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2016-2022

EDUCATION
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GEN IV International Forum
Expertise | Collaboration | Excellence

Role of Nuclear Energy in Reducing CO_2 Emissions

Your presenters:
Dr. Shannon Bragg-Sitton, INL
Mr. Huang Wei, IAEA
Ms Diane Cameron, NEA

Your moderators:
Dr. Patricia Paviet, PNNL
Dr. Tatjana Jevremovic, IAEA

April 19, 2022

Our Moderators for this Special Webinar Event

Dr. Patricia Paviet is the Group Leader of the Radiological Materials Group, at the Pacific Northwest National Laboratory and National Technical Director of the Molten Salt Reactor Program on behalf of the US Department of Energy, Office of Nuclear Energy. She is currently Chair of the Generation IV International Forum, Education and Training Working Group.

Dr. Tatjana Jevremovic is Team Leader and Project Manager for Water Cooled Reactor Technology Development at the International Atomic Energy Agency (IAEA), and Technical Selection Committee Chair for the IAEA Marie Sklodowska-Curie Fellowship Programme. Highlights of her eminent career: project director and chief engineer in Europe and Japanese nuclear industry, university professor in Japan and USA, director of the university research reactor in USA, over 300 scientific papers and technical reports.

Ms. Diane Cameron is the Head of the Nuclear Technology Development and Economics Division in the Nuclear Energy Agency (NEA). She has a distinguished career in the Canadian government and served as Director of the Nuclear Energy Division at Natural Resources Canada (2014 to 2021). As Director, she headed up the division responsible for leading and coordinating Canadian public policy on nuclear energy. She was one of Canada's Generation IV International Forum Policy Group members.

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MEETING CLIMATE CHANGE TARGETS:

THE ROLE OF NUCLEAR ENERGY

Diane Cameron
Head of Division
Nuclear Technology Development and Economics

Presentation to the Generation IV International forum (GIF)
2022

Outline

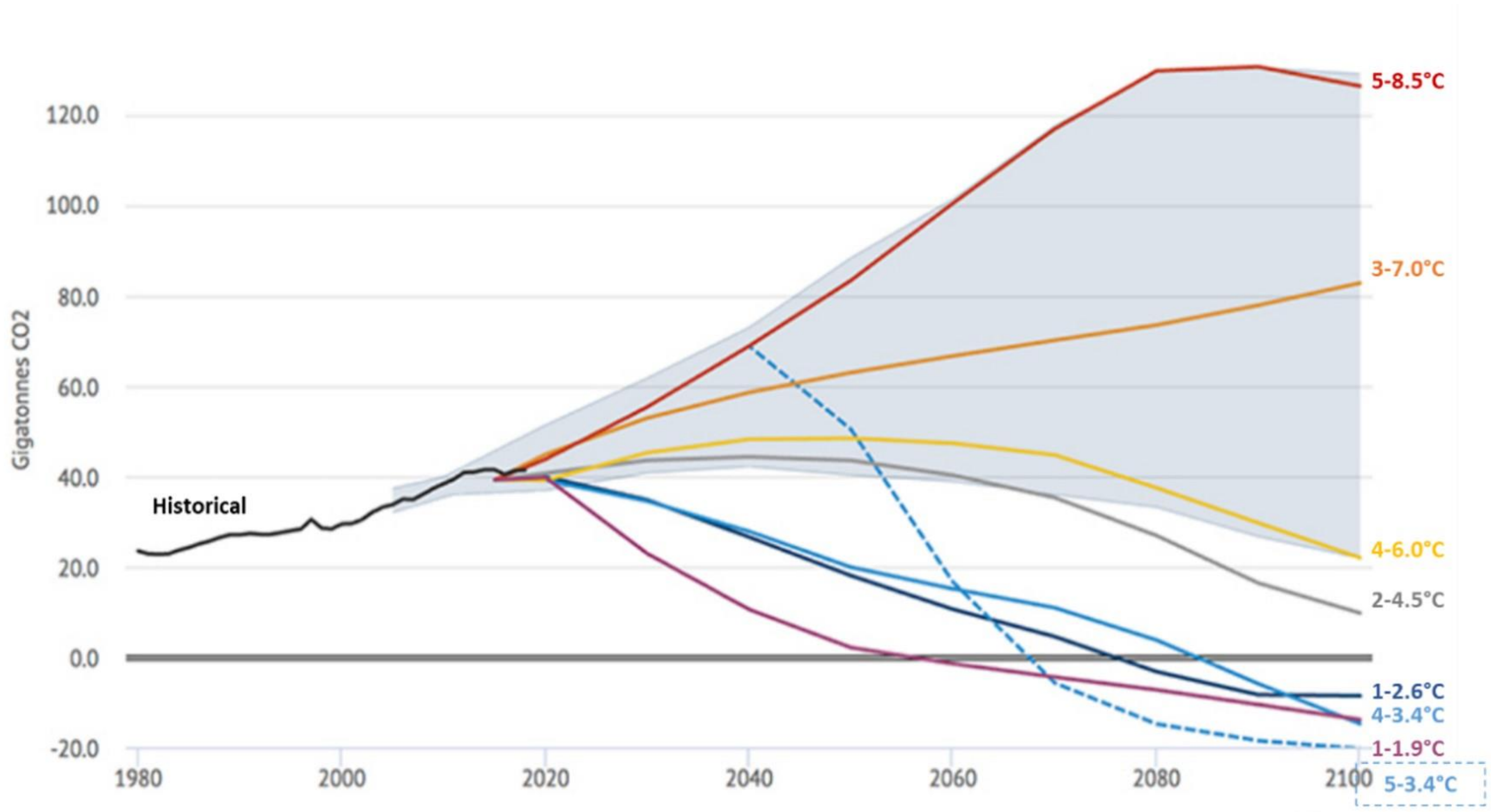
1. **Context**
   - Global action is urgently needed
   - Pathways to net zero emissions
2. **The Role of Nuclear Energy**
   - The future of nuclear energy systems
   - The full potential of nuclear contributions to net zero
3. **Opportunities and Challenges**
4. **Conditions for Success**

1. Context

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
- None of the published pathways project aspirational scenarios for nuclear innovation
- 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 (2021c)	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%

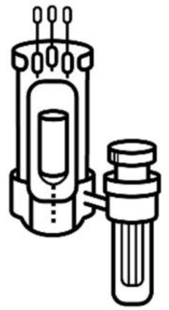
All pathways require global installed nuclear capacity to grow significantly, often more than doubling by 2050.

2. The Role of Nuclear Energy

The Full Potential of Nuclear Energy to Contribute to Emissions Reductions

Long Term Operation

Gen-III Reactors



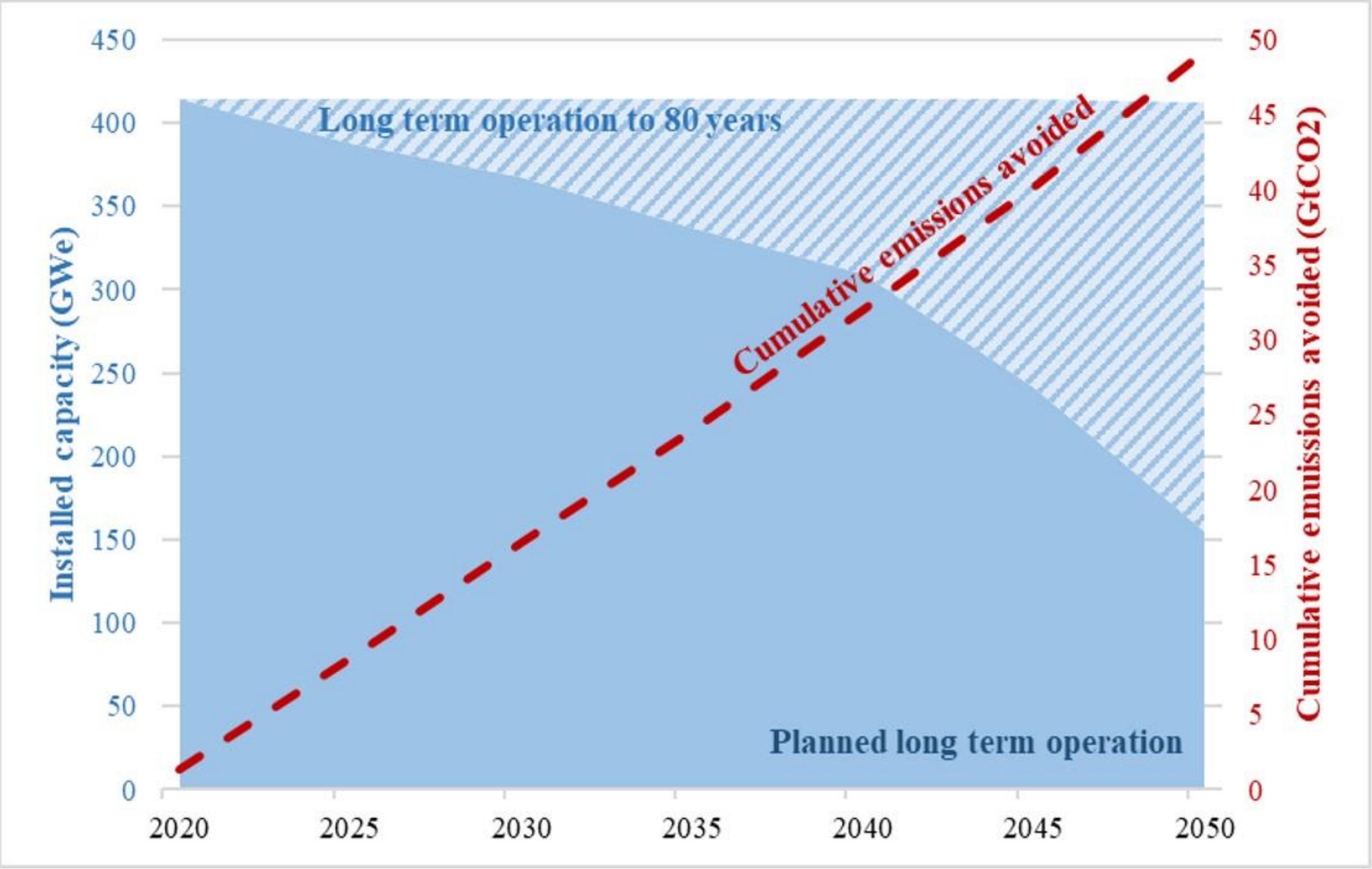
Small Modular Reactors

Non-Electrical applications

Long-term Operation

- Presently, the average age of nuclear power plants in OECD countries is 36 years
- The technical potential exists in most cases for long-term operation for several more decades
- Long-term operation is one of the most cost-competitive sources of low-carbon electricity
- Beyond technical feasibility, adequate policy and market are key conditions of success of long-term operation
- Long-term operation could save up to 49 gigatonnes of cumulative emissions between 2020 and 2050

