World Federation of Engineering Organizations
Fédération Mondiale des Organisations d'Ingénieurs

WORLD ENERGY COUNCIL | CONSEIL FRANÇAIS DE L'ÉNERGIE

« Why is nuclear power making a comeback »

24 April 2025
1 to 2 PM CET

Moderator

Marie-Line Vaiani
Chair of the Committee on Energy, WFEO
Secretary General of the World Energy Council France

Speaker

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The international organization for the engineering profession

Cooperates with United Nations bodies and other international organizations

Acts through thirteen Committees and Working Groups addressing key engineering issues

Why is nuclear power making a comeback

Henri PAILLERE, Head Planning and Economic Studies Section, IAEA

WFEO – WEC Webinar,

Wednesday 24 April 2025

Outline

1. Nuclear Power today and tomorrow
2. Attributes of nuclear power
3. Nuclear Power and Climate Change mitigation
   - Nuclear power in IPCC 6th AR scenarios
   - COP28 Outcomes
   - International Energy Agency (IEA) on nuclear & net zero
4. Nuclear capacity projections to 2050 and investment needs
   - IAEA nuclear capacity projections to 2050
   - Financing nuclear power expansion
5. The potential role of Small Modular Reactors
6. Some “new” applications of nuclear power
7. Takeaways

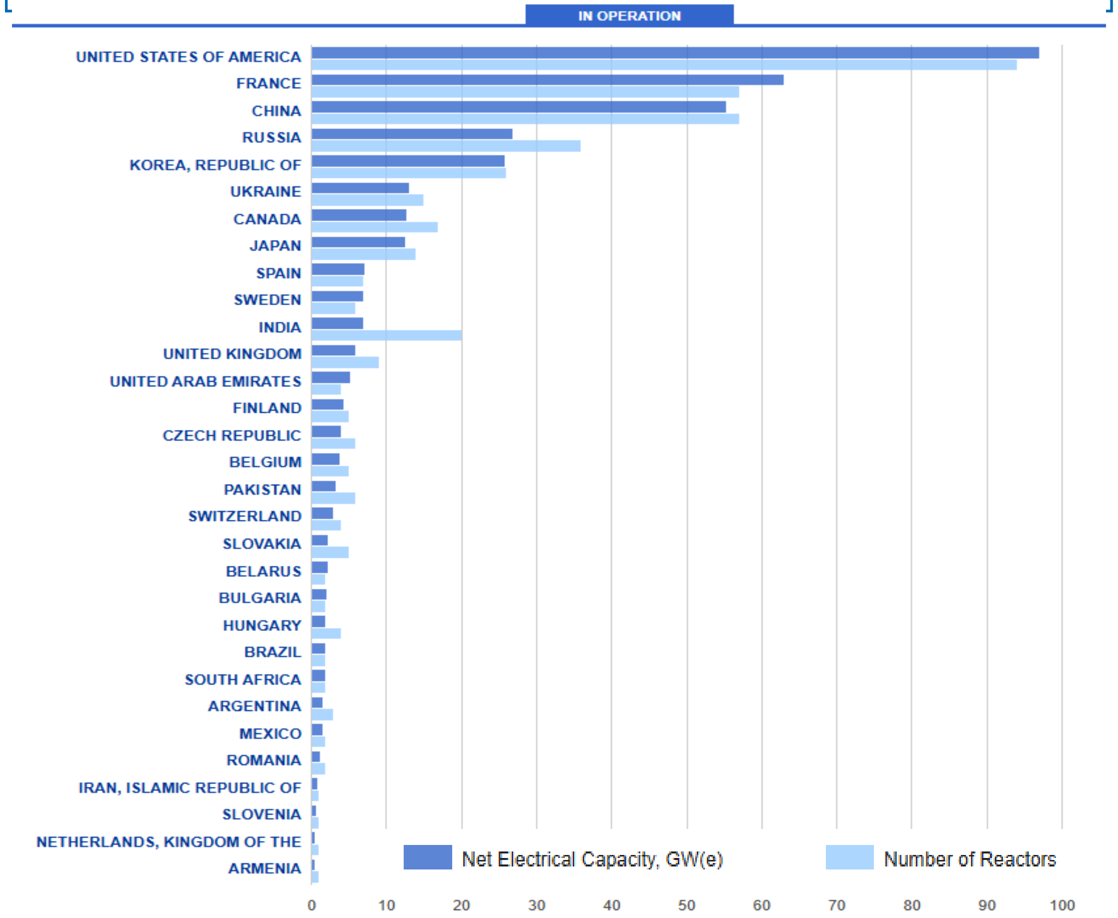
1. Nuclear Power today and tomorrow

Nuclear energy today

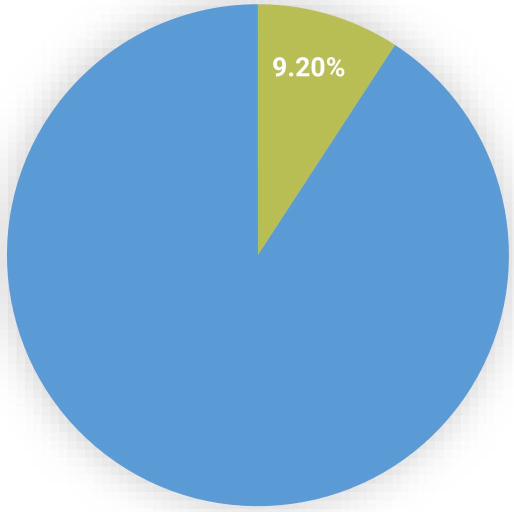
31 Operating countries

417 Reactors **in operation**

61 reactors **under construction**

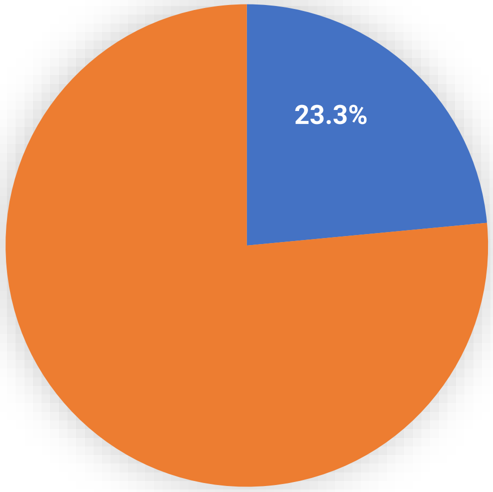


Nuclear Share of World's total electricity production



9.2% share electricity

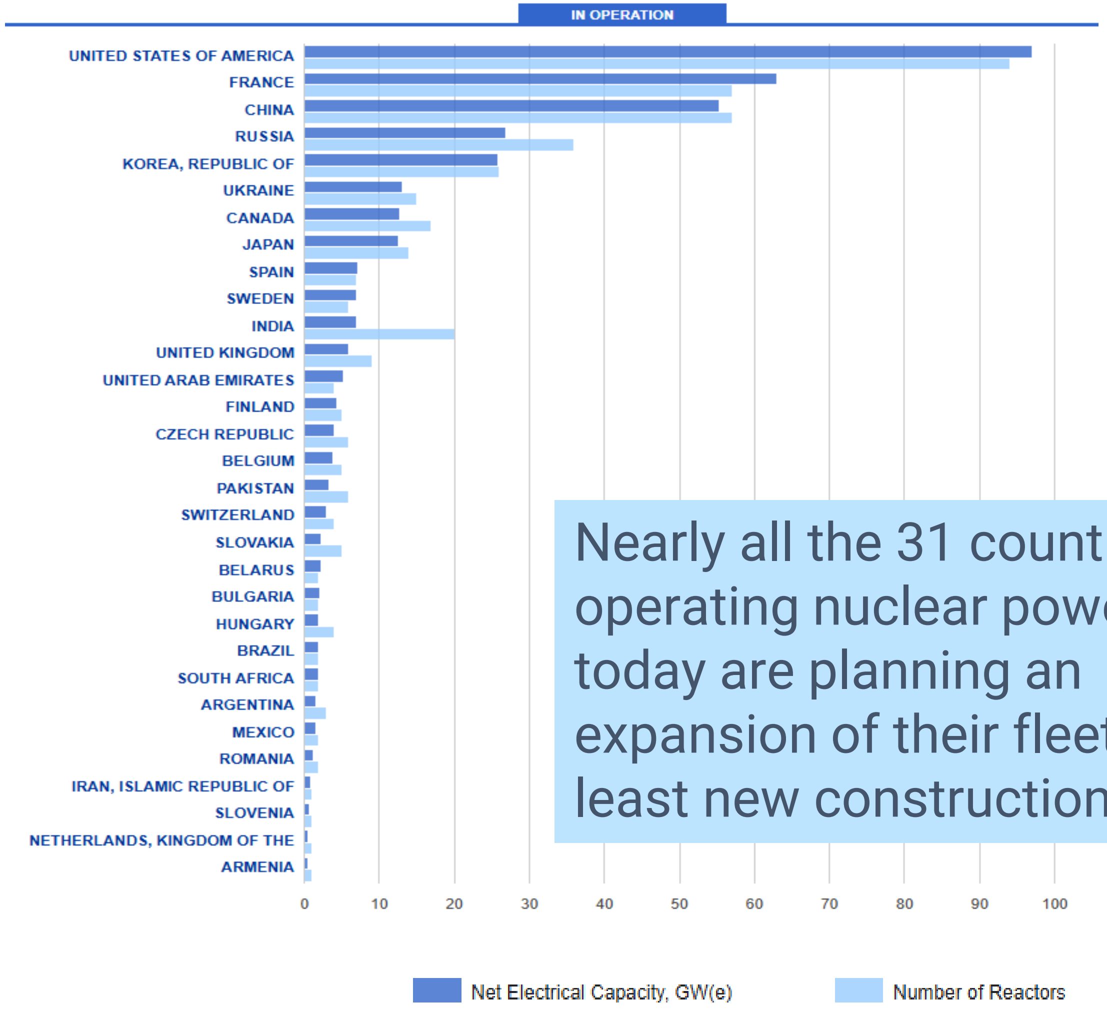
Nuclear Share of world's low-carbon electricity production

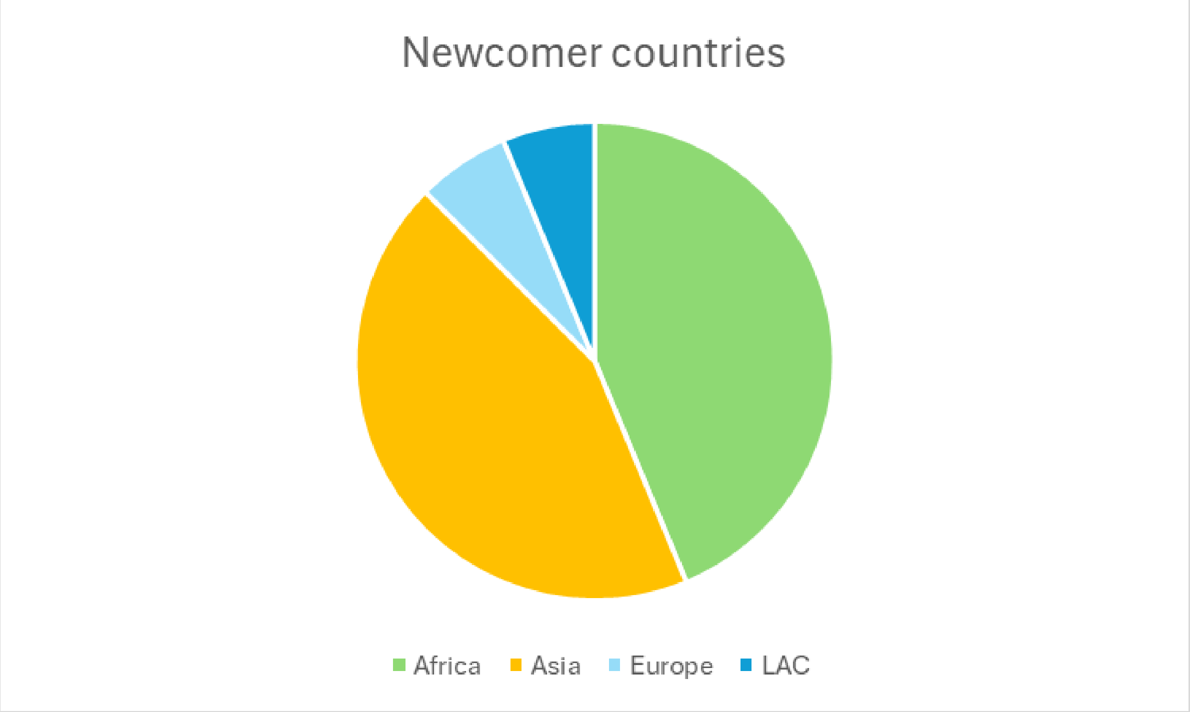


23.3% share low C electricity

Source: IAEA Power Reactor Information System (PRIS)

Nuclear energy tomorrow?





