

Small Modular Reactors

International perspectives on opportunities and challenges

Diane Cameron

Head of Division of Nuclear Technology
Development and Economics



The NEA: 34 Countries Seeking Excellence in Nuclear Safety, Technology, and Policy

- The premier international platform for cooperation in nuclear technology, policy, regulation, research, and education.
- 34 member countries + strategic partners (e.g., China and India).
- 8 standing committees and more than 80 working parties and expert groups.
- Global relationships with industry and universities.

 Argentina	 Australia	 Austria	 Belgium
 Bulgaria	 Canada	 Czech Republic	 Denmark
 Finland	 France	 Germany	 Greece
 Hungary	 Iceland	 Ireland	 Italy
 Japan	 Korea	 Luxembourg	 Mexico
 Netherlands	 Norway	 Poland	 Portugal
 Romania	 Russia	 Slovak Republic	 Slovenia
 Spain	 Sweden	 Switzerland	 Turkey
 United Kingdom	 United States		

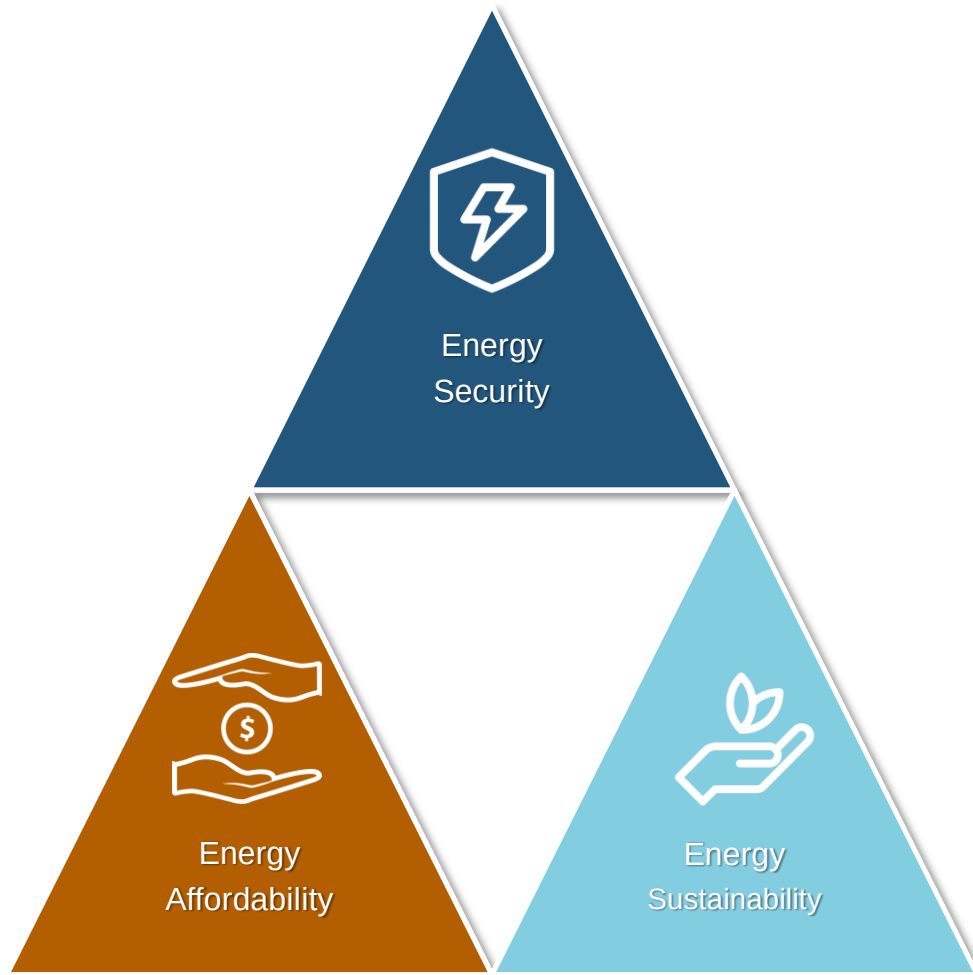
**NEA countries operate about 81%
of the world's installed nuclear capacity**

Outline

1. Nuclear Energy in Today's Energy Policy Context
2. The Role of Nuclear Energy in Pathways to Net Zero
3. Small Modular Reactors
4. Policy Frameworks to Support SMR deployment

Context

The “Energy Trilemma”



There are NO magic solutions to the Energy Trilemma

National conditions, available natural resources and policy preferences will continue to shape energy policy decisions

Key Observations

- **Energy security is now the driving issue in many capitals** as electricity prices rise dramatically around the world and recent geopolitical events create fears of a gas supply crisis in Europe.
- **Coal use is shrinking** as policies, markets, and public perception turn against its use in many countries.
- **Recent focus on 2030 targets for CO₂ reductions** have forced both increased investment in energy and a much larger degree of reality.
- **Particularly in the aftermath of COP26, many OECD and emerging economies view nuclear energy as a key element in their decarbonization strategies**



Countries are Reviewing their Energy Strategies

Many are looking to Nuclear Energy

U.K.'s Johnson Pushes to Make Nuclear 25% 2050 Power Mix

- Government is drawing up an energy plan to boost clean supply
- Prime Minister met with nuclear industry executives Monday

Nuclear makes a comeback in the Netherlands

15 December 2021



The Netherlands' new coalition government has placed nuclear power at the heart of its climate and energy policy. Some EUR500 million (USD564 million) has been earmarked to support new nuclear build in the period to 2025.

Energy crisis: Belgians get behind nuclear power

Tuesday, 29 March 2022

By Ugo Realfonzo

NUCLEAR POLITICS

Italy / Nuclear Back On Agenda As Support For Advanced Reactor Technologies Grows

By Mattia Baldoni

Nuclear energy + Add to myFT

Macron restarts France's 'nuclear adventure' with plans for 6 reactors

Atomic energy is central to plan to meet net zero carbon emissions, French president says

