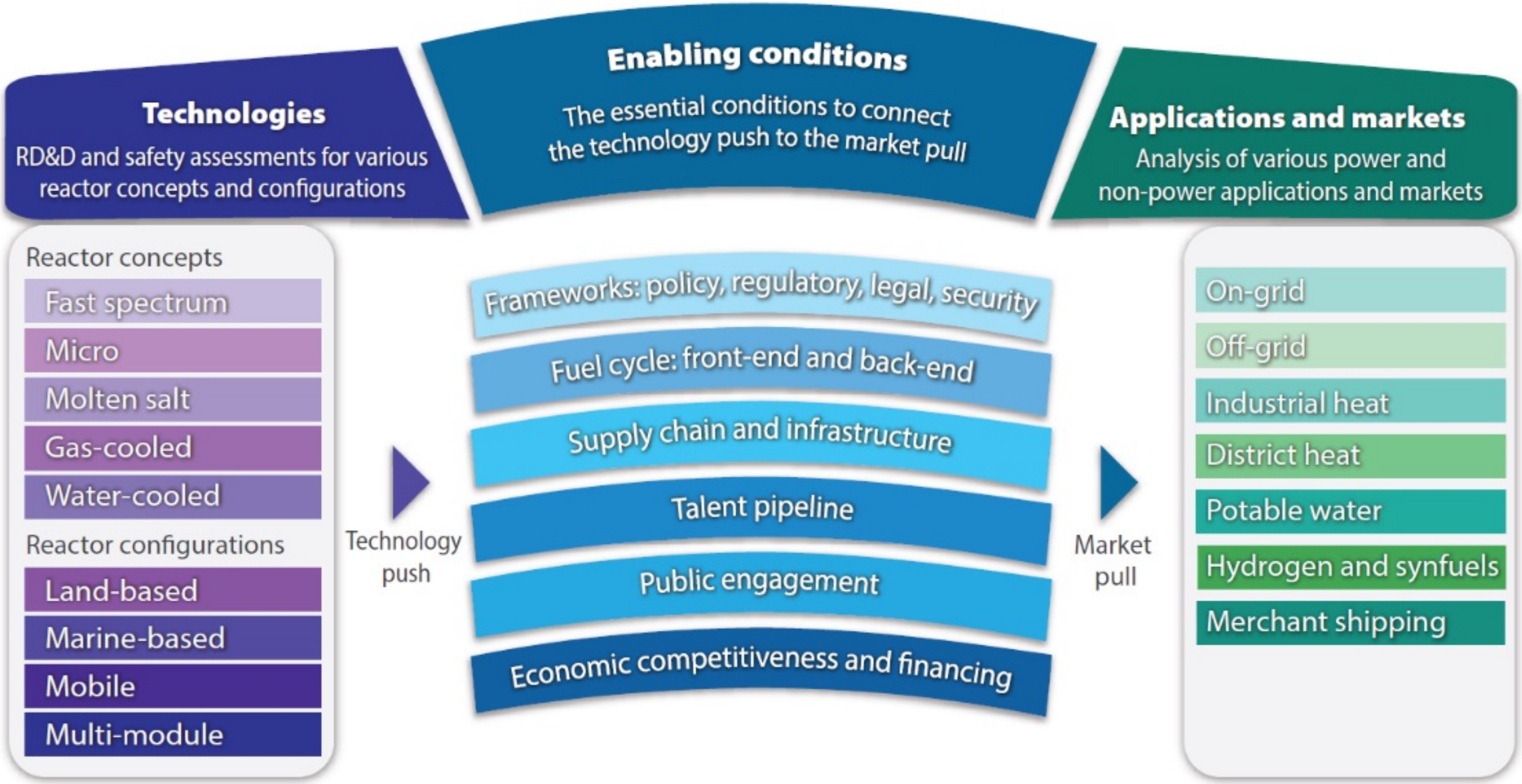
4. non-electric applications

(NEA 2022)