Nearly all the 31 countries operating nuclear power today are planning an expansion of their fleet (or at least new constructions)

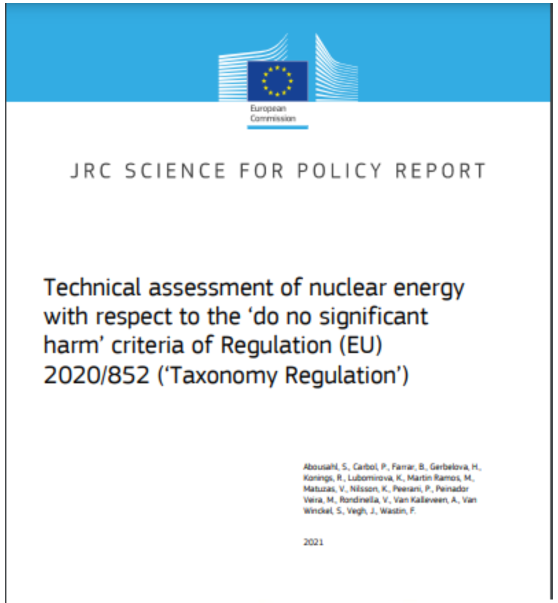
About 32 additional countries are planning to embark on nuclear power, with assistance from IAEA. Three are completing construction of their first NPP (Türkiye, Bangladesh, Egypt)

Source: IAEA Power Reactor Information System (PRIS)

2. Attributes of nuclear power

Low carbon and sustainability

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

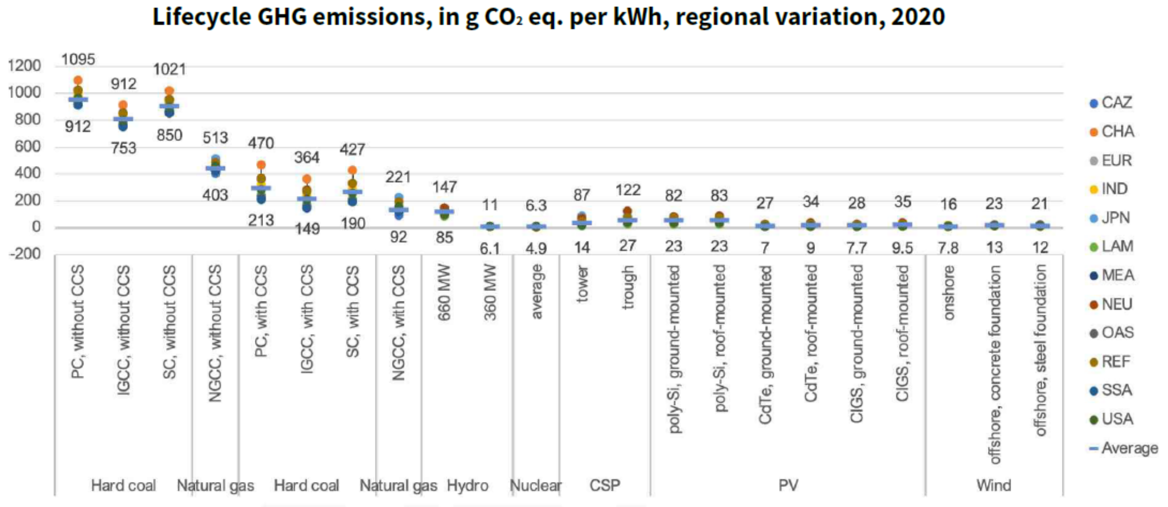

JRC SCIENCE FOR POLICY REPORT

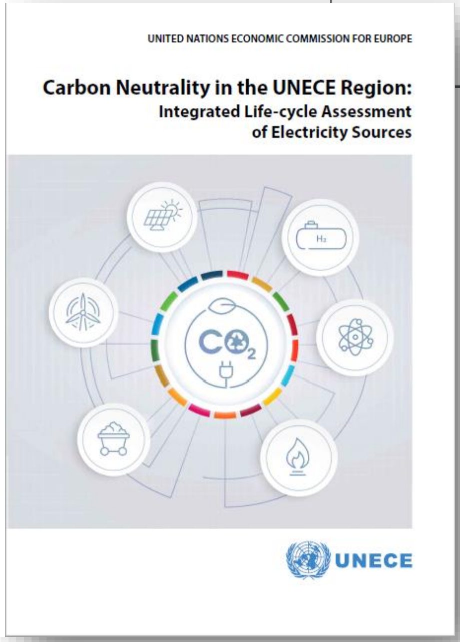
Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation')

Abousahl, S., Carbol, P., Farrar, B., Gerbelova, H., Konings, R., Lubomirova, K., Martin Ramos, M., Matuzas, V., Nilsson, K., Peerani, P., Peinador Veira, M., Rondinella, V., Van Kalleveen, A., Van Winckel, S., Vegh, J., Wastin, F.

2021

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.




UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE

Carbon Neutrality in the UNECE Region:
Integrated Life-cycle Assessment of Electricity Sources

UNECE

(2022)

Finland Completes Key Trial For World's First Deep Geological Nuclear Waste Repository

By Kamen Kraev
4 March 2025

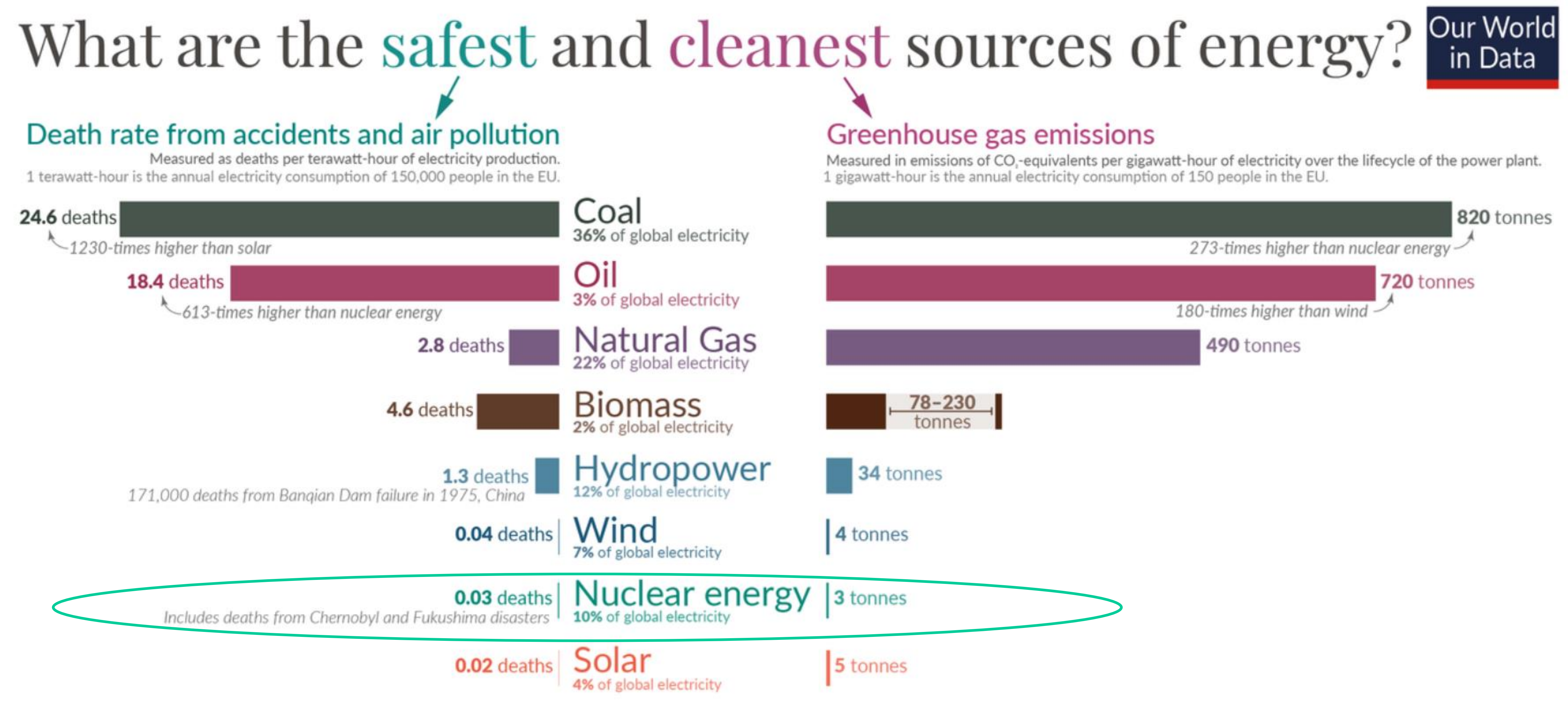
Posiva concludes successful test of above-ground encapsulation process

Four of the test spent fuel canisters used for the encapsulation plant trial run. Image courtesy Posiva.

Smallest carbon footprint among low C technologies

35 YEARS NUCNET

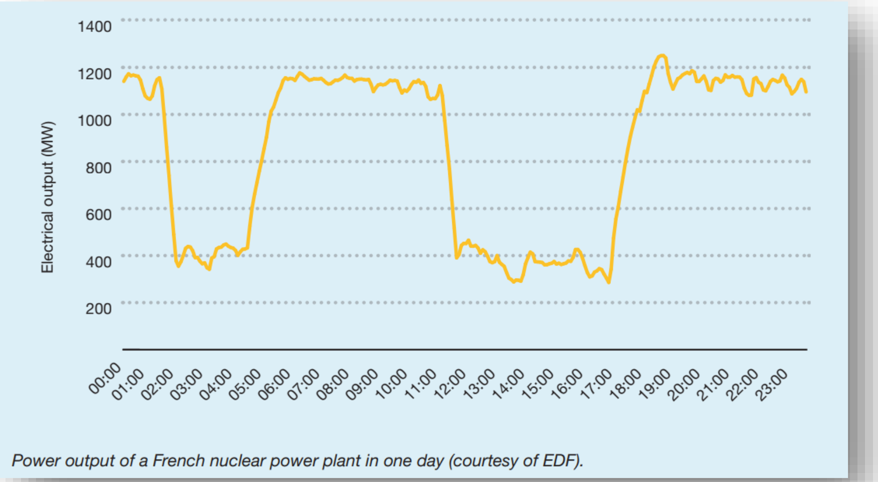
Nuclear, a safe and clean technology



Enabling integration of large % renewables

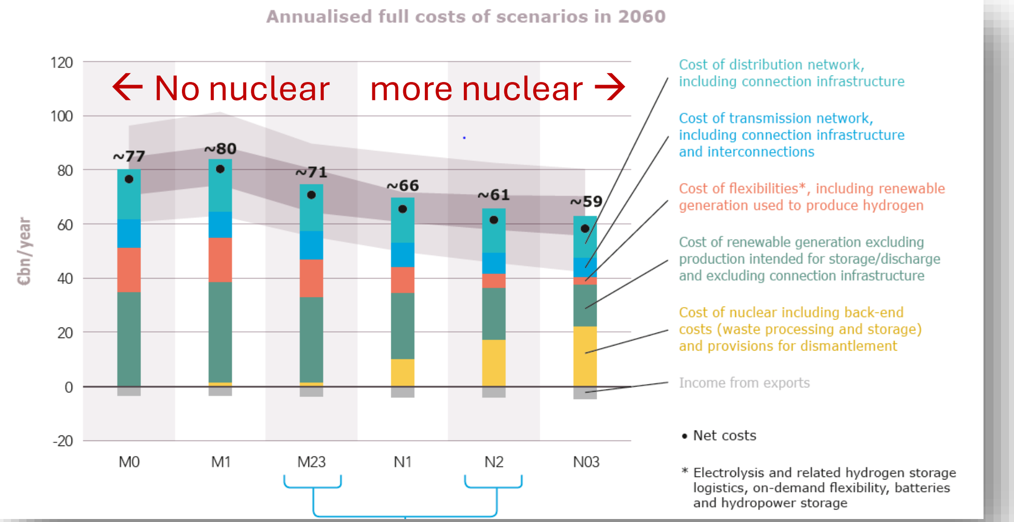
- Nuclear is a **dispatchable and flexible** source of low C power that can support the deployment of large shares of variable renewables such as solar PV and wind.
- Without nuclear (or other low C dispatchable such as hydro), need to overbuild Re capacities and energy storage (cost)
- Analysis of overall (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).