News

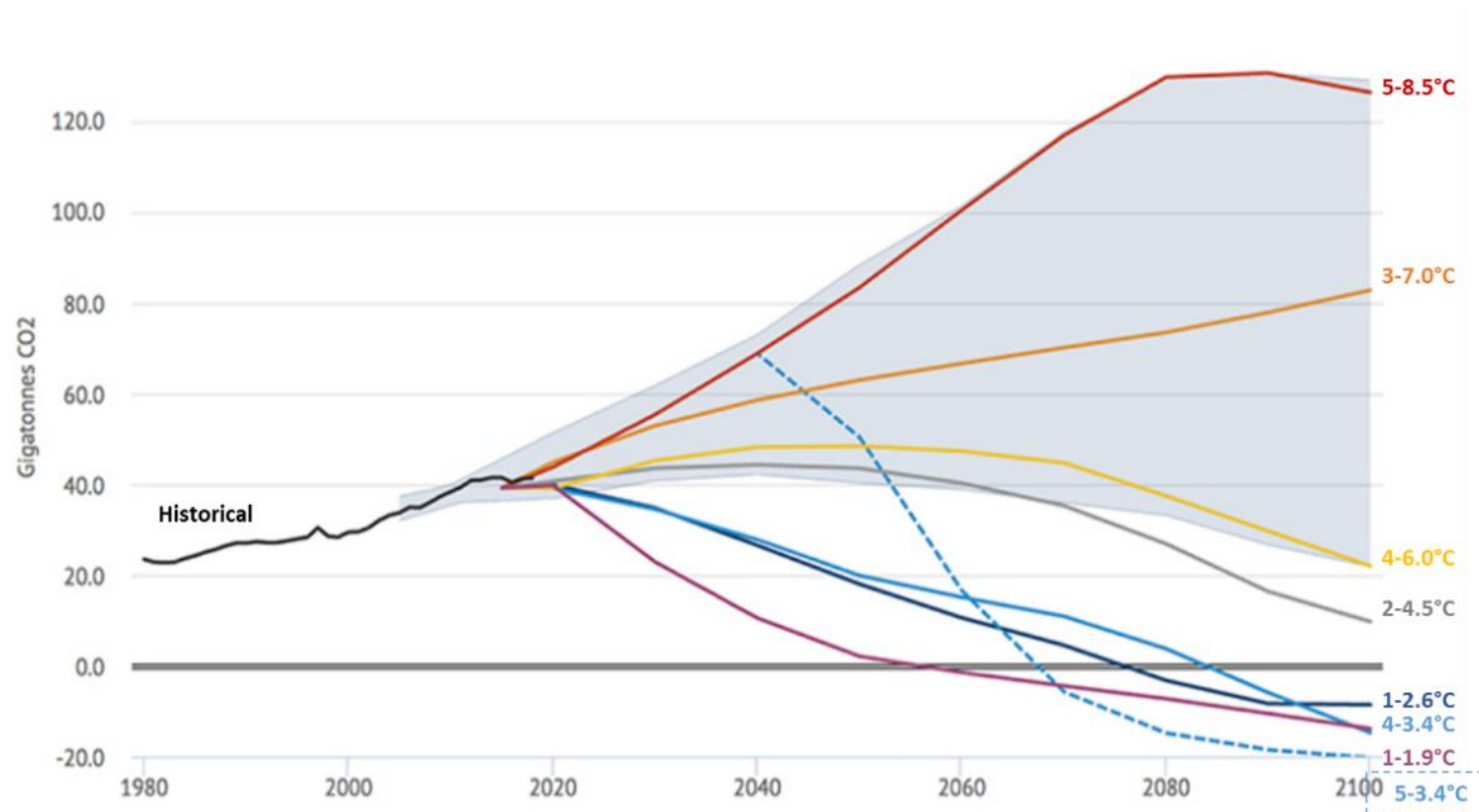
South Korea's new president wants nuclear U-turn

Net Zero

Global Action Is Urgently Needed

- The magnitude of the challenge should not be underestimated
- The planet has a “carbon budget” of 420 gigatonnes of carbon dioxide emissions for the 1.5°C scenario
- At current levels of emissions, the entire carbon budget would be consumed within 8 years
- Emissions must go to net zero, but the world is not on track

Temperature outcomes for various emissions futures



Source: Carbon Brief (2019).

Pathways to Net Zero Emissions

- Pathways based on the world's carbon budget, emissions reductions targets and timelines have been modelled and published by various organisations.
- All published pathways include levels of nuclear energy deployment based on currently available commercial technologies
- Nuclear innovation does not feature prominently because of a lack of specialised expertise in nuclear technologies among modelling teams

Samples of ambitious and aspirational pathways to net zero

Organisation	Scenario	Parameter	2020	2050	Growth rate (2020-50)
IIASA (2021)	Divergent Net Zero Scenario (1.5°C)	Cost of carbon (USD per tCO ₂)	0	1 647	-
		Wind (in GWe)	600	9 371	1461%
		Solar (in GWe)	620	11 428	1743%
IEA (2021)	Net Zero Scenario (1.5°C)	Hydrogen (MtH ₂)	90	530	490%
		CCUS (GtCO ₂)	<0.1	7.6	-
		Energy intensity (MJ per USD)	4.6	1.7	-63%
Bloomberg NEF (2021)	New Energy Outlook Green Scenario (1.5°C)	Wind (in GWe)	603	25 000	4045%
		Solar (in GWe)	623	20 000	3110%

Nuclear in Emissions Reduction Pathways

Organisation	Scenario	Climate target	Nuclear innovation	Description	Role of nuclear energy by 2050	
					Capacity (GW)	Nuclear growth (2020-50)
IAEA (2021b)	High Scenario	2°C	Not included	Conservative projections based on current plans and industry announcements.	792	98%
IEA (2021c)	Net Zero Scenario (NZE)	1.5°C	Not included but HTGR and nuclear heat potential are acknowledged.	Conservative nuclear capacity estimates. NZE projects 100 gigawatts more nuclear energy than the IEA sustainable development scenario.	812	103%
Shell (2021)	Sky 1.5 Scenario	1.5°C	Not specified	Ambitious estimates based on massive investments to boost economic recovery and build resilient energy systems.	1 043	160%
IIASA (2021)	Divergent Net Zero Scenario	1.5°C	Not specified	Ambitious projections required to compensate for delayed actions and divergent climate policies.	1 232	208%
Bloomberg NEF (2021)	New Energy Outlook Red Scenario	1.5°C	Explicit focus on SMRs and nuclear hydrogen	Highly ambitious nuclear pathway with large scale deployment of nuclear innovation.	7 080	1670%

Many pathways require global installed nuclear capacity to grow significantly, often more than doubling by 2050.

Nuclear Energy Today



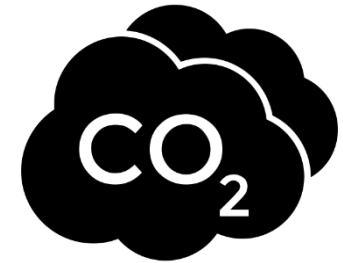
444
Nuclear
reactors in
operation
globally



