

The Economics of Nuclear Energy today



Dr. Sama Bilbao y Leon
Director General

Seminar
ETSII-UPM Ingenieria Energetica
8 April 2021

A global network of nuclear companies

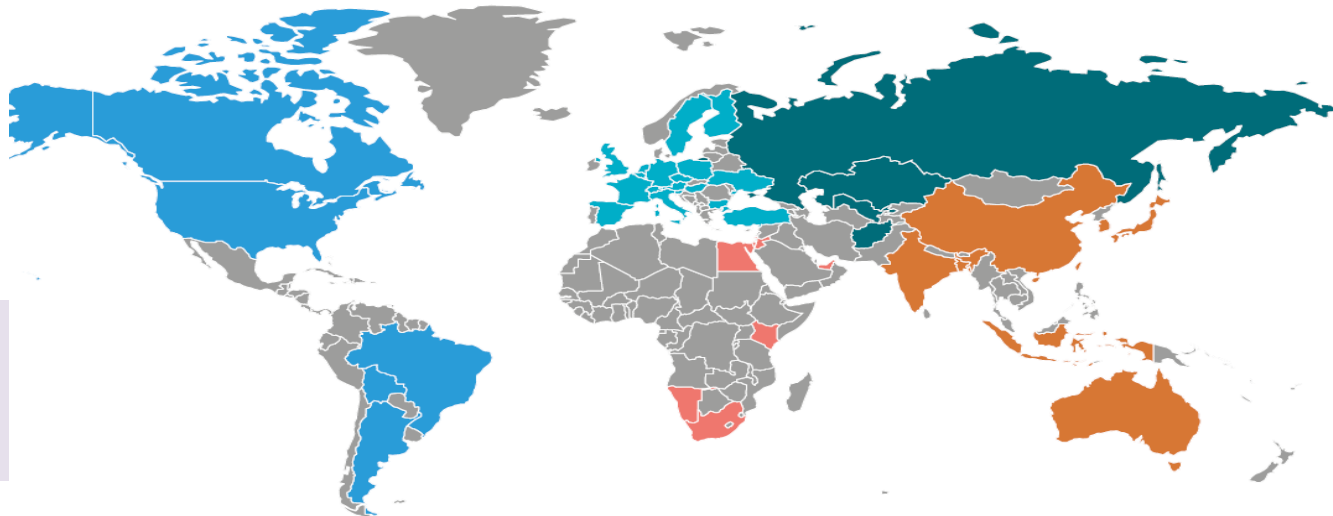
Europe | 62 members

Austria, Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Hungary, Italy, Luxembourg, Netherlands, Poland, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom

Russia and Central Asia | 14 members

Afghanistan, Kazakhstan, Russia, Uzbekistan

WORLD NUCLEAR
ASSOCIATION



Americas | 45 members

Argentina, Bolivia, Brazil, Canada, USA

Africa and Middle East | 10 members

Egypt, Israel, Jordan, Kenya, Namibia, South Africa, United Arab Emirates

Asia-Pacific | 52 members

Australia, Bangladesh, China mainland and Taiwan, India, Indonesia, Japan, Singapore, South Korea

185
members

43
countries

Major reactor vendors - nuclear utility companies - uranium mining, conversion, enrichment, and fuel fabrication companies - nuclear engineering, construction and waste management companies – R&D organizations - transport, law, insurance and finance service companies

World Nuclear Association



We work with industry



We inform and communicate on nuclear energy



We train the leaders of tomorrow



We drive global action towards the Harmony goal

We work with industry

We develop industry positions on the issues that matter through our Members Groups

Working Groups

Fuel Cycle Working Groups

- Fuel Report
- Sustainable Used Fuel Management
- Transport
- International Network for Safety Assurance of Fuel Cycle Industries

Plant Performance Working Groups

- Cooperation in Reactor Design Evaluation & Licensing
- Supply Chain
- Capacity Optimization
- Waste Management & Decommissioning

Cross-Cutting Working Groups

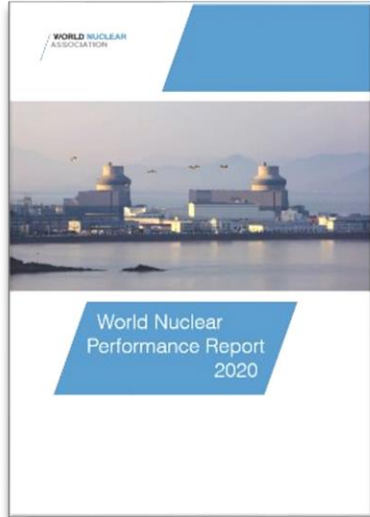
- Radiological Protection
- Law
- Economics
- Security

Advisory Groups

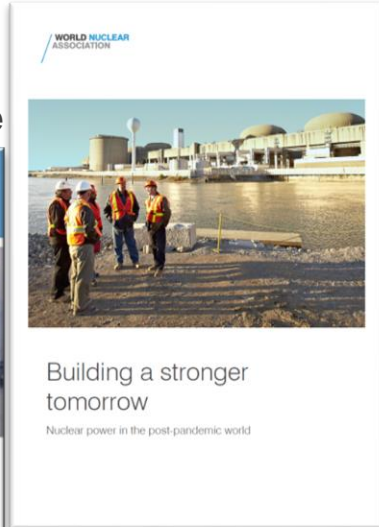
- Advisory Panel
- Communication Group

We produce key publications compiling the state of the art in nuclear energy and its contributions

Nuclear Performance

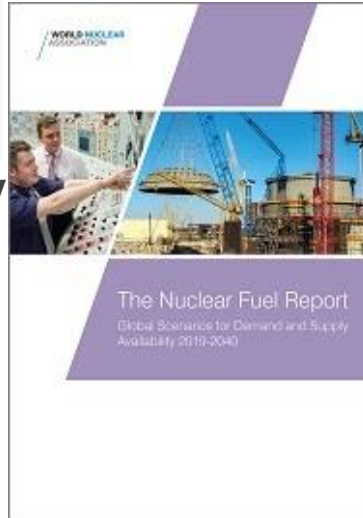


<https://www.world-nuclear.org/our-association/publications/global-trends-reports/world-nuclear-performance-report.aspx>



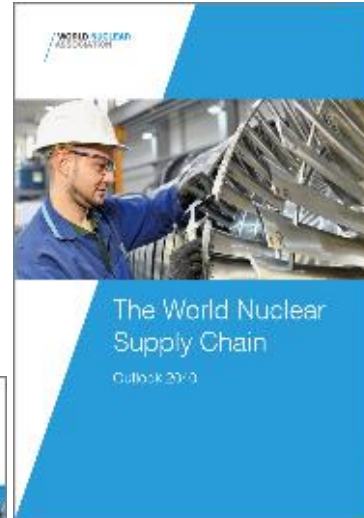
COVID-19 recovery

<https://world-nuclear.org/our-association/publications/policy-papers/building-a-stronger-tomorrow.aspx>



Nuclear Fuel

<https://world-nuclear.org/shop/products/the-nuclear-fuel-report-global-scenarios-for-demand.aspx>



Supply Chain

<https://world-nuclear.org/shop/products/the-world-nuclear-supply-chain-outlook-2040.aspx>



Nuclear jobs

<https://www.world-nuclear.org/our-association/publications/technical-positions/employment-in-the-nuclear-and-wind-electricity-gen.aspx>

We inform on nuclear energy

- Free daily nuclear news service (<https://www.world-nuclear-news.org/>)



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New Nuclear



BWXT and X-Energy selected to develop Project Pele **mobile microreactor**

The Strategic Capabilities Office of the US Department of Defense has selected BWXT Advanced Technologies and X-energy LLC to develop a final design for a prototype mobile microreactor under the



Leningrad II-2 enters commercial operation

The second VVER-1200 reactor at the Leningrad nuclear power plant in western Russia began commercial operation today. Leningrad II-2 is the fourth VVER-1200 in operation in Russia and brings the total number of nuclear power units in the

Most Read

GE Steam Power unveils 'largest last-stage blade ever made'