Full potential of nuclear contributions to Net Zero



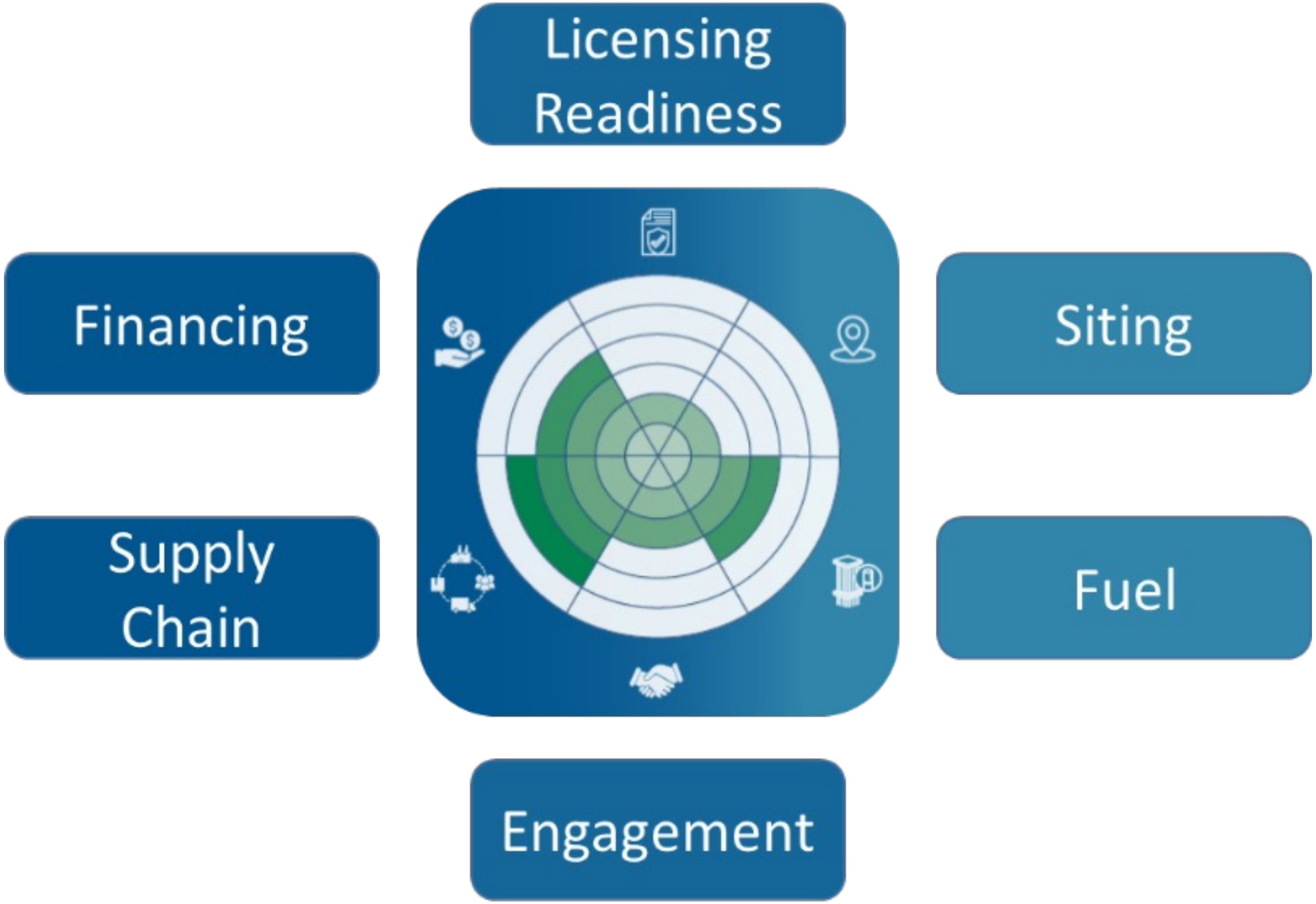
NEA SMR Strategy: Enabling Conditions



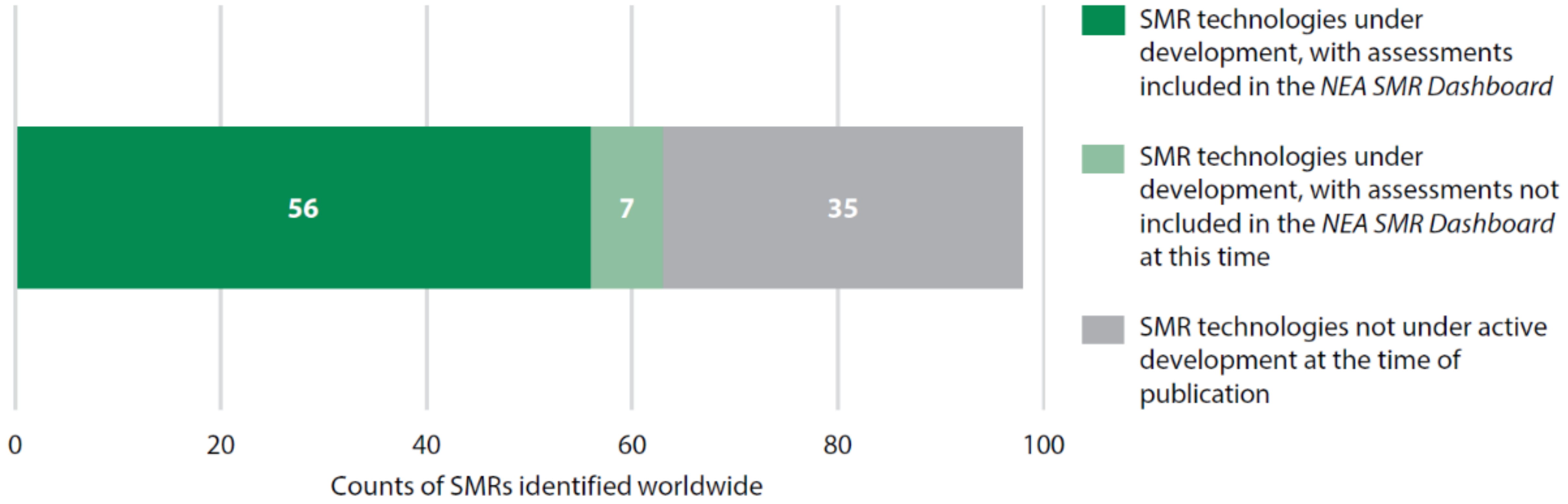
https://www.oecd-nea.org/jcms/pl_26297/the-nea-small-modular-reactor-smr-strategy

Tracking Progress: *Six new indicators by NEA*

- "Technology readiness level" is useful, but only reveals part of the picture
- NEA defines six additional indicators of progress
- With NEA's new indicators, the picture becomes clearer

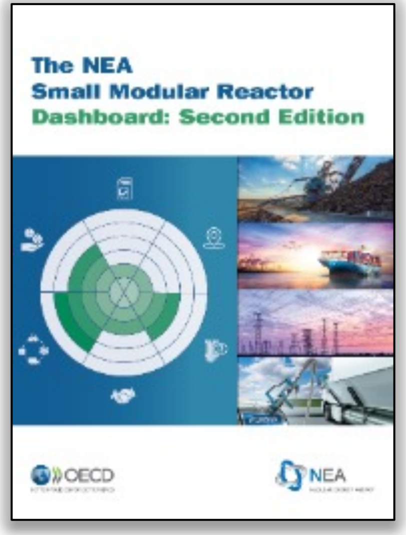


The Most Comprehensive Assessment to Date of Global Progress towards SMR Commercialization