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)

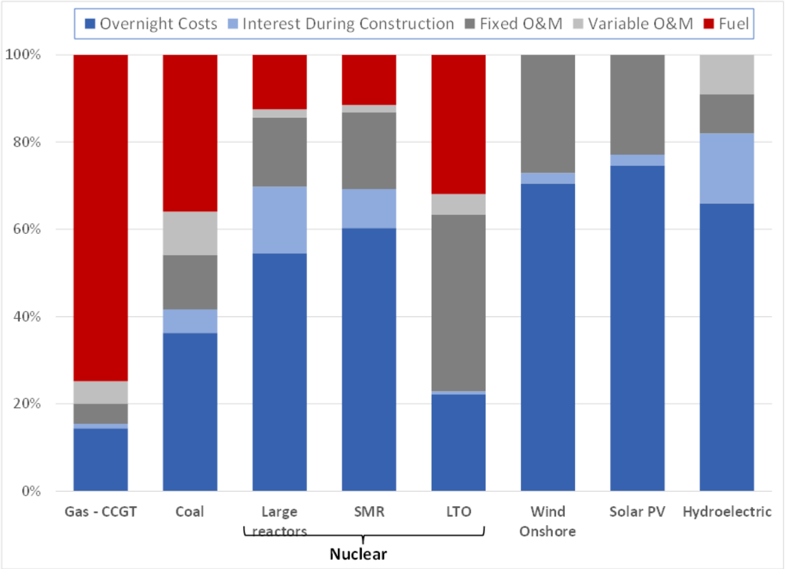


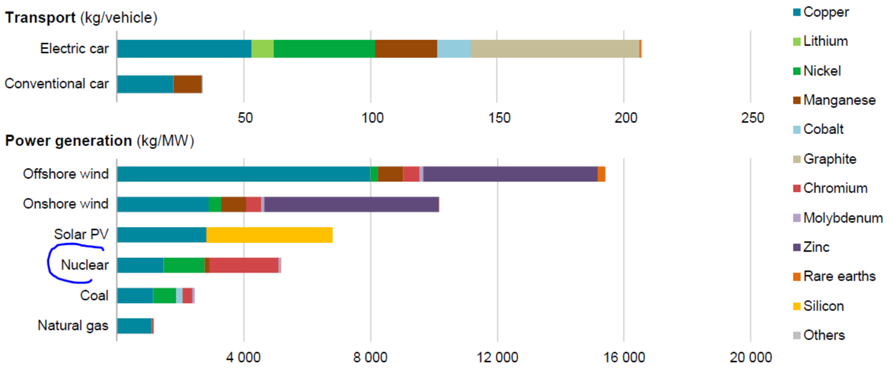
French grid operator RTE report "Energy Pathways to 2050" (2021)

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**
- **In the long term, fast reactors and closed fuel cycles:**
  - For the same quantity of U, energy output can be multiplied by 60 or more
- Nuclear generation is among the low C technologies **least dependent on critical minerals** – *IEA report on Critical Minerals (2021)*

Cost structure of electricity-generation technologies
(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 → **diversification**
- Investment needed in **climate resilient energy infrastructures & technologies (including cooling)**
- IAEA operational data (PRIS) suggests that nuclear is resilient – and adaption measures can be deployed to reduce vulnerabilities.
  - In 2022, all weather-related production losses amounted to 0.35% of global nuclear generation.
- **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
- Another aspect of **Security of Energy Supply**

Palo Verde Generating Station, Arizona

Decarbonization beyond electricity

- Nuclear energy = **source of low carbon heat, electricity and hydrogen**

- **Nuclear heat supply:**
    - Long experience (+30y) of nuclear District Heating (Switzerland, former Soviet Union countries)
    - Advanced reactors can also deliver high temperature steam for industrial applications. Example DOW Chemical + X-Energy in US
    - Recent applications in China (District Heating, process heat for industry), feasibility studies of nuclear DH in several countries (with SMRs)

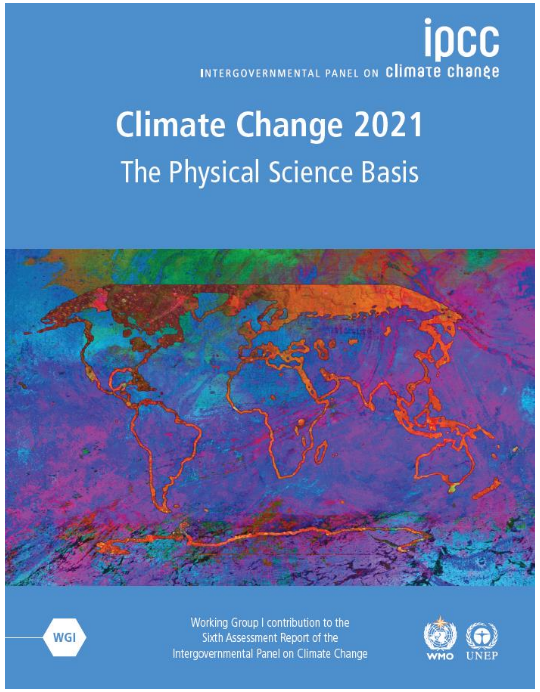
      [besides CO2 reduction, air pollution reduction as well]

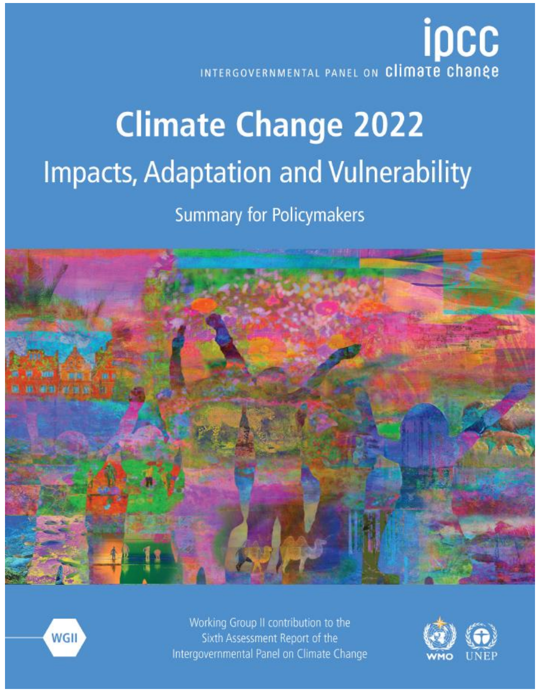
- Growing interest in **low C H_2** as an enabler of the transition to NZ (storage, flexibility, heat, etc). Nuclear can produce low C H_2
    - Through electrolysis like other low C technologies
    - Through thermal splitting processes (more efficient)

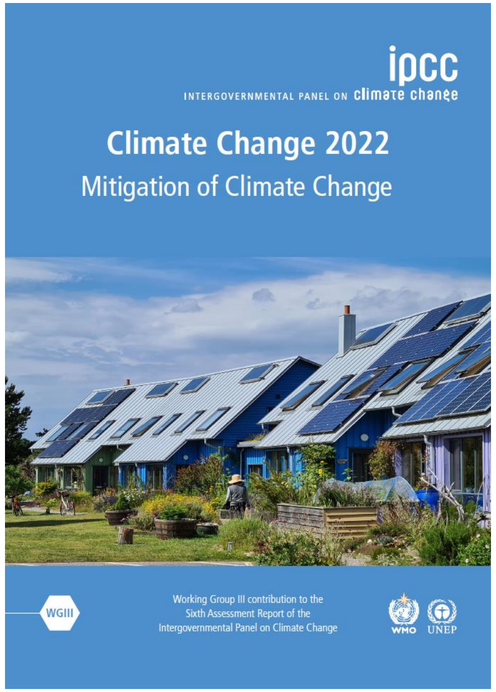
3. Nuclear Power and Climate Change Mitigation

Sixth Assessment Report of the IPCC

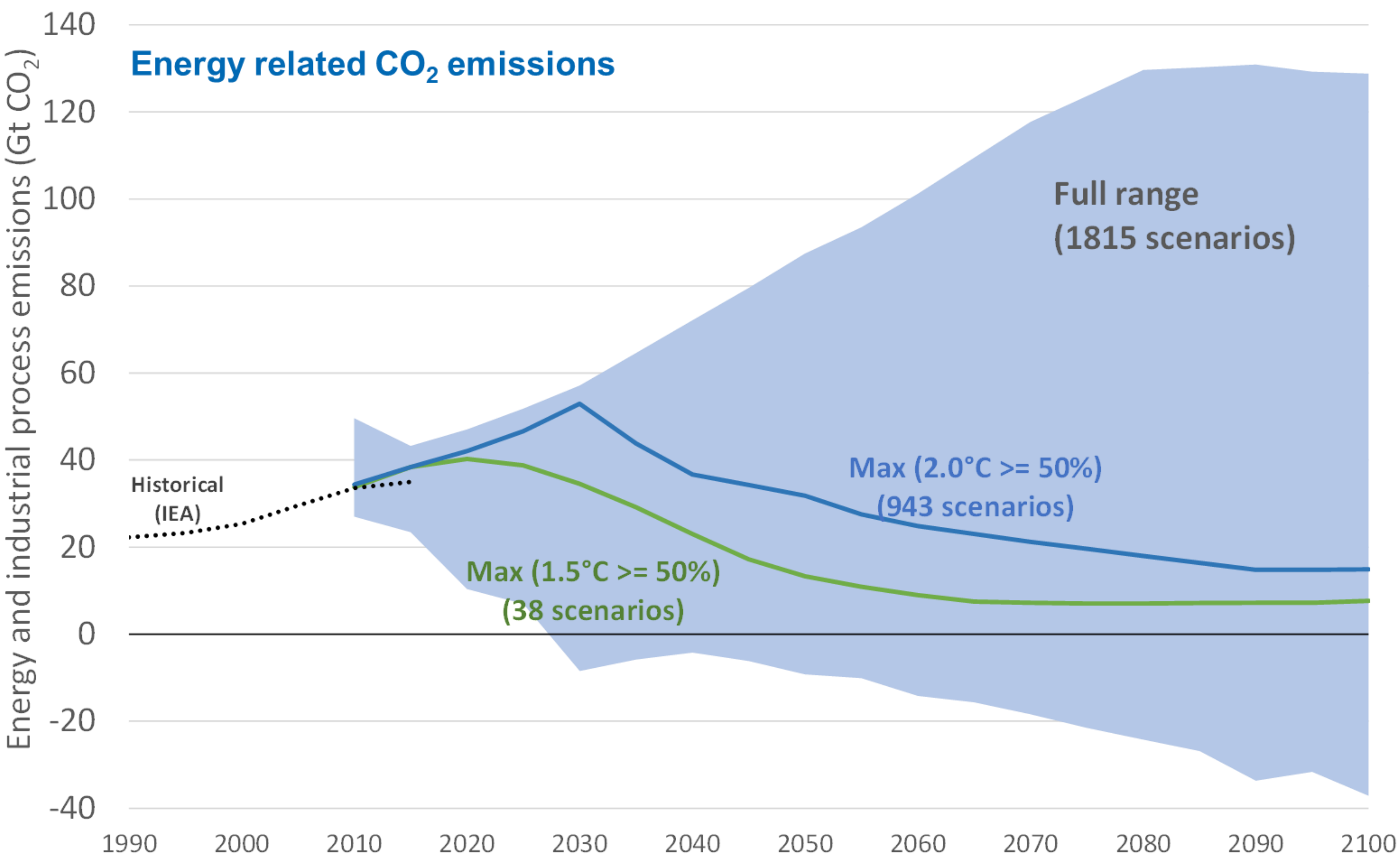
- Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change
- Sixth Assessment Report (AR6) addresses the state of scientific, technical and socio-economic knowledge on climate change, its impacts and future risks, and options for reducing the rate of climate change



