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International Atomic Energy Agency
Atoms for Peace and Development

Small Modular Reactors – a more feasible route to decarbonization?

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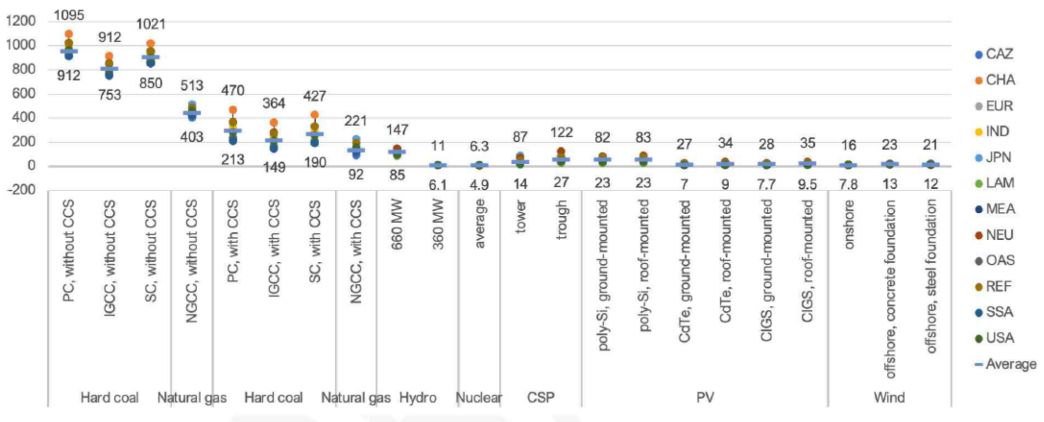
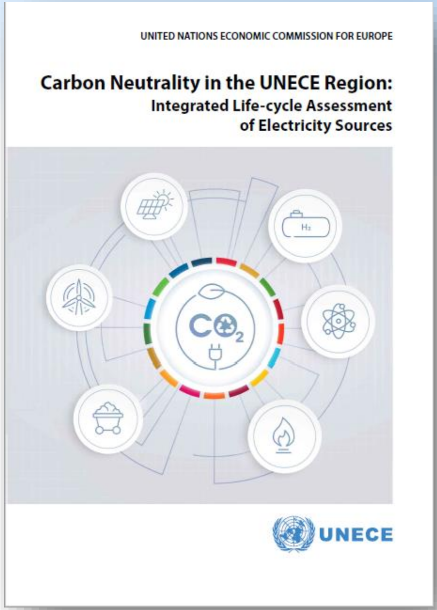
Austrian Energy Day,
Palais Hansen Kempinski, Vienna,
28 September 2023

A low carbon source

Figure 37 Lifecycle greenhouse gas emissions' regional variations for year 2020. Variability is explained by several factors: electricity mix (all regions), methane leakage rates (fossil fuels), load factors (renewables). Nuclear power is modelled as a global average except for back-end.



Smallest carbon footprint among low C technologies



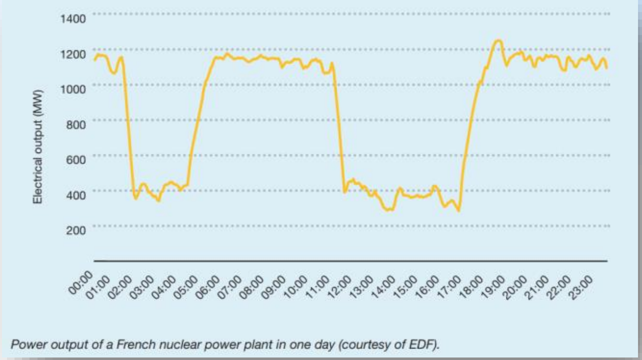
(2022)

*IAEA estimates that over the last 5 decades, about **70Gt CO_2** have been avoided thanks to NP*

Enabling integration of large % renewables

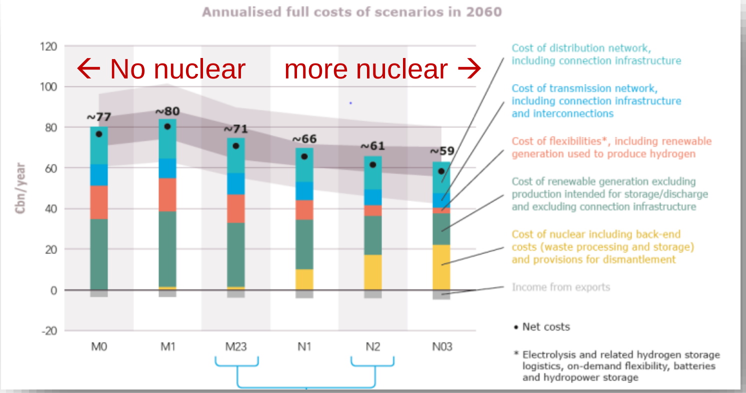
- Nuclear is a **dispatchable and flexible** source of low C power that can support the deployment of large shares of variable renewables such as solar PV and wind.
- Without nuclear, even more renewable capacities and energy storage technologies would need to be deployed.
- Analysis of overall (system) costs of energy transitions show that **transitions with nuclear are less costly** than transitions without nuclear, even if nuclear is more expensive than wind/solar (LCOE).
- It's also a question of **risk** for transitions

Flexibility of nuclear generation



Power output of a French nuclear power plant in one day (courtesy of EDF).