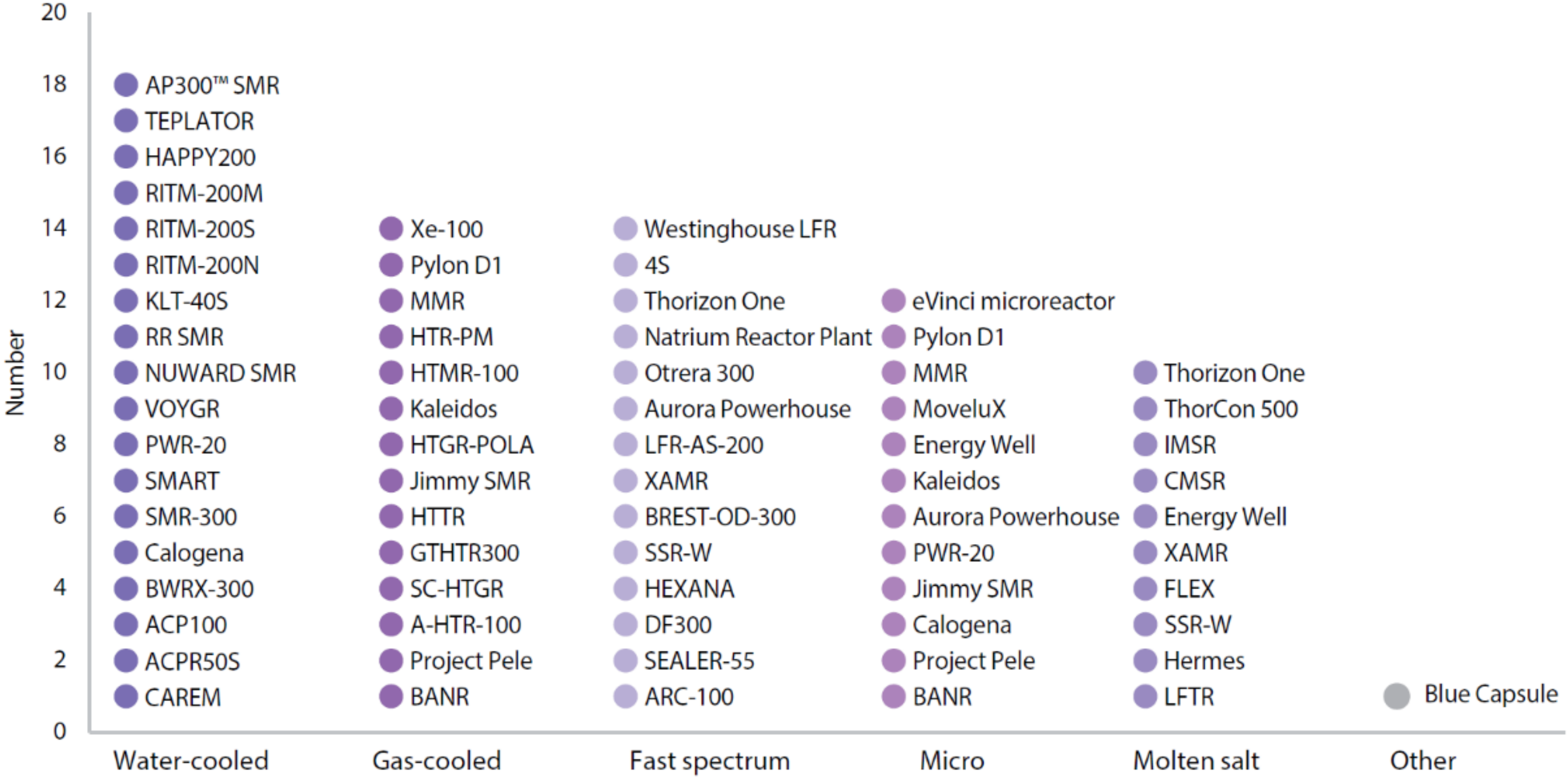
NEA SMR Dashboard: Second Edition

Launched on 29th February 2024 on the margins of the
Canadian Nuclear Association 2024 Conference in Ottawa, Canada.

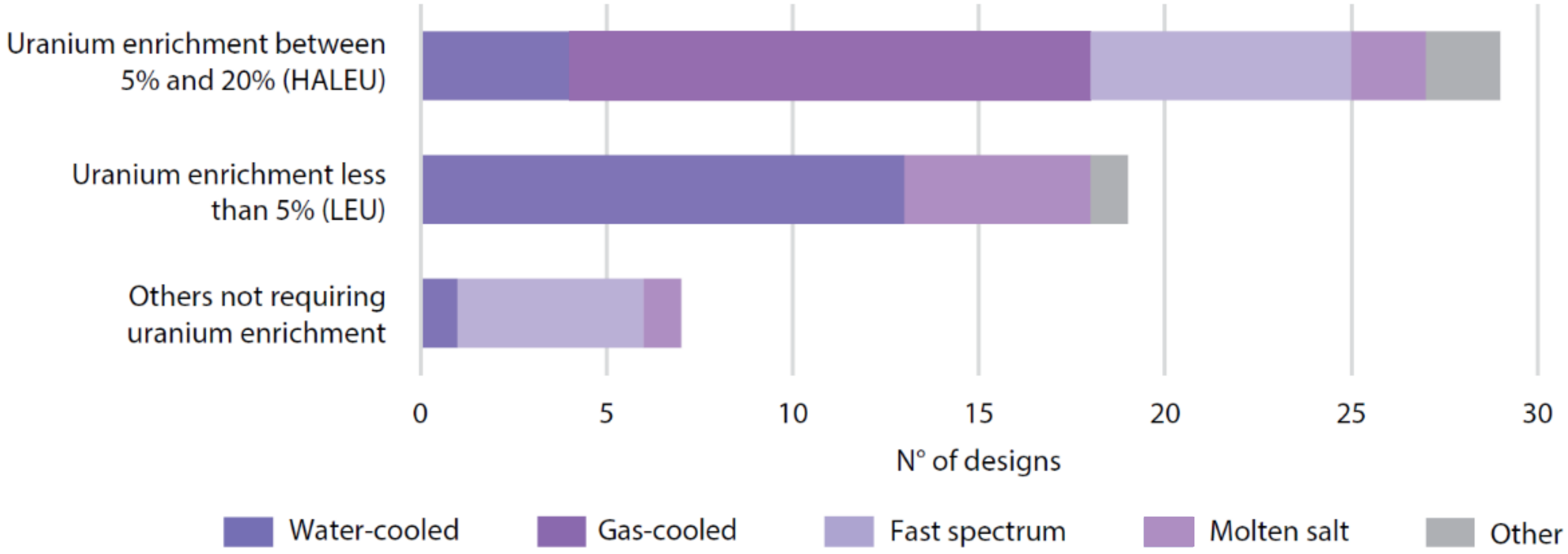


The logos represented were preferentially sourced from the websites dedicated to the SMR or the design organisation associated with the SMR. Minor modifications were applied related to sizing and colouring