30
Countries
with nuclear
reactors



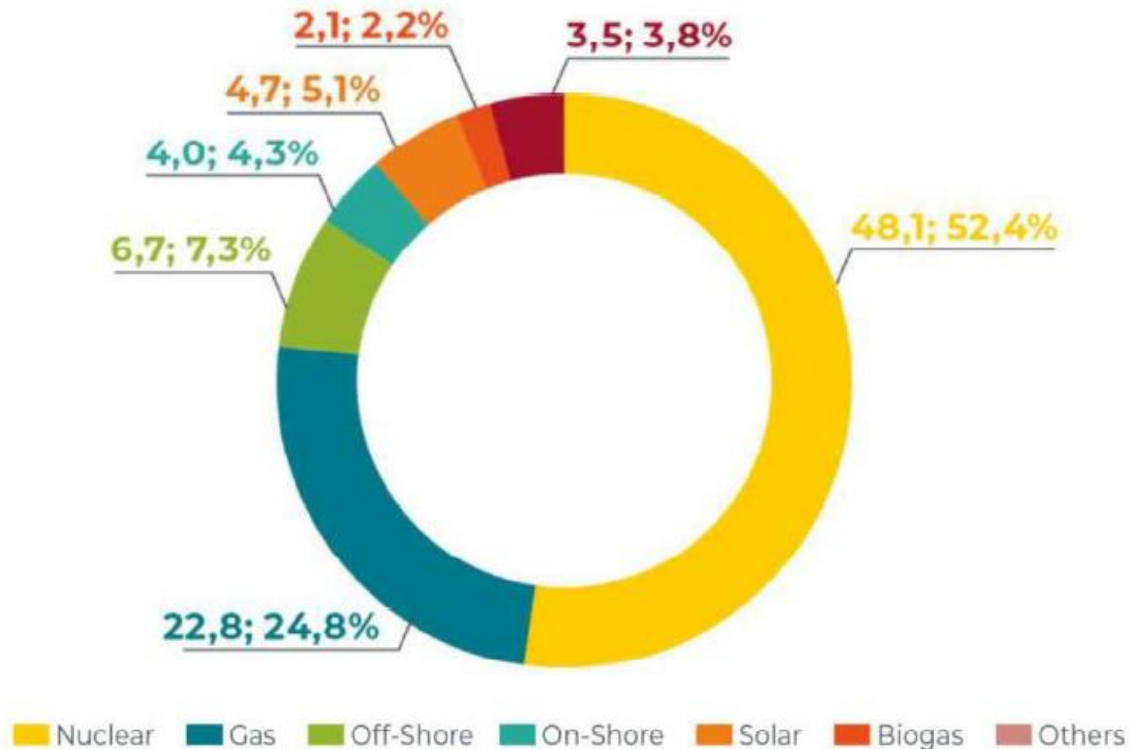
10%
of global
electricity



66 GtCO₂
emissions
avoided
since 1971

Nuclear Power in Belgium

Belgium electricity mix 2021



- 30-50 TWh from nuclear power
- Nearly 50% of electricity supply

Belgium nuclear power plants



- 7 power plants in operation at 2 sites
- 48,000 jobs

Nuclear Energy Can and Must Play a Larger Role Toward Net Zero

In its 2018 special report, the IPCC reviewed **90 pathways consistent with a 1.5°C scenario** – i.e., pathways with emissions reductions sufficient to limit average global warming to less than 1.5°C.

The IPCC found that, on average, **global installed nuclear capacity needs to triple**, reaching **1160 gigawatts of electricity by 2050**, up from 394 gigawatts in 2020.



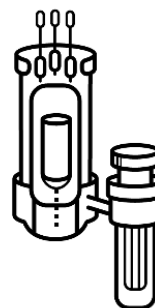
The Full Potential of Nuclear Energy to Contribute to Emissions Reductions



**Long Term
Operation**



**Large Gen-III
Reactors**



**Small Modular
Reactors**



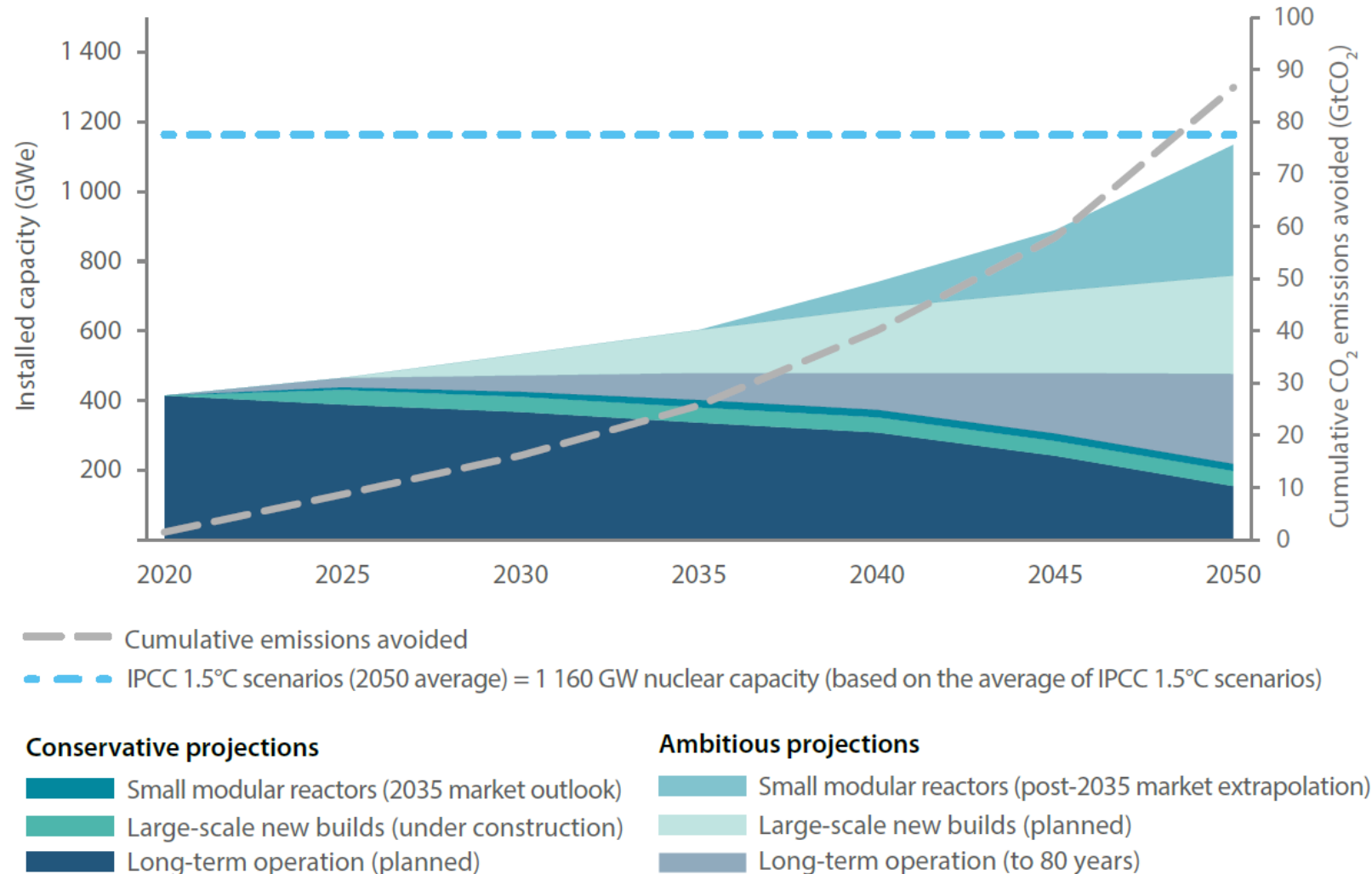
**Non-Electrical
applications**

Complementary nuclear technologies and applications

SMRs Have an Important Role to Play *Alongside Long-term Operation Aand New Builds of Large Nuclear Power Plants*

Reaching the target of 1160 gigawatts of global installed nuclear capacity by 2050 will require a **combination of long-term operation, large-scale Generation III, small modular reactors, and non-electric applications** such as nuclear-produced heat and hydrogen.