IAEA: Nuclear Energy for a Net Zero World (2021)

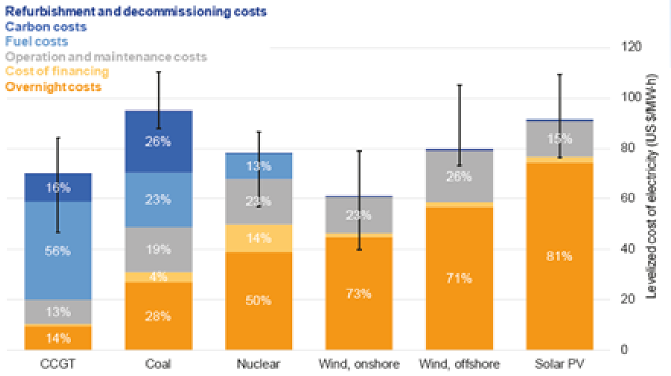


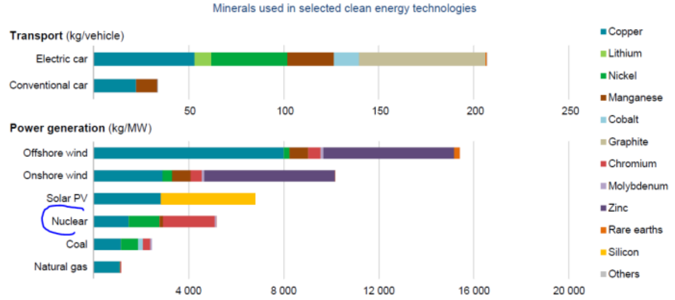
French grid operator RTE report "Energy Pathways to 2050" (2021)

Security of energy supply

- Cost of nuclear generation is **not very sensitive to the cost of fuel** (contrary to coal and gas generation)
- **Uranium resources are widely available** globally.
- Nuclear fuel can easily be **stored on site**
- Nuclear generation is among the low C technologies **least dependent on critical minerals** – *IEA report on Critical Minerals (2021)*

Adapted from IEA/NEA Projected Costs of Electricity Generation (2020)



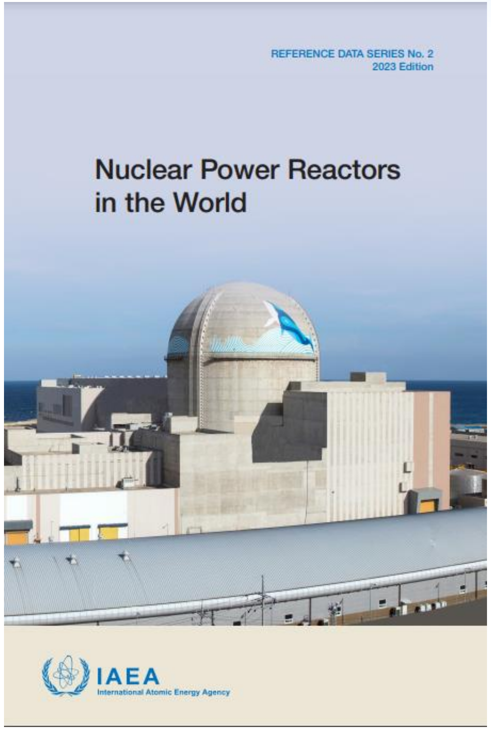


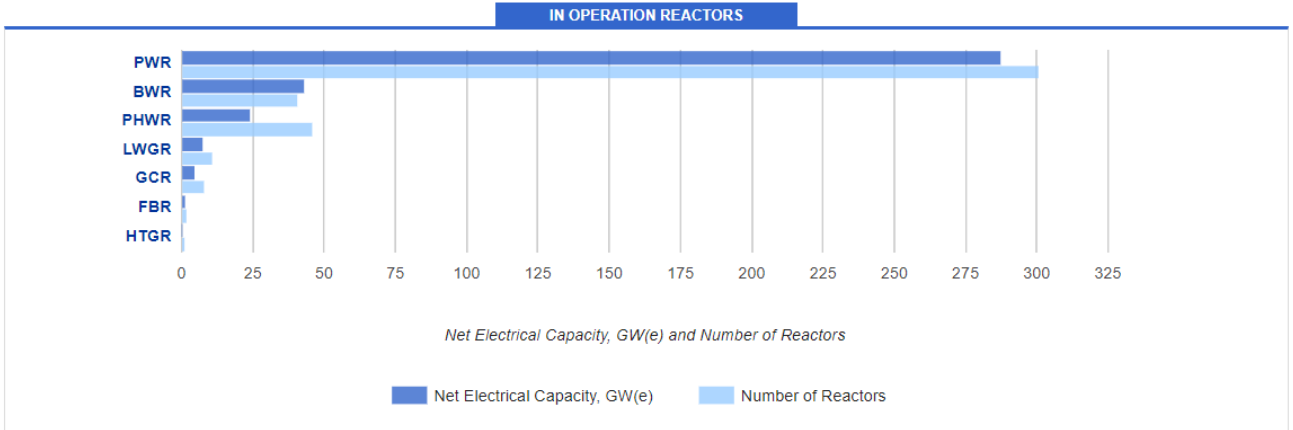
IEA, The Role of Critical Minerals in Clean Energy Transitions (2021)

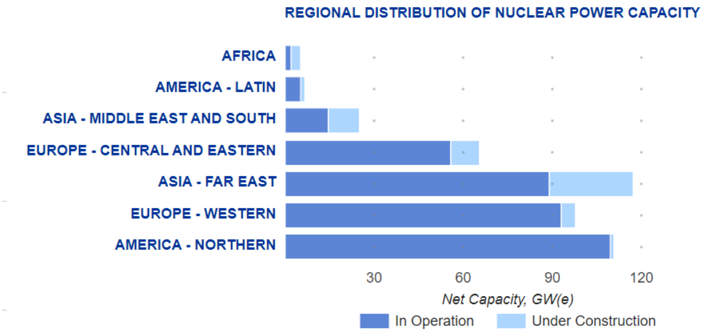
Climate resilience

- **Climate Change / extreme weather can impact all technologies**, including nuclear power– and affect the resilience of energy systems.
- IAEA operational data (PRIS) suggests that nuclear is resilient – and adaption measures can be deployed to reduce vulnerabilities.
- In 2022, reported weather-related production losses accounted for approximately **0.35%** of global nuclear energy generation, up from 0.29% five years earlier
- **Nuclear power can contribute to increase the resilience of energy systems**:
    - Resilience to extreme weather events
    - Adaptation, preparedness of nuclear industry – to maintain safety and improve efficiency