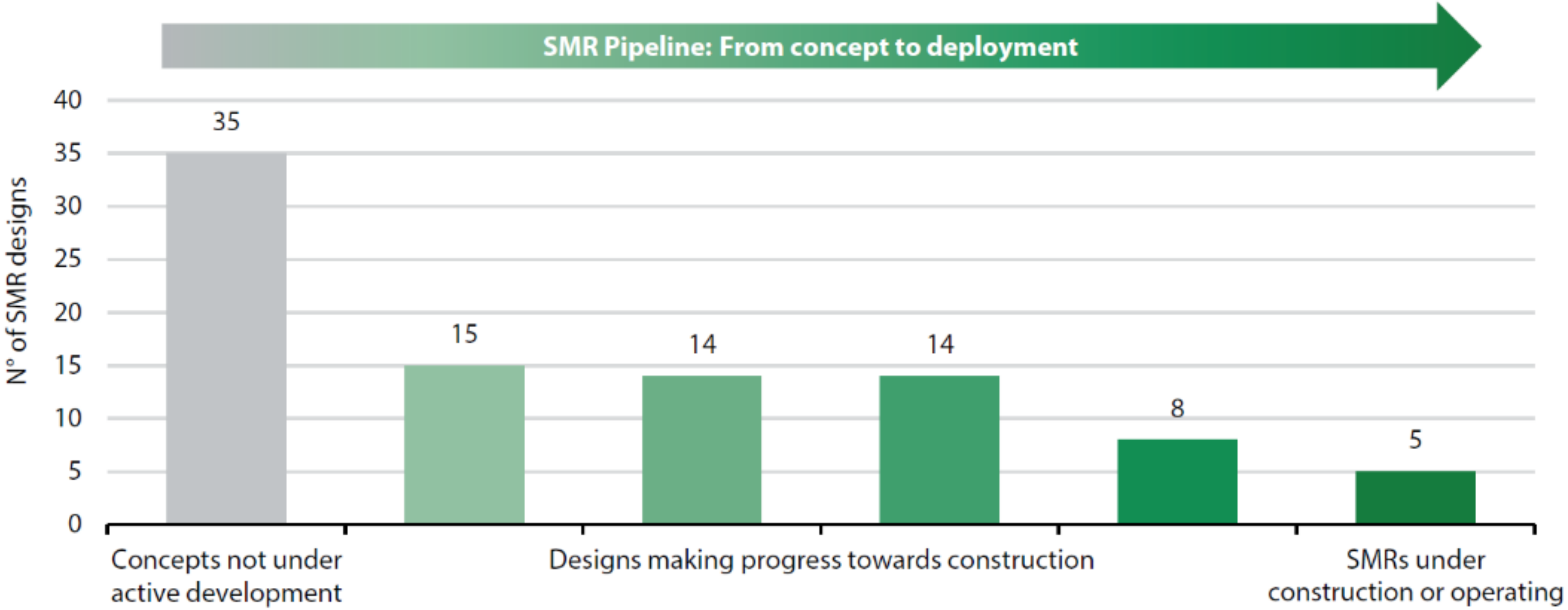
Reactor Concepts



SMR Uranium Enrichment Requirements

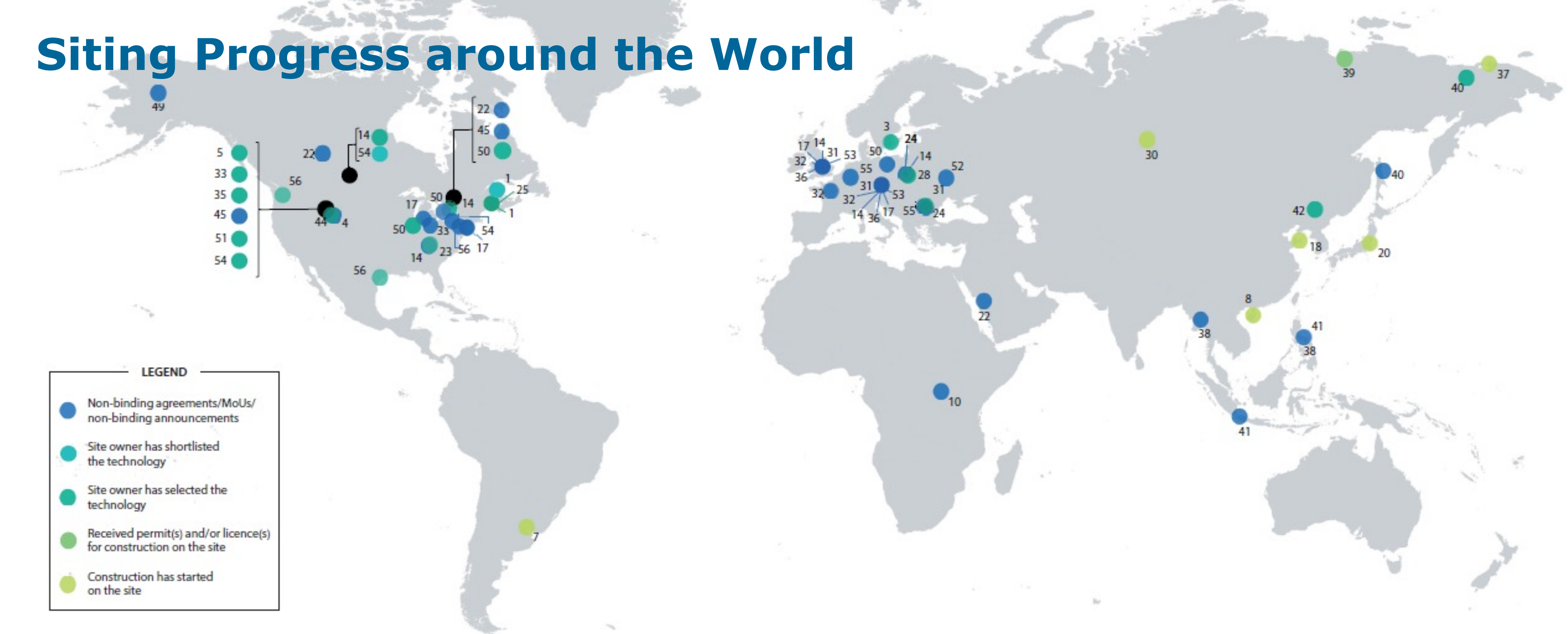


SMR Pipeline: Progress from Concept towards First Commercial Deployment



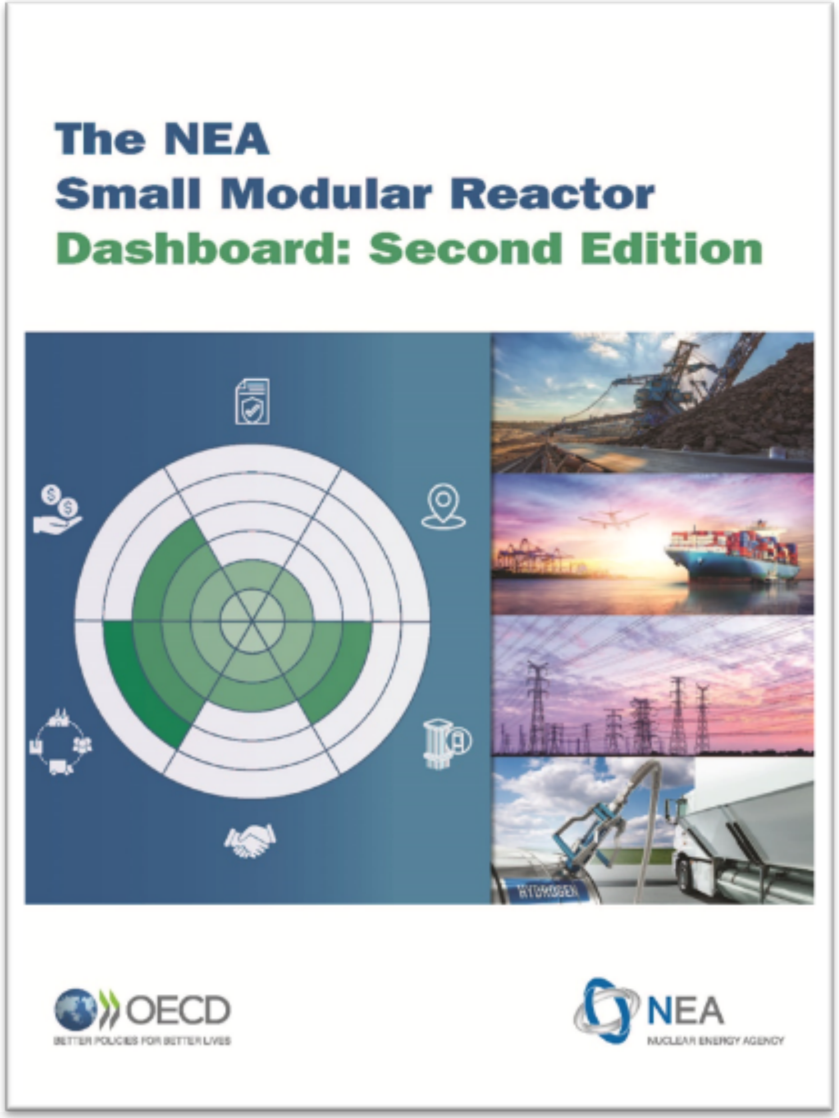
✓ A few designs are already operating, and there is a robust pipeline of SMRs making progress towards first-of-a-kind deployment.