Canadian government invests in **SMR project**

X-energy formally begins **SMR partnership** with DOE

China launches Iter **tritium breeding project**

GE Hitachi, Fermi Energia extend SMR cooperation

Rosatom targets **24 new reactor units** in Russia by 2045

Rosatom starts building reactor for **Akkuyu unit 3**

Grid connection for **Pakistani Hualong One unit**

We inform on nuclear energy

- Information Library contains 185+ papers continuously updated

Reactor Database

Operable Reactors



394,103 MWe

Share of Global Electricity Generation

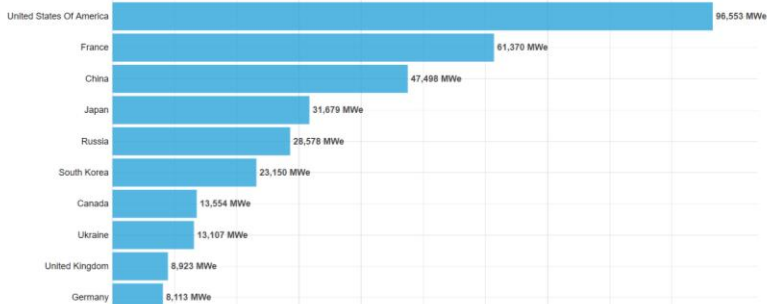


Reactors Under Construction



55,023 MWe

Total Operable Reactor Net Capacity (Top 10)



Home / Information Library

- Facts and Figures
- Nuclear Fuel Cycle
- Non-power Nuclear Applications
- Energy and the Environment
- Country Profiles
- Safety and Security
- Current and Future Generation
- Economic Aspects

Facts and Figures

- World Nuclear Power Reactors and Uranium Requirements
- Nuclear Generation by Country
- Uranium Production Figures
- Heat Values of Various Fuels
- Reactor Database
- Reactor Database Search
- Reactor Database Summary and Guide
- Nuclear Glossary

Country Profiles

- Countries A-F
- Countries G-N
- Countries O-S
- Countries T-Z
- Others

Safety and Security

- Safety of Plants
- Radiation and Health
- Non-Proliferation
- Security

Nuclear Fuel Cycle

- Introduction
- Uranium Resources
- Mining of Uranium
- Conversion Enrichment and Fabrication
- Nuclear Power Reactors
- Fuel Recycling
- Nuclear Waste
- Transport

Energy and the Environment

- 'Clean Coal' Technologies
- Climate Change - The Science
- CO2 Implications of Electricity Generation
- Electric Vehicles
- Energiewende
- Energy Return on Investment
- Environment and Health in Electricity Generation
- Hydrogen Production and Uses
- Nuclear Energy and Sustainable Development
- Policy Responses to Climate Change

Current and Future Generation

- Nuclear Power in the World Today
- Outline History of Nuclear Energy
- World Energy Needs and Nuclear Power
- Accelerator-driven Nuclear Energy
- Cooling Power Plants
- Cooperation in Nuclear Power
- COVID-19 Coronavirus and Nuclear Energy
- Electricity and Energy Storage
- Electricity Transmission Systems
- Fast Neutron Reactors
- International Framework for Nuclear Energy Cooperation
- Lithium
- Molten Salt Reactors
- Nuclear Fusion Power
- Plans For New Reactors Worldwide
- The Nuclear Debate
- Thorium

Economic Aspects

- Economics of Nuclear Power

The World Nuclear University Global Network

Vision:

- a) to develop competencies of the future world class nuclear leaders
- b) a leading global nuclear educational organization developing talents for the advancement of the nuclear science and technology

Mission:

To enhance international education and leadership in the peaceful uses of nuclear energy and the applications of nuclear science and technology, by providing top level training for future world class nuclear leaders



WNU Programmes



Summer Institute



**School on Radiation
Technologies**



**The World Nuclear Industry
Today**



**School of Uranium
Production**



Nuclear Olympiad



**Executive Enhancement
Course**



Nuclear English Course



**SI Alumni Extended
Leadership Development**

WNU Summer Institute

- 2005: Idaho Falls, US
- 2006: Stockholm, Sweden
- 2007: Daejeon, Korea
- 2008: Ottawa, Canada
- 2009 - 2014: Oxford, UK
- 2015: Uppsala, Sweden
- 2016: Ottawa, Canada
- 2017: Uppsala, Sweden
- 2018: Busan and Gyeongju, Korea
- 2019: Romania and Switzerland
- **Next programme: Japan**



We represent the global nuclear industry in key international fora



IAEA

International Atomic Energy Agency

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

ICRP



International
Energy Agency



NEA

NUCLEAR ENERGY AGENCY



UNECE



United Nations
Framework Convention on
Climate Change

**WORLD
ENERGY
COUNCIL**

Collaborative projects

The Association works collaboratively with major international energy organizations, including:

OECD NEA - The role of nuclear energy during COVID-19 and beyond policy briefs

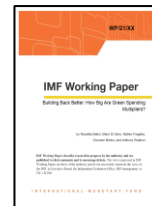
United Nations Economic Commission for Europe (UNECE) - supporting the UNECE Carbon Neutrality Project, with a number of nuclear activities and contributing to range policy briefs, including recent report on The Use of Nuclear Fuel Resource for Sustainable Development Entry Pathways.

World Energy Council - Joint report on The Future of Global Nuclear to 2060

Clean Energy Ministerial NICE Future Initiative – contribution to Breakthroughs: Flexible Nuclear Energy Systems in a Clean Energy World events and report.

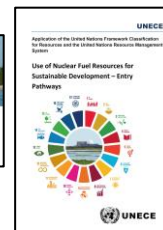
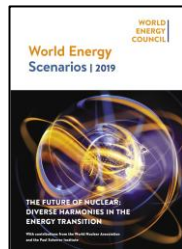
International Monetary Fund (IMF) supporting IMF Working Paper on economic multipliers from energy and other infrastructure developments.

ASEAN Centre for Energy (ACE) supporting capacity building in nuclear energy South East Asia



UNECE

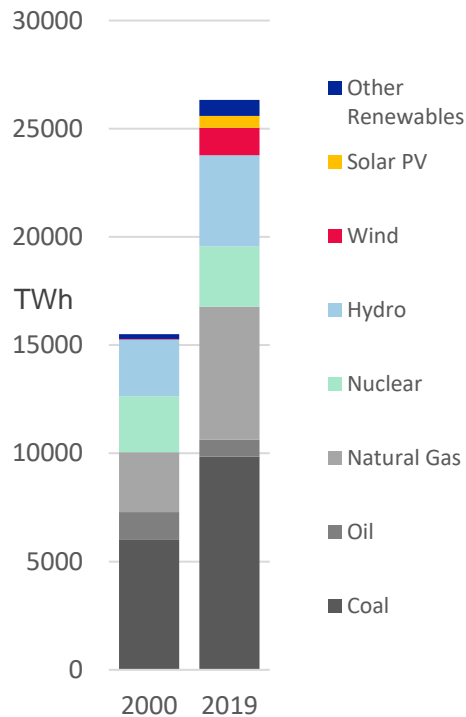
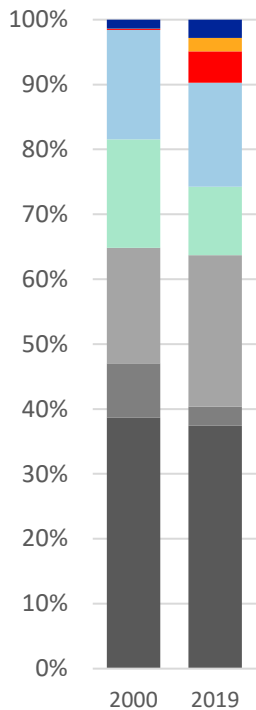
WORLD
ENERGY
COUNCIL