Overview of today’s nuclear fleet (at end 2022)



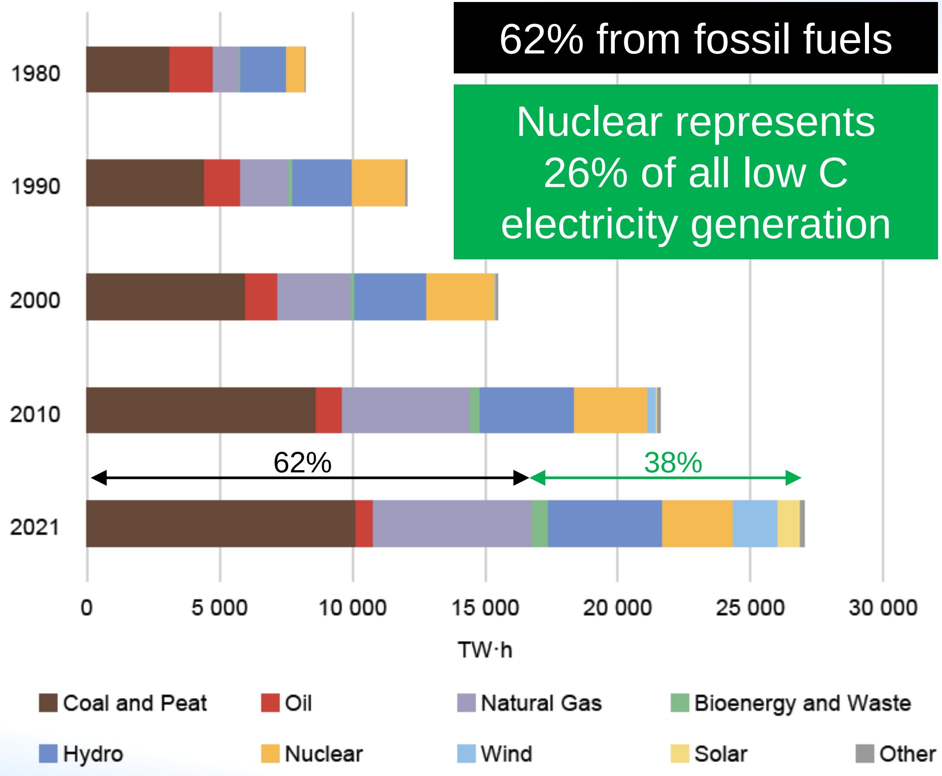




- Domination of (large) Light Water Reactor technologies (PWR, BWR) (>83%)
- 2 SMR-plants in operation: HTR-PM (China) and Akademik Lomonosov FNPP (RF)