Siting Progress around the World



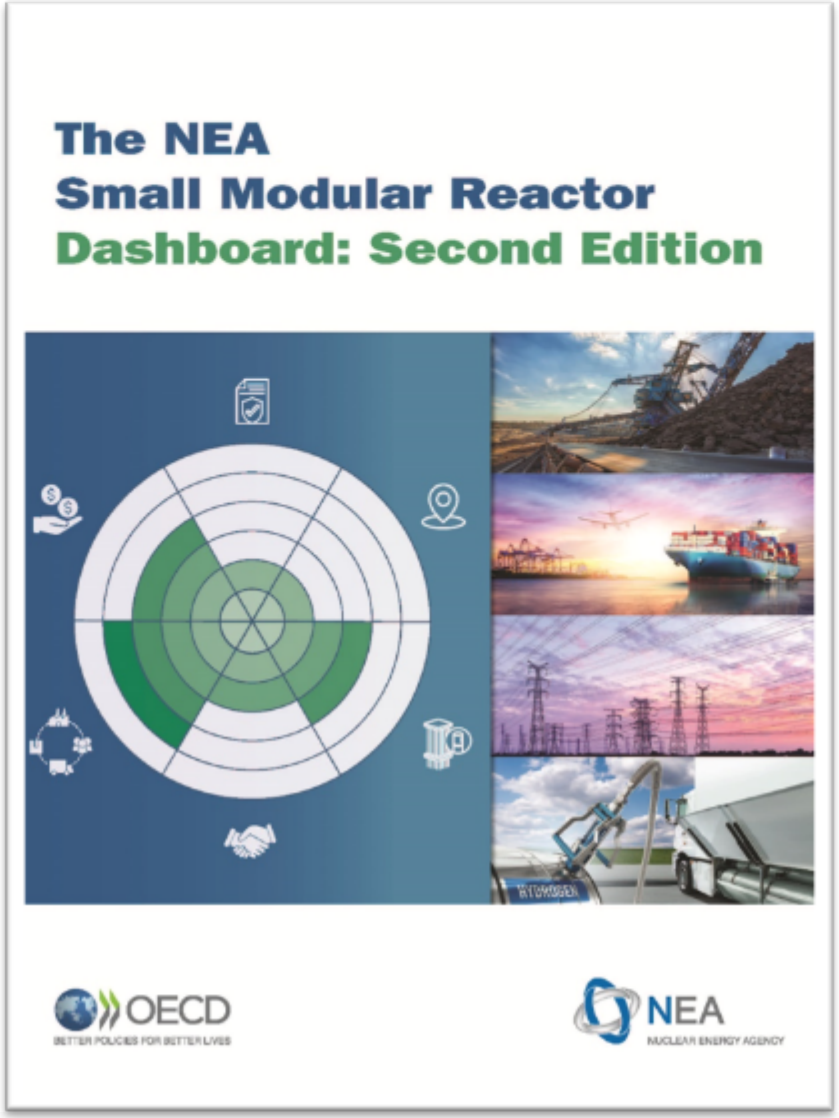
1	ARC-100	ARC Clean Technology
2	Blue Capsule	Blue Capsule Technology
3	SEALER-55	Blykalla
4	BANR	BWXT
5	Project Pele	BWXT
6	ACPR50S	CGN
7	CAREM	CNEA
8	ACP100	CNNC
9	Energy Well	CVŘ
10	DF300	Dual Fluid Energy
11	A-HTR-100	Eskom
12	LFTR	Flibe Energy
13	SC-HTGR	Framatome
14	BWRX-300	GE Hitachi Nuclear Energy
15	Calogena	Gorgé
16	HEXANA	Hexana
17	SMR-300	Holtec International
18	HTR-PM	INET
19	GTHTR300	JAEA
20	HTTR	JAEA
21	Jimmy SMR	Jimmy
22	SMART	KAERI
23	Hermes	Kairos Power
24	PWR-20	Last Energy
25	SSR-W	Moltex Energy
26	FLEX	MoltexFLEX
27	XAMR	NAAREA
28	HTGR-POLA	NCBJ
29	LFR-AS-200	*newcleo*
30	BREST-OD-300	NIKIET
31	VOYGR	NuScale Power
32	NUWARD SMR	NUWARD
33	Aurora Powerhouse	Oklo
34	Otrera 300	Otrera Nuclear Energy
35	Kaleidos	Radiant Industries
36	RR SMR	Rolls-Royce SMR
37	KLT-40S	ROSATOM
38	RITM-200M	ROSATOM
39	RITM-200N	ROSATOM
40	RITM-200S	ROSATOM
41	CMSR	Seaborg Technologies
42	HAPPY200	SPIC
43	HTMR-100	Stratek Global
44	Natrium Reactor Plant	TerraPower
45	IMSR	Terrestrial Energy
46	ThorCon 500	ThorCon International
47	Thorizon One	Thorizon
48	MoveluX	Toshiba Energy Systems & Solutions Corporation
49	4S	Toshiba Energy Systems & Solutions Corporation
50	MMR	USNC
51	Pylon D1	USNC
52	TEPLATOR	UWB and CIIRC CTU
53	AP300™ SMR	Westinghouse Electric Company
54	eVinci microreactor	Westinghouse Electric Company
55	Westinghouse LFR	Westinghouse Electric Company
56	Xe-100	X-energy

NEA SMR Dashboard: Second Edition



www.oecd-nea.org/SMR-Dashboard-2nd-edition

NEA SMR Dashboard: Second Edition



www.oecd-nea.org/SMR-Dashboard-2nd-edition

Generation IV International Forum
Non-Electric Applications of Nuclear Heat Task Force (NEANH TF)

Generation IV International Forum (GIF)

A framework for international co-operation in research and development for the next generation of nuclear energy systems

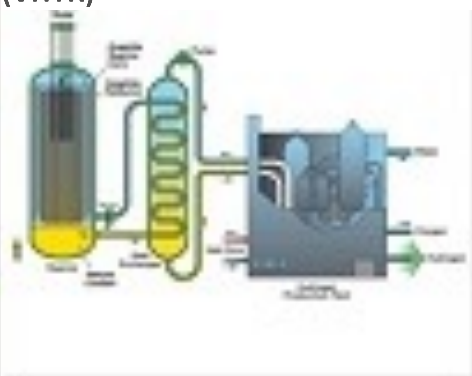
Thirteen Member Countries Plus the EU

GEN IV International Forum
Expertise | Collaboration | Excellence

Launched in 2001…

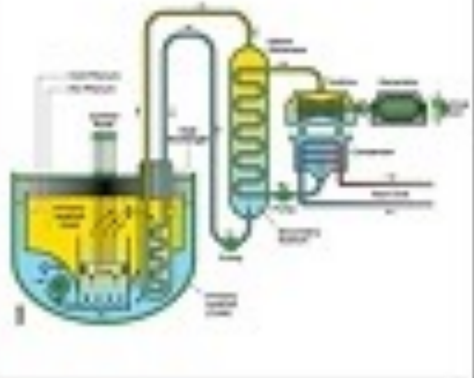
Six Generation IV Reactor Technologies

Very High Temperature Reactor (VHTR)