Installed Capacity And Cumulative Emissions Avoided

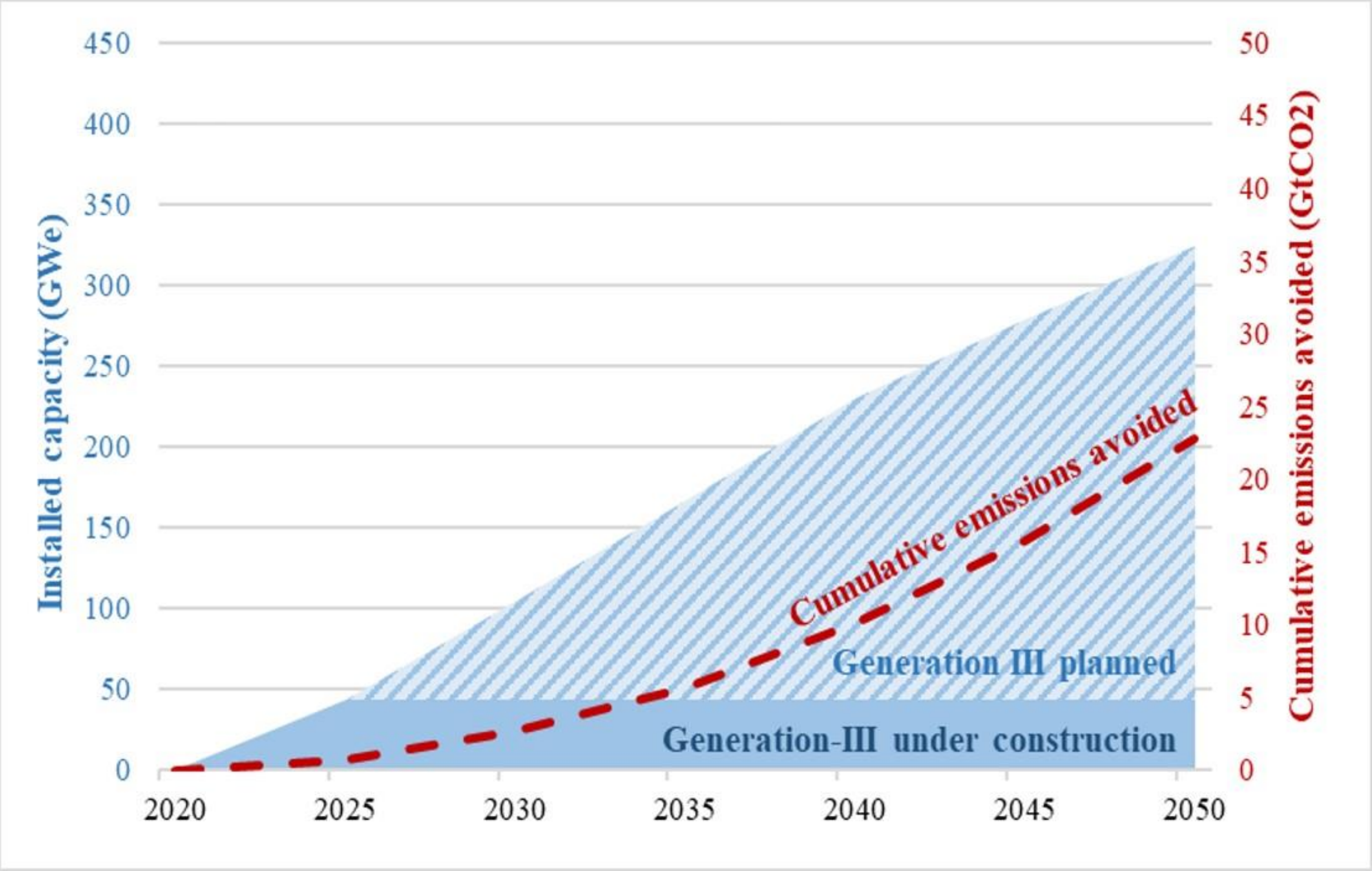


Source: NEA (forthcoming).

New builds of large Generation III nuclear technologies

- At the end of 2020, 55 gigawatts of new nuclear capacity in the form of large-scale Generation III reactors were under construction around the world driven largely by new builds outside the current OECD membership
- Taken together, large-scale Generation III reactors that are under construction and planned are expected to reach over 300 gigawatts of installed capacity by 2050, avoiding 23 gigatonnes of cumulative carbon emissions between 2020 and 2050

Installed Capacity And Cumulative Emissions Avoided



Source: NEA (forthcoming).

What is a Small Modular Reactor?

DEFINITION

SMALL
- Smaller output
- Small physical size
- 1-300 MWe

MODULAR
- Factory Production
- Portable
- Scalable

REACTOR
- Nuclear Fission
- Heat
- Electricity

BENEFITS

SIMPLIFIED SAFETY
- Lessons learned from 60 years of operations

FLEXIBILITY
- Adapted to back up variable renewables

APPLICATIONS

ON-GRID
- 200-300 MWe
- Off coal

MERCHANT SHIPPING
- Marine Production
- Off bunker fuel

OFF-GRID
- Remote sites
- Off diesel

HEAT
- 285 – 850 °C
- Industrial cogeneration

Small Modular Reactors – Ranges of Sizes and Temperatures

POWER

- SMRs vary in size from 1 to 300 megawatts electric

TEMPERATURE

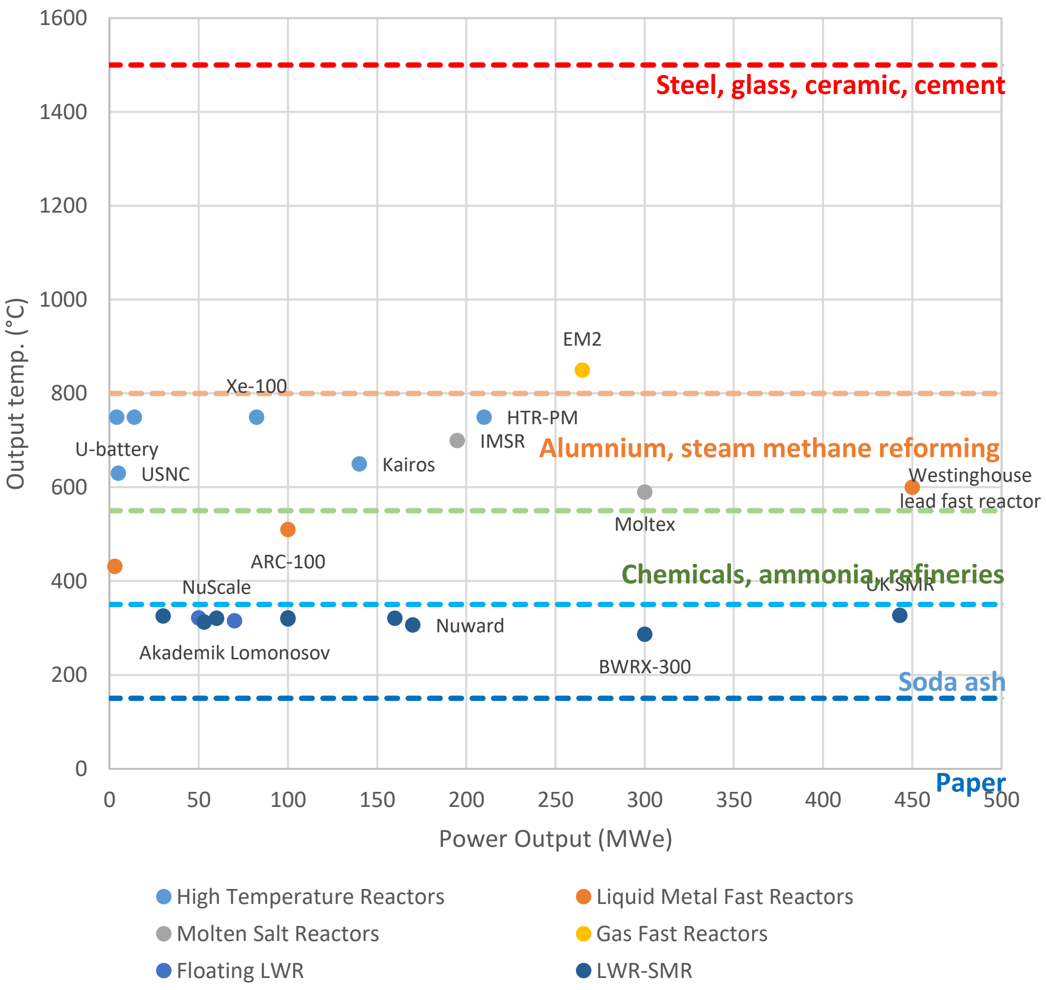
- From 285°C to 850°C in the near-term and up to or over 1,000°C in the future