https://pris.iaea.org/pris/

World Electricity Production in 2021 by Energy Source

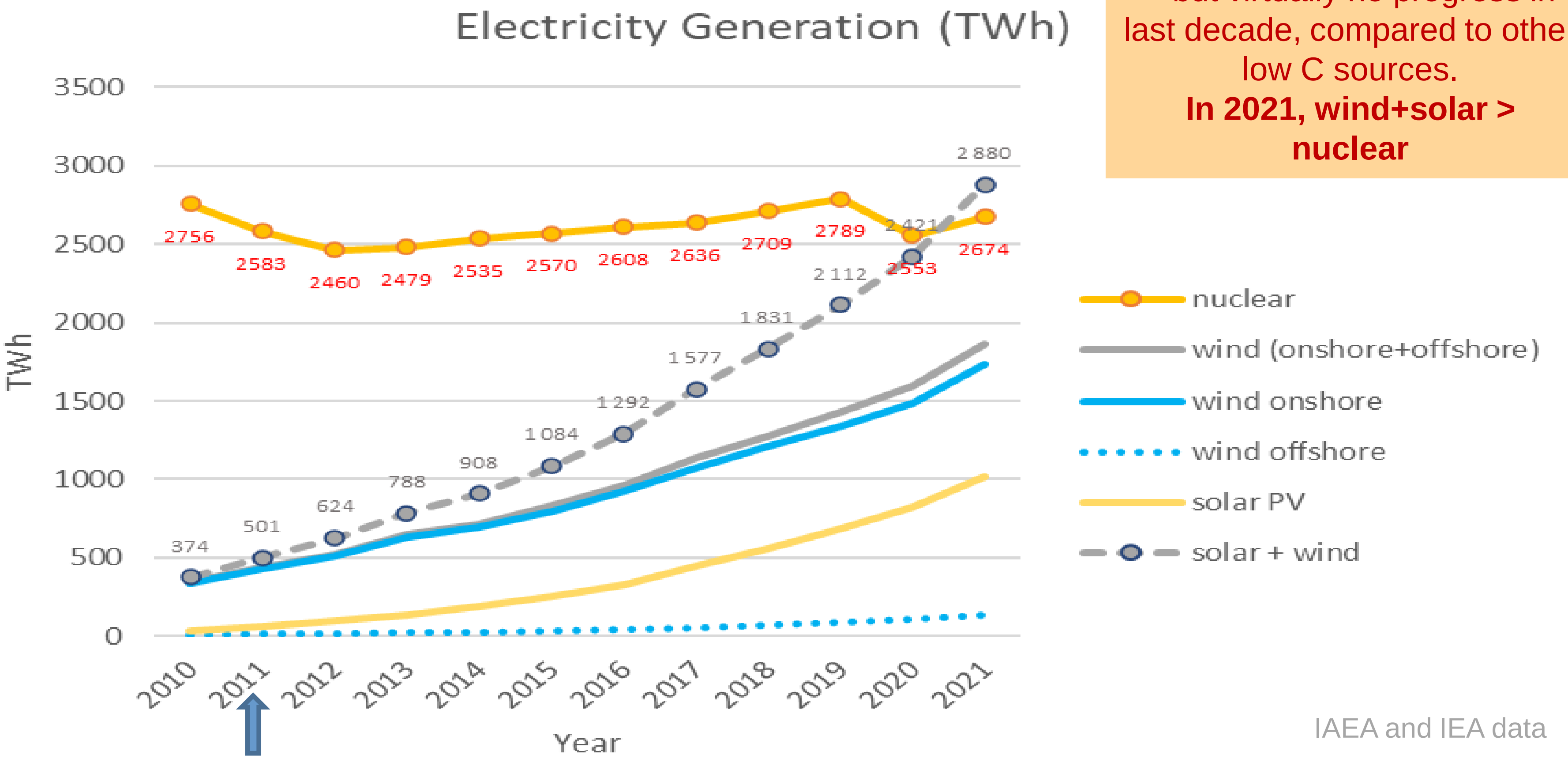


62% from fossil fuels

Nuclear represents 26% of all low C electricity generation

Low C electricity trends (2010-2021)

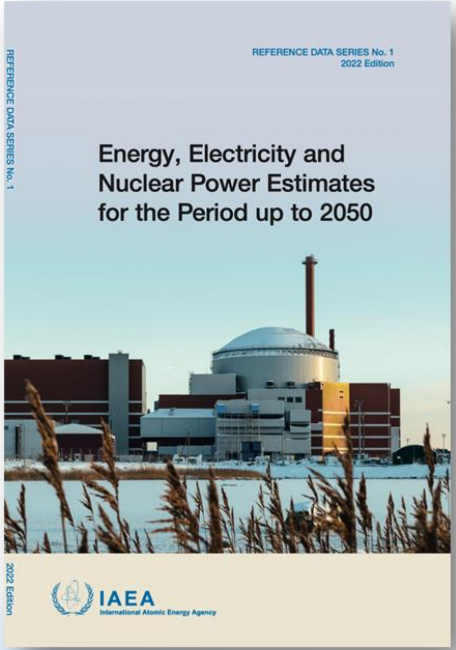
Nuclear power: still the 2nd source of low C power globally – but virtually no progress in last decade, compared to other low C sources.
In 2021, wind+solar > nuclear