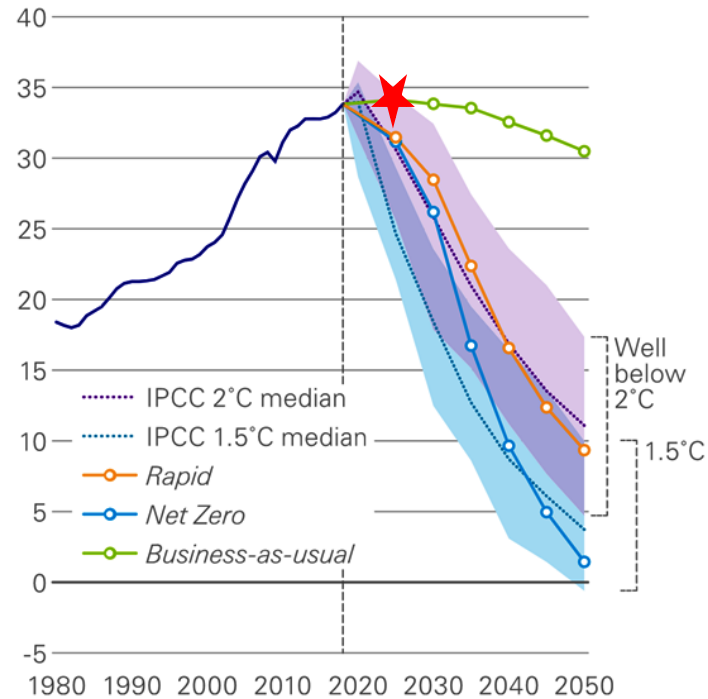
NICE FUTURE
INITIATIVE



Greenhouse gas emissions must decline rapidly



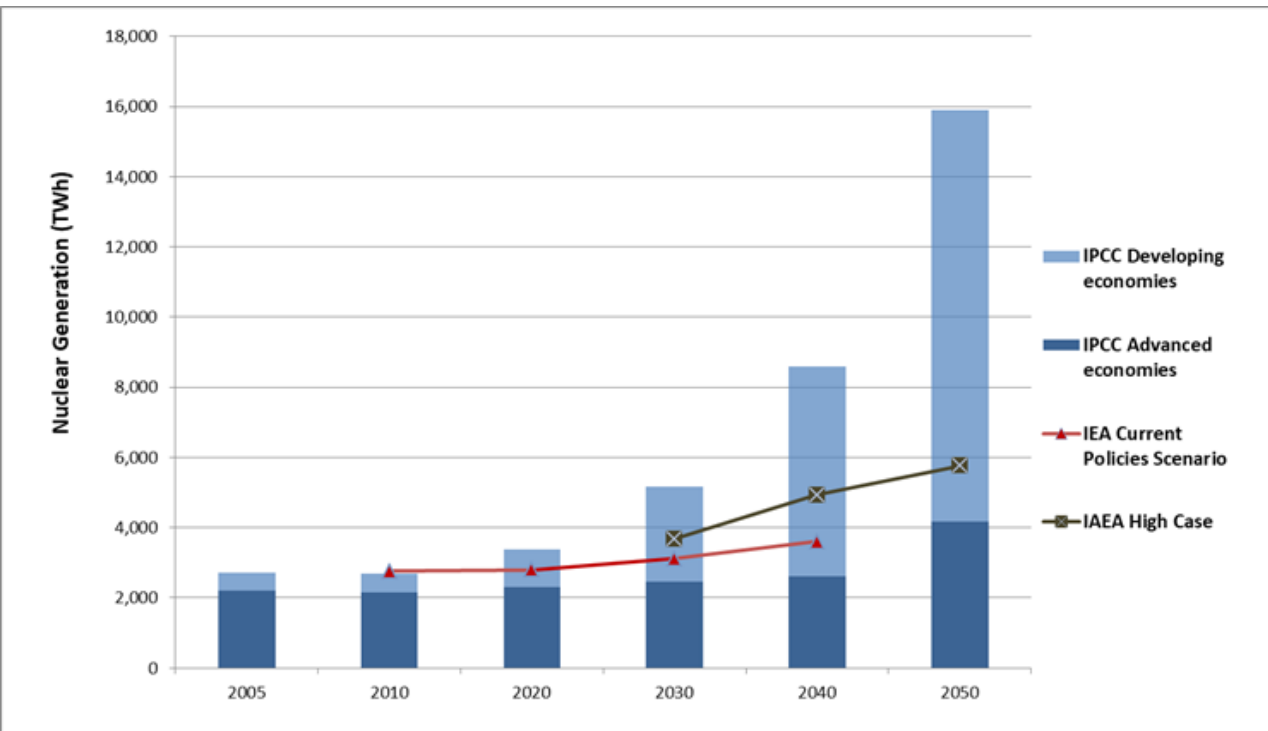
Electricity generation from fossil fuels in 2019 higher than total generation in 2000



CO₂ emissions must decline over next 30 years.

The share of fossil electricity generation has not significantly reduced since 2000

Nuclear energy has an important role to play in decarbonizing electricity

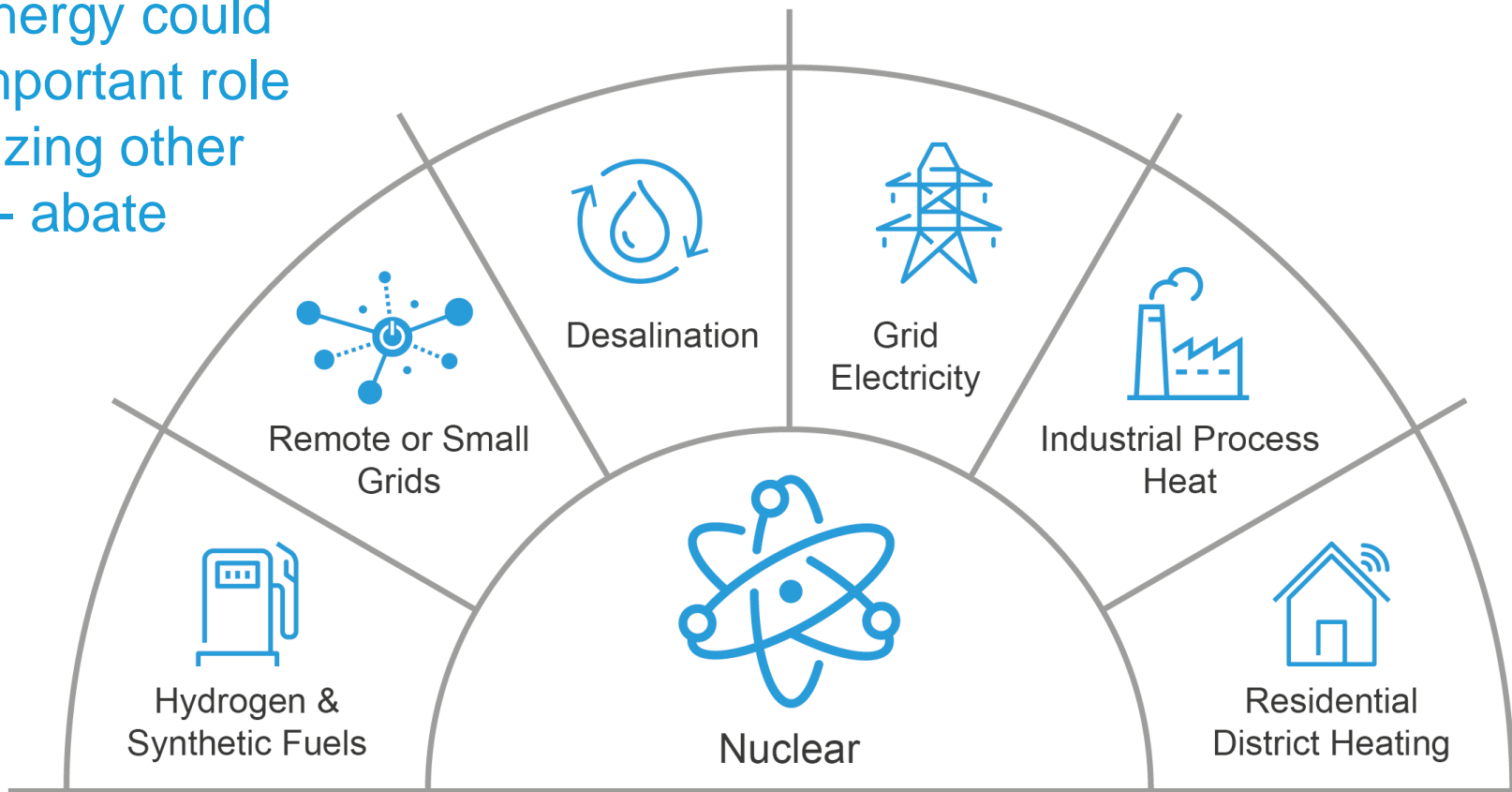


Nuclear energy needs to grow rapidly if we are to satisfy energy demand, achieve climate targets and help the world meet the sustainable development goals.