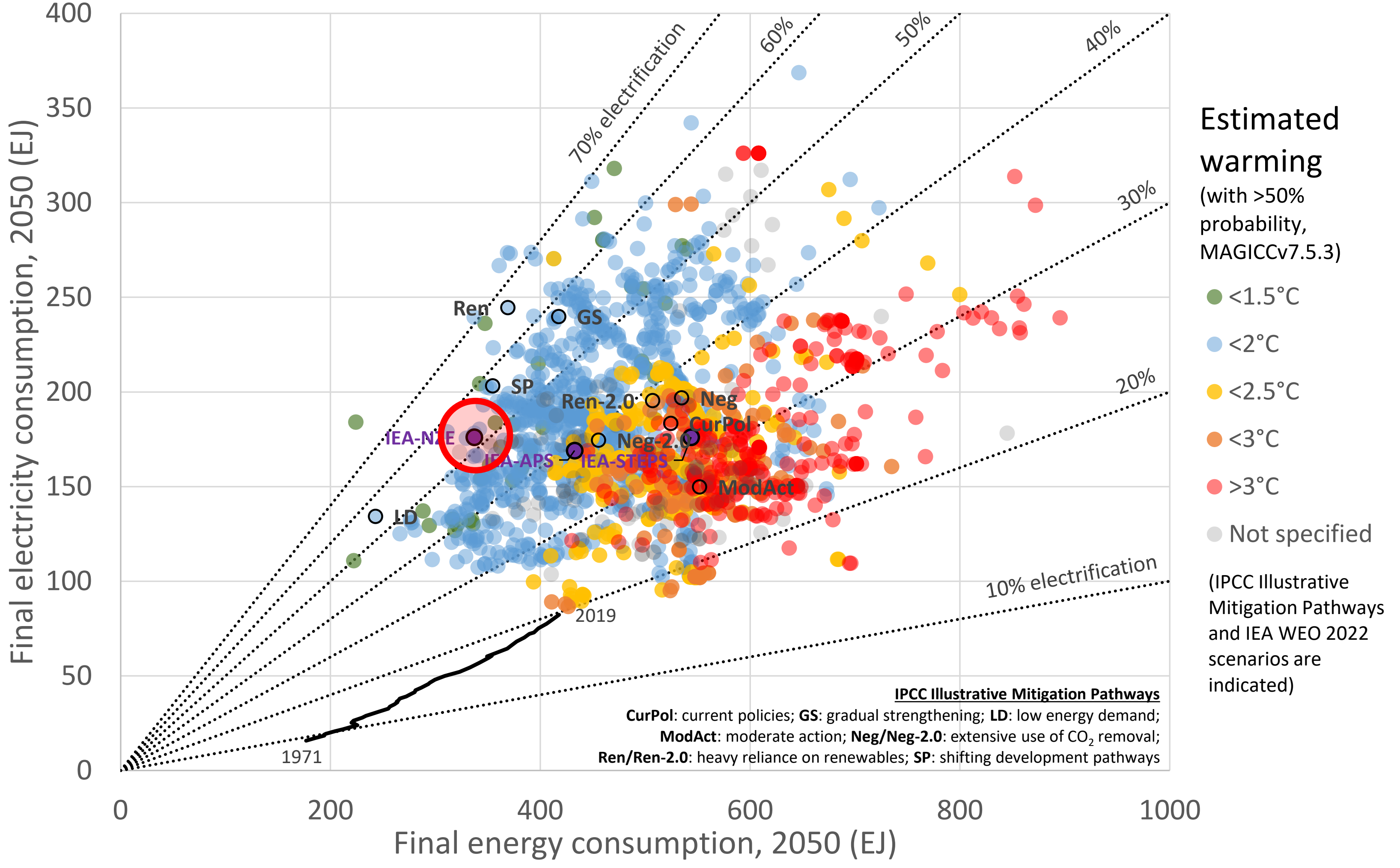




AR6 covers a wide range of future GHG emission scenarios



Key trends: Energy and electricity demand, 2050

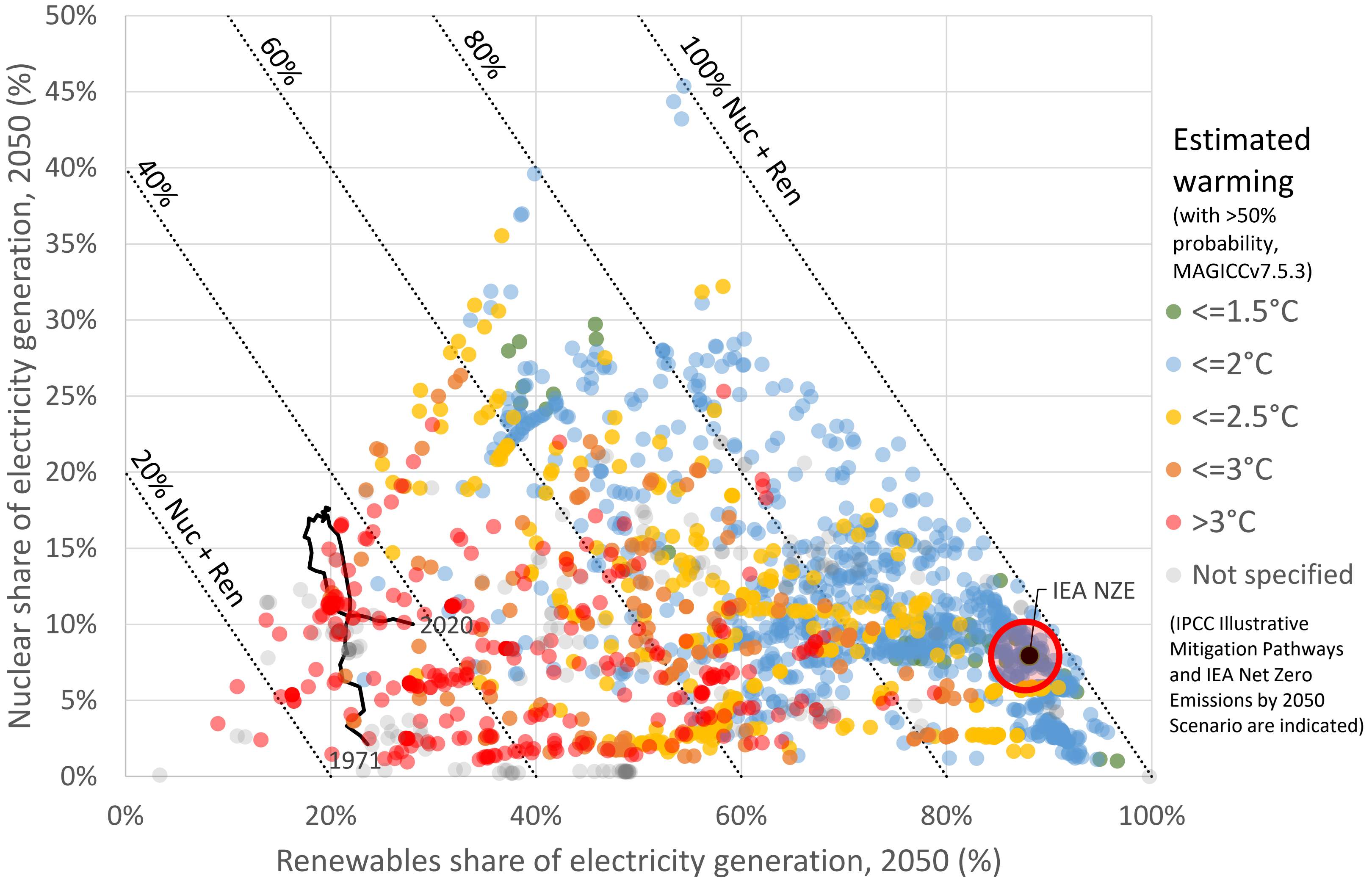


- 1971−2019
  →>2x final energy (FE), >5x electricity
- 2019−2050
  >3° → trends continue
  2−3° → up to +50% FE, ~+100% elec
  <2° → +/-50% FE, up to ~4x elec

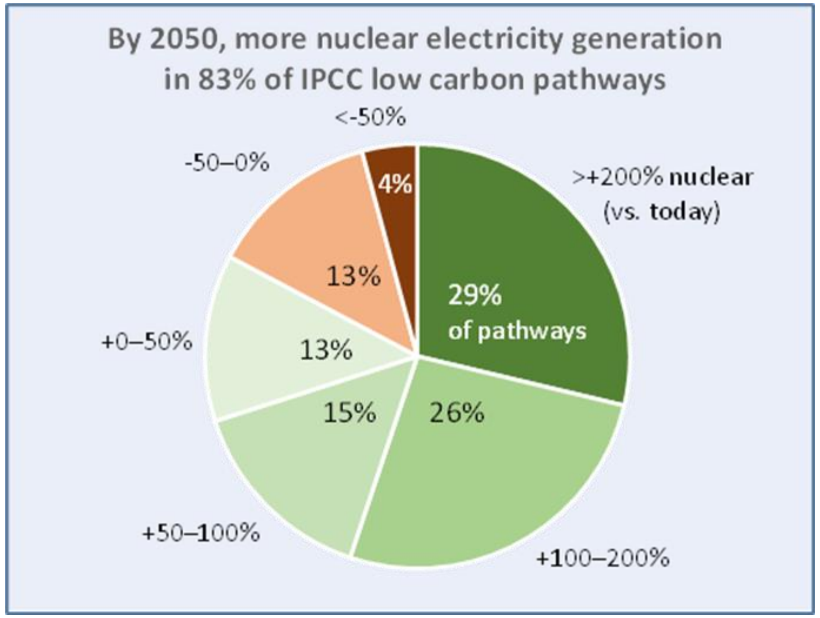
  IEA-NZE: -20% FE, >x2 elec

- Strong electrification
- Reduction in FE consumption

Clean electricity mix, 2050



- Many scenarios envisage an increase in nuclear generation vs. 2020; very few (5) see a complete phase out



- Nuclear **and** renewables

COP28 outcomes

- Plenary adopted the Outcome of the first global stocktake by consensus on December 13
- Text calls to **accelerate nuclear**, “particularly in hard-to-abate sectors”
  - https://unfccc.int/documents/636608
- On the margins of COP28, Tripling pledge by 22 countries

28. *Further recognizes* the need for deep, rapid and sustained reductions in greenhouse gas emissions in line with 1.5 °C pathways and *calls on* Parties to contribute to the following global efforts, in a nationally determined manner, taking into account the Paris Agreement and their different national circumstances, pathways and approaches:

(a) Tripling renewable energy capacity globally and doubling the global average annual rate of energy efficiency improvements by 2030;

(b) Accelerating efforts towards the phase-down of unabated coal power;

(c) Accelerating efforts globally towards net zero emission energy systems, utilizing zero- and low-carbon fuels well before or by around mid-century;

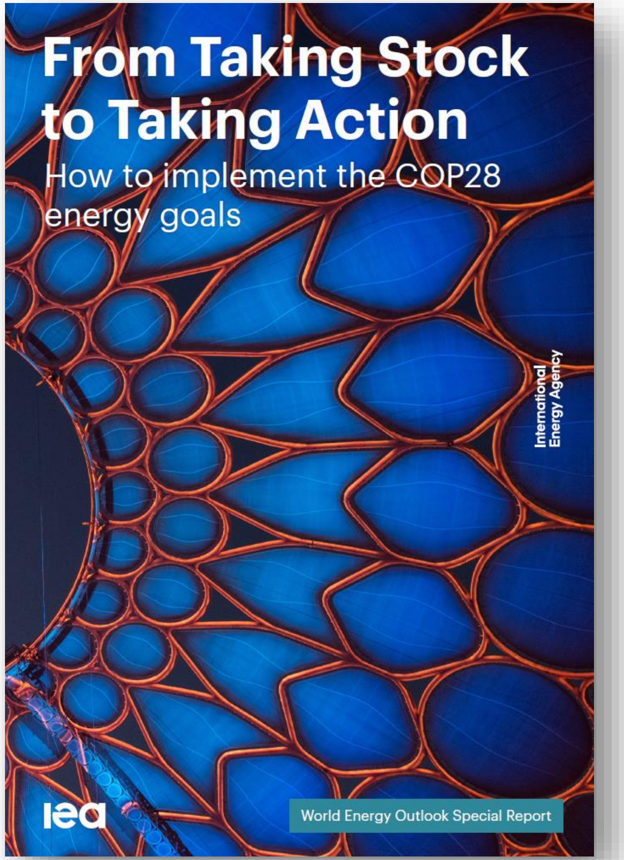
(d) Transitioning away from fossil fuels in energy systems, in a just, orderly and equitable manner, accelerating action in this critical decade, so as to achieve net zero by 2050 in keeping with the science;

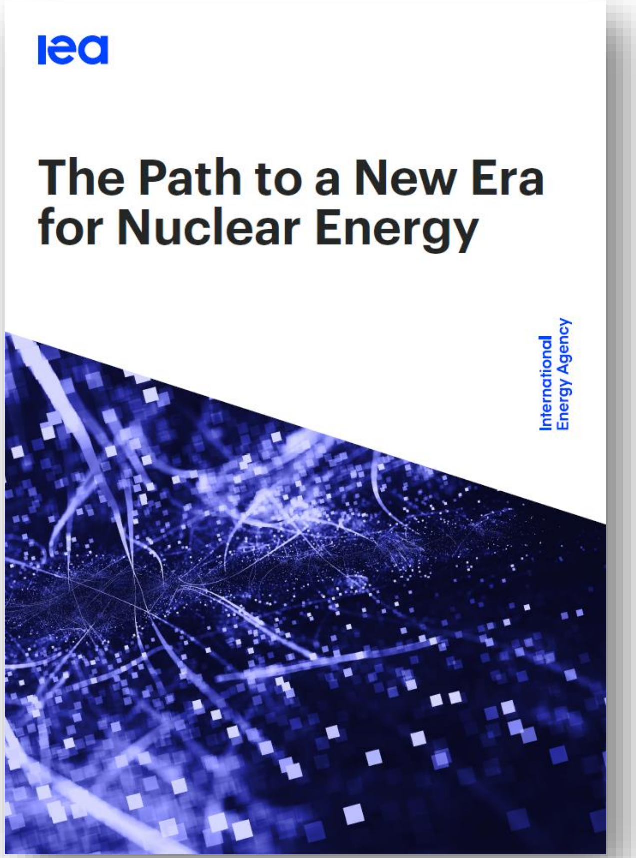
(e) Accelerating zero- and low-emission technologies, including, inter alia, renewables, nuclear, abatement and removal technologies such as carbon capture and utilization and storage, particularly in hard-to-abate sectors, and low-carbon hydrogen production;

COP28UAE

IEA on nuclear & net zero

“If we want to reach net zero, without having any nuclear, it is **impossible**,” Dr Birol said (March 2024)