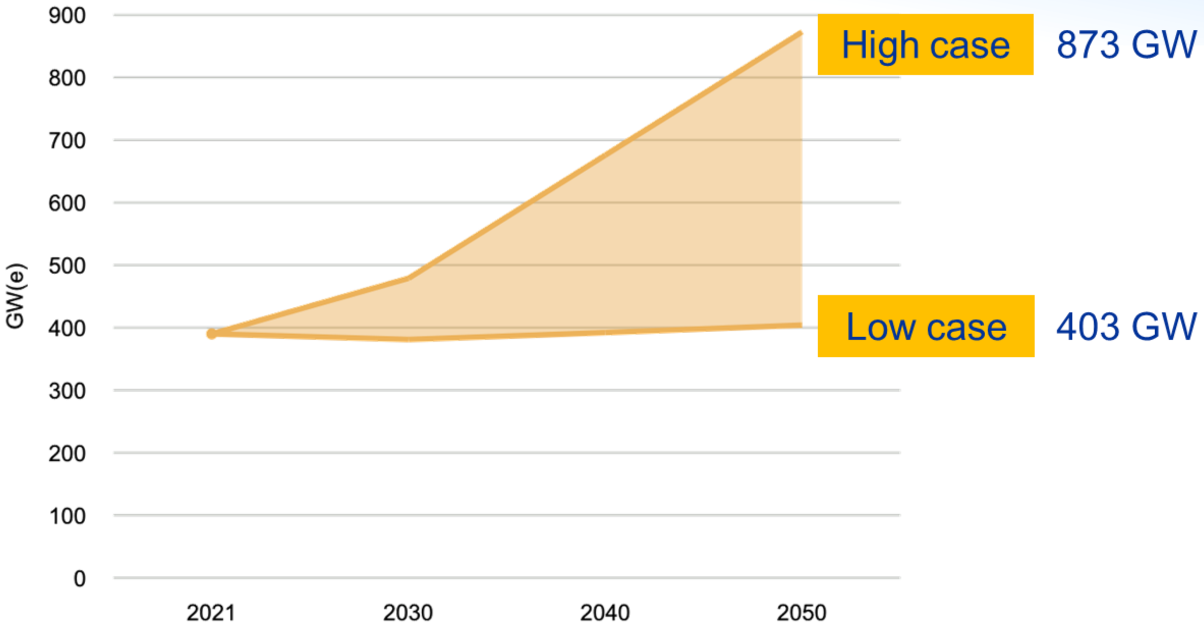


Fukushima Daiichi accident, 11 March 2011

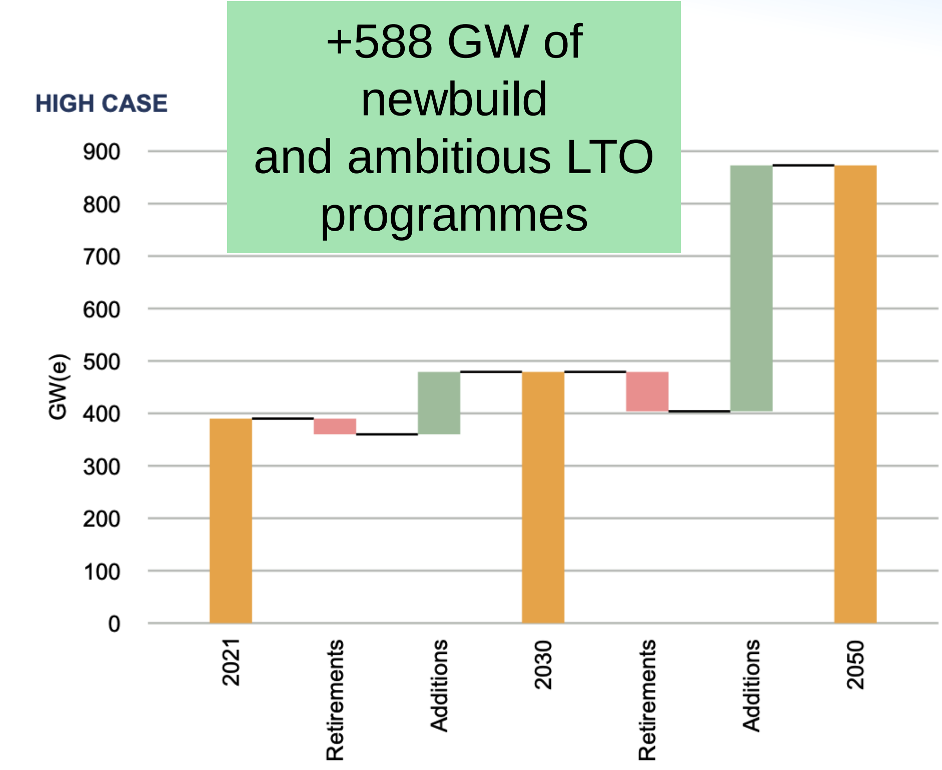
IAEA and IEA data

Global Nuclear Power Projections to 2050





World Nuclear Capacity: Actual, Retirements and Additions, in the high case



Newbuild – what technology?

588 GW on new build in the high case:

- Essentially large Gen III reactors
- But also advanced reactors:
  - LWR-based SMRs
  - Non-LWR based reactors, SMR-scale or larger

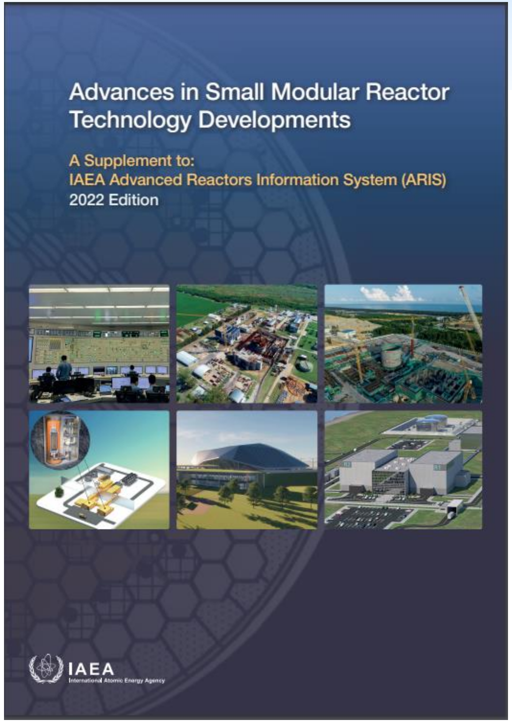
- Contribution of advanced reactors will depend on **how fast they can reach commercial status and be licensed** – but also on how they can **substitute fossil fuels in non-power applications**.

Small Modular Reactors

Latest IAEA Booklet on Advanced in SMR Technology Developments: (NPTDS Section)

- Design description and main features of more than 80 SMR designs (56 in 2018)
- SMRs are categorized in types based on coolant type/neutron spectrum:
  - Land Based Water-cooled Reactors (2 under construction, CAREM, Argentina, and LingLong-1 in China)
  - Marine Based Water-cooled Reactors (2 units in operation, Floating Nuclear Power plant, Russia)
  - High Temp gas cooled reactors (1 in operation, HTR-PM, in China)
  - Fast Reactors
  - Molten Salt Reactors
  - Micro reactors

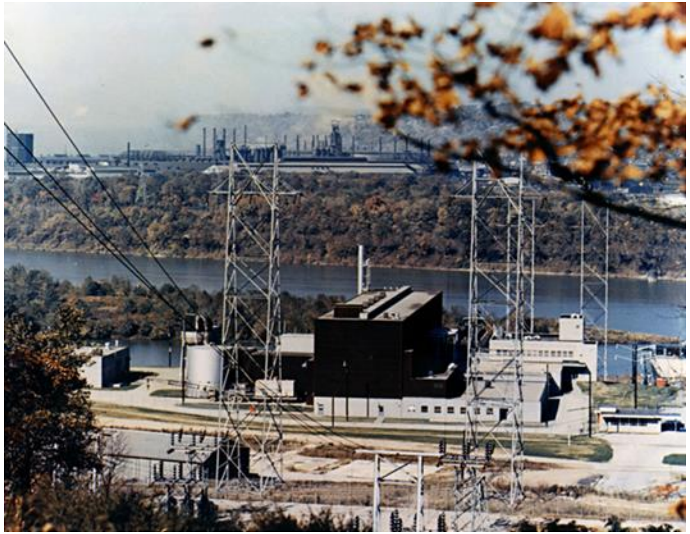
2022 Edition



https://aris.iaea.org/Publications/SMR_booklet_2022.pdf

Large reactors: Economies of Scale

IAEA



Shippingport PWR (1958, **60MW**)

x 30

In 60 years

Photo: courtesy of China General Nuclear Power Corporation

EPR Taishan 1 PWR (2018, **1750MW**)

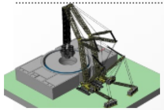
But what **about future energy markets**? What are the best “technological” solutions? As countries move towards low-carbon energy systems, with large shares of variable generation (wind, solar), importance of nuclear power to provide low C dispatchable power, maintain grid stability, provide low C heat and hydrogen, etc. **Role for SMRs?**

SMR: Rationale for Development

Advanced Reactors that produce typically up to 300 MWe, built in factories and transported as Modules to sites for Installation as Demand arises.