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

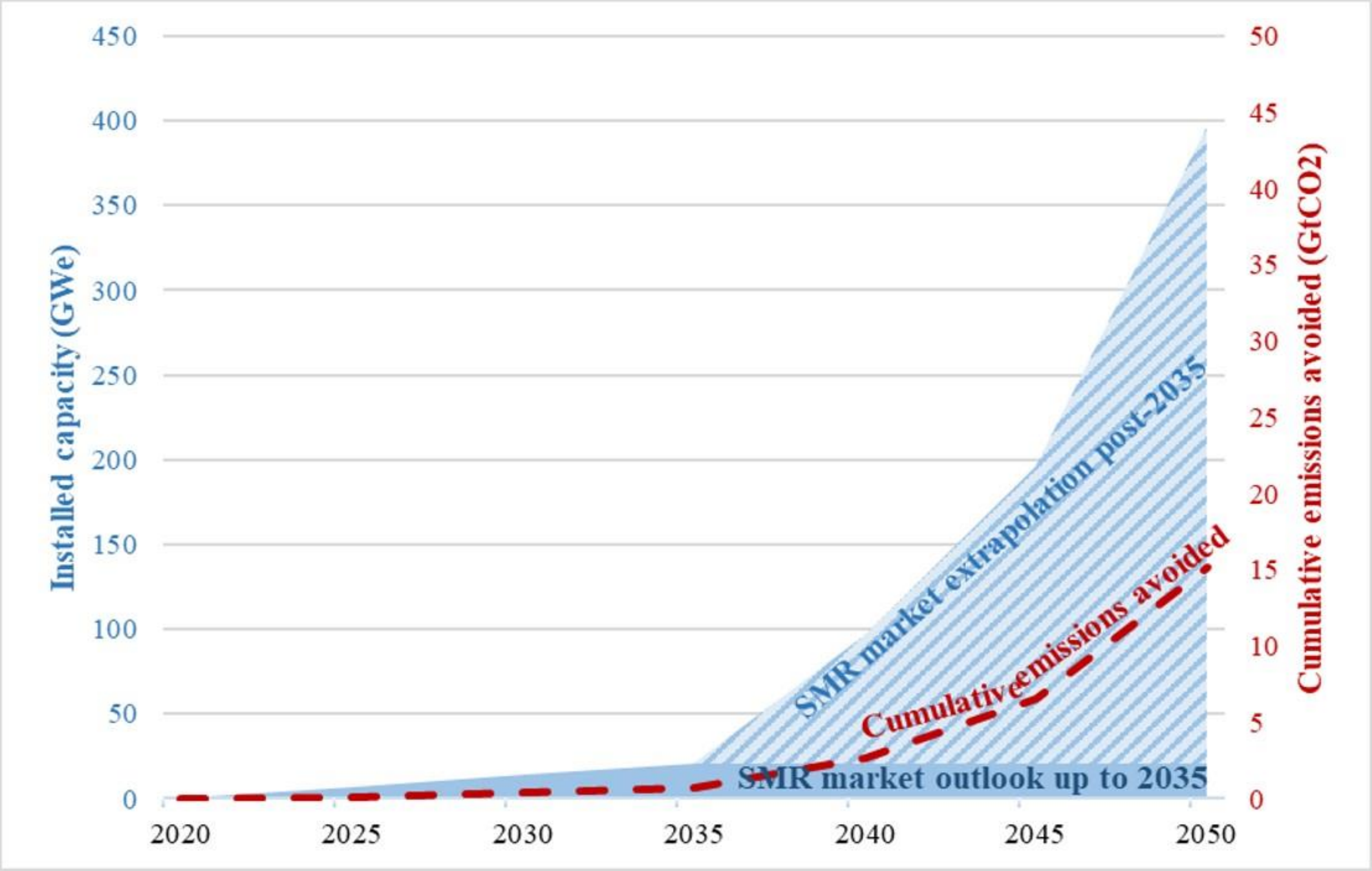


Source: NEA (forthcoming).

Small Modular Reactors

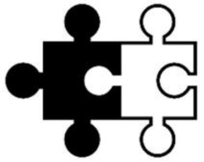
- Several SMR designs are expected to be commercially deployed within 5-10 years and ready to contribute to near-term and medium-term emissions reductions
- SMRs could see rapidly increasing rates of construction in net zero pathways
- Up to 2035, the global SMR market could reach 21 gigawatts
- Thereafter, a rapid increase in build rate can be envisaged with construction between 15 and 150 gigawatts per year

Installed Capacity And Cumulative Emissions Avoided

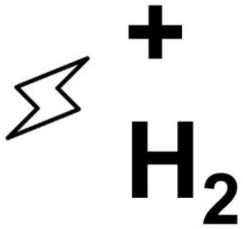


Source: NEA (forthcoming).

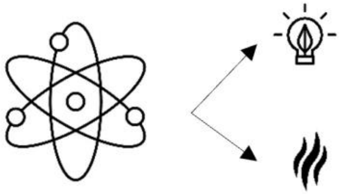
Nuclear hybrid energy systems including heat and hydrogen



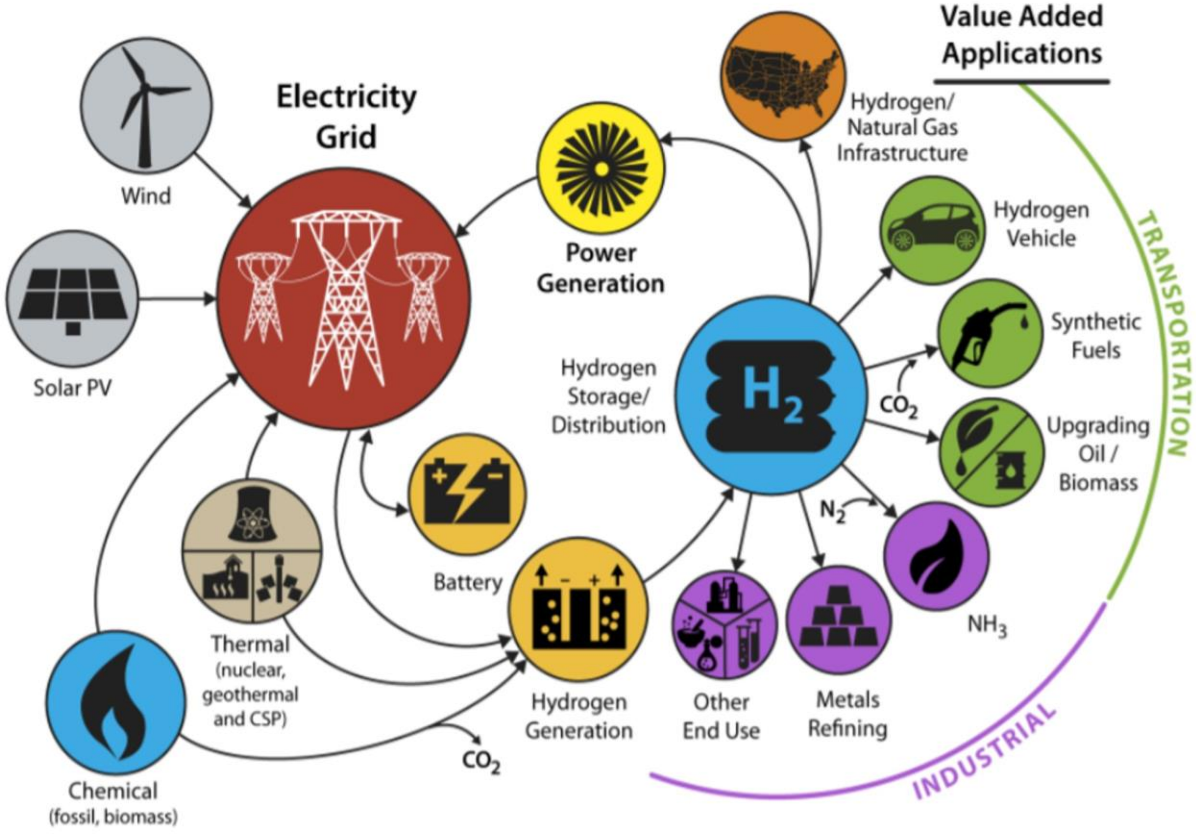
There is **no silver bullet**, all available clean technologies have to contribute to decarbonization