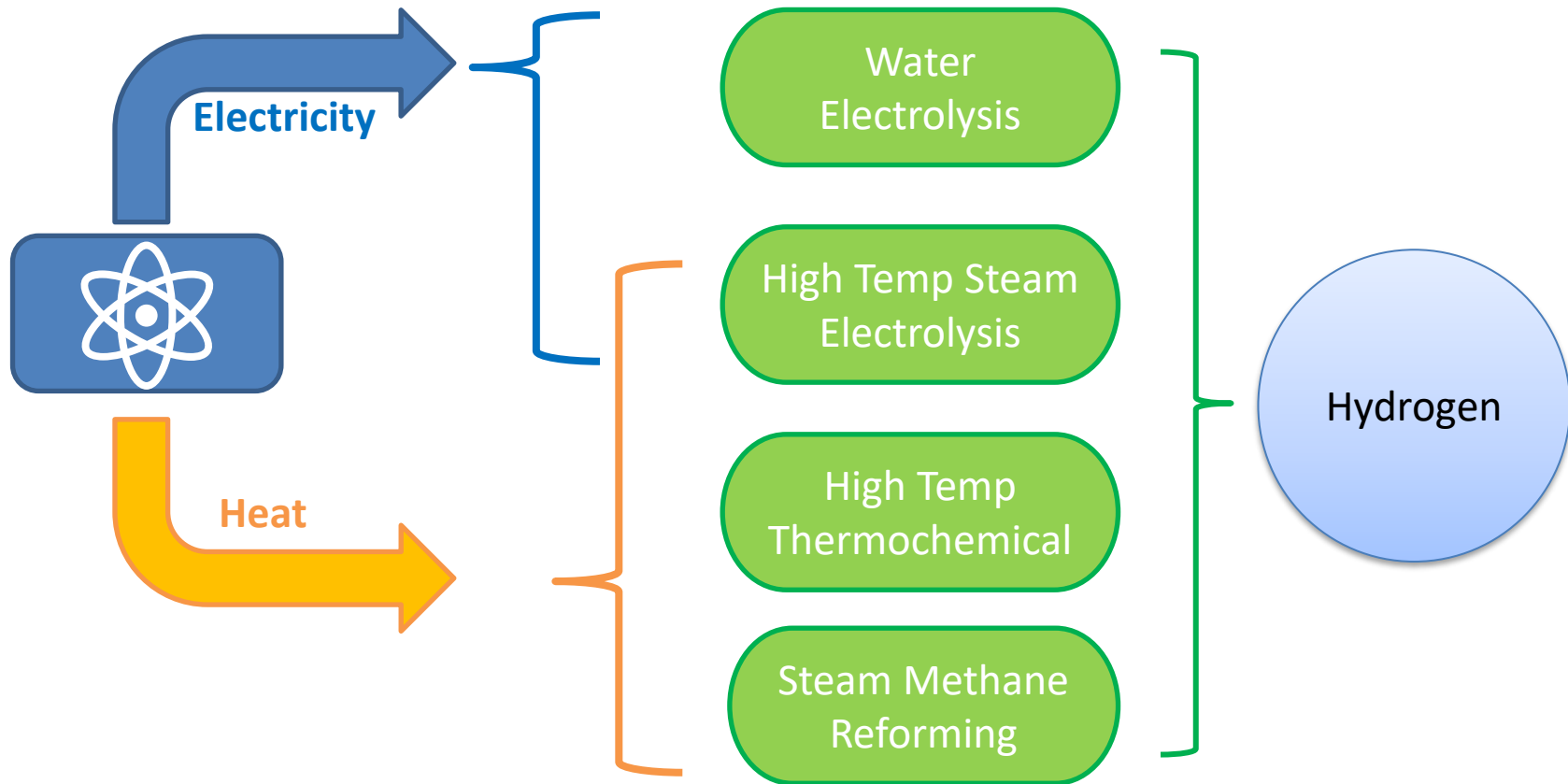
The projections from the IPCC 1.5°C Report “middle of the road” scenario see nuclear energy grow six-fold by 2050, with 2243 GWe capacity, representing 25% of electricity generation

Data Source: IPCC Special report on the impacts of global warming of 1.5 °C, 2018, IEA World Energy Outlook 2019, IAEA Electricity and Nuclear Power Estimates for the Period up to 2050, 2020

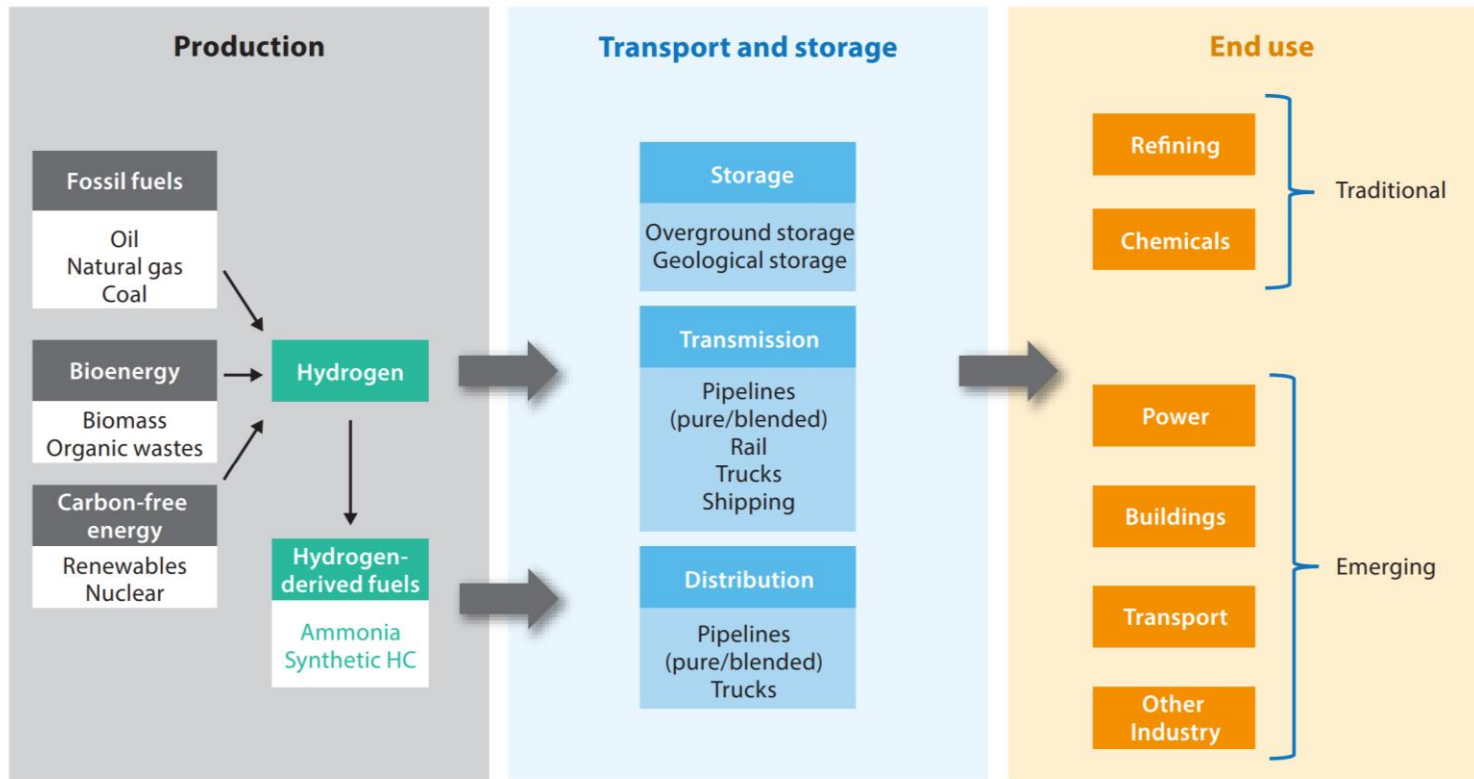
As the only low-carbon source that can produce electricity and heat, nuclear energy could play an important role decarbonizing other difficult-to-abate sectors



Nuclear energy can generate zero-carbon hydrogen



Hydrogen offers new opportunities for wider decarbonization

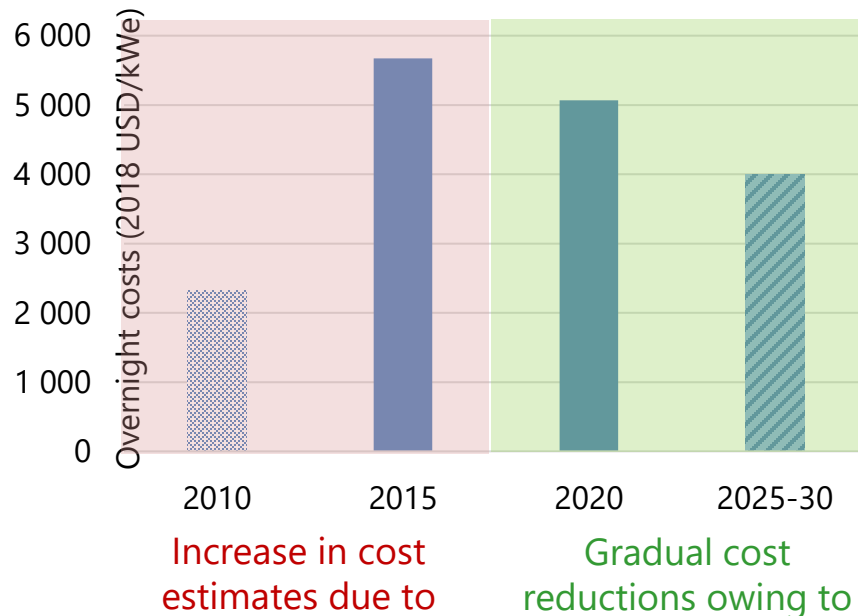


Note: Synthetic HC = synthetic hydrocarbons.