Economic
- Lower Upfront capital cost
- Economy of serial production

Better Affordability



Modularization
- Multi-module
- Modular Construction

Shorter construction time

Flexible Application
- Remote regions
- Small grids

Wider range of Users

Smaller footprint
- Reduced Emergency planning zone

Site flexibility

Replacement for aging fossil-fired plants

Reduced CO_2 production

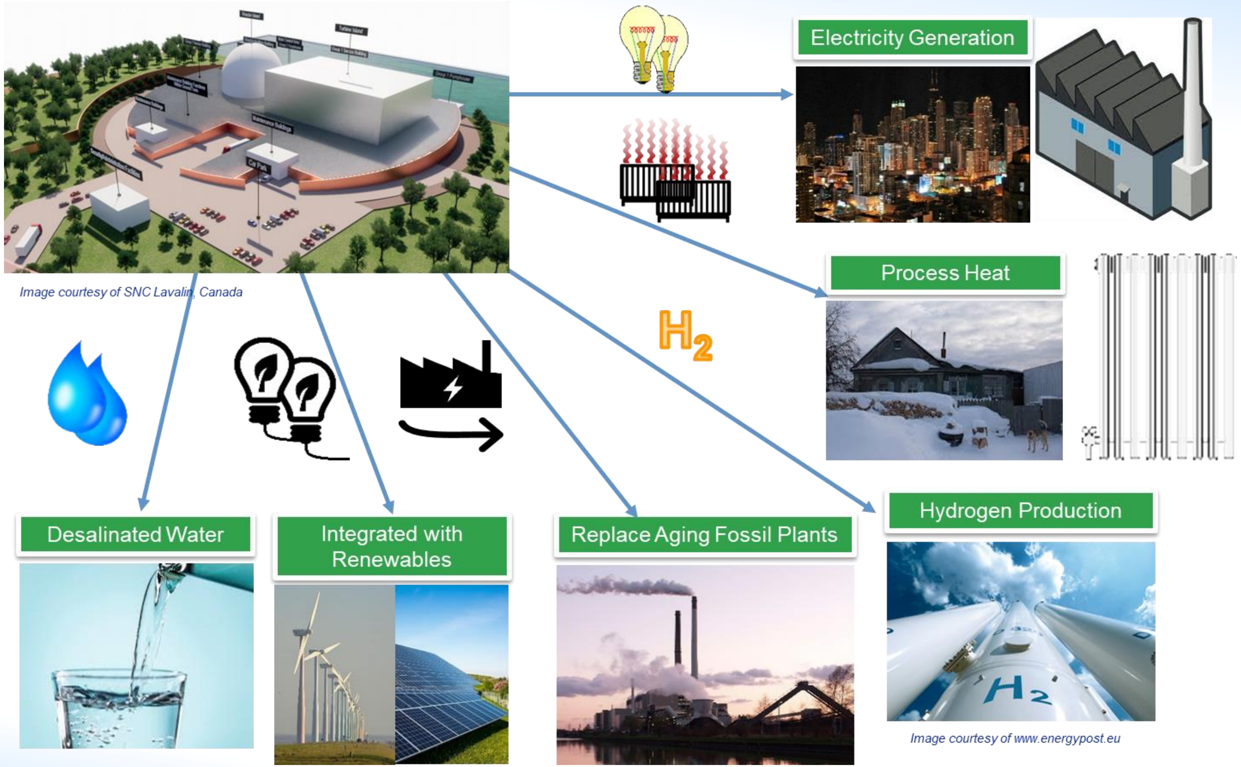
Potential Hybrid Energy System

Integration with Renewables

Microreactors (typically up to 10 MWe) serve niche markets, i.e. to replace diesel generators in small islands, remote regions or in hybrid use with renewables

From Dr. Hadid Subki (IAEA)

SMRs targeting new markets – beyond electricity

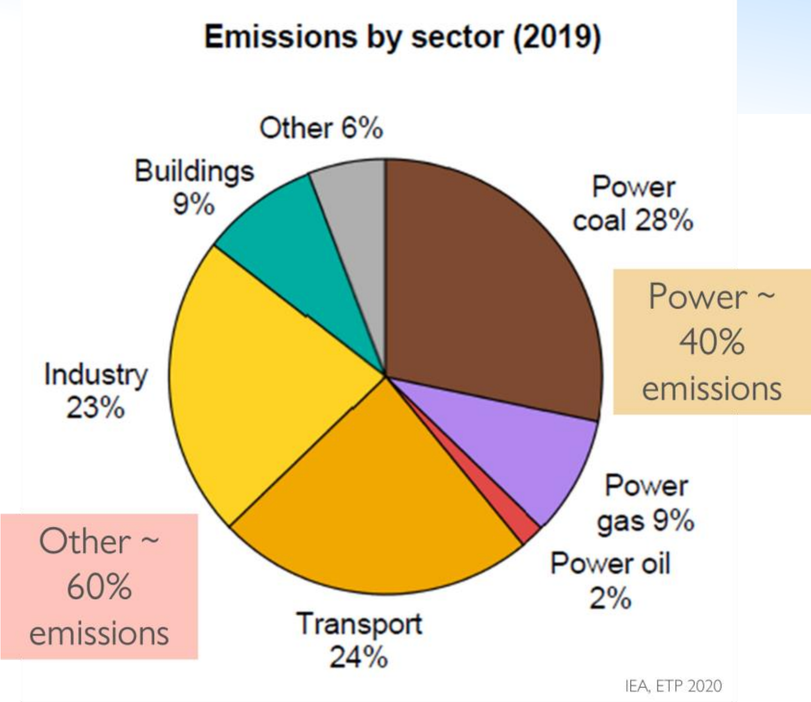


SMRs vs. large reactors

- "**Small**" refers to the electricity generation capacity (up to 300 MWe, as opposed to large – or very large reactors in operation today, up to 1650 MWe). Some SMRs can be **large** in (physical) size!
- Small reactors are **not new**! The earlier reactors (including earlier PWRs) were of the size of current SMRs designs (e.g. Shippingport)
- "Modularity" is **not specific** to SMRs – some large reactors also include (in part) modular design and/or assembly (ABWR, AP1000)
- SMRs are not necessarily more **flexible** than large reactors (load-following of large French or German LWRs for example)
- Non-electric applications are **not specific** to SMRs - large reactors can also provide (district) heating, hydrogen production, etc. (but non-LWR based SMRs can target **larger range** of non-electric applications).