Electricity and clean-hydrogen is the new energy paradigm

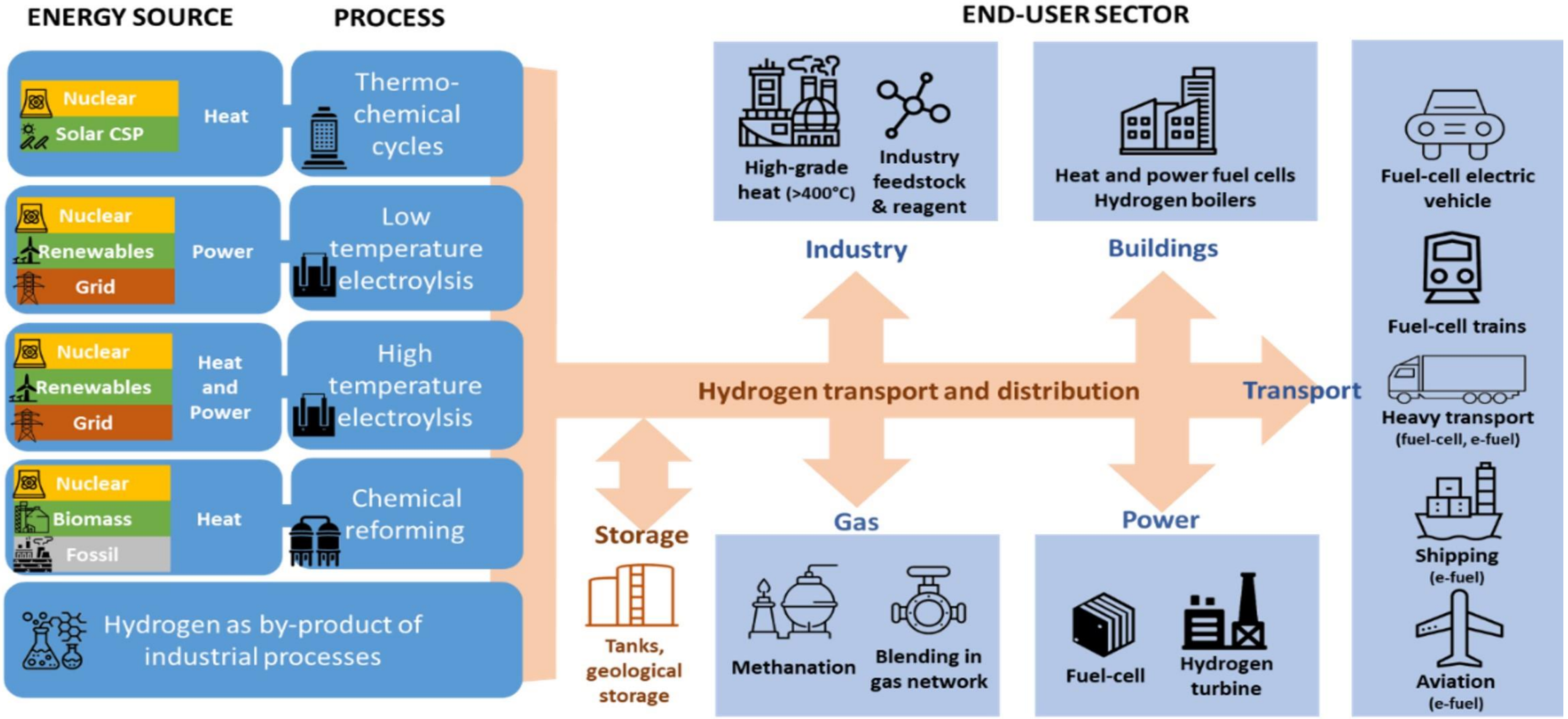


As a **reliable source of clean electricity and high heat**, nuclear is a key pillar of future energy systems



Credit: US Department of Energy, Idaho National Lab

The Hydrogen Economy – sources, production processes, and end-uses

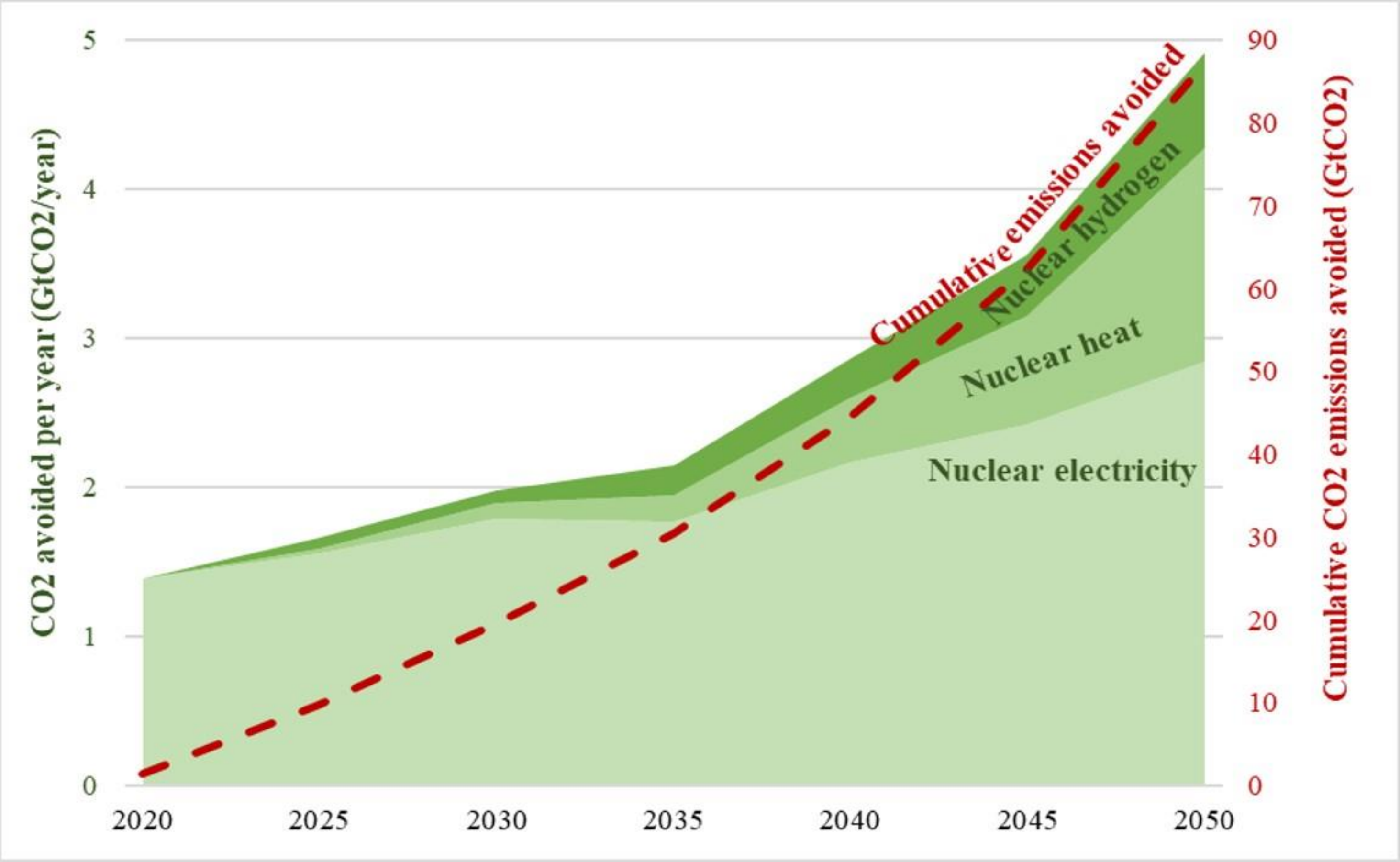


Source: NEA (forthcoming).

Power and Non-power Applications of Nuclear Energy

- Taken together, nuclear hybrid systems with non-electric applications including hydrogen can contribute to avoiding nearly 23 gigatonnes of cumulative emissions between 2020 and 2050
- Further, nuclear energy enables more *extensive*, more *rapid*, and more *cost-effective* deployment of variable renewables, by providing much needed flexibility
- The role of nuclear energy in emissions reductions for future energy systems is therefore even greater

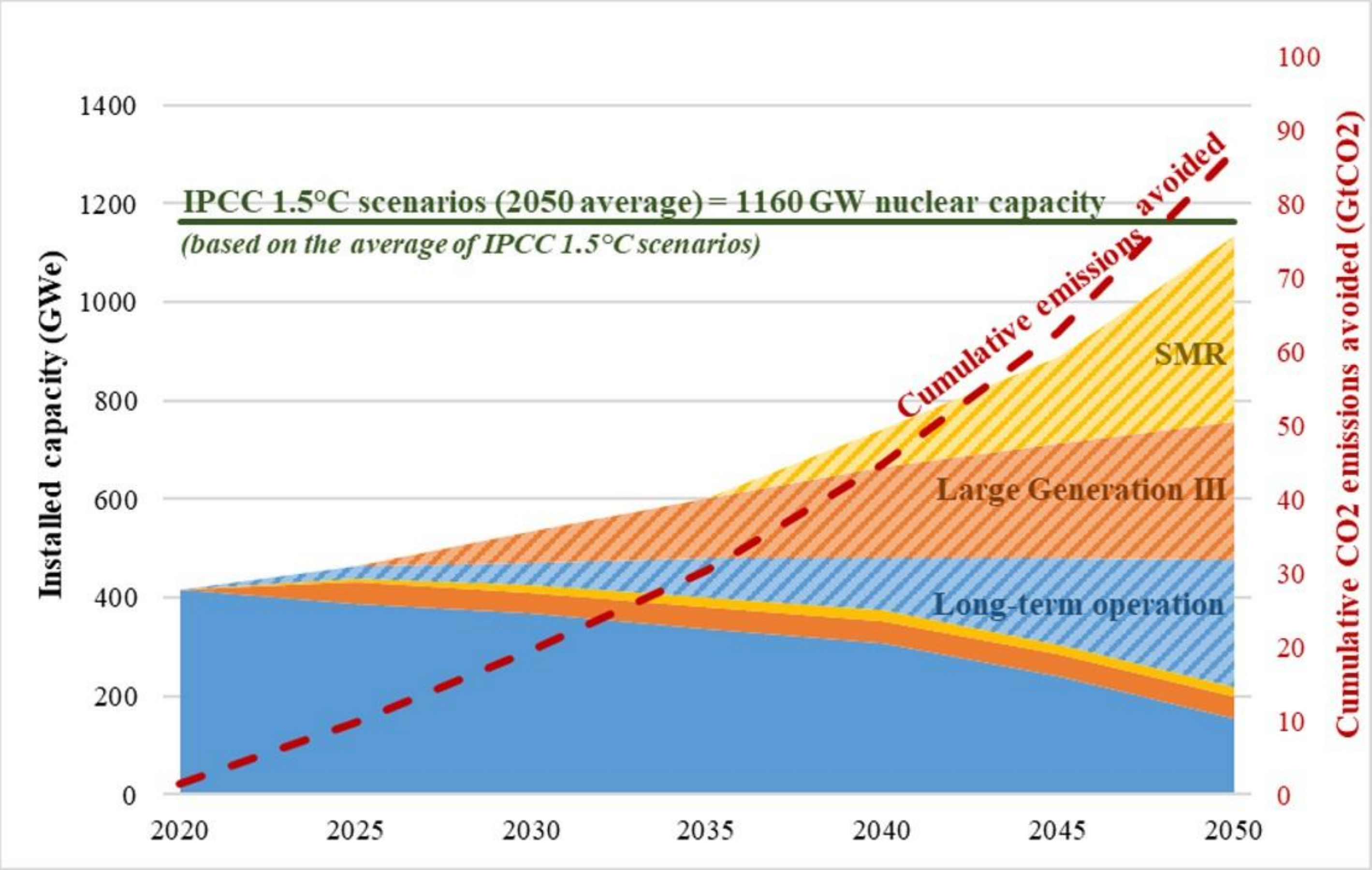
Carbon emissions avoided by nuclear power and non-power applications



Source: NEA (forthcoming).