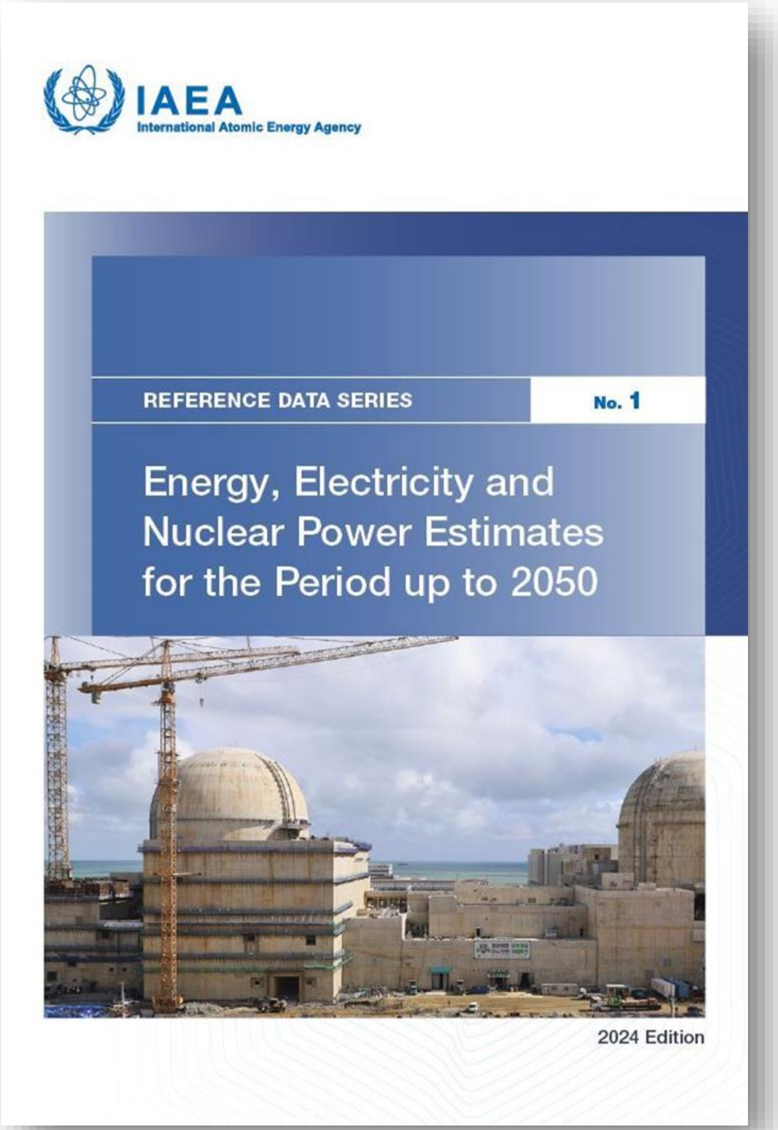




Nuclear power is ‘making a comeback’ around the world, IEA Executive Director Fatih Birol (February 2025)

4. IAEA nuclear capacity projections to 2050 & investment needs

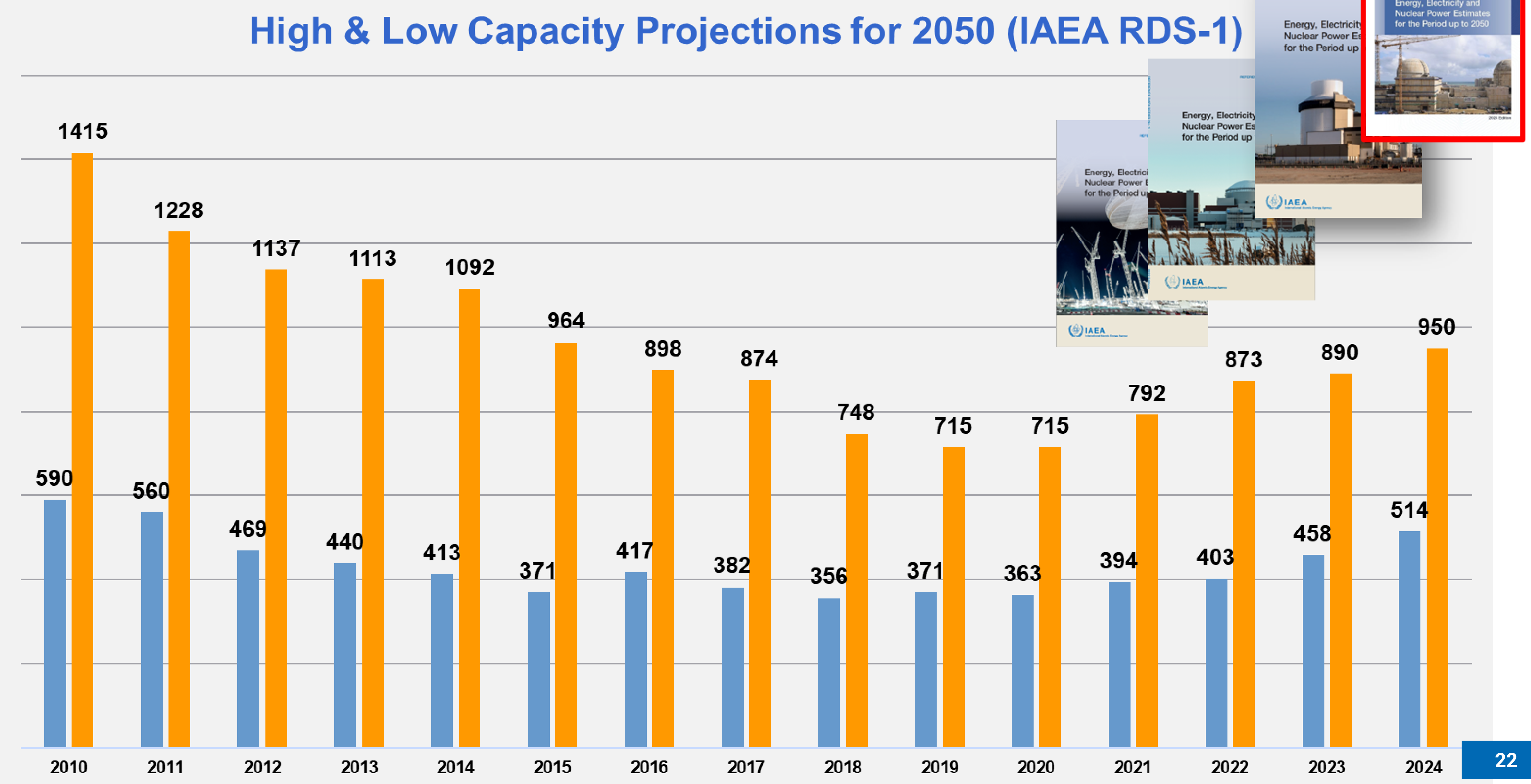
Reference Data Series No. 1



- Reference Data Series No. 1 (RDS-1) is an annual publication containing estimates of energy, electricity and nuclear power trends up to the year 2050.
- 44 editions – 40+ years of experience.
- Global overview with regional focus, based on bottom-up approach.
- 2024 edition contains data from 2023 and projections of nuclear capacity up to 2050.

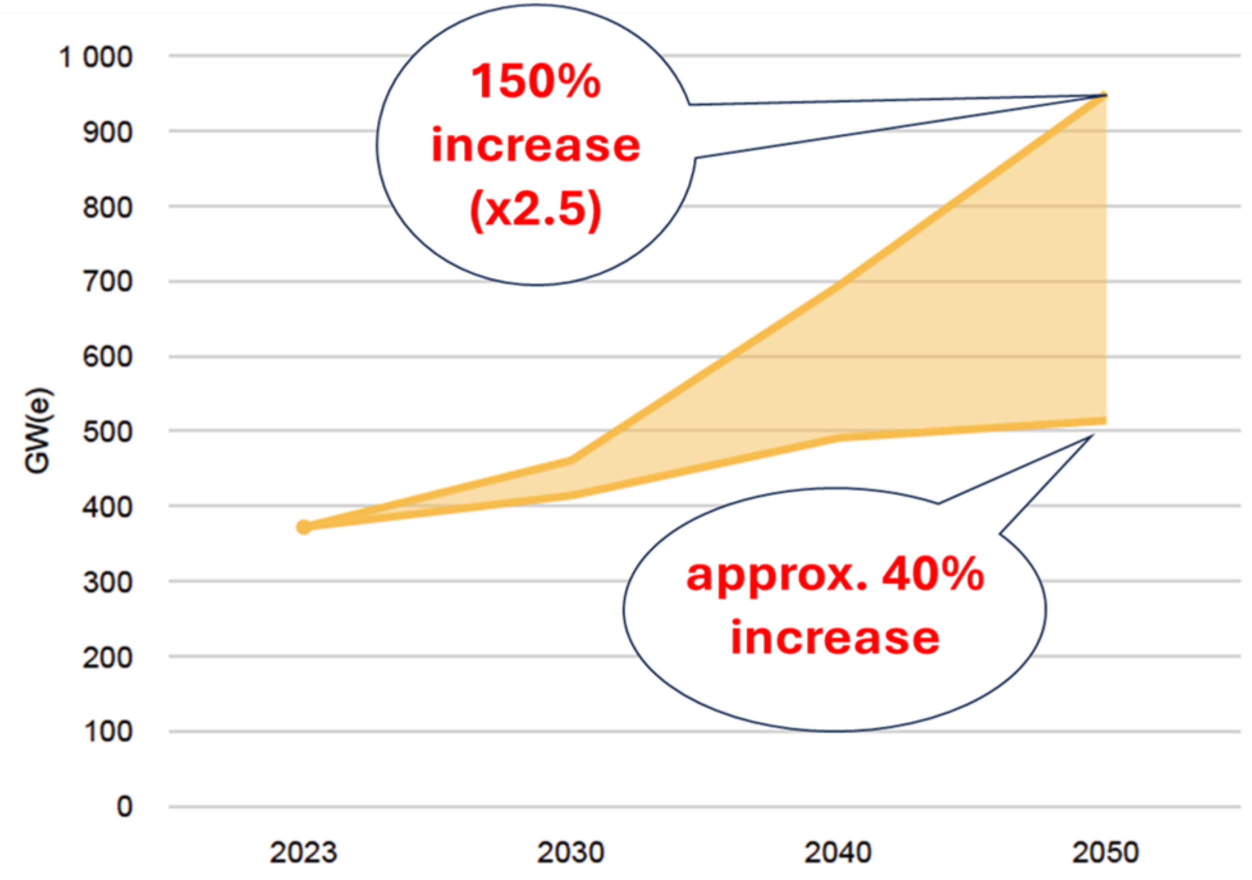
Reference Data Series | IAEA

Positive trend in the last 4 years



IAEA 2024 Nuclear Capacity Projections (RDS-1)

- 2023: 372 GW(e)
- Low case: 514 GW(e)
- High Case: **950 GW(e)**
- Long Term Operation and power uprates important in both low & high cases
- To reach 950GW, **641GW of new build needed**:
  - IAEA projects up to **24%** of added capacity from SMRs
  - Global average grid connection rate needs to reach **25GW/year** (average over last 5 years: 5.7 GW/year)



Newbuild – what technology?

641 GW of new build in the high case:

Essentially large Gen III reactors (76%)

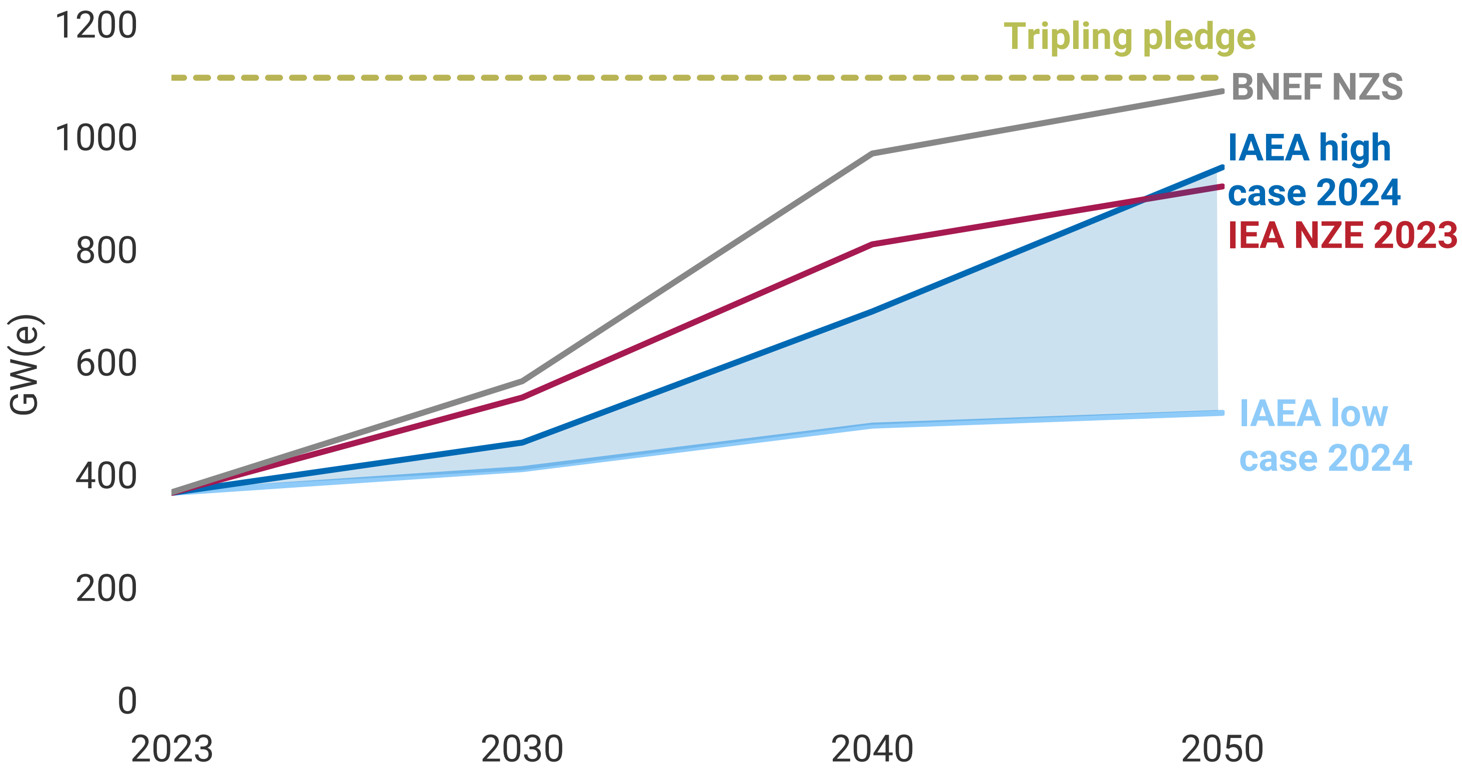
But also advanced reactors and SMRs (24%)

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.