Towards net-zero emissions

- Decarbonising the power sector will not be sufficient.
- Need to decarbonize other sectors, representing 60% of emissions today:
- **Electrification** whenever possible (so increased demand for clean electricity)
- Need **low C heat sources**
- Need **low C fuels**, including hydrogen, produced from clean electricity
- IEA: "*Almost half of the emissions reductions needed to reach net zero by 2050 will need to come from* ***technologies that have not reached the market today***"



District Heating and Process Heat

- **District Heating**: decades of experience, in Russia, Hungary, Switzerland, etc
- In June 2020, the new **Floating Nuclear Power Plant** Akademic Lomonosov, powered by two SMR units, provided 1st heat to Pevesk district (1st grid connection in Dec 2019)
- In November 2020, **Haiyang NPP** (AP1000) started delivering commercial DH

Source: http://fnpp.info/

Haiyang begins commercial-scale district heat supply

20 November 2020

Share

China's Haiyang nuclear power plant in Shandong province has officially started providing district heat to the surrounding area. A trial of the project - the country's first commercial nuclear heating project - was carried out last winter, providing heat to 700,000 square metres of housing, including the plant's dormitory and some local residents.

A pipeline carrying heated water from the Haiyang plant (Image: SPIC)

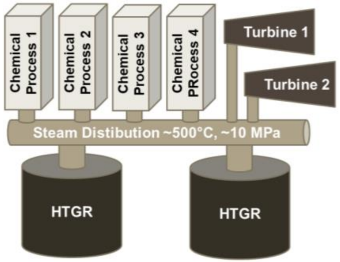
Source: WNN

- **Process Heat**: can be delivered by **High Temperature Reactors**
- Interest of Poland to replace coal-fired boilers
- In the past, projects were developed in US, Korea, etc, including for "clean steel" production

MINISTRY OF ENERGY

Possibilities for deployment of high-temperature nuclear reactors in Poland

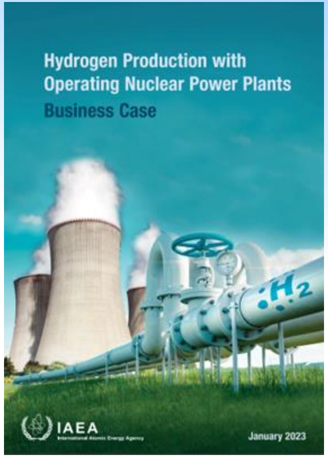
Report of the Committee for Analysis and Preparation of Conditions for Deployment of High-Temperature Nuclear Reactors



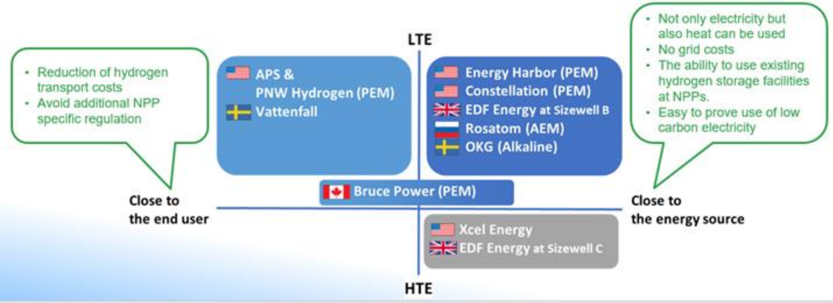
PL Gov source

Hydrogen

- Need for **large amounts of low-carbon hydrogen** to decarbonize hard to abate sectors
- Low-carbon H_2 from **dedicated sources**: renewables, fossil with CCS, or nuclear, or from **decarbonized electric grids** → carbon content of H2 rather than "colour coding"
- IAEA working on business opportunities for existing NPP (with low temperature electrolysis or high temperature steam electrolysis) as well as production of H_2 with SMRs and HTSE
- Importance of policies / incentives



- **Electrolyser system location**
  - Utilities whose primary objective is to use hydrogen in their own NPP are planning to locate electrolyser near their NPP.
  - When hydrogen demand is certain, the electrolyser is planned to be sited near the end-use facilities.



Scope:

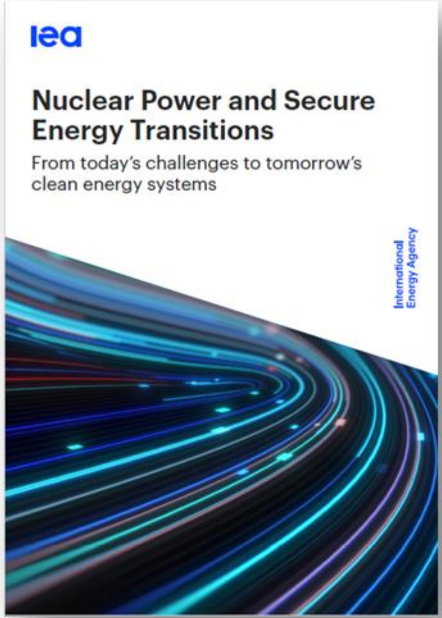
- Hydrogen production using **existing nuclear power plants** as a near-term low carbon hydrogen production method and a basis for future expansion.