Full Potential of Nuclear Contributions to Net Zero

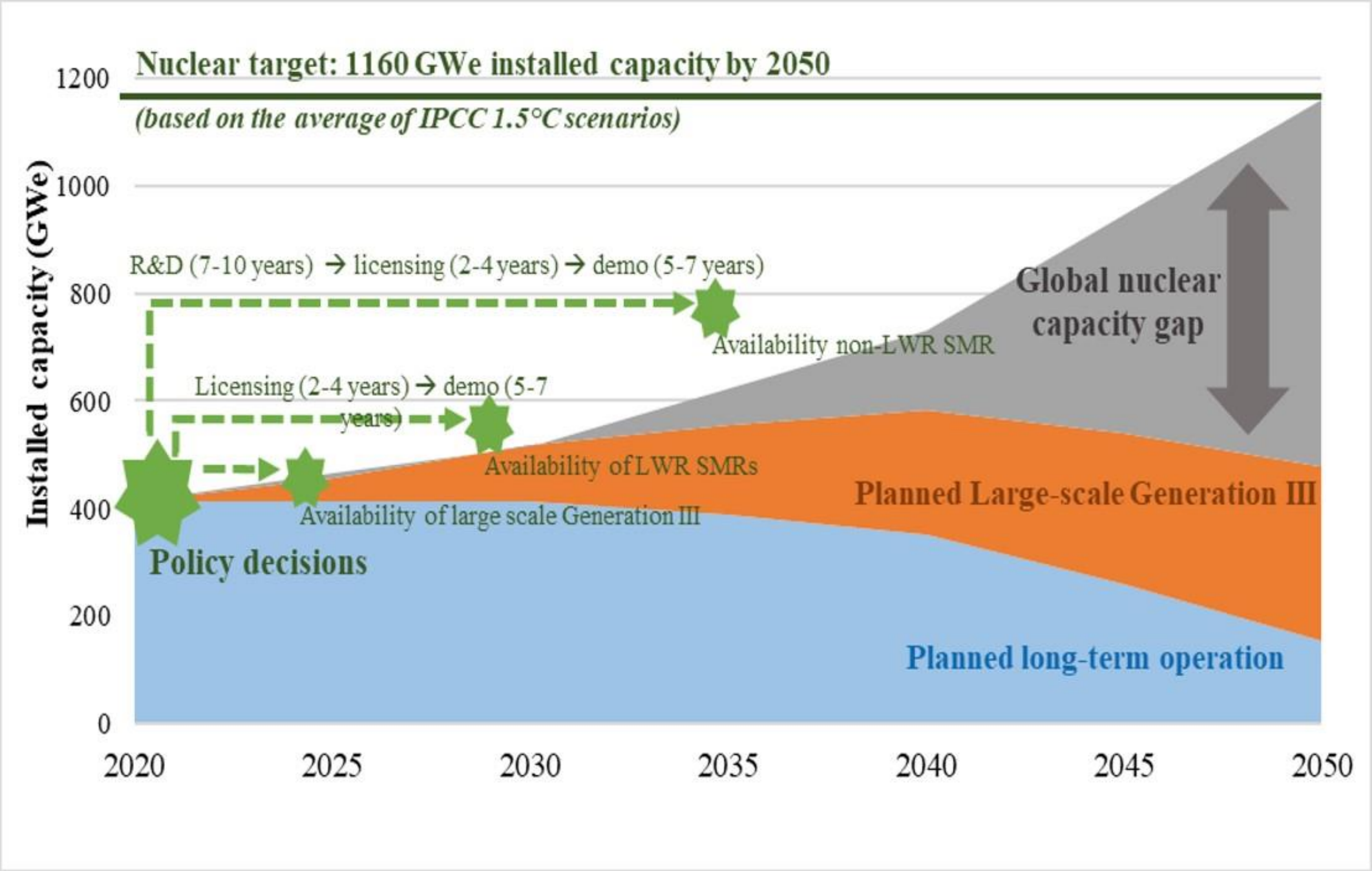
- The contributions from long-term operation, new builds of large-scale Generation III nuclear technologies, small modular reactors, nuclear hybrid energy and hydrogen systems project the full potential of nuclear energy to contribute to net-zero
- Reaching the target of 1160 gigawatts of nuclear by 2050 would avoid 87 gigatonnes of cumulative emissions between 2020 and 2050, positioning nuclear energy's contribution to preserve 20% of the world's carbon budget most likely de to be consistent with a 1.5°C scenario



Source: NEA (forthcoming).

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
- There is a projected gap between the *minimum required global installed nuclear capacity* and *planned global nuclear capacity* of nearly 300 gigawatts by 2050
- Owing to the timelines for nuclear projects, there is an urgency to action now to close the gap in 2030-2050



Source: NEA (forthcoming).

3. Challenges

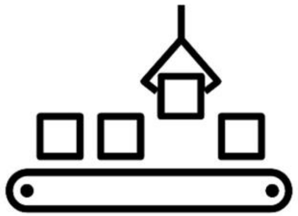
Nuclear Energy Faces Many Challenges

- **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

4. Conditions for Success

Conditions for Success – *beyond technical feasibility…*

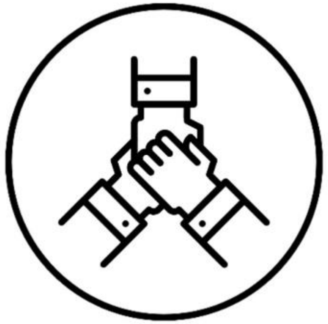
Regulatory and Policy Enabling Frameworks



Ramped up Supply Chains and Talent Pipeline

Market Demand and Good Fit

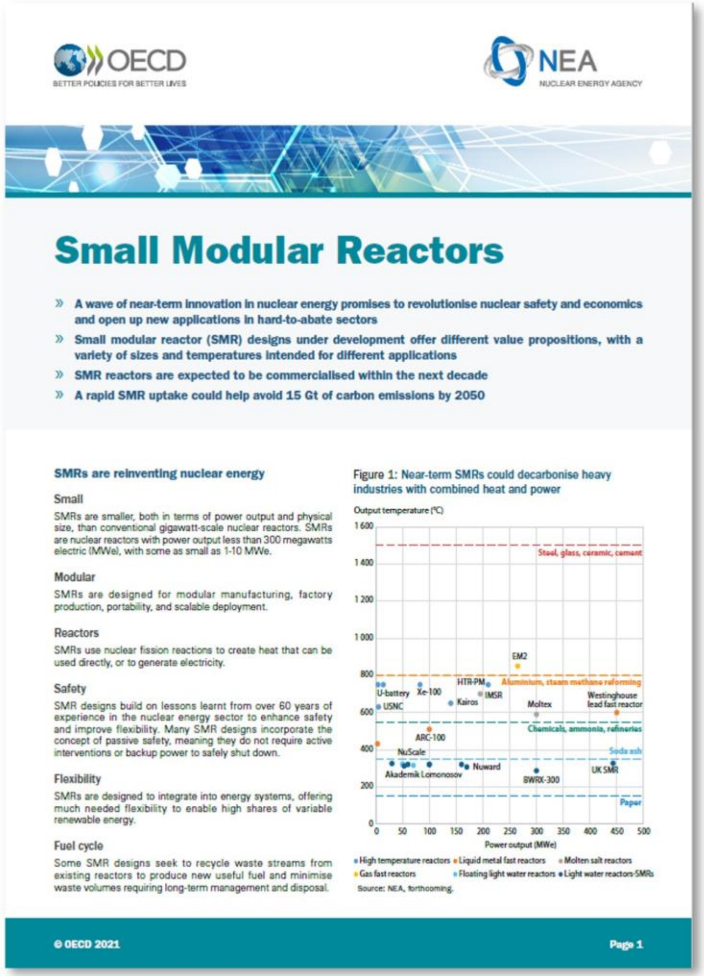
Public Confidence and Community Support



Strategic Partnerships – Public-Private, Indigenous, International

Public-Private Financing

NEA brochures



Small Modular Reactors

» A wave of near-term innovation in nuclear energy promises to revolutionise nuclear safety and economics and open up new applications in hard-to-abate sectors
» Small modular reactor (SMR) designs under development offer different value propositions, with a variety of sizes and temperatures intended for different applications
» SMR reactors are expected to be commercialised within the next decade
» A rapid SMR uptake could help avoid 15 Gt of carbon emissions by 2050