Recent FOAK Gen-III projects don't tell a good story about nuclear

- Gen-III initial costs estimates driven by **low level of design maturity** and the **specific political context** of announced budgets
- Recent trend in projected costs reflects **increased design maturity** and **lessons learned** for post-FOAK projects
- Gap between two sets of projections has impacted overall **perceived investment risks** and has potential to impact **public acceptance**

Capital Costs in Western FOAK



Notes: 2010, 2015 and 2020 OECD average overnight construction cost data based on 2005, 2010, 2015 and 2020 NEA/IEA Projected Cost of Generating Electricity reports, adjusted for USD inflation using OECD statistics.

Source OECD/NEA, 2020 https://www.oecd-nea.org/jcms/61082_Media/unlocking-reductions-in-the-construction-costs-of-nuclear-a-practical-guide-for-stakeholders

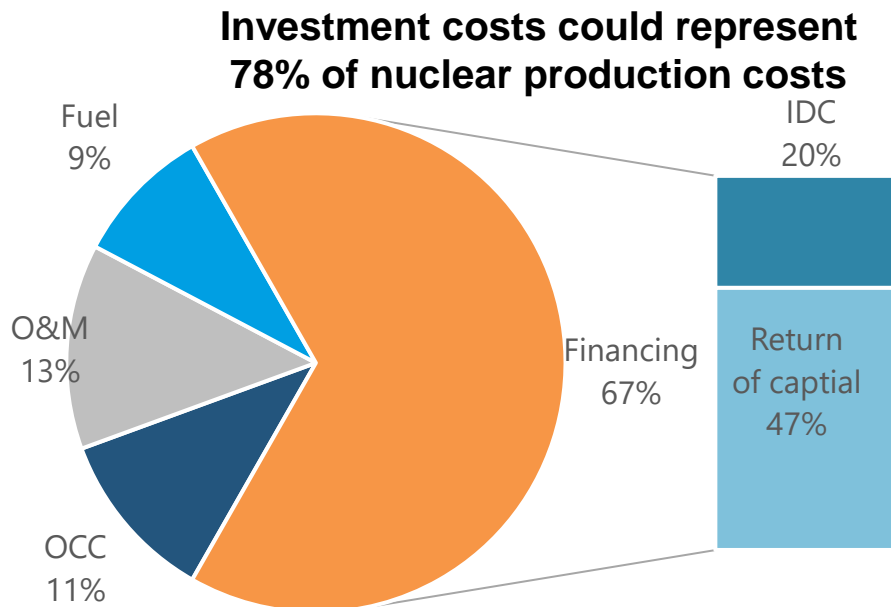
https://www.oecd-nea.org/jcms/pl_51110/projected-costs-of-generating-electricity-2020-edition

Nuclear energy projects are misaligned with traditional sources of capital

Nuclear power plant construction is a complex infrastructure undertaking that can present significant financial risks

- capital-intensive
- multi-decadal project lifetimes

Loss of confidence due to delays and cost overruns in some recent Western FOAK projects

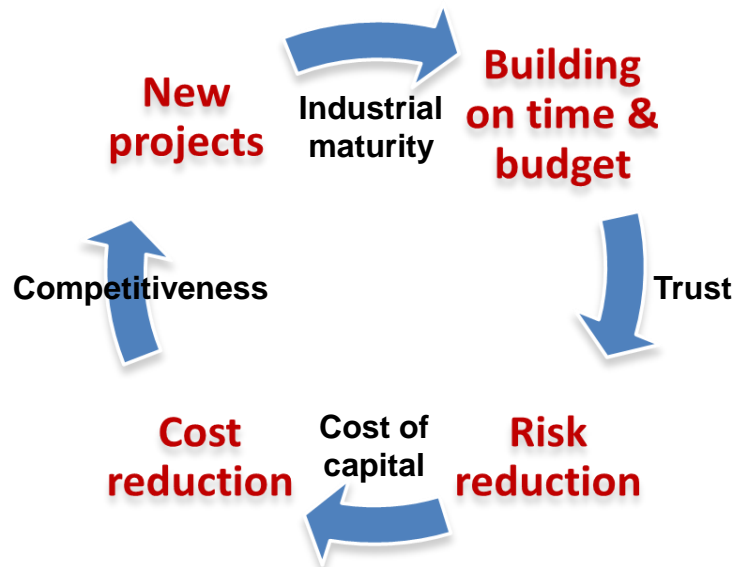


Source: NEA, 2020

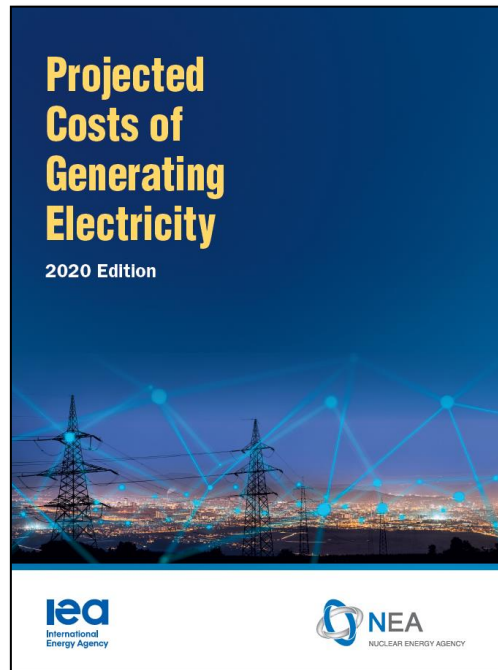
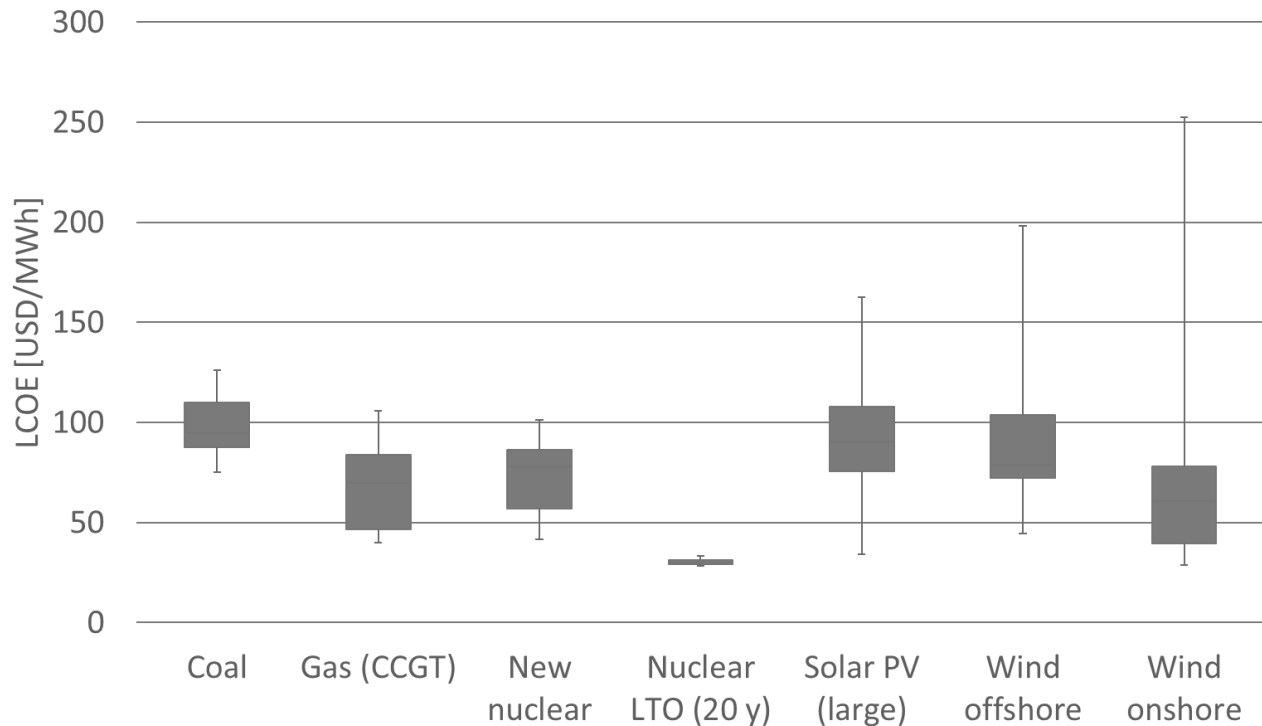
Note: Calculations based on OCC of USD 4 500 per kilowatt of electrical capacity (/kW_e), a load factor of 85%, 60-year lifetime and 7-year construction time at a real discount rate of 9%.