Other scenarios (net zero transitions) and projections (including tripling pledge)

- To achieve net zero emissions by 2050, the IEA estimates that installed capacity of nuclear needs to more than double, in line with the IAEA's high case projection (950 GW in 2050.)

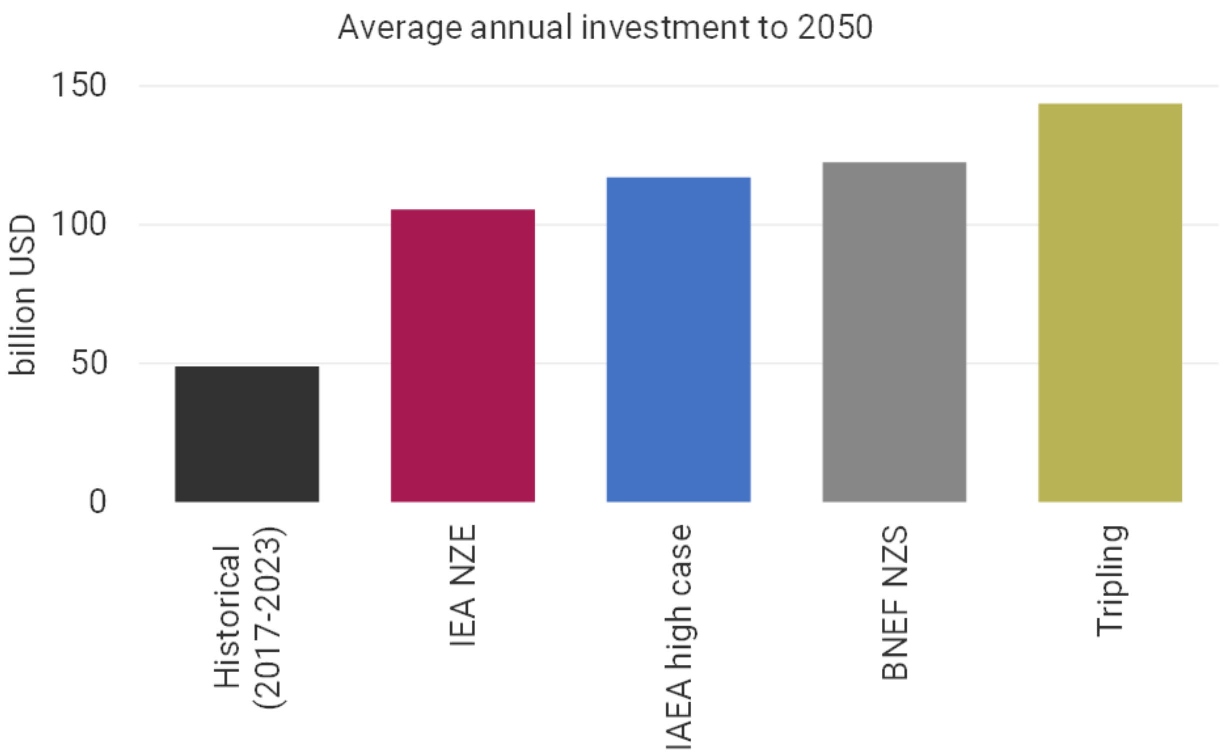
- At COP 28, 22 countries and nuclear industry committed to an even more ambitious target to triple nuclear capacity by 2050. Today, 31 countries have pledged to work together to triple nuclear capacity by 2050.



Is this a second Renaissance of nuclear power?

Investement needed to reach net zero

- Nuclear investment must increase to **$125 billion** annually from 2031-50 to meet the IAEA's high case projection for nuclear capacity in 2050 (or $117 bn from 2024-2050), from around $50 billion per year during 2017-2023.
- Tripling the existing nuclear capacity would require closer to $150 billion annually.
- To mobilize such capital, nuclear projects must offer sound economics to meet rigorous financing requirements.
- As an order of magnitude, the tripling of renewables by 2030 (COP28) is estimated to require about USD 1.5 trillion.



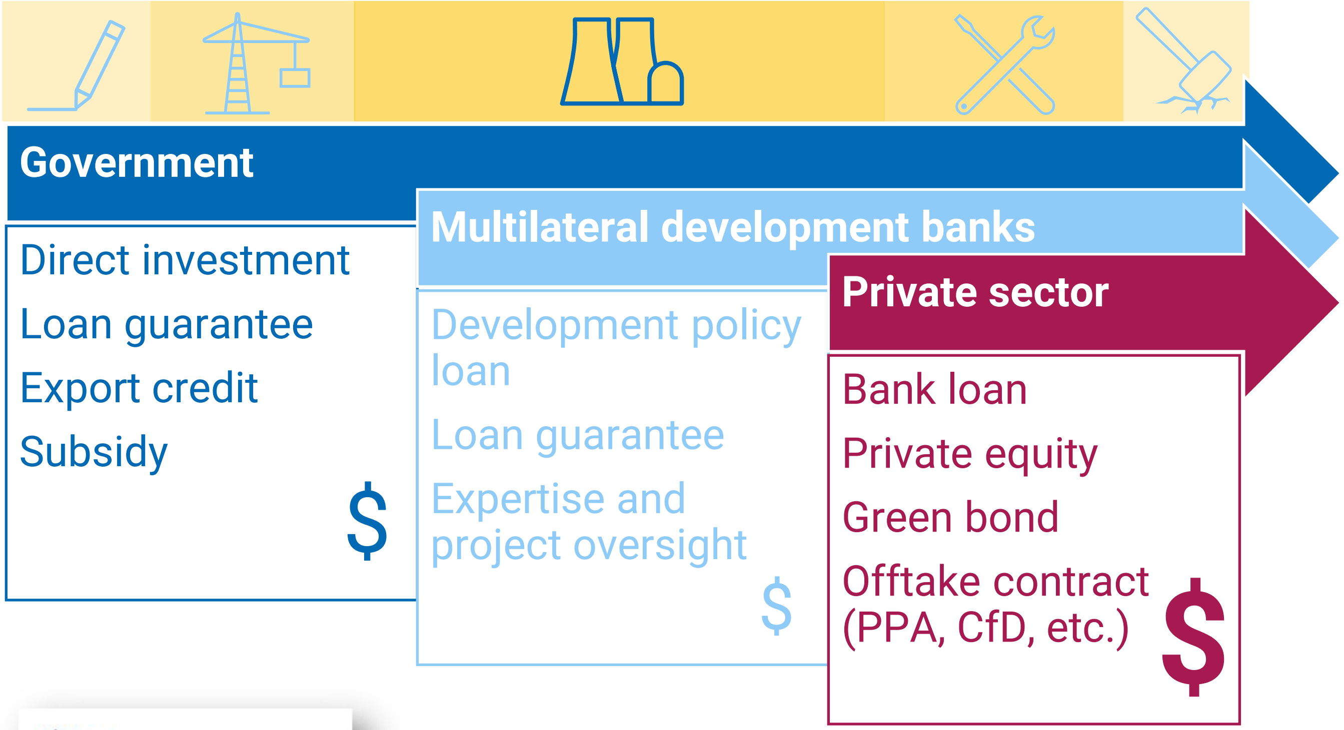
Getting to “in time and on budget”

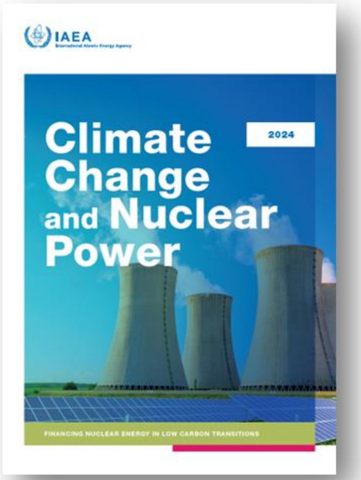
Nuclear programmes which historically achieved construction and cost predictability tend to share several key elements:

- **Standardization of reactor technology** prior to the start of construction
- **Commitment to volume and series construction** within a country or region
- **Effective interactions with regulators**, and harmonization of regulatory requirements
- **Shared ownership models** to more efficiently utilize capital and expertise
- **(Re)build supply chain and workforce**
- **Willingness to take on learning costs**, budgeting for FOAK construction delays and subsequent cost overruns

Financing pathways

- Attracting private sector capital is becoming increasingly essential and viable for nuclear energy projects.
- Financial mechanisms such as green bonds and loans, coupled with guarantees, offer tools for risk mitigation and broader investor participation.
- Inclusion of nuclear power in sustainable taxonomies could further catalyse commercial bank involvement with multilateral development banks potentially playing a supportive role.





Report “Financing Nuclear Energy in Low Carbon Transitions” (2024 edition of Climate Change and Nuclear Power), released at Clean Energy Ministerial Brazil, October 2024

5. The potential role of SMRs

Small Modular Reactors

2024 Edition

IAEA Booklet on Advanced in SMR Technology Developments:

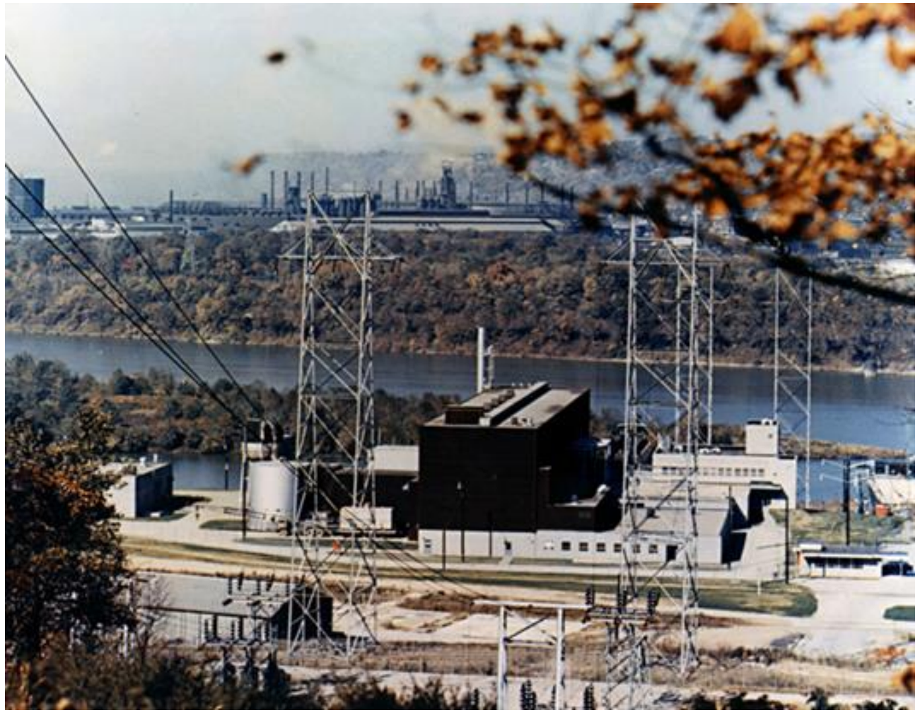
Design description and main features of more than 80 SMR designs (56 in 2018). Current publication lists only "active" designs:

- 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

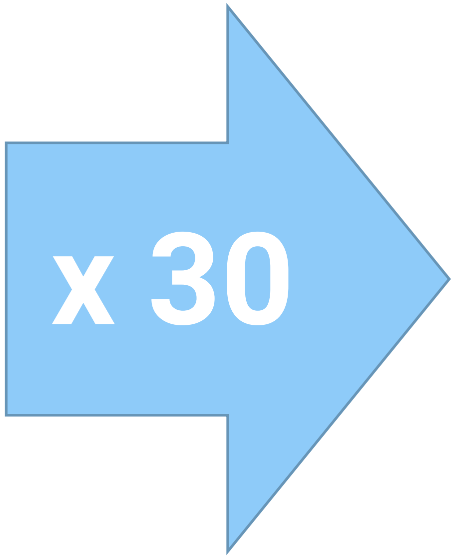
A supplement to:
IAEA Advanced Reactors Information System (ARIS)

https://aris.iaea.org/Publications/SMR_catalogue_2024.pdf

Large reactors: Economies of Scale



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



In 60 years

Photo: courtesy of China General Nuclear Power Corporation

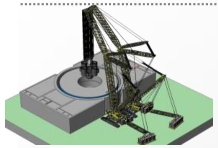
EPR Taishan 1 PWR (2018, **1750MW**)

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

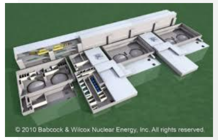
Advanced Reactors that produce typically up to 300 MWe, built in factories and transported as Modules to sites for Installation as Demand arises.