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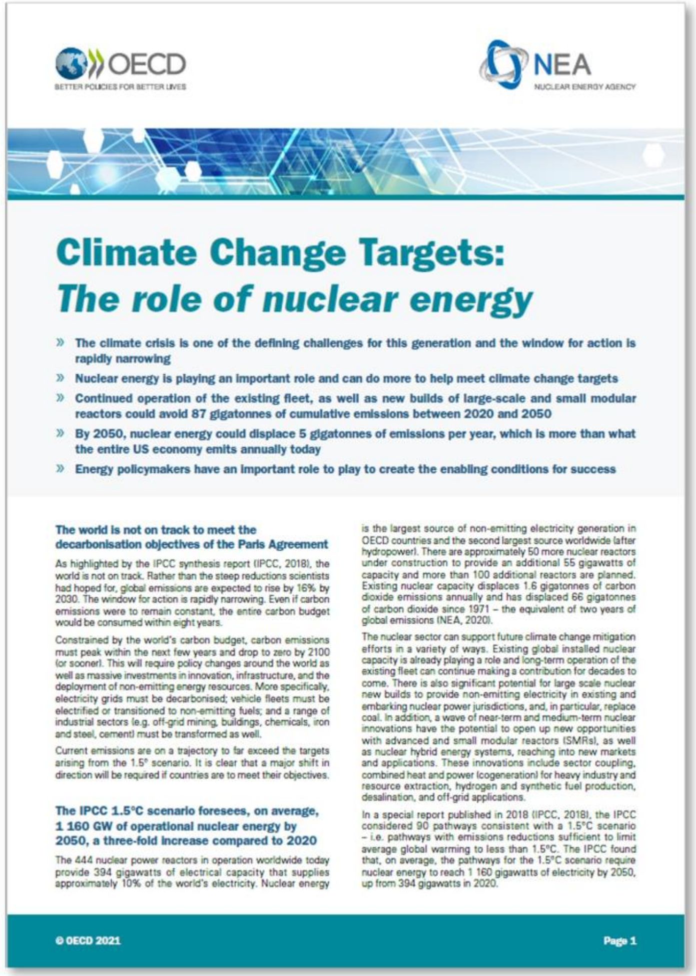

Climate Change Targets: *The role of nuclear energy*

» The climate crisis is one of the defining challenges for this generation and the window for action is rapidly narrowing
» Nuclear energy is playing an important role and can do more to help meet climate change targets
» Continued operation of the existing fleet, as well as new builds of large-scale and small modular reactors could avoid 87 gigatonnes of cumulative emissions between 2020 and 2050
» By 2050, nuclear energy could displace 5 gigatonnes of emissions per year, which is more than what the entire US economy emits annually today
» Energy policymakers have an important role to play to create the enabling conditions for success

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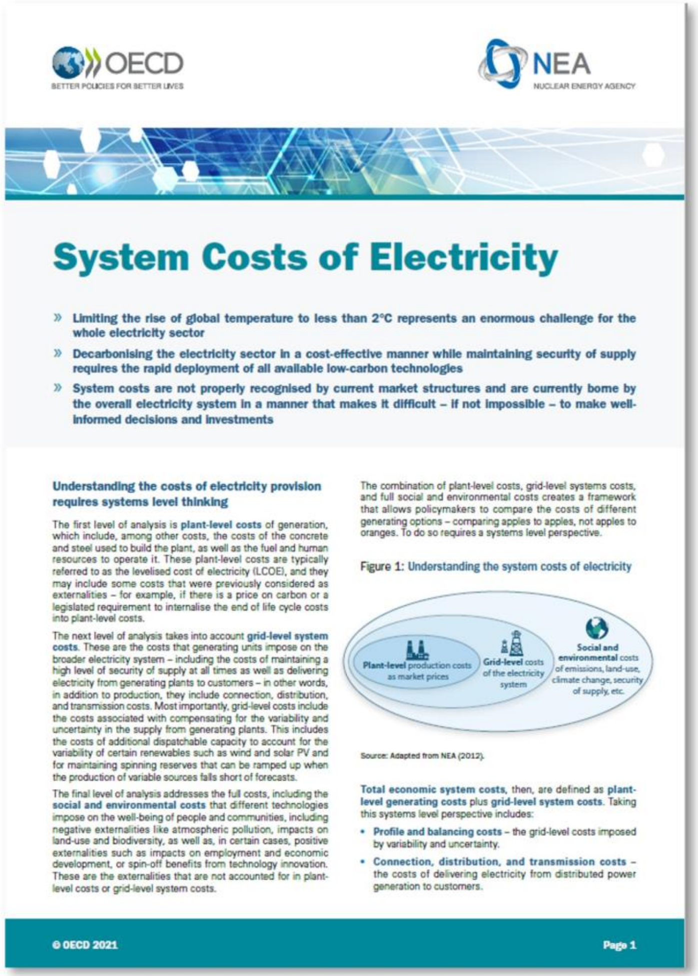

System Costs of Electricity

» Limiting the rise of global temperature to less than 2°C represents an enormous challenge for the whole electricity sector
» Decarbonising the electricity sector in a cost-effective manner while maintaining security of supply requires the rapid deployment of all available low-carbon technologies
» System costs are not properly recognised by current market structures and are currently borne by the overall electricity system in a manner that makes it difficult – if not impossible – to make well-informed decisions and investments

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https://www.oecd-nea.org/jcms/pl_61161/nea-and-cop26

Thank you.

Mr. Wei Huang is the Director of Division of Planning, Information, and Knowledge Management in the Department of Nuclear Energy (NEPIK), IAEA. Since joining the IAEA in March 2016, Mr. Huang has led the Agency's activities in the capacity building in Member States in energy planning and information and knowledge management. In addition to coordinating joint energy planning initiatives with UNDESA, IRENA, and UN Regional Commissions, he has also served as the organizational focal point to the IPCC and UNFCCC and directly contributed to many key international events on SDGs and climate change, such as UN High Level Political Forum (HLPF), UN High Level Dialogue on Energy (HLDE), UN Global Conference on Strengthening Synergies between SDGs and Paris Agreement and a number of COPs including COP 26. He was the lead Scientific Secretary of the first IAEA International Conference on Climate Change and the Role of Nuclear Power convened in October 2019.

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IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Nuclear Energy, an Important Part of the Solution to a Net Zero World

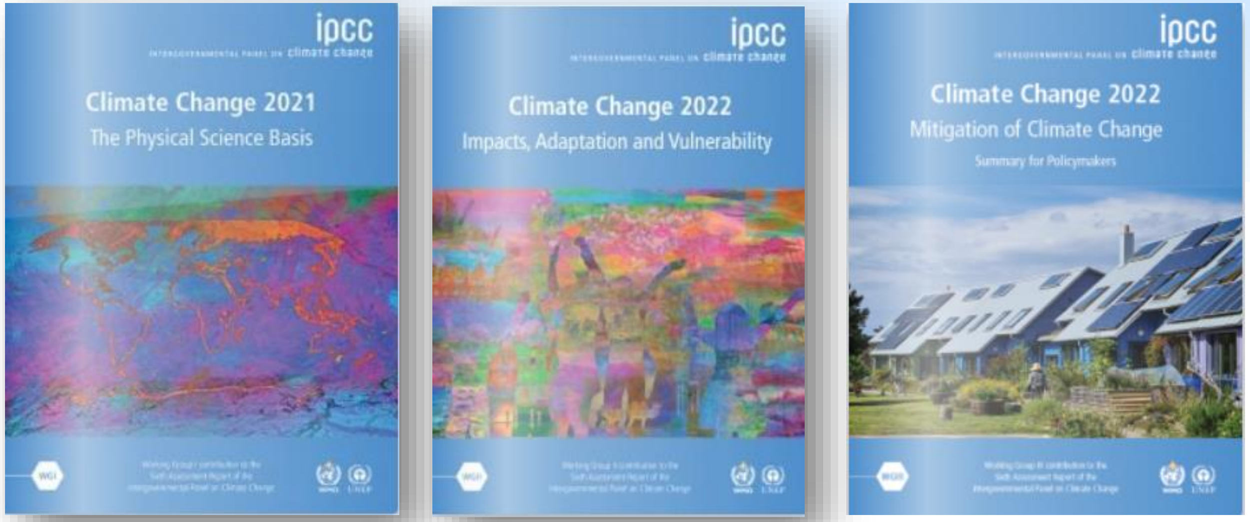
GIF/IAEA/NEA Webinar

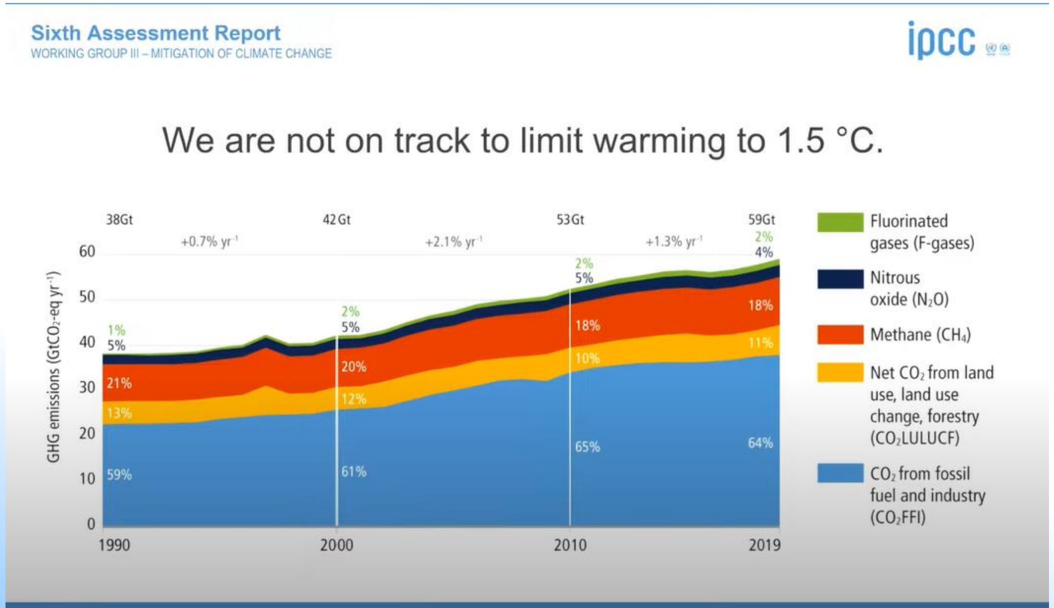
Wei HUANG
Director, Division of Planning, Information and Knowledge Management
Department of Nuclear Energy
IAEA

Climate emergency

"This is a climate emergency…To keep the 1.5°C limit agreed in Paris Agreement within reach, we need to cut global emissions by 45 per cent this decade."