Government support needed to instil confidence and incentivise long term planning and investment

Direct Financial support	Indirect financial support	
	Power purchasing agreements	Regulated assets
Equity, debt, ECAs, loan guarantee	Contract-for-difference (UK), Mankala model (Finland)	Rate-of-return (US), Regulated Asset Base (UK)
Equity stake can be transitional as additional sources of financing should become available once the plant is operational	PPAs focus on market risks but often do not address explicitly construction risks, which impacts risk premium	Specific conditions can be specified for the allocation of certain risks (e.g. cost sharing and cap with hybrid RAB model)



Nuclear LTO and new nuclear are competitive low-carbon solutions in OECD countries



Source: IEA/NEA 2020 with cost of capital of 7% and CO2 price @ 30 USD/tCO2
https://www.oecd-nea.org/jcms/pl_51110/projected-costs-of-generating-electricity-2020-edition

There is a lot of excitement about SMR development globally



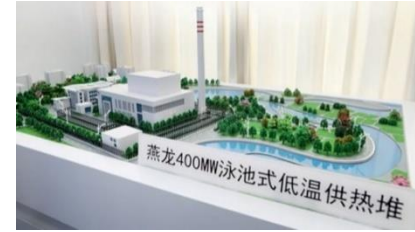
Carem 25, Argentina
25 MWe PWR
Under Construction



IMSR, Canada, US, UK
190 MWe Molten Salt
Under Development



HTR-PM, China
2x110 MWe HTGR
Under Commissioning



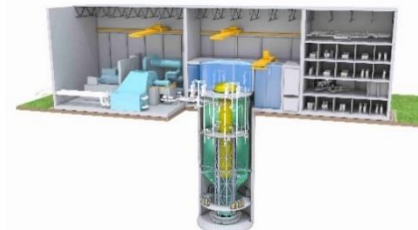
Yanlong DHR, China
400 MWth Pool
Under Development



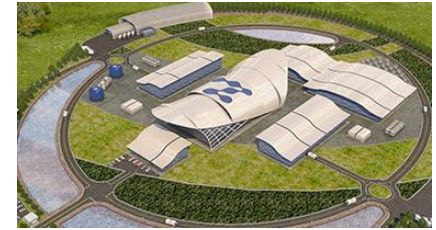
Seaborg, Denmark
250 MWth MSR
Under Development



SMART, South Korea
100 MWe PWR
Design Licensed



BWRX300, US
300 MWe BWR
Under Review



NuScale, US
77 MWe PWR
Design Licensed

SMRs may be a game-changer for nuclear energy

More Affordable: Business Model

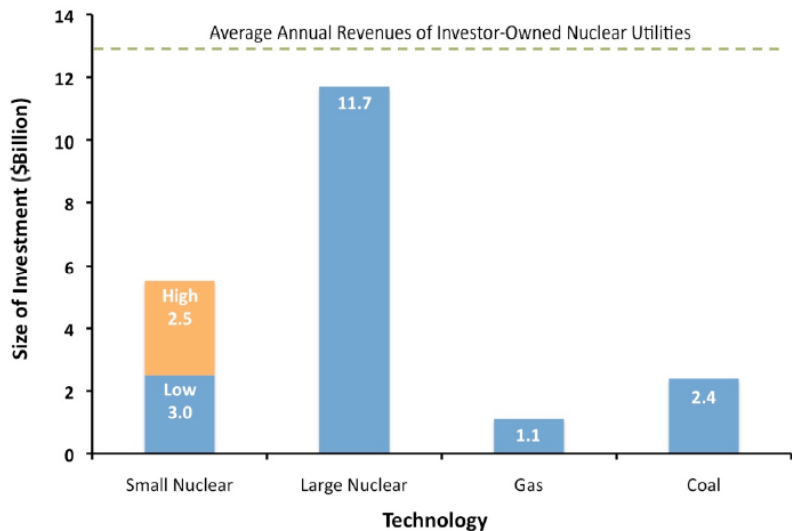


FIGURE 1 Comparison of Size of Investment (i.e., Overnight Cost) with Average Annual Revenues of Investor-Owned Nuclear Utilities¹⁷

Less Risky: Financing

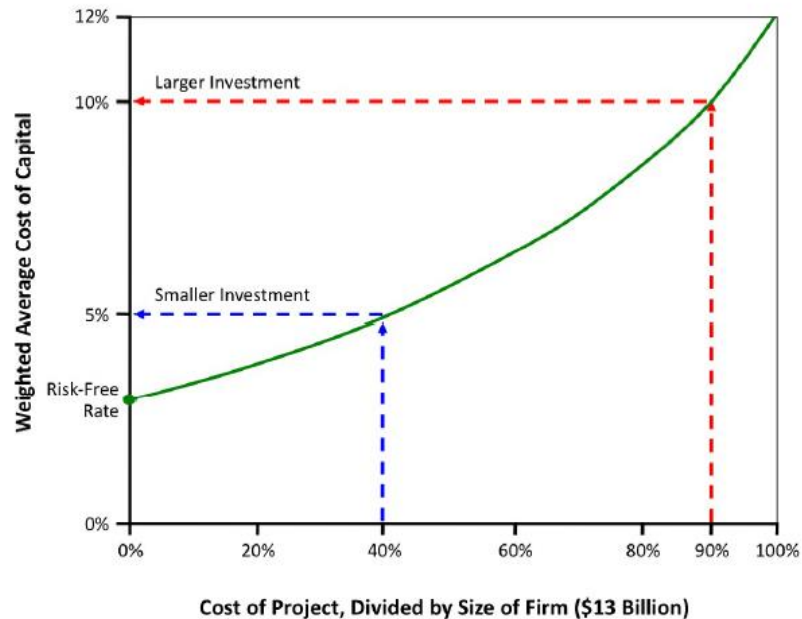
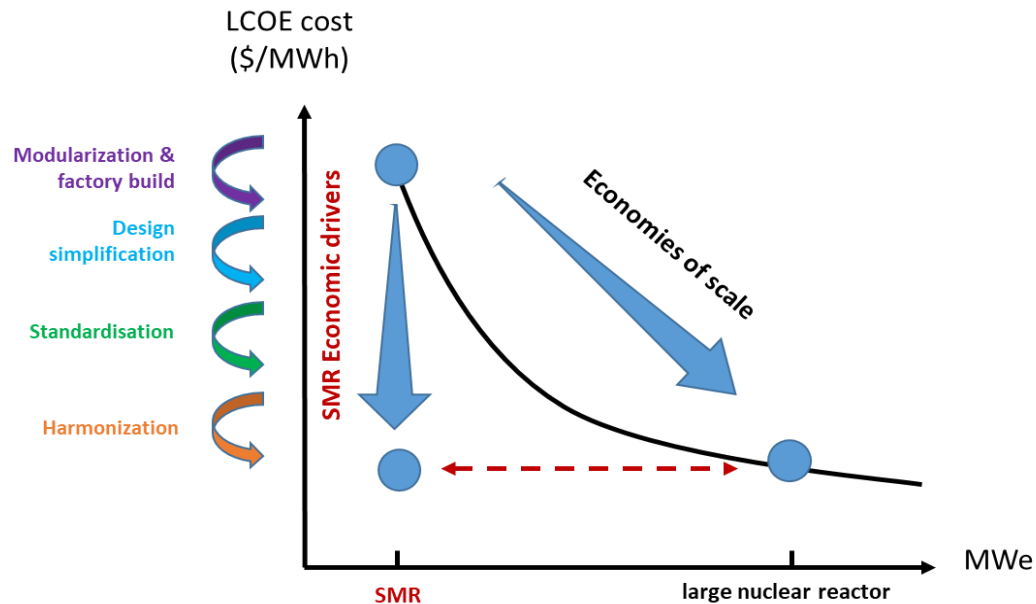