Economic
- Lower Upfront capital cost
- Economy of serial production



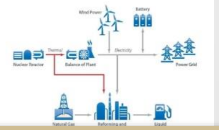
Modularization
- Multi-module
- Modular Construction

Flexible Application
- Remote regions
- Small grids



Smaller footprint
- Reduced Emergency planning zone

Replacement for aging fossil-fired plants



Potential Hybrid Energy System

Better Affordability

Shorter construction time

Wider range of Users

Site flexibility

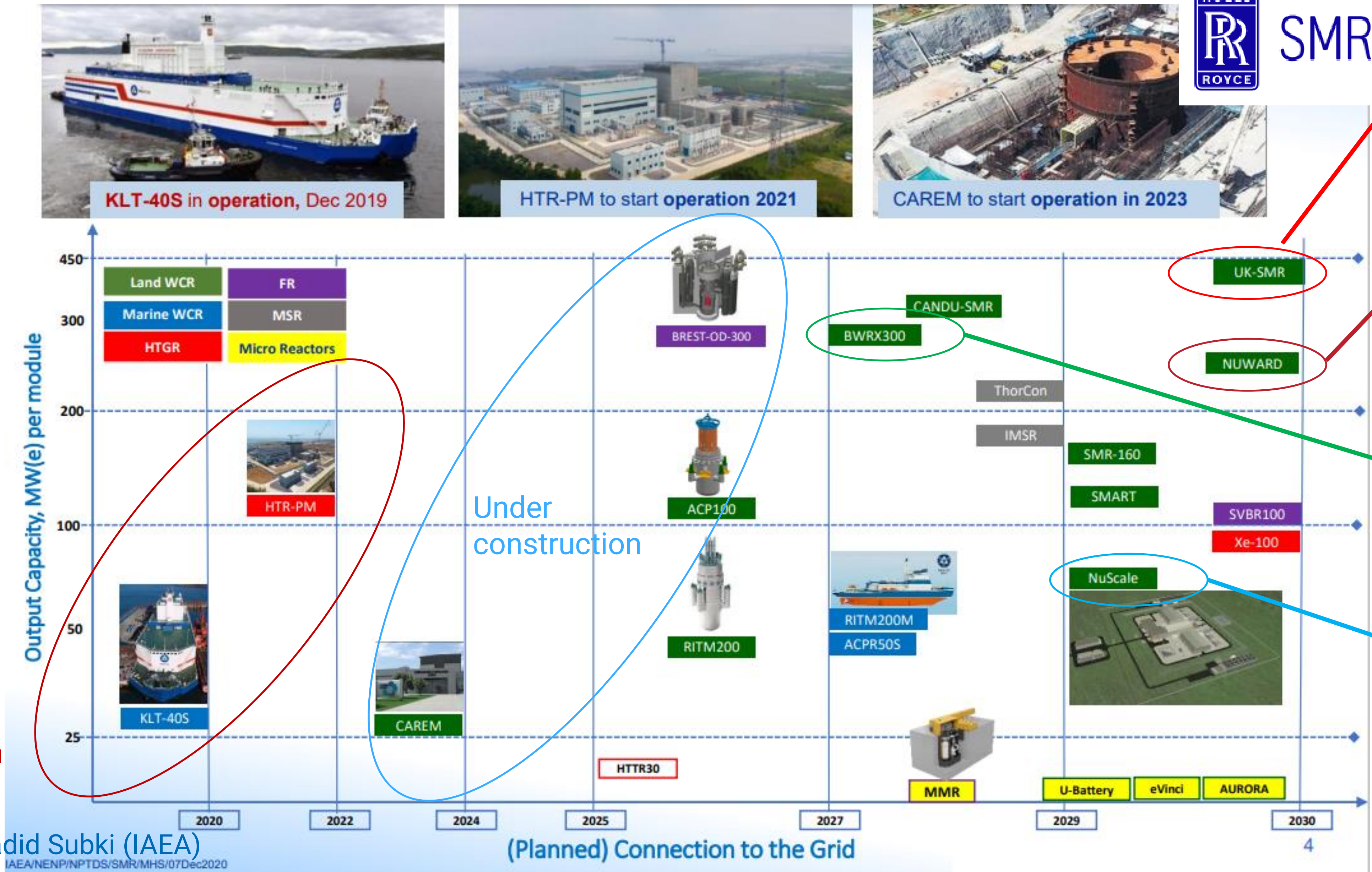
Reduced CO_2 production

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 (NPTDS)

SMR: First ten-year deployment horizon



Under construction

In operation

Step 2 of the UK ONR Generic Design Assessment (GDA)

Plans to build in France (2030), under early regulatory review in FR, FI and CZ to be joined by PL, SWE and NL

Under regulatory review in Canada and US; Plans to build in Canada, Sweden, Estonia, Poland…

50MW design certified by NRC, 77MW uprate under review. Plans to build in US, Romania, Poland, Ukraine

From Dr. Hadid Subki (IAEA)

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


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

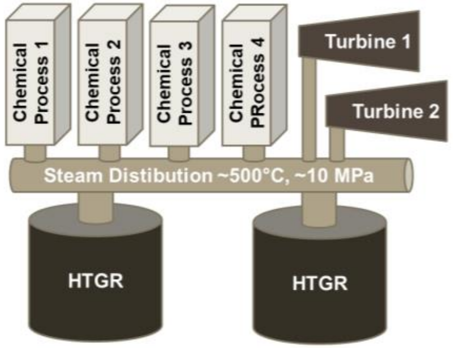
Source: http://fnpp.info/

- **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

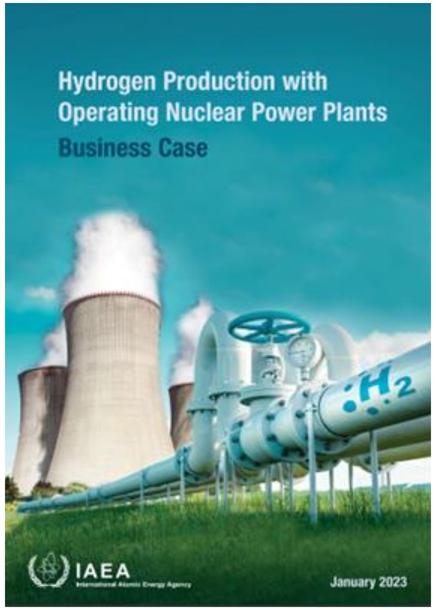
Report of the Committee for Analysis and Preparation of Conditions for Deployment of High-Temperature Nuclear Reactors

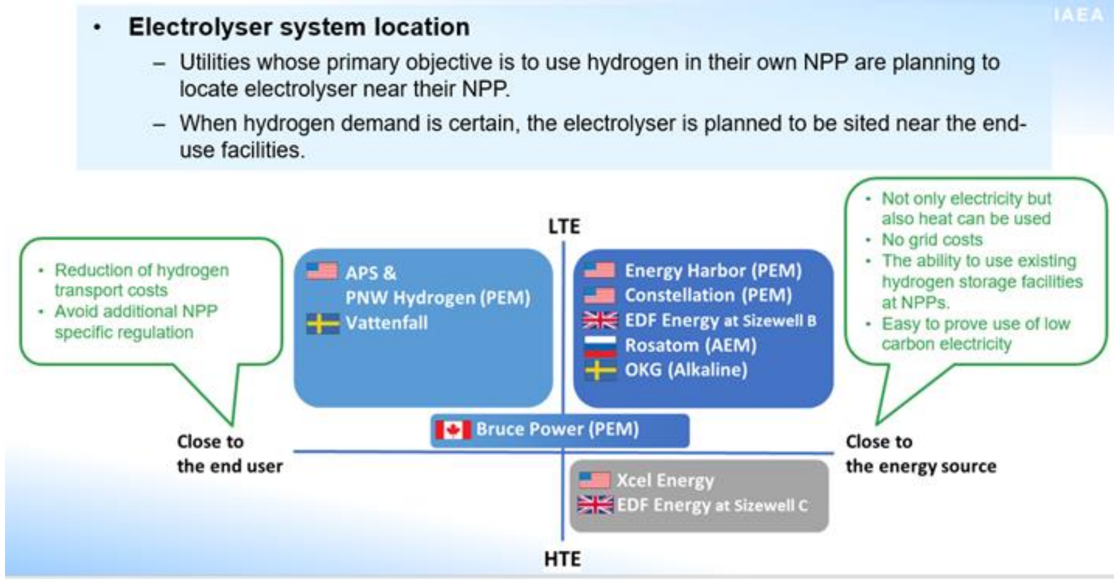


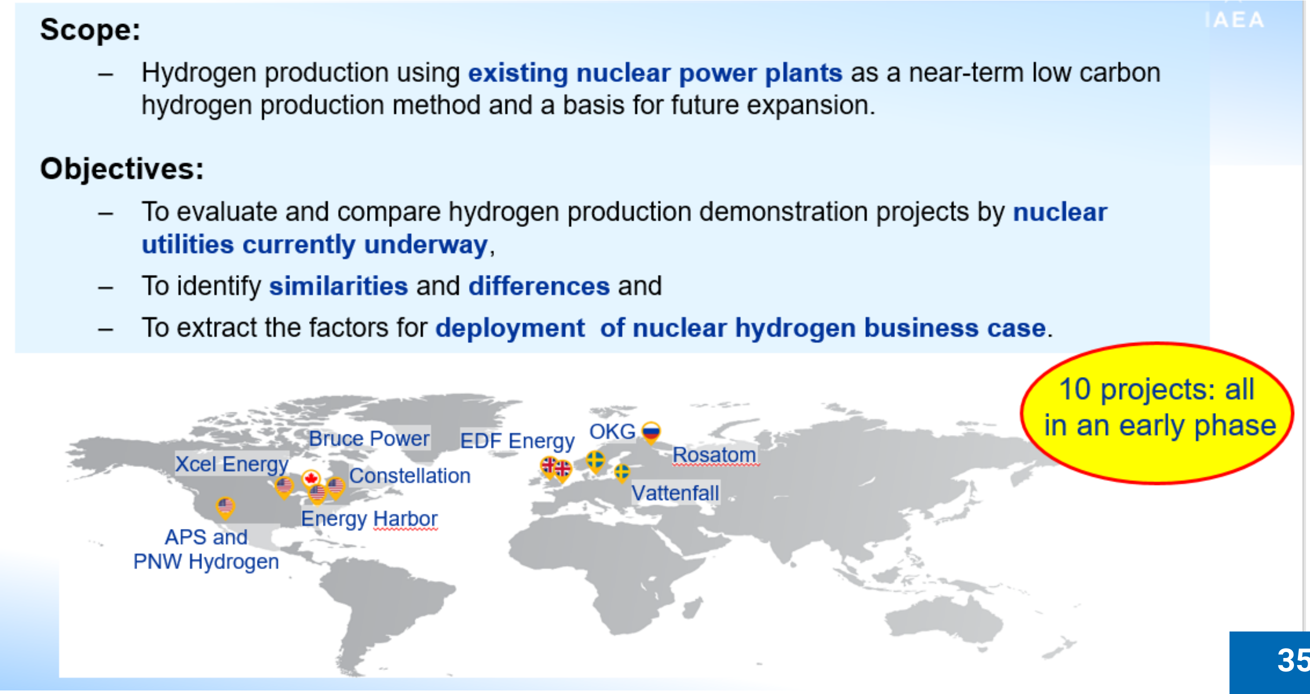
PL Gov source

Hydrogen

- Need for large amounts of low-carbon hydrogen to decarbonize hard to abate sectors
- Low-carbon H2 from renewables, fossil with CCS, or nuclear → carbon content of H2 rather than “colour coding”
- IAEA work on business opportunities for existing NPP (with low temperature electrolysis or high temperature steam electrolysis) as well as work related to SMRs and HTSE
- Importance of policies / incentives







6. Some “new” applications of nuclear power

Phasing out coal to align with 1.5ºC goal

"We have a collective and urgent responsibility to address the serious challenges that come with the speed and scale of the transition. The needs of coal communities must be recognized, and concrete solutions must be provided at a very local level"

Why Coal to Nuclear?