UN Secretary General

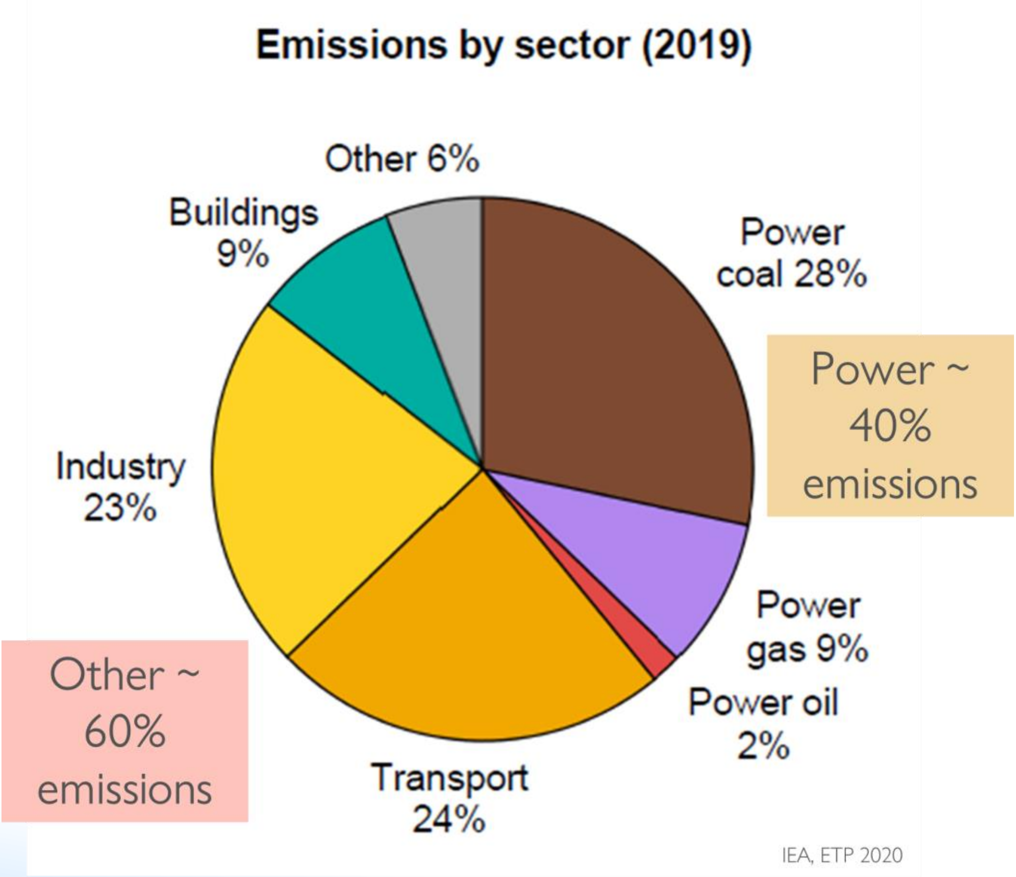




"We have the tools and know-how required to limit warming… There are policies, regulations and market instruments that are proving effective. If these are scaled up and applied more widely and equitably, they can support deep emissions reductions and stimulate innovation."

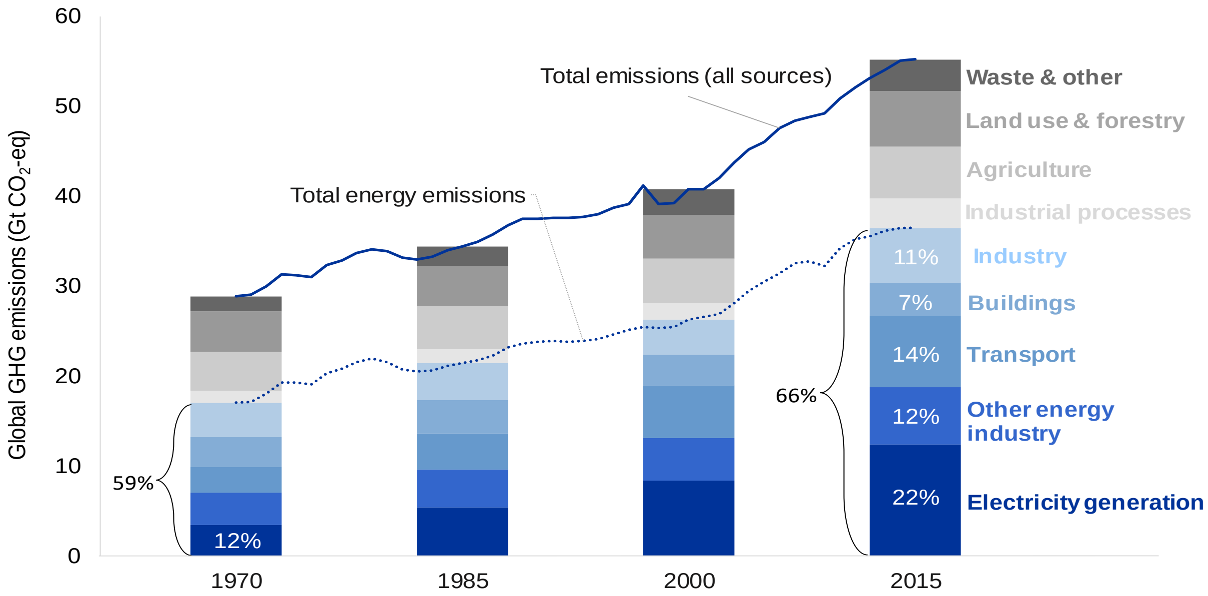
IPCC Chair

Net Zero and options



Two key elements:

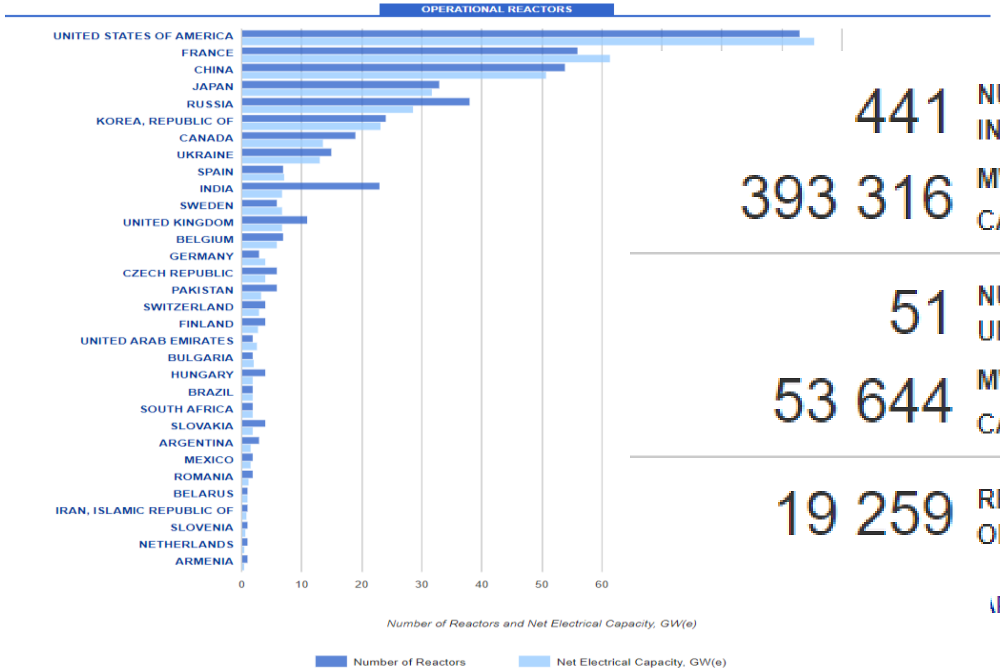
- *Extensive electrification of economy with low carbon electricity*
- *Deployment of other low carbon energy carriers*



Source: International Energy Agency, CO_2 Emissions from Fuel Combustion, OECD Publishing, Paris (2019)