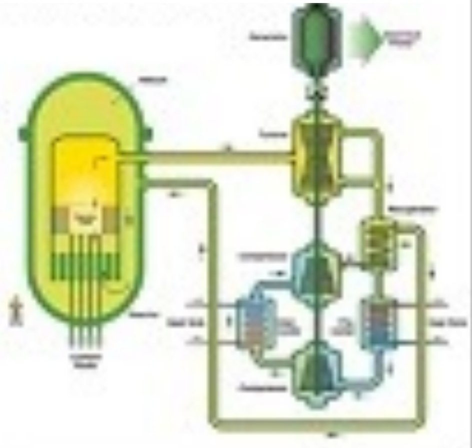
Molten Salt Reactor (MSR)

Sodium-cooled Fast Reactor (SFR)

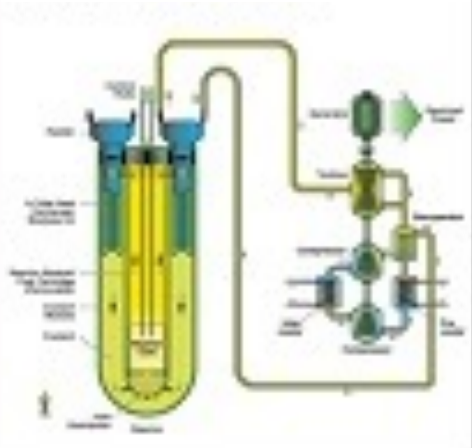


Supercritical Water-cooled Reactor (SCWR)

Gas-cooled Fast Reactor (GFR)



Lead-cooled Fast Reactor (LFR)



Cross-cutting Collaborations

- Economics & Modelling
- Education & Training
- Proliferation Resistance & Physical Protection
- Risk & Safety
- Safety Design Criteria
- R&D Infrastructure

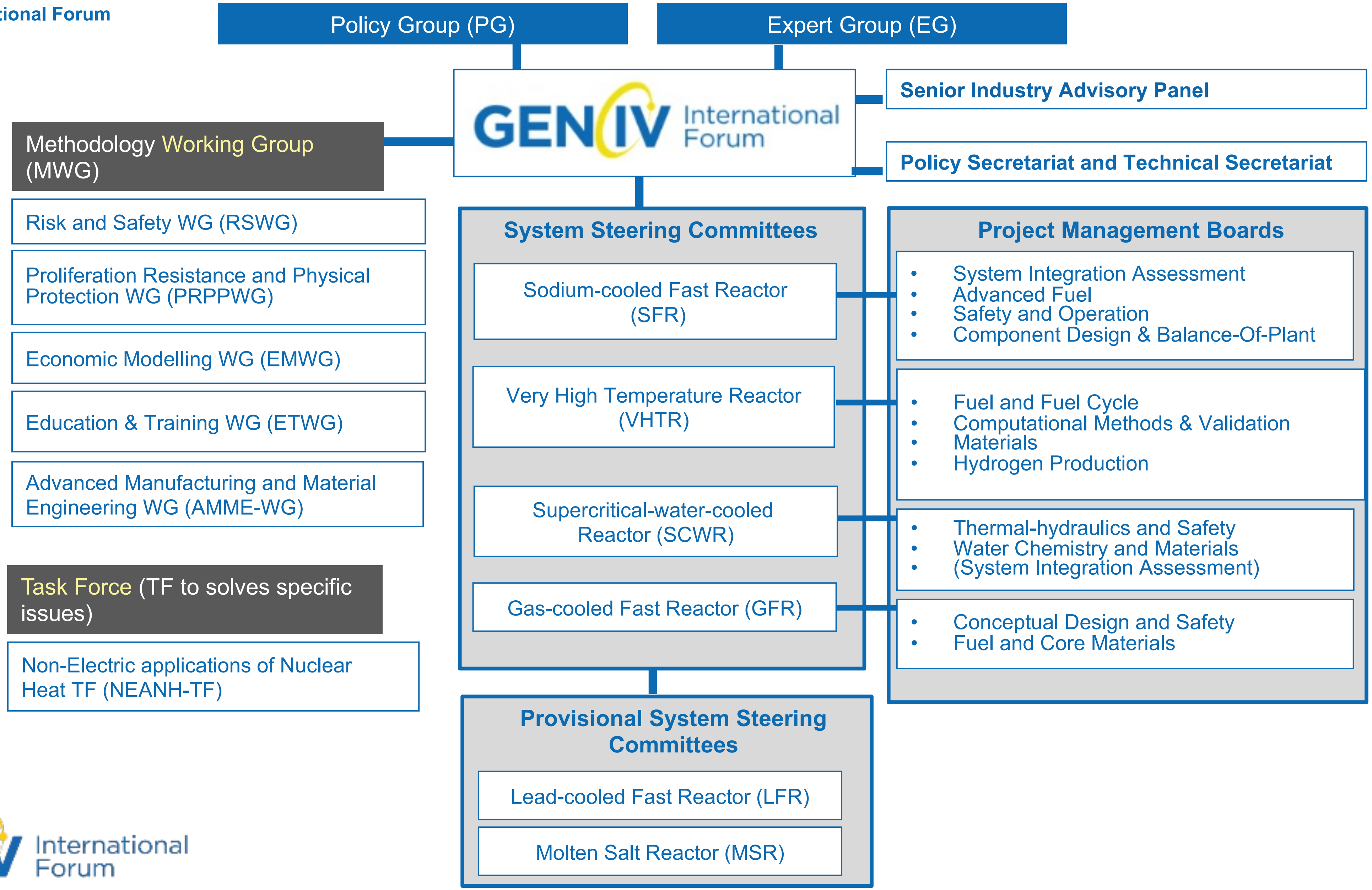
To achieve goals in four areas:

1. Sustainable energy with minimum waste
2. Life cycle cost advantages
3. Safety and reliability
4. Proliferation resistance & physical protection

GEN IV International Forum
Expertise | Collaboration | Excellence

…aiming to be ready for industrial deployment by 2030.

GEN IV International Forum



Expertise | Collaboration | Excellence

GIF Task Force on Non-Electric Applications of Nuclear Heat (NEANH)

Scope: Consider various combinations of the six GIF technology areas, across three power brackets, and six application areas.

GIF Technology Areas (6)	Power Brackets (3)	Application Areas (6)
• Gas-cooled fast reactors • Supercritical water-cooled reactors • Sodium-cooled fast reactors • Very high temperature reactors • Lead-cooled reactors • Molten salt reactors	• Gigawatt scale (~1000 Mwe) • Large SMR (~300 Mwe) • Micro-SMR (~10 Mwe)	• Hydrogen • Industrial heat • Desalination • Flexibility • Thermal storage • Power to gas

Timeline: Formed in October 2021 for an initial term of 24 months; recently extended to 36 months.