- Coal is among the most CO_2 emissions intensive fossil fuels per unit of energy produced.

  Combustion of coal accounts for almost 45% of energy sector

- CO_2 emissions worldwide as well as substantial local air pollution linked to millions of premature deaths every year

- Cumulative global coal use has remained roughly stable since 2011

  In 2022, coal consumption reached a new high in 2022 as a consequence of energy crisis

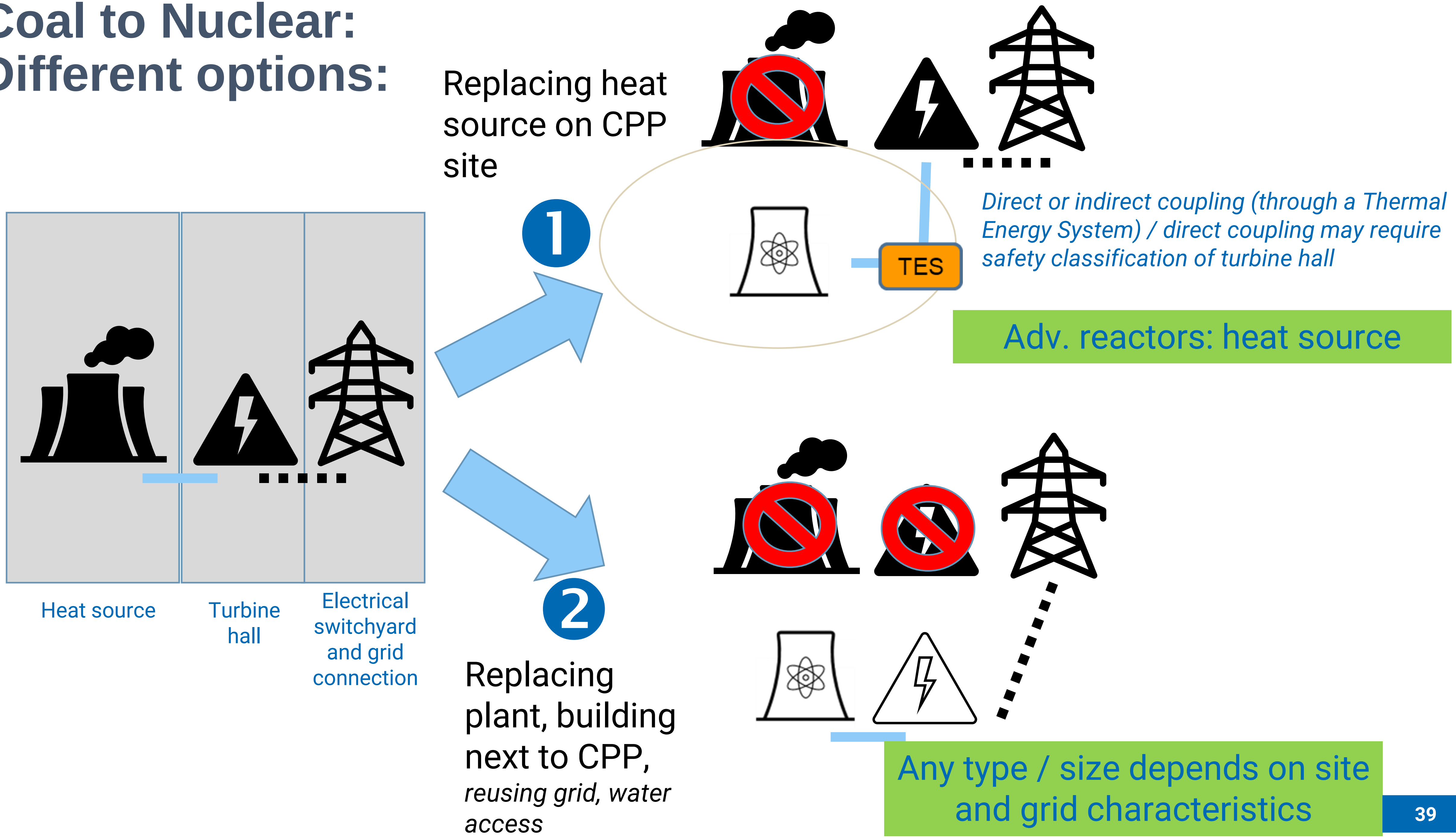
- The majority of emissions from coal use arise in electricity generation,

  Accounting for 30% of the total emissions from the energy sector.

- Given that nuclear and coal fired plants have certain similarities — e.g. they are both thermal power plants relying on similar components (and supply chains):

  nuclear power can be a **suitable replacement for coal on the path to net zero**

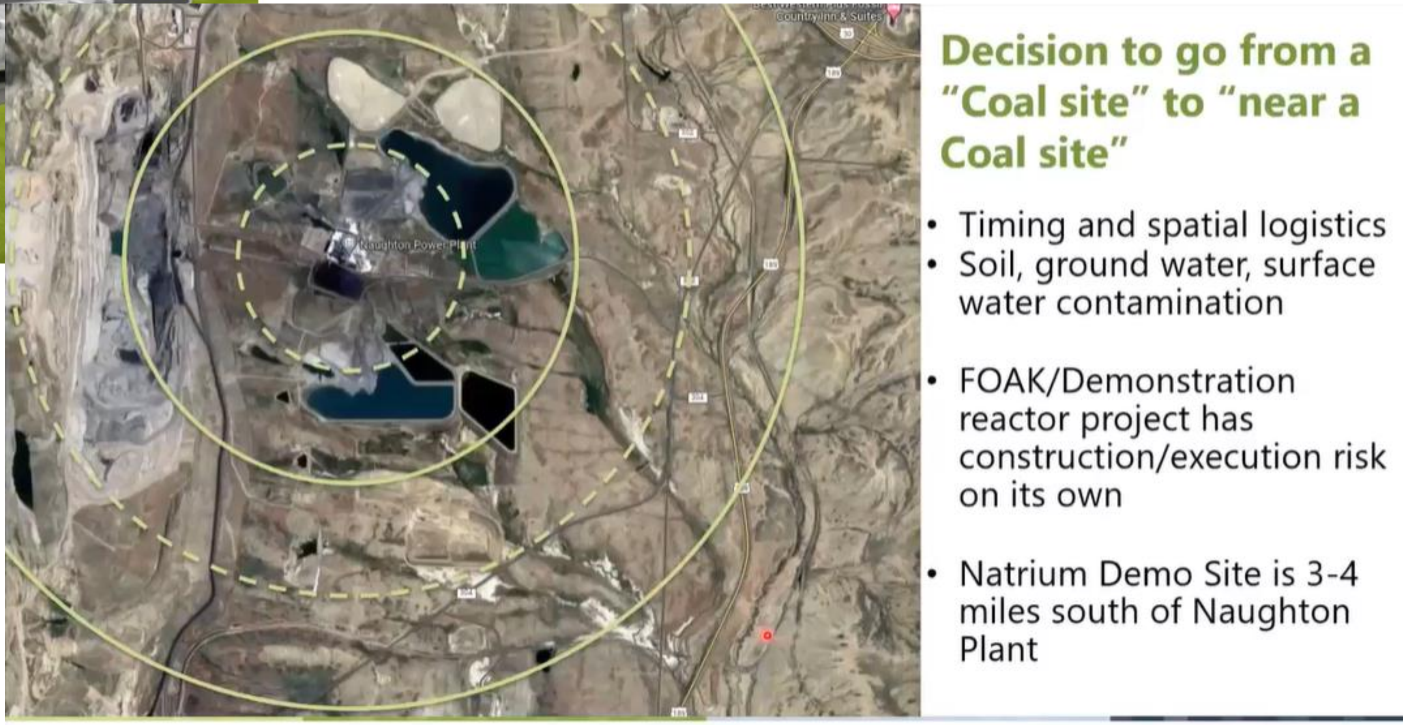
Coal to Nuclear: Different options:



Example of Natrium SMR plant in Wyoming

https://www.energy.gov/ne/articles/next-gen-nuclear-plant-and-jobs-are-coming-wyoming

TerraPower will build its Natrium demonstration reactor at a retiring coal plant in Wyoming.



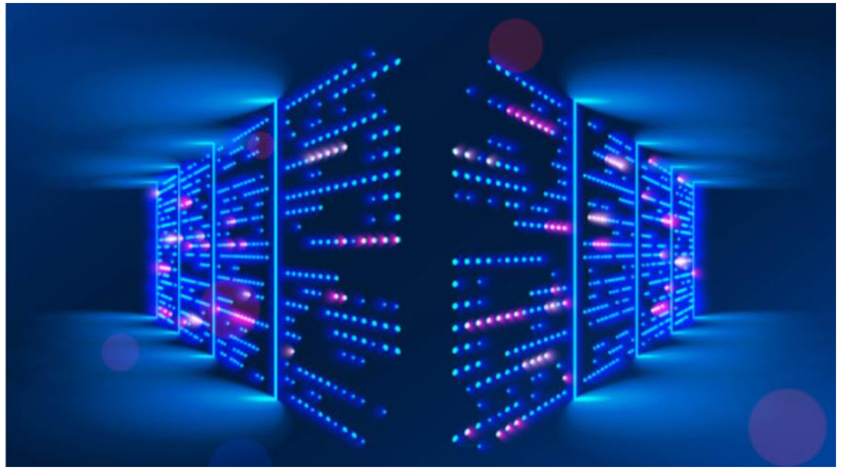
TerraPower

NATRIUM

a TerraPower & GE-Hitachi technology

IAEA / Fossil Fuel Repurpose
5/31/2022

Powering Data centers and AI – and other large energy users



- As electricity consumption by data centres and artificial intelligence companies is expected to **double from 2022 to 2026**, some companies are seeking the next generation of clean energy technologies that can help to meet their goals.
- Technology companies like Microsoft and Google plan to utilise all clean energy technologies to achieve 24/7 carbon free or annual carbon negative targets by 2030 – and are open to using nuclear energy to get there.
- At CERAWeek 2025, **big tech companies and other large energy users supported pledge to triple nuclear by 2050**

At #CERAWeek 2025, industry giants—including Amazon, Google, Meta, Dow, Oxy, Allseas, Fly Green Alliance (FGA) - travel & transport and OSGE—have pledged their support for tripling global nuclear capacity by 2050. This commitment underscores the role of nuclear energy in meeting growing power demands while advancing sustainability and energy security.

Nuclear propulsion for maritime transport?

The International Maritime Organization (IMO) Secretary-General, Arsenio Dominguez, confirmed that nuclear propulsion is being actively considered as a future marine fuel solution within the organisation's Marine Environmental Protection Committee's (MEPC) processes.

According to CorePower, the Secretary-General emphasised that the international organisation maintains a technology-agnostic stance, recognising that different countries will pursue various renewable solutions based on their specific opportunities and capabilities.

> " Nuclear is very much on the table. It's been included in the life cycle assessments for future analysis, "

... the IMO chief stated during a compelling exchange at the 2024 Global Maritime Forum in Japan, where industry leaders discussed the challenges of maritime decarbonisation.

1962-1971, NS Savannah

Russian nuclear ice-breaker (in operation)

7. Takeaways

Takeaways

- Nuclear is back
- Circumstances are different from the 2000s “Nuclear Renaissance”
- Climate urgency
- Increased need for clean electricity, 24/7
- Realization that renewable-only transition might not work – all low Carbon solutions are needed
- Beyond electricity – need for low carbon heat (and hydrogen)
- New technologies (SMRs, advanced reactors, Gen IV)
- Interest from the private sector, including financial communities
- Role of governments remain essential, but the context is favourable to an expansion of nuclear power use


IAEA

EFFICIENTLY COMBINING ELECTRICITY GENERATION SOURCES FOR A FUTURE LOW-CARBON NETWORK

COMBINER EFFICACEMENT LES MOYENS DE PRODUCTION ÉLECTRIQUE POUR UN FUTUR RÉSEAU DÉCARBONÉ

The increasing use of variable and non-dispatchable renewable energies has led to an assessment of the costs of these different generation sources within the electricity system as a whole. Three main conclusions can be drawn for the period to 2050. (1) Due to system effects, despite the continuing decline in the discounted cost of renewable energies, these technologies will not dominate the system, even though the cost of nuclear power will remain higher. (2) Taking climate risk into account has led to the introduction of tools that now exclude fossil fuel generation. (3) To reach a minimum cost, it is necessary to combine renewables with nuclear power, with each of these two families of technologies making up several tens of percent of the system in energy terms.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Patrice Geoffron

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Ma thèse en une page, Anastasia Popiolek
Regards sur l'Allemagne

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