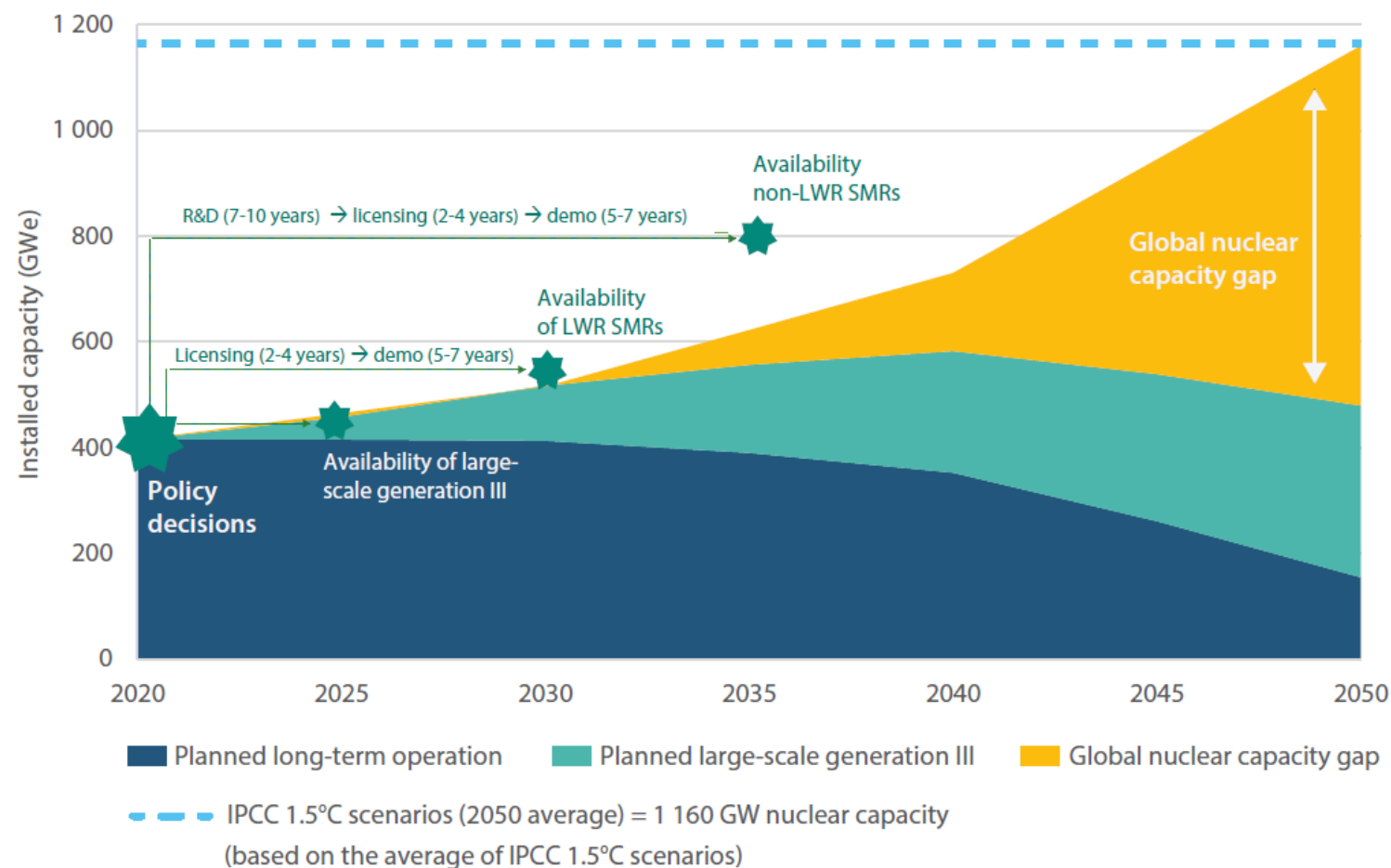
Full potential of nuclear contributions to Net Zero



Global Installed Nuclear Capacity Gap

- Under current policy trends, nuclear capacity in 2050 is expected to reach **479 gigawatts** – well below the target of 1160 gigawatts of electricity
- Owing to the timelines for nuclear projects, there is an **urgency to action now to close the gap in 2030-2050**

Global installed nuclear capacity gap (2020-2050)



Small Modular Reactors

Markets are signaling demand for SMRs with new attributes and potential benefits

SAFETY



- Passive and inherent safety
- Reduced off-site emergency planning zone (EPZ)

SPENT FUEL AND WASTE MANAGEMENT



- Innovative nuclear systems for the back-end of the fuel cycle (closed fuel cycle)

ENVIRONMENTAL FOOTPRINT



- Optimized land, minerals and water requirements

FLEXIBILITY



- Enhanced load following
- Deployment capabilities
- Diversity of energy products

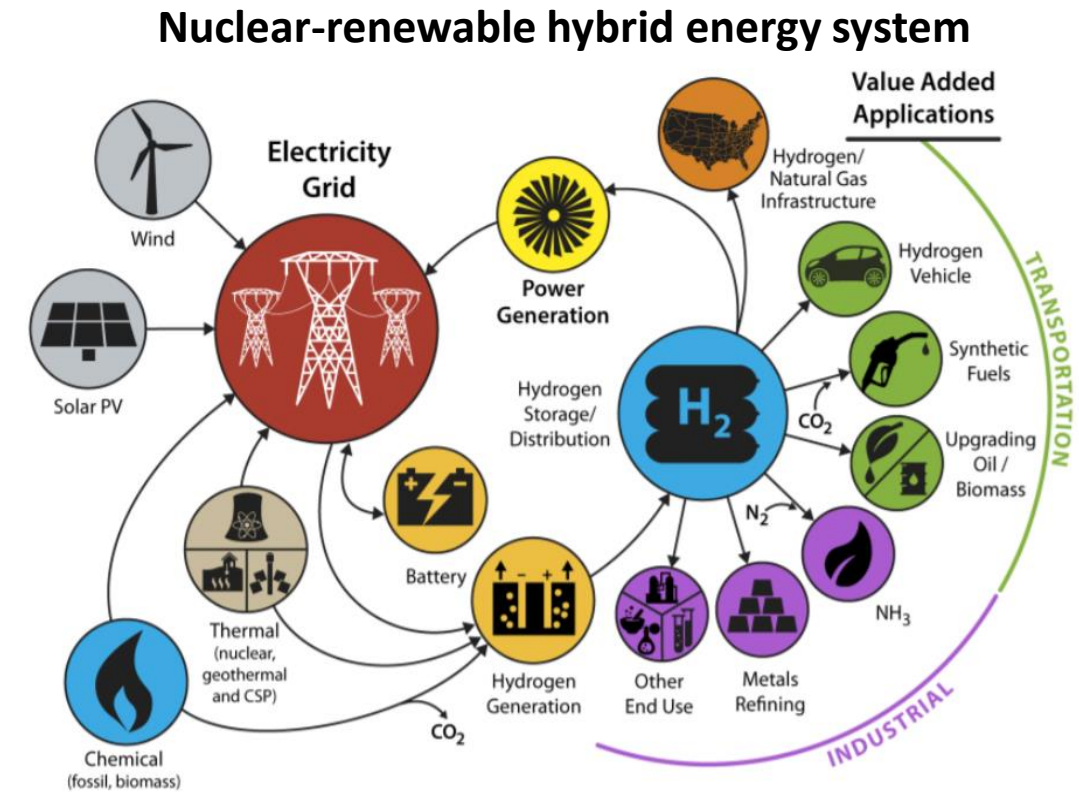
COSTS AND COMPETITIVENESS



- Economies of scale vs. economies of multiples
- Favourable competitiveness in key hard-to-abate sectors