Members: Australia, Canada, China, Euratom, France, Japan, Korea, Russia, UK, USA, South Africa (Observer), IAEA (Observer)

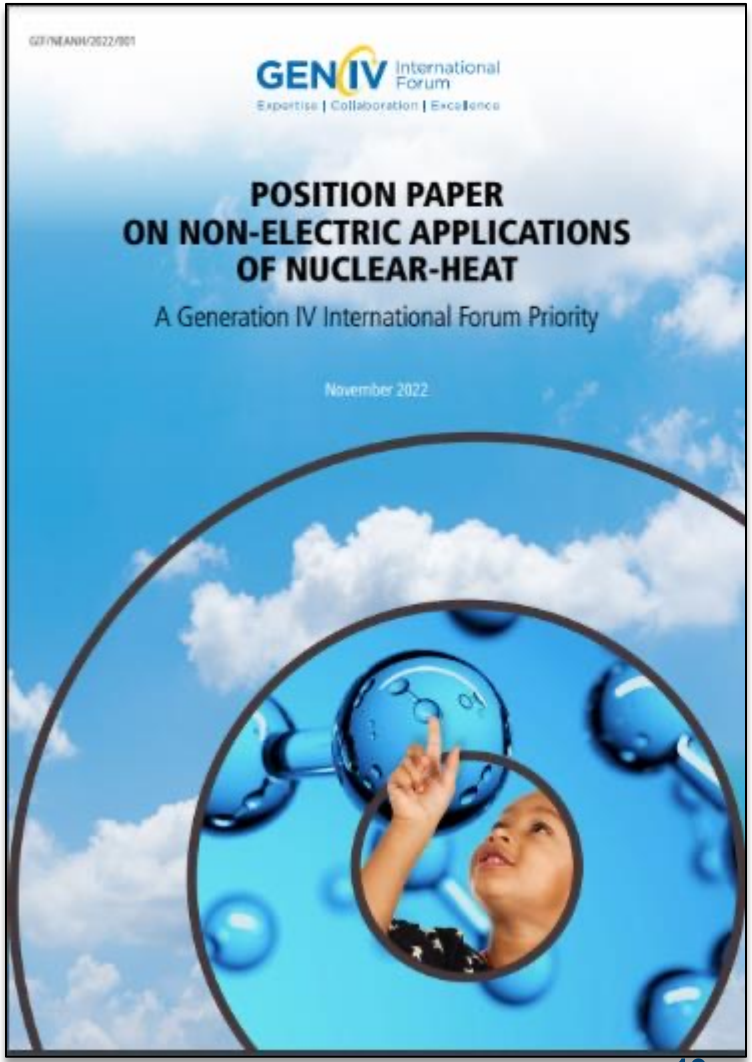
GIF Position Paper on Non-Electric Applications of Nuclear Heat

Completed

NEANH Task Force members completed the ***Position Paper on Non-Electric Applications of Nuclear-Heat: A Generation IV International Forum Priority*** in November 2022, and published to the GIF website in 2023.

The position paper reaffirms that GIF will:

- Consider and assess all potential solutions, including those that may not be ready until or after 2050.
- Communicate the role of Gen IV systems to provide diversified services ranging from electricity to numerous heat applications at the required scale.
- Leverage their members' collective skills, knowledge, and expertise to propose and evaluate relevant coupling and cogeneration options for the short and medium to long term.
- Define a portfolio of realistic, technically and economically feasible NEANH solutions coupled to Gen IV reactors to help accelerate decarbonisation.



NEANH workshop at GIF Industry Forum 2022

October 2022 in Toronto, Canada

150+ attendees to the NEANH workshop!

Workshop Structure:

- Concept Overview / setting the stage
- Three panel sessions:
  - Researchers panel
  - Industry: Energy end users
  - Industry: Advanced reactor developers
- Moderated Discussion

Meeting proceedings were made publicly available in 2023.

NEANH workshop at GIF Industry Forum 2022

October 2022 in Toronto, Canada

Industry Panel: Energy End-Users

Panel Participants:

- Nuclear Energy Agency: Overview on NEA studies
- The Pathways Alliance / Canadian **oil sands industry**
- Dow Chemical / **chemical industry** leader
- Chevron Technology Ventures / **oil & gas, refineries**
- Ammonia Energy Association / **ammonia**
- Electric Power Research Institute / **district energy**

Key findings:

- Several end-user companies/consortia of companies have initiated studies on the utilization of nuclear energy to support decarbonization efforts.
- Companies need reliable data to support technology assessments.
- End-users do not want to operate nuclear reactors - opportunity for partnership with utilities.
- Key stakeholders need to be engaged (e.g., licensees and regulators, both nuclear and for industrial processes).

Non-Electric and Hybrid Applications 2024 Workshop

April 2024 in Busan, Korea

approx. 75 attendees

1. ***Background and Overview:*** History of success and international perspectives on the future opportunity.
2. ***Industrial End-Users****:* A dialogue with those exploring Gen IV systems among a range of solutions to support industrial decarbonisation.
3. ***Challenges and Operational Experience:*** Challenges and experiences of systems coupled with industry.
4. ***Nuclear Technology Developers*****:** Technology developers discuss recent advancements and applications of their respective technologies.
5. ***Interactive Discussion*****:** A summary of the day's discussions with interactive audience participation.

Non-Electric and hybrid Applications 2024 Workshop

April 2024 in Busan, Korea

Industry Panel: Energy End-Users

Panel Participants:

- KAERI (Alliance for Nuclear Heat Utilization)
- Myongji University (**Chemical sector**)
- Korean Cogeneration Association (**District Energy**)
- Institute of Energy Technology Evaluation & Planning (**Hydrogen**)
- POSCO (**Steel**)

Key findings:

- Immediate opportunity for low temperature heat applications below 250C
- Higher temperature processes require a dedicated effort to develop integration technologies
- Significant demand for reliable thermal energy, at scale—competitive advantage for nuclear
- Partnerships and transparent information sharing is essential to enable the opportunity
- Government support is likely required to enable this transition as the scale is significant

Ongoing: Non-electric and hybrid applications database

NEANH Database (first draft inventory completed in 2023)

- Global repository of activities relevant to non-electric applications coupled with nuclear energy systems.
  1. Studies
  2. Collaborative initiatives
  3. Past or existing demonstration projects (or relevant commercial systems)
  4. Planned demonstrations or commercial systems
  5. Modelling tools
- The database will evolve to summarize entries or systems and to characterize them using **key performance indicators.**
- Targeting end-users beyond the nuclear field, such as:
  - Hard to abate industrial sectors,
  - Licensing authorities, and
  - Investors.