Objectives:

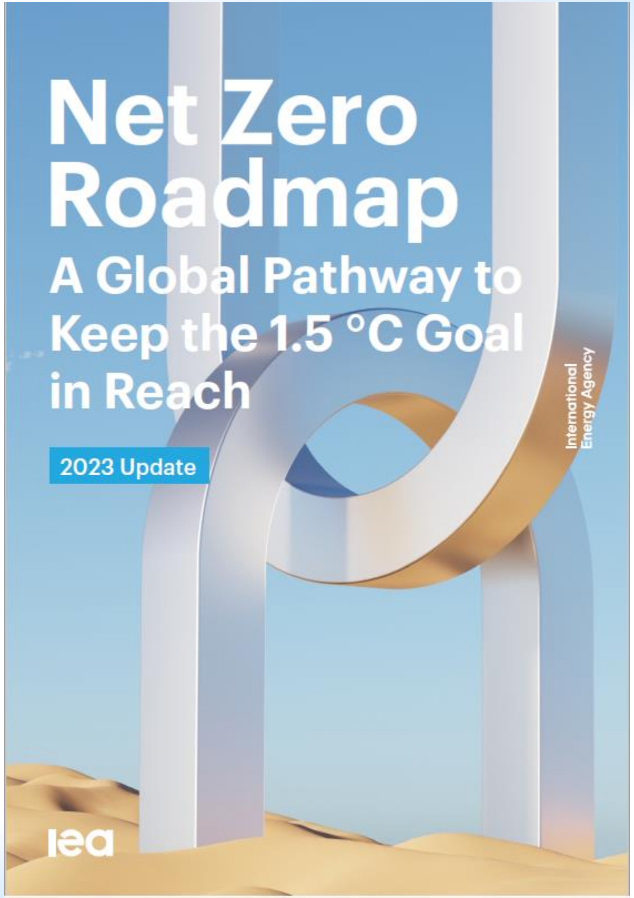
- To evaluate and compare hydrogen production demonstration projects by **nuclear utilities currently underway**,
- To identify **similarities** and **differences** and
- To extract the factors for **deployment of nuclear hydrogen business case**.

10 projects: all in an early phase

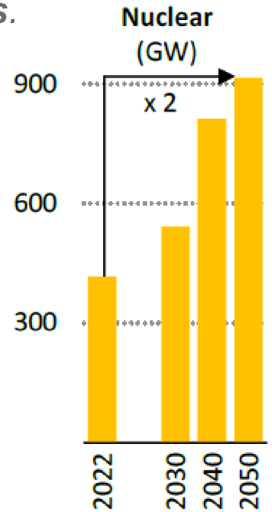
What does the IEA say about nuclear?



Without additional nuclear, the clean energy transition becomes ***more difficult and more expensive*** *(IEA)*



Nuclear power expansion also proceeds more vigorously, with almost 15% more capacity in 2050 in the updated NZE Scenario than in the 2021 version, reflecting strengthened policy support in leading markets and ***brighter prospects for small modular reactors****.*

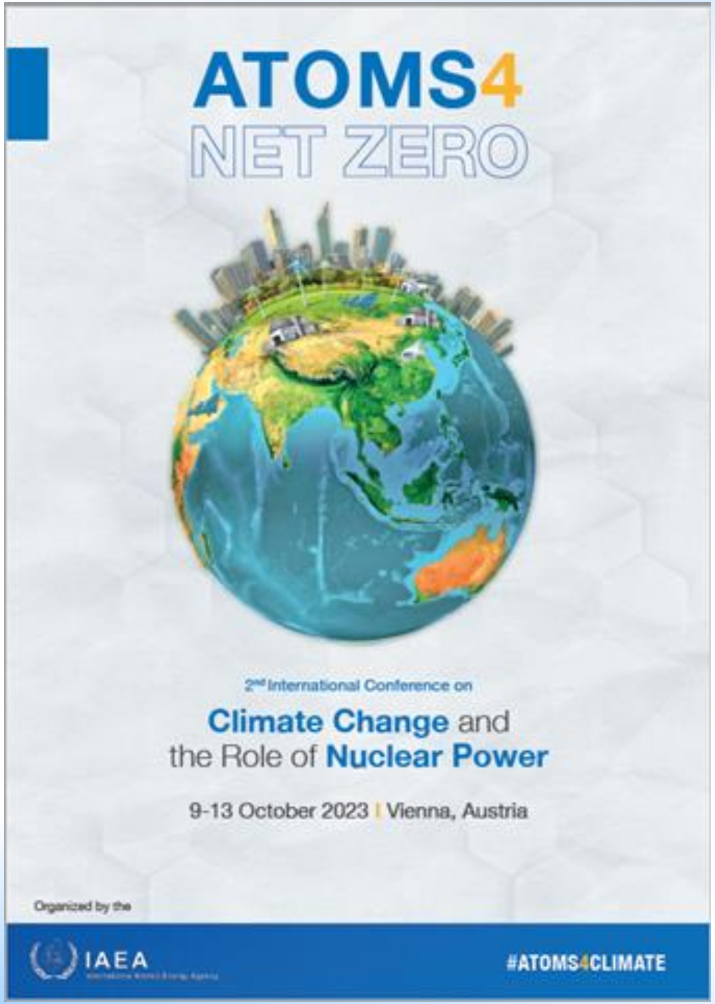


SMRs, a more feasible route to decarbonization?

IAEA

- **All low C sources**, including nuclear power for countries wishing to include it in their mix, **will be needed to get to net zero**. A diversified mix is also a more **resilient** one.
- Consensus that the bulk of the decarbonization of the electricity system will be achieved through the massive deployment of wind and solar (and storage)
  - But **clean, firm/baseload and dispatchable power** – such as hydro or nuclear - **needed** to integrate very high % of RES (also for grid stability)
- Nuclear power will come in different sizes – from microreactors (~10MW) to SMRs (~300MW) to large reactors (~1 to 1.6GW)
  - Can address **different grid sizes / demand**
  - Sites not suitable for large NPPs could be suitable for SMRs
  - Strong interest in **Coal to Nuclear**, replacing coal-fired PP by SMRs
- Decarbonizing electricity will not be enough to get to net zero:
  - Need **massive amounts of low-carbon heat and H_2** – which nuclear can supply
  - Many SMR designs target specific applications (heat, desalination, hydrogen)

→ **SMRs increased opportunities to succeed in net zero transitions**



Everyone welcome to attend.

Register (no fees) through the Conference website:

https://www.iaea.org/events/atoms4climate-2023

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Thank you!

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