Nuclear energy and SMRs integrate well with variable renewables

- According to the IEA Net Zero Scenario, nuclear energy will provide an *"essential foundation for Net Zero transitions as a source of dispatchable, secure and increasingly flexible electricity"* and support integration of variable renewables
- Nuclear-renewables complementarities are not limited to the electricity sector. Nuclear, including SMRs, have a central role to play as part of the mix of low carbon solutions:
 - For **hard to abate sectors** where variable renewables will have limitations (e.g. industry, heat, mining)
 - Where low carbon alternatives **have yet to be demonstrated at scale** (e.g. CCUS)



Source: INL

SMRs are expected in a range of sizes and temperatures

POWER

- SMRs vary in size from 1 to 300 megawatts electric

TEMPERATURE

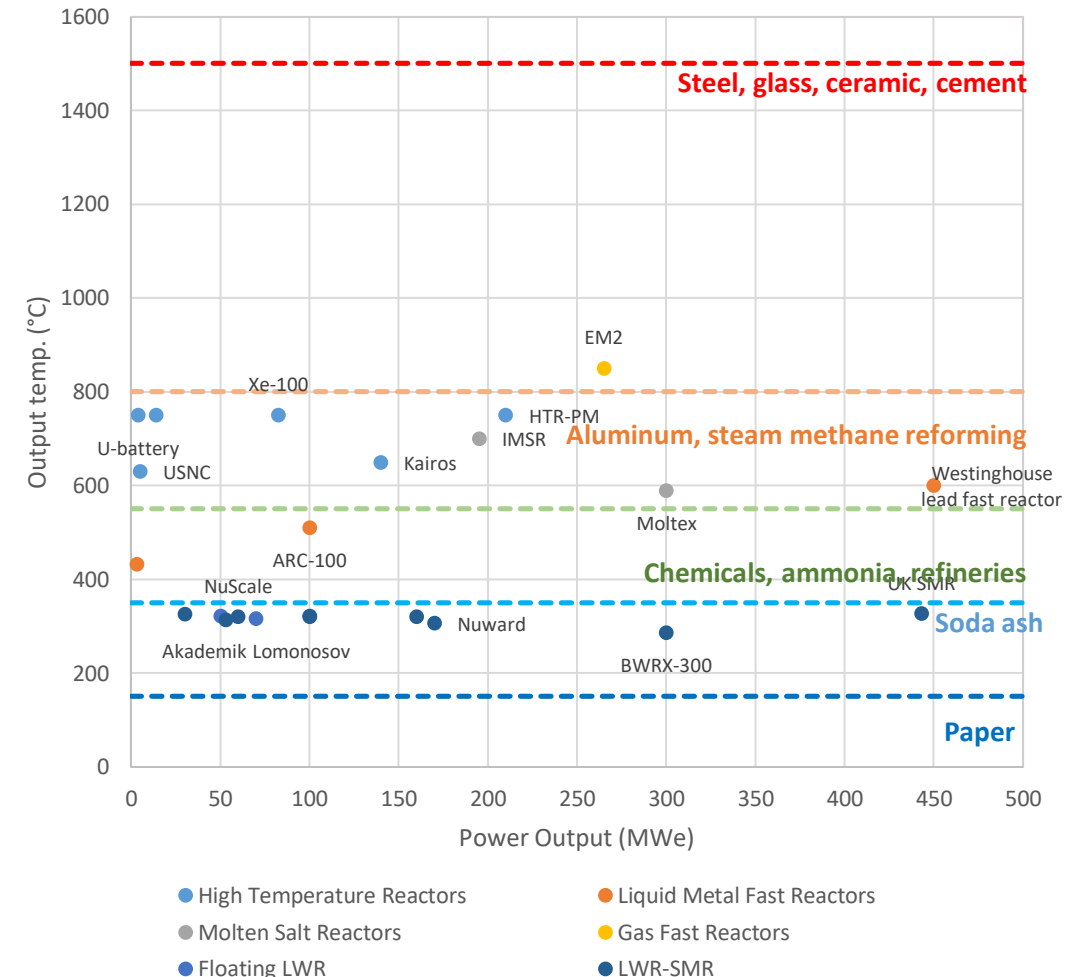
- From 285°C to 850°C in the near-term and up to or over 1,000°C in the future

TECHNOLOGY

- Some SMRs are based on Generation III and Light Water reactor technologies
- Other are based on Generation IV and advanced reactor technologies

FUEL CYCLE

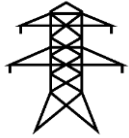
- Some SMRS are based on a once-through fuel cycle
- Other seek to close the fuel cycle by recycling waste streams to produce new useful fuel and minimize waste streams requiring long-term management and disposal



Source: NEA (forthcoming).

Even in very high renewable scenarios, there are hard to abate sectors where SMRs can play an important role

Coal replacement for on-grid power



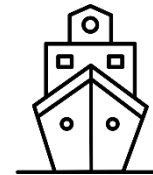
- More than 2 TWe of coal power plants in operation that will have to be phased-out to meet Net Zero objectives
- Larger SMRs (200-300 MWe) are designed primarily for on-grid power generation and is well-suited to coal power plant replacement

Diesel replacement for off-grid mining



- Smaller SMRs could create an alternative to diesel generation in remote communities and at resource extraction sites
- SMRs could be used to provide power as well as heat for various purposes such as district heating or mine-shaft heating

Merchant Shipping



- SMRs could provide a non-emitting alternative for marine merchant shipping propulsion
- SMRs for marine merchant shipping could yield significant emissions reductions as shipping remains a very hard-to-abate industrial sector