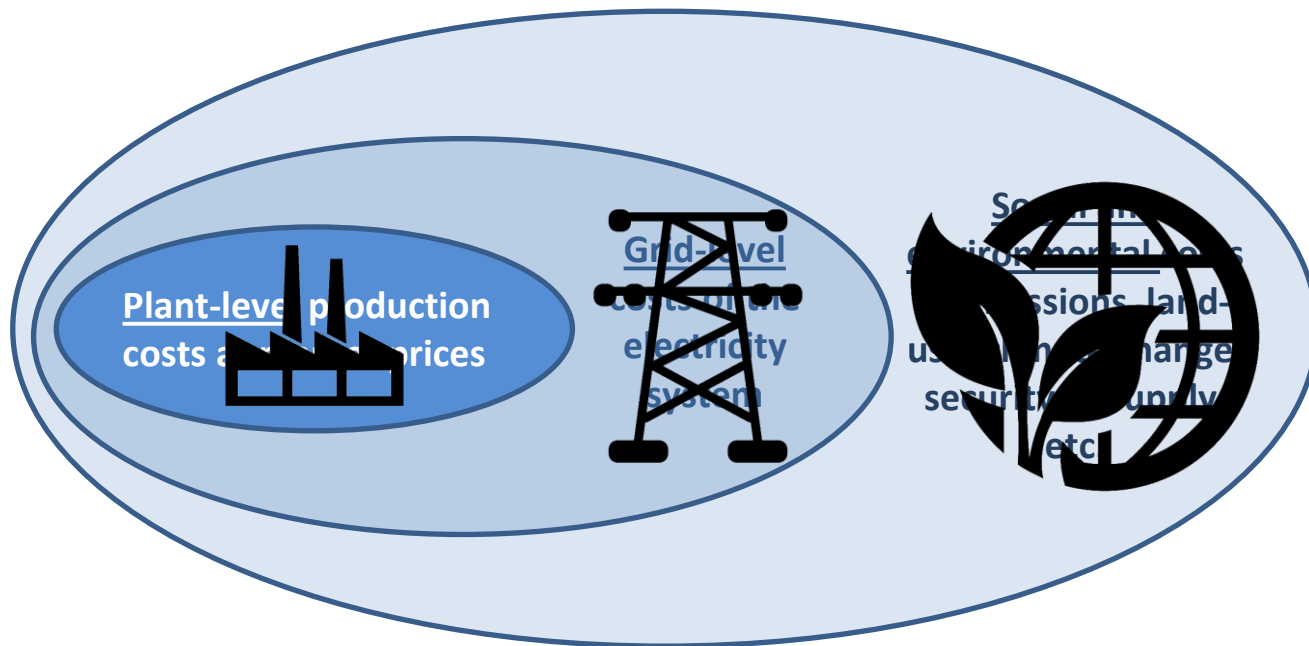
FIGURE F.1 Firm's Investment in Nuclear Reactor Project for SMRs and GW-LWRs⁸²

There are still some challenges for the global deployment of SMRs

- Technology choice
- Role of demonstration project
- Streamlining of International licensing
- Supply chain consolidation
- Public / private partnerships



In current electricity systems LCOE is not enough to measure the cost of electricity



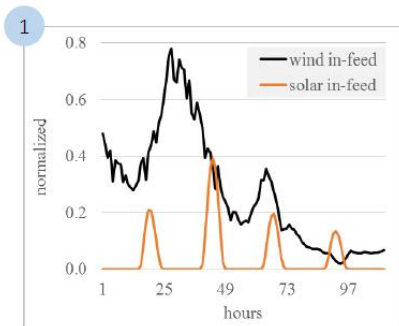
Source: OECD/NEA, 2019 https://www.oecd-nea.org/jcms/pl_15000/the-costs-of-decarbonisation-system-costs-with-high-shares-of-nuclear-and-renewables

OECD/NEA, 2018 https://www.oecd-nea.org/jcms/pl_14998/the-full-costs-of-electricity-provision

IEA/NEA, 2020 https://www.oecd-nea.org/jcms/pl_51110/projected-costs-of-generating-electricity-2020-edition

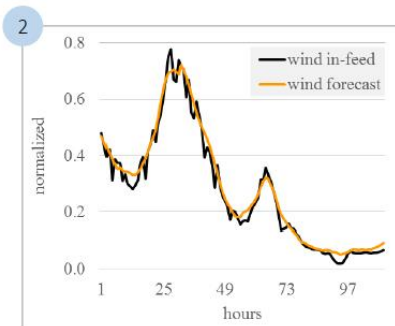
True Costs of Electricity currently do not account for system costs

- Total system costs are the sum of plant-level generation costs and grid-level system costs
- System costs are mainly due to characteristics intrinsic to variable generation



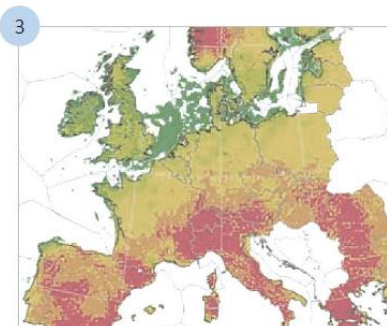
VREs are not always available

Profile costs
(Changing mix)



VREs are difficult to predict

Balancing costs
(Short-term variations)



Good VRE sites are distant from load centers

Transmission and distribution costs

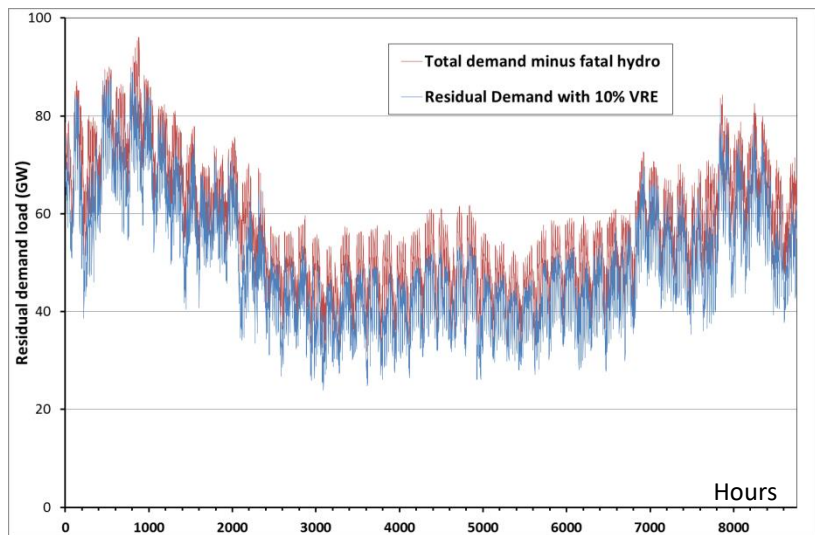
System costs depend on:

- Local & regional factors and the existing mix
- VRE penetration and load profiles
- Flexibility resources (hydro, storage, interconnections)

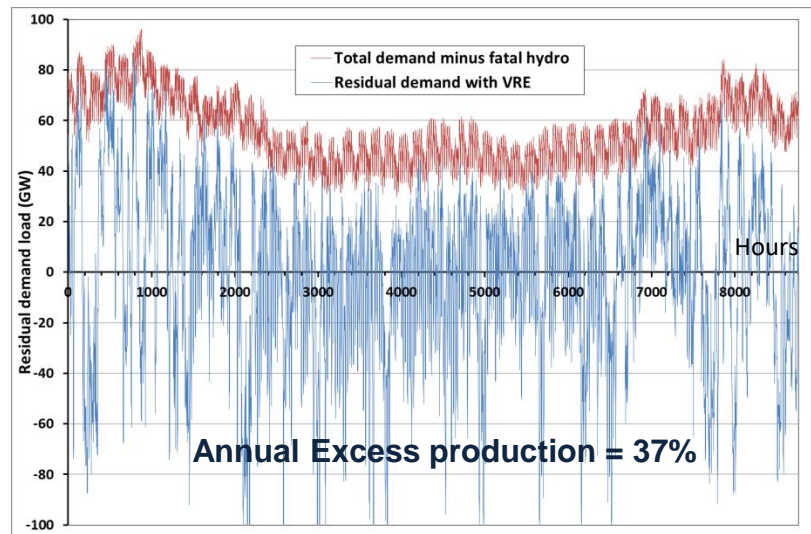
Additional impacts on load factors of dispatchable generators and prices.