Urgent and ambitious GHG reduction across all activities and sectors

Nuclear power, reliable low carbon source



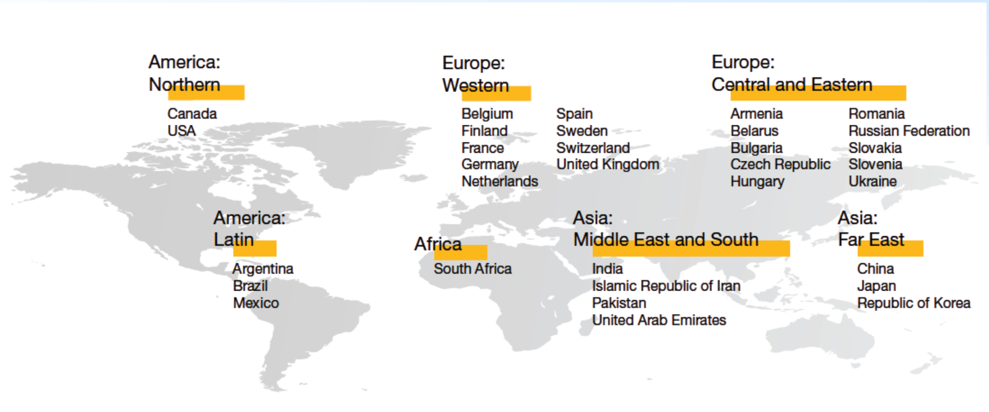
441 NUCLEAR POWER REACTORS IN OPERATION

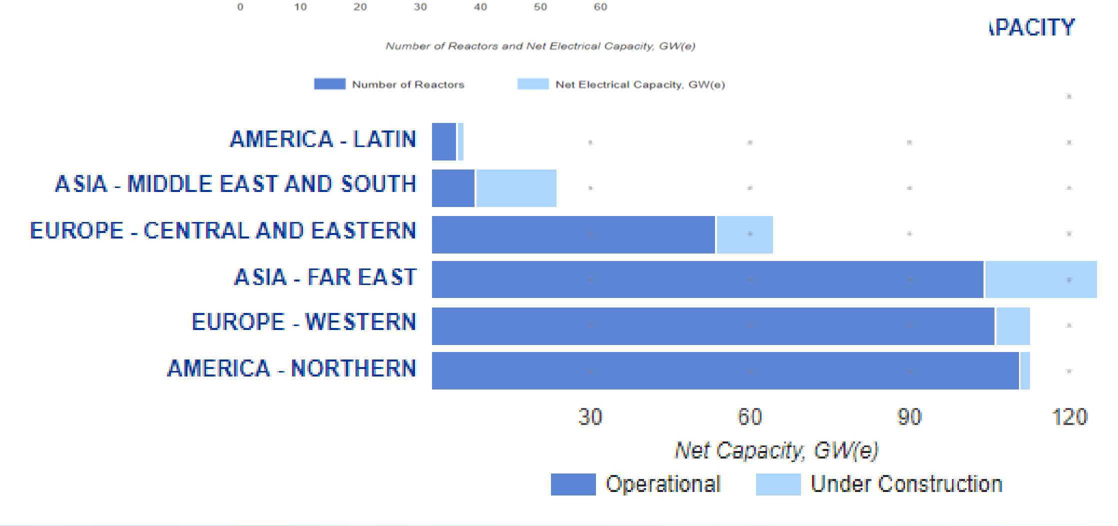
393 316 MW_e TOTAL NET INSTALLED CAPACITY

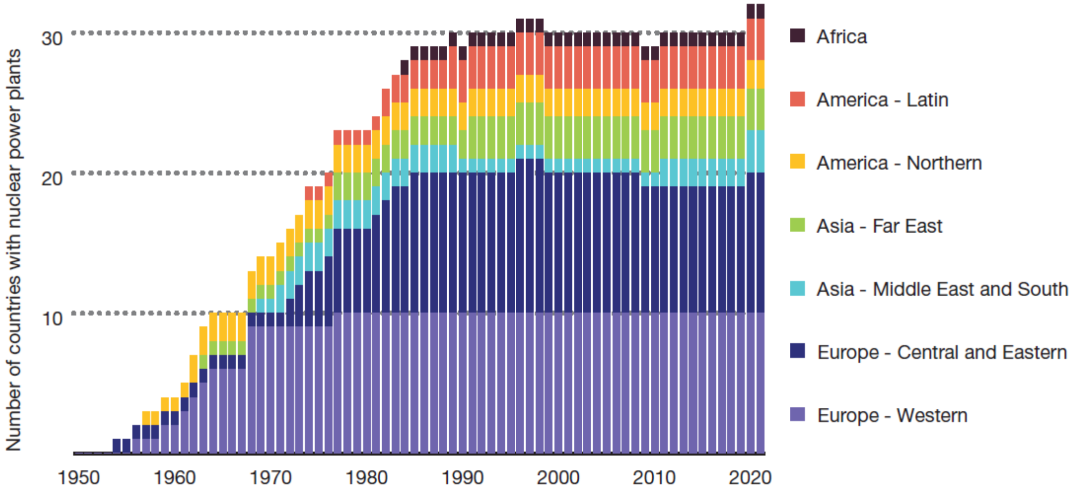
51 NUCLEAR POWER REACTORS UNDER CONSTRUCTION

53 644 MW_e TOTAL NET INSTALLED CAPACITY

19 259 REACTOR-YEARS OF OPERATION

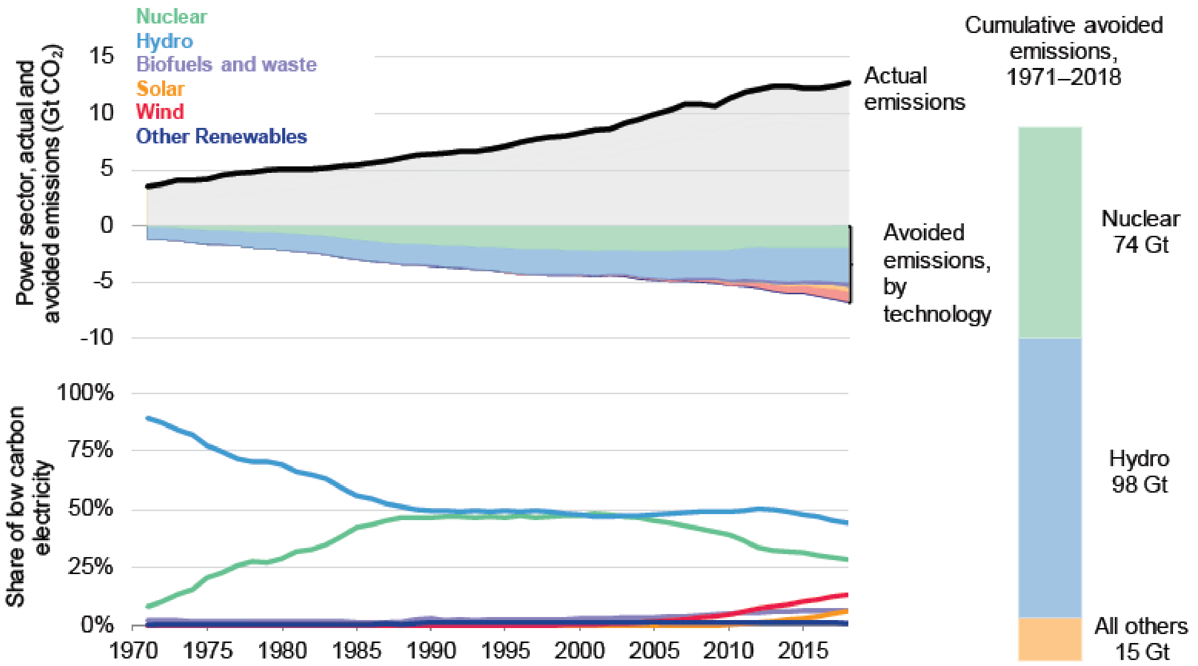


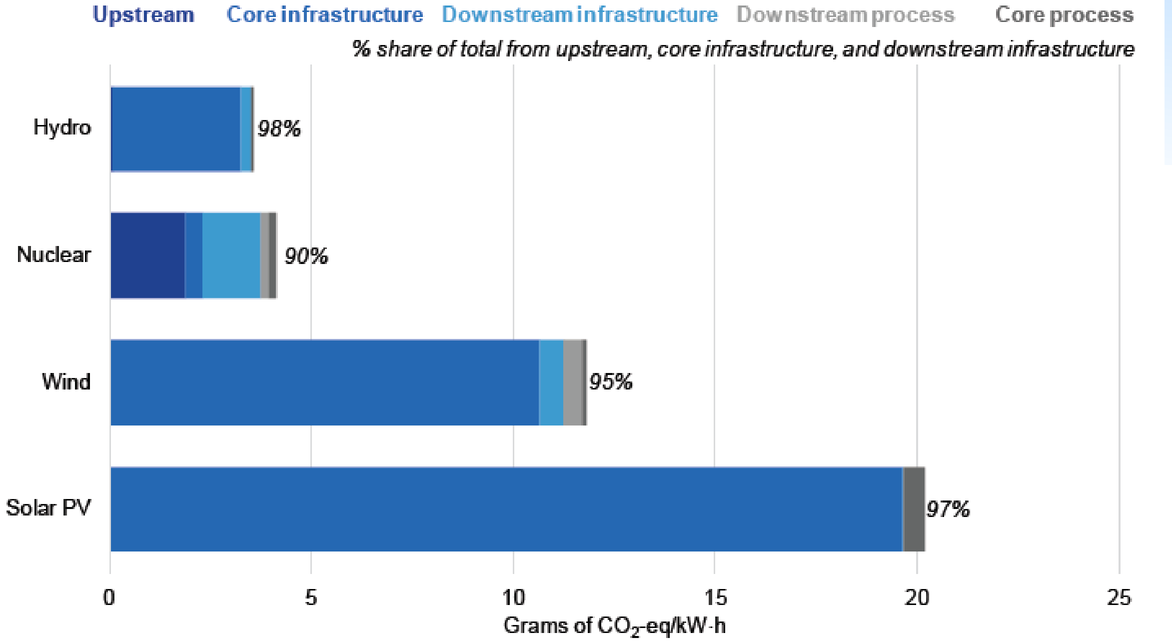




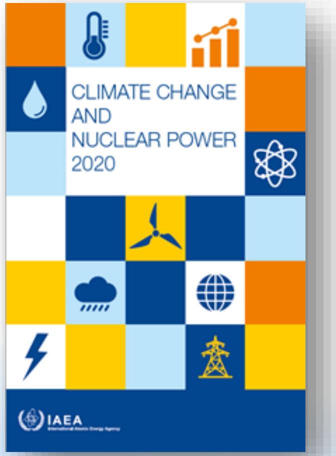
IAEA Power Reactor Information System (PRIS)

Low life cycle carbon emission