Heat & hydrogen



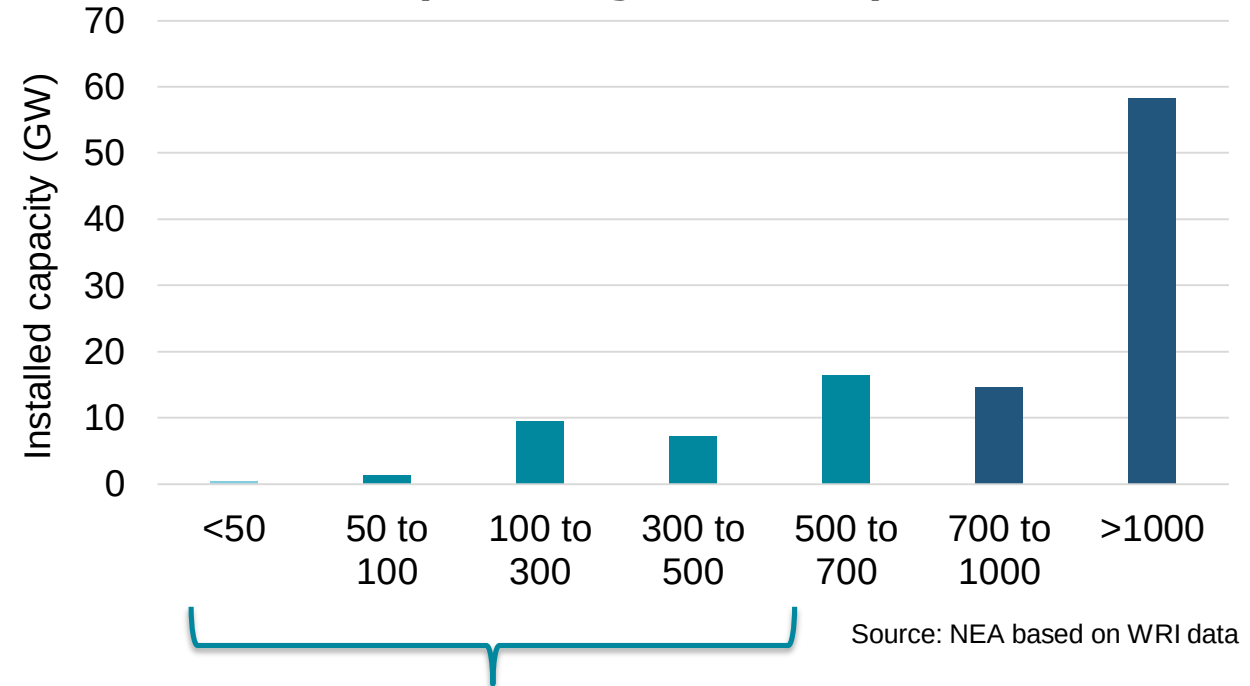
- Fossil cogeneration replacement for industries: High-temperature SMRs to unlock non-emitting alternatives for industry
- Fossil replacement for district heating : Most district heating network rely on fossil fuels and lack scalable decarbonization options
- Hydrogen and synthetic fuels: SMRs localization near industrial demand hubs can unlock large-scale production

Case Study: The Case for SMRs to Support Coal Replacement For On-grid Power

Convergence of a number of key decision drivers:

- **Deployment timelines:** SMR commercialization expected in late 2020's
- **Sizes:** SMR sizes are a good match for a large share of the coal fleet (including potentially larger coal plans)
- **Site characteristics:** potentially suitable sites, e.g., with cooling sources and grid integration
- **Just transition:** replacing coal with SMRs could create jobs for a just transition

**EU coal power fleet by capacity range
(excluding DE, AU, LU)**



The magnitude of the challenge

To replace 34 GW of installed coal capacity from coal units between 50 and 700 MWe in size, which represents 32% of the coal fleet.

More than 50% of these reactors are over 40 years old.

Policy Frameworks and SMR Roadmaps

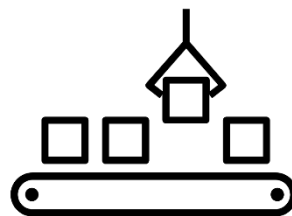
Nuclear Energy Faces Many Challenges

- **The nuclear sector must move quickly to demonstrate and deploy near-term and medium-term innovations** including advanced and small modular reactors, as well as nuclear hybrid energy systems including hydrogen
- **There are key enabling conditions for success** that the nuclear sector and energy policy-makers more broadly should address in the areas of system costs, project timelines, public confidence and clean energy financing
- **A systems approach is required to understand the full costs of electricity provision**, and to ensure that markets value desired outcomes: low carbon baseload, dispatchability, and reliability
- **Rapid build-out of new nuclear power is possible, but requires a clear vision and plan**
- **Building trust is central to building public confidence** and requires sustained investments in open and transparent engagement as well as science communication. A common mistake is to assume that public confidence is primarily a communication issue
- **Governments have a role to play in all capital intensive infrastructure projects** – including nuclear energy projects. This role can include direct funding, but also enabling policy frameworks that allow an efficient allocation of risks and for nuclear energy projects to compete on their merits on equal footing with other emitting energy projects

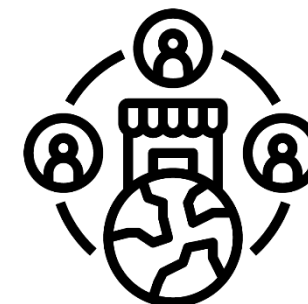
Conditions for Success – beyond technical feasibility...



**Regulatory and Policy
Enabling Frameworks**



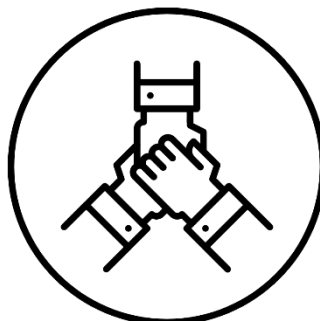
**Ramped up Supply
Chains and Talent
Pipeline**



**Market Demand and
Good Fit**



**Public Confidence and
Community Support**



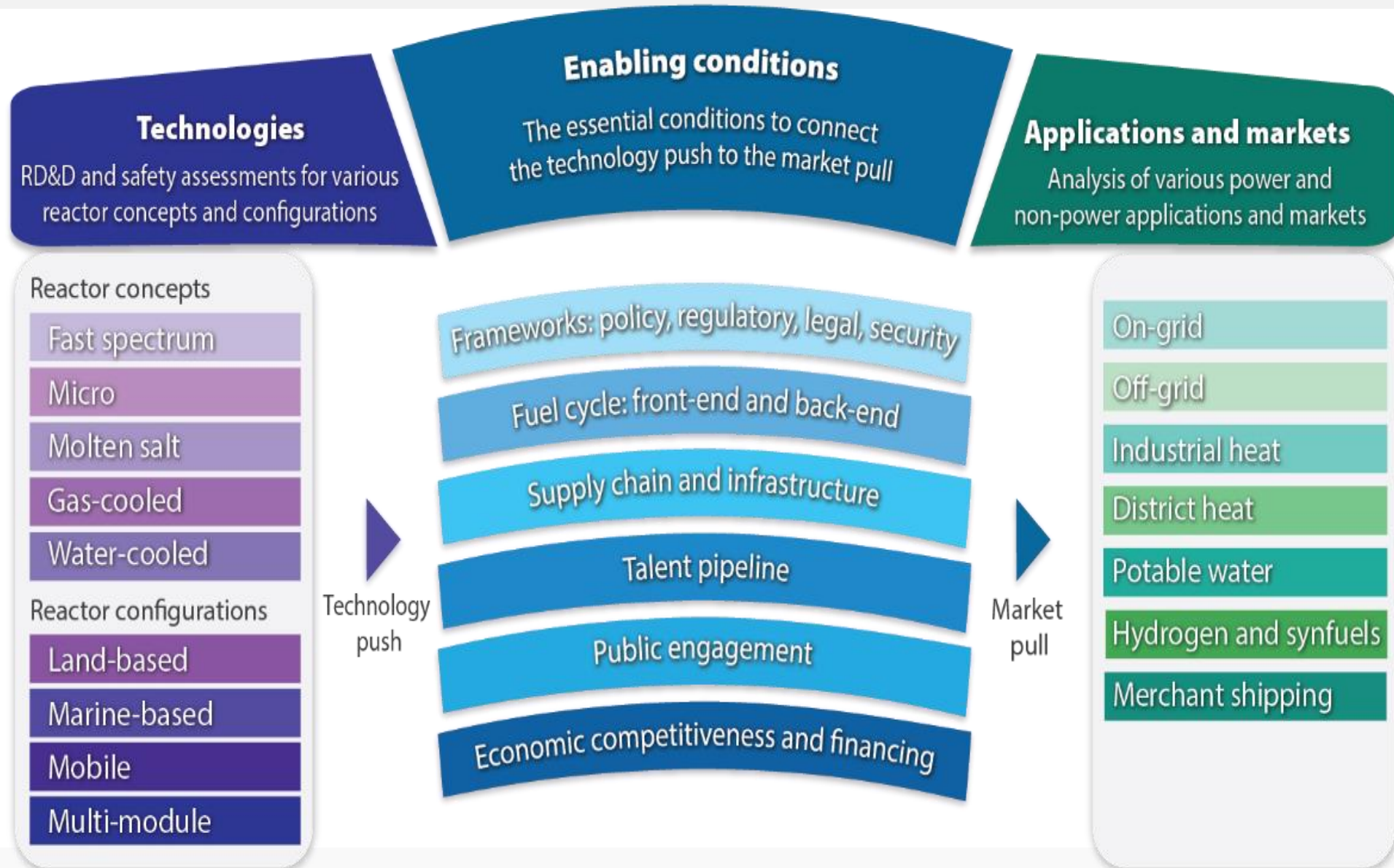
**Strategic Partnerships –
Public-Private, Indigenous,
International**