High penetration of variable generation results in large system Inefficiencies

10% Variable Renewables



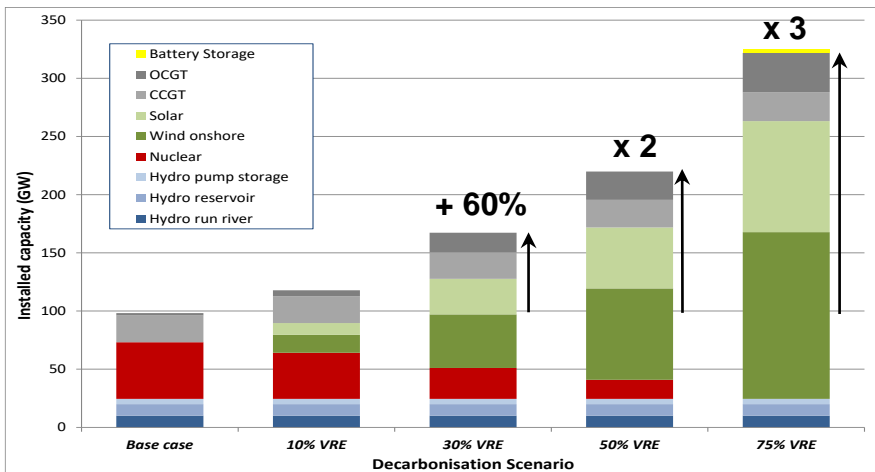
75% Variable Renewables



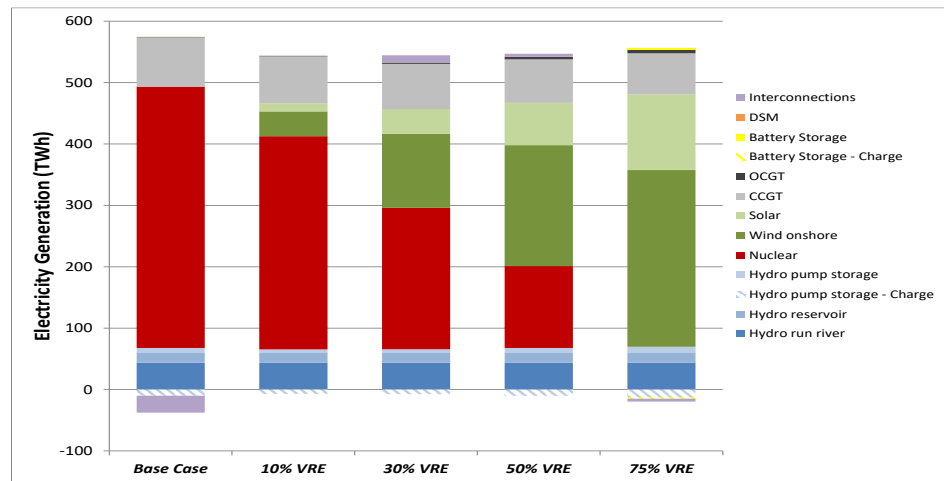
- High VRE penetration result in challenges for system management.
- Residual demand (**BLUE** line) – the available market for dispatchable generation becomes volatile and unpredictable.

Systems with high penetration of variable generation require large excess capacity to meet same demand

Installed Capacity



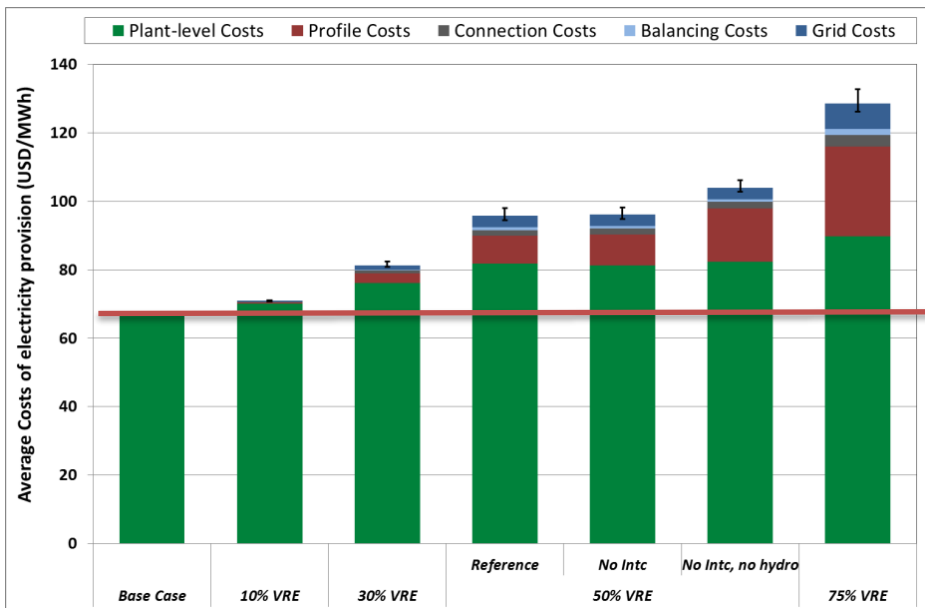
Electricity Generation



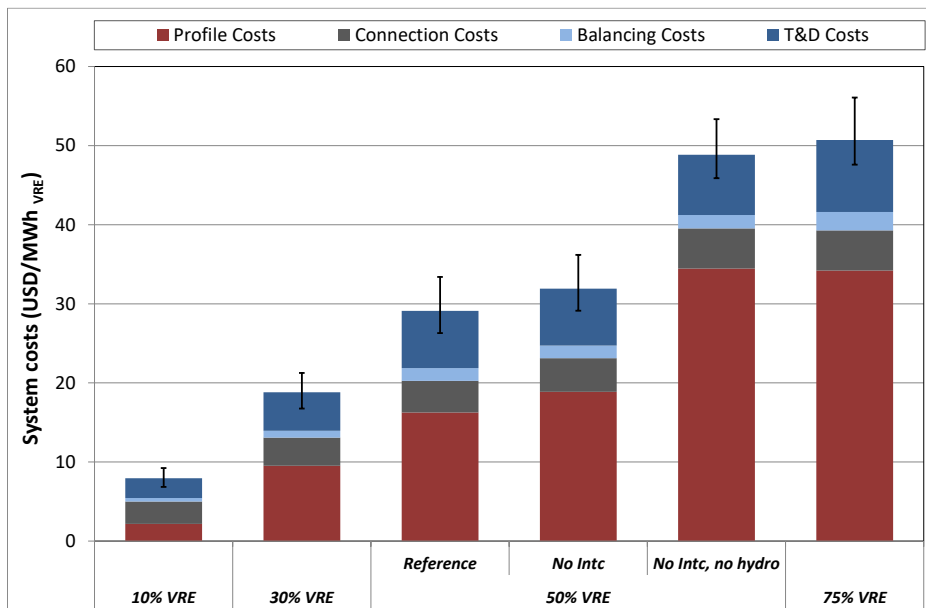
- Rising VRE share results in significantly larger capacity needs.
- Due to carbon constraint, coal no longer included, but gas provides flexibility. Battery storage deployed only at high VRE penetration levels.

Nuclear energy can contribute to least cost solutions for the low carbon energy systems of the future

Total System Costs



Added Costs per MWh of VRE



Long Term Operation (LTO) of the existing nuclear fleet will be important in the near term



- Most cost-effective decarbonisation tool
- Shovel-ready jobs able to contribute to post-COVID economic recovery and beyond.
- Preserves know-how.
- Technology & socio-economic spill-overs in local and national economies.

New nuclear projects needed to maintain long term clean electricity goals and sustained economic development

- New build economic multiplier effect brings enhanced benefits from initial investment.
- The development of nuclear power has historically proven to be a catalyst for industrial and economic growth and prosperity across the world.
- Promotes energy independence and security of supply, and builds resilience against geopolitical shocks.



Shinjoh 1&2, with Shinjoh under construction 3 in foreground (Kyodo)

World Nuclear Association calls upon policymakers to:

- Support nuclear **LTO** as a near-term cost-effective measure for decarbonization
- Fast-track the deployment of **large-scale reactors**, to meet the increasing demand for clean and reliable electricity and fulfil climate change commitments.
- Accelerate the development and commercialization of **SMRs**.
- Prioritize the **streamlining** of international reactor design licensing.
- Actively explore the application of nuclear technologies in applications such as industrial **heat** and the production of green **hydrogen**.
- Incentivize **investment** and facilitate the appropriate frameworks to unlock low-cost finance for nuclear projects: LTO and new build
- Work closely with multilateral banks in order to find ways to ensure that the growing need for electricity in **developing countries** can be met with nuclear solutions.

WORLD NUCLEAR ASSOCIATION

The Harmony programme is a global initiative of the nuclear industry coordinated by World Nuclear Association.



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