Key Performance Indicators:
Technological Readiness Level
Market readiness
License readiness
Timelines
Geographic Adaptability
GHG emission reduction potential
Energy security benefits
Cost/Benefit ($/t CO2 saved)
Economic viability
Supply chain
Investment considerations
Scalability
Ease of integration
Market size
Sustainability

Ongoing: System analysis on non-electric and hybrid energy systems

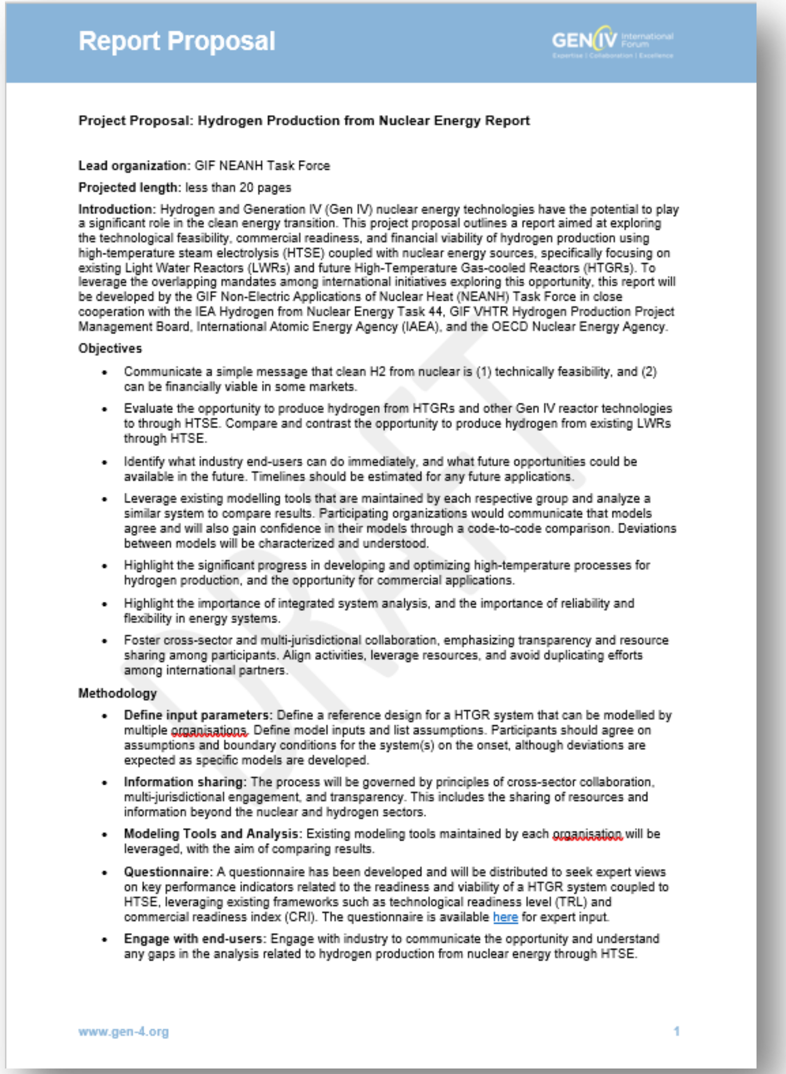
Systems analysis workshop held in January 2024

- The NEANH TF is working with international partners to conduct system analysis of Gen IV systems, including:
  - IEA Hydrogen from Nuclear Energy Task 44
  - GIF VHTR Hydrogen Production PMB
  - International Atomic Energy Agency (IAEA)
  - OECD Nuclear Energy Agency
- Initial focus is on a **high-temperature gas reactor to produce hydrogen through high-temperature steam electrolysis**.
- The report will communicate a simple message that clean hydrogen from nuclear is
  - (1) technically feasibility, and
  - (2) can be financially viable in some markets.
- Other systems will be considered based on stakeholder interest

Initial system Analysis workshop as part of the Joint IEA-GIF Meeting on Hydrogen from Nuclear Energy on January 23-25, 2024, at Idaho National Laboratory, Idaho Falls, Idaho, USA

Ongoing: System analysis on non-electric and hybrid energy systems

Initial focus on hydrogen production from high-temperature steam electrolysis using a HTGR in 2024



Report Proposal

GEN IV International Forum
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Project Proposal: Hydrogen Production from Nuclear Energy Report

Lead organization: GIF NEANH Task Force

Projected length: less than 20 pages

Introduction: Hydrogen and Generation IV (Gen IV) nuclear energy technologies have the potential to play a significant role in the clean energy transition. This project proposal outlines a report aimed at exploring the technological feasibility, commercial readiness, and financial viability of hydrogen production using high-temperature steam electrolysis (HTSE) coupled with nuclear energy sources, specifically focusing on existing Light Water Reactors (LWRs) and future High-Temperature Gas-cooled Reactors (HTGRs). To leverage the overlapping mandates among international initiatives exploring this opportunity, this report will be developed by the GIF Non-Electric Applications of Nuclear Heat (NEANH) Task Force in close cooperation with the IEA Hydrogen from Nuclear Energy Task 44, GIF VHTR Hydrogen Production Project Management Board, International Atomic Energy Agency (IAEA), and the OECD Nuclear Energy Agency.

Objectives

- Communicate a simple message that clean H2 from nuclear is (1) technically feasibility, and (2) can be financially viable in some markets.
- Evaluate the opportunity to produce hydrogen from HTGRs and other Gen IV reactor technologies to through HTSE. Compare and contrast the opportunity to produce hydrogen from existing LWRs through HTSE.
- Identify what industry end-users can do immediately, and what future opportunities could be available in the future. Timelines should be estimated for any future applications.
- Leverage existing modelling tools that are maintained by each respective group and analyze a similar system to compare results. Participating organizations would communicate that models agree and will also gain confidence in their models through a code-to-code comparison. Deviations between models will be characterized and understood.
- Highlight the significant progress in developing and optimizing high-temperature processes for hydrogen production, and the opportunity for commercial applications.
- Highlight the importance of integrated system analysis, and the importance of reliability and flexibility in energy systems.
- Foster cross-sector and multi-jurisdictional collaboration, emphasizing transparency and resource sharing among participants. Align activities, leverage resources, and avoid duplicating efforts among international partners.

Methodology

- **Define input parameters:** Define a reference design for a HTGR system that can be modelled by multiple organisations. Define model inputs and list assumptions. Participants should agree on assumptions and boundary conditions for the system(s) on the onset, although deviations are expected as specific models are developed.
- **Information sharing:** The process will be governed by principles of cross-sector collaboration, multi-jurisdictional engagement, and transparency. This includes the sharing of resources and information beyond the nuclear and hydrogen sectors.
- **Modeling Tools and Analysis:** Existing modeling tools maintained by each organisation will be leveraged, with the aim of comparing results.
- **Questionnaire:** A questionnaire has been developed and will be distributed to seek expert views on key performance indicators related to the readiness and viability of a HTGR system coupled to HTSE, leveraging existing frameworks such as technological readiness level (TRL) and commercial readiness index (CRI). The questionnaire is available here for expert input.
- **Engage with end-users:** Engage with industry to communicate the opportunity and understand any gaps in the analysis related to hydrogen production from nuclear energy through HTSE.

www.gen-4.org 1

1 - Objective system modelling and analysis

– Assessment of generic NEANH system scenarios using modelling tools

2 - Subjective survey of system readiness

– Leverage existing frameworks

– Seeks expert views on the status or readiness of each system

– Identifying gaps associated with specific systems

– Could identify challenges that are common regardless of country

– Please follow this link to complete the questionnaire: https://forms.office.com/e/khU53G4x4u

Thank you

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