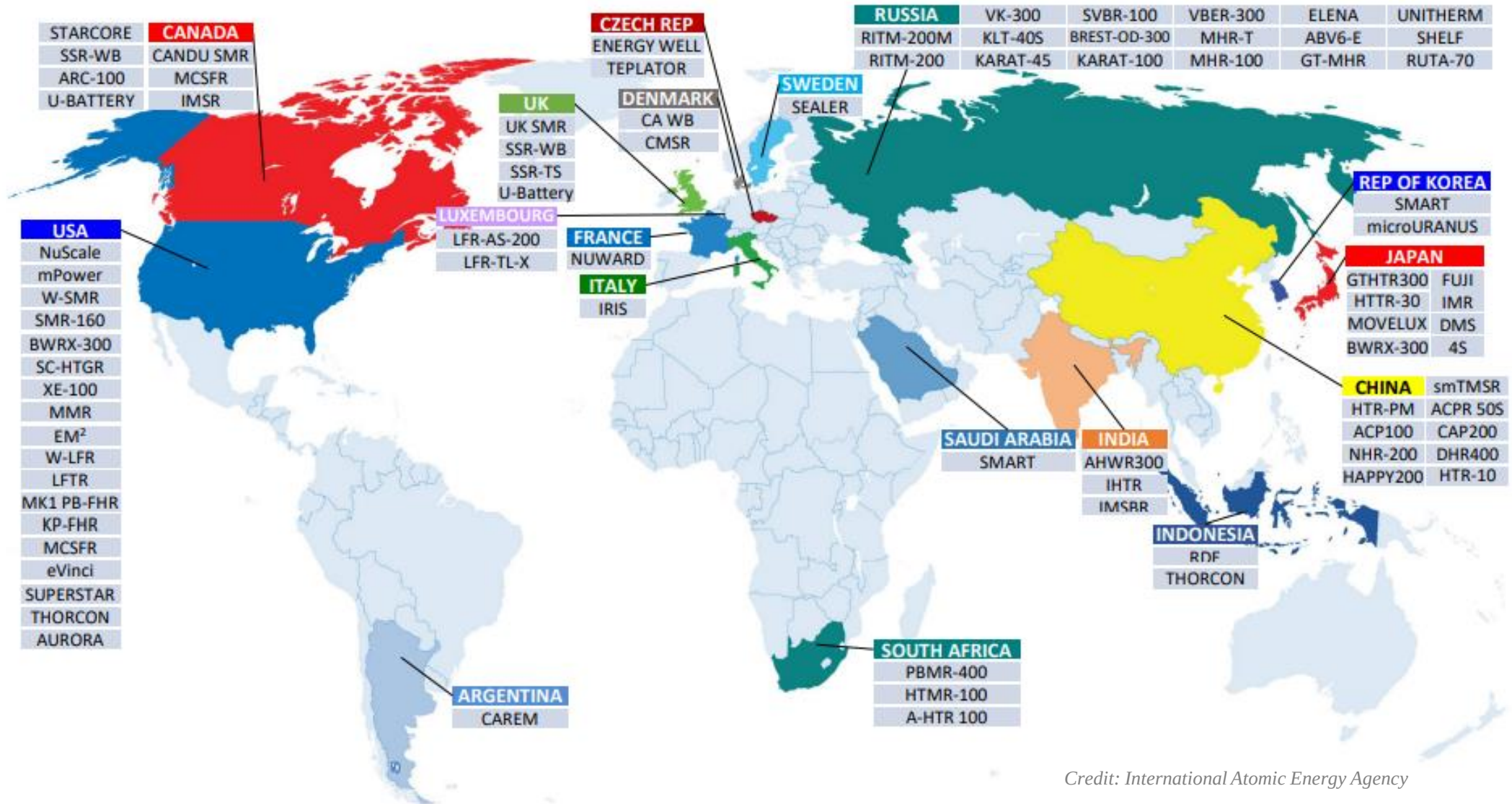
**Public-Private
Financing**

The NEA SMR Strategy:

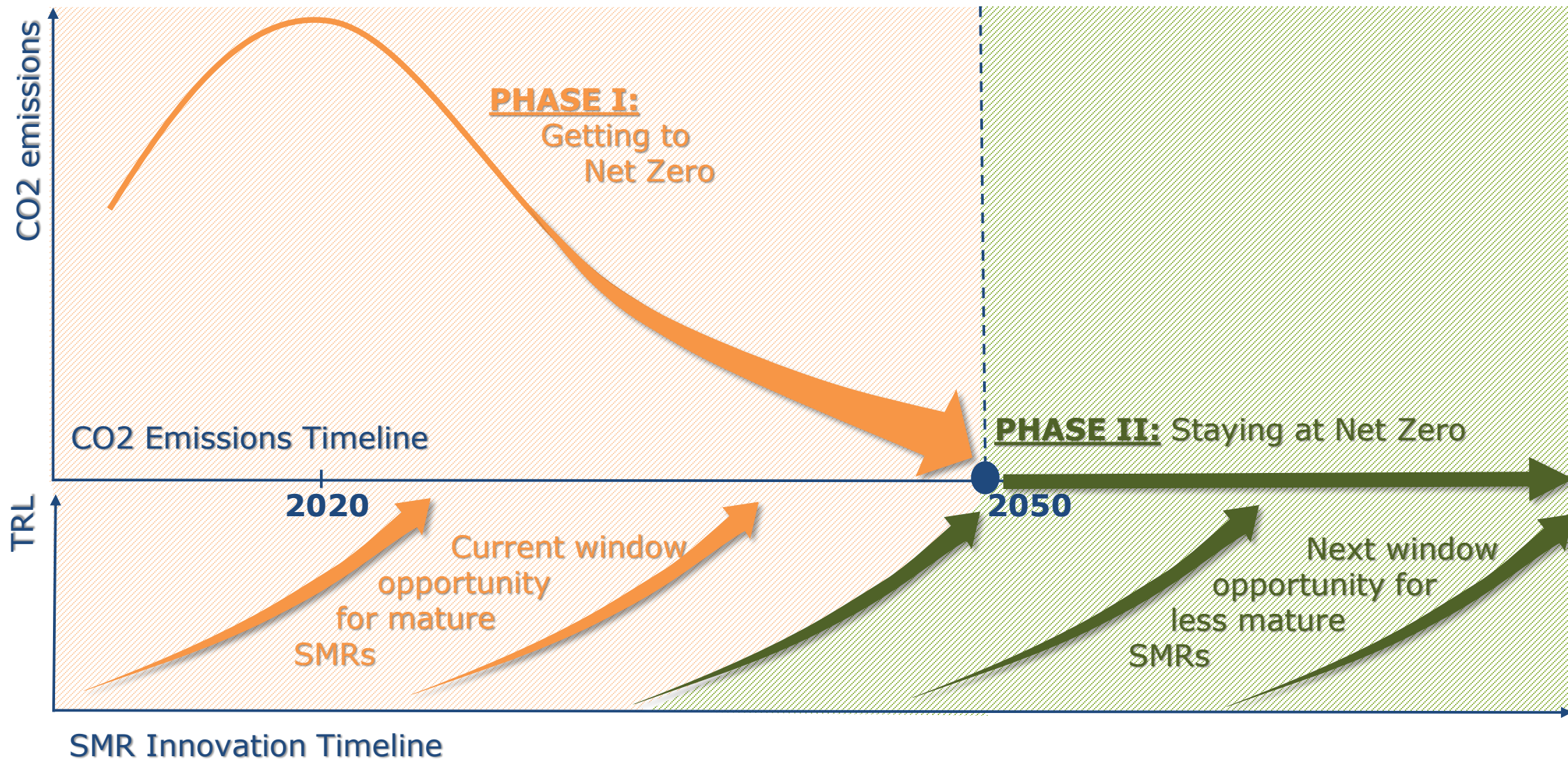
Enabling success from technology development to market application



The Status of SMR Development Globally



Near-term SMRs can contribute to Net Zero by 2050, with more innovative designs contributing to staying at Net Zero post-2050



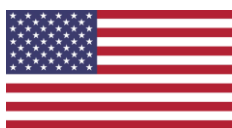
Recent developments in SMR national policies



- **UK Net Zero Strategy:** £385M Advanced Nuclear Fund and SMR demonstration by 2030s
- **British Energy Security Strategy:** up to 24 GW of new nuclear by 2050 and enhanced international collaboration to accelerate work on AMRs



- **France 2030:** EUR 1B for SMR development
- **New Nuclear Programme** of 6 EPR2s by 2035 with an option of 8 more



- **US Advanced Reactor Demonstration Program (ARDP):** The DOE will invest a total of USD 3.2B over seven years to support AMR demonstration by 2030
- **Civil Nuclear Credit Program:** USD 6B for continued operation of the existing nuclear fleet



- **Refurbishments:** CAD 26B for refurbishment of existing CANDU fleet
- **SMR Roadmap (2018) and SMR Action Plan (2020)**
- **2022 Budget:** CAD 250M for clean electricity technology RD&D (incl SMR), CAD 120M for SMR enabling conditions, CAD 5B in clean infrastructure loan guarantees (incl SMR), CAD 15B for clean growth (incl SMR)



- **Belgium Existing Fleet:** Extension of 2 GW of existing nuclear capacity beyond 2025
- **SMRs:** EUR 100M to for SMR R&D

For Climate Action to be Successful, An Enhanced Vision of the Future is Needed



If action on climate is associated with limits to life, economic growth, and freedom, a successful energy transition will be extremely difficult.

Innovative Nuclear Technologies Help Provide a Solution Set

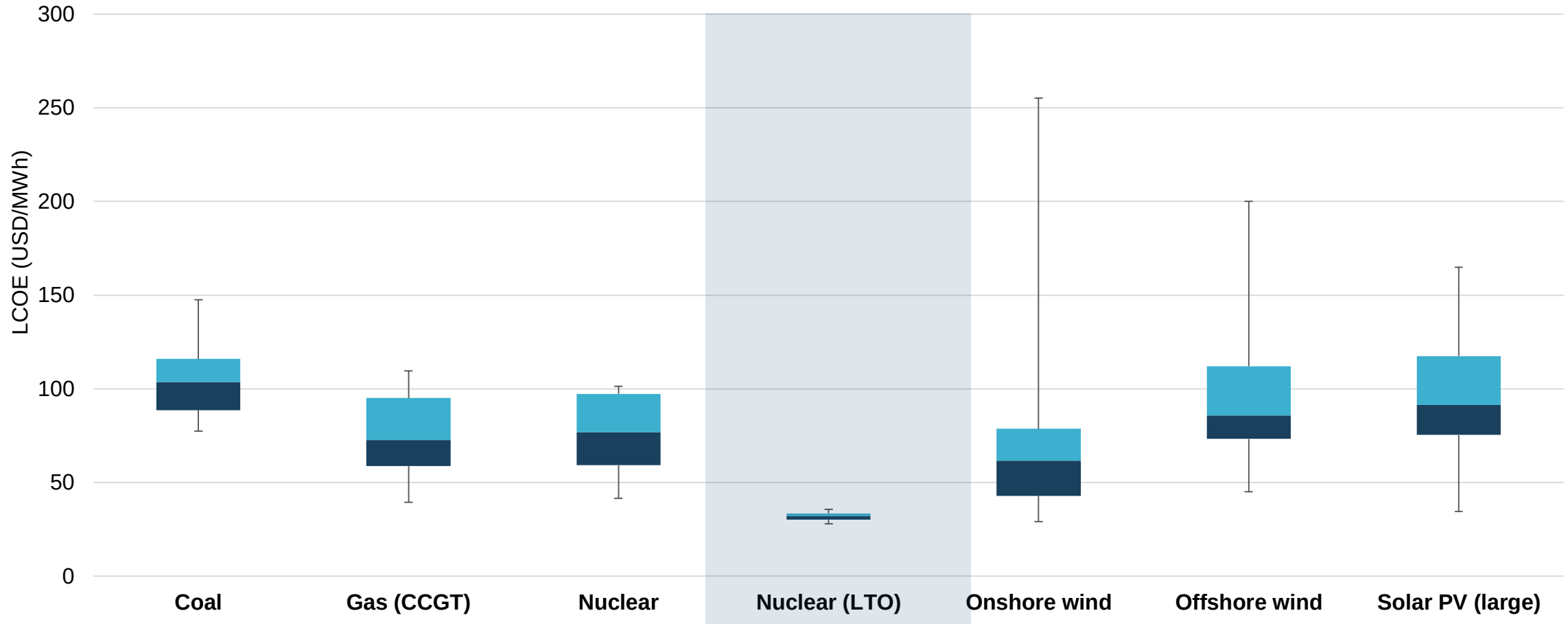


**Thank you for
your attention**

Annex

NEA-IEA Projected Costs of Generating Electricity 2020 Edition

Levelized Costs of Electricity (LCOE) for 2025



Note: Coal includes lignite plants. Discount rate of 7% and carbon price of USD30/tCO₂

Source: IEA/NEA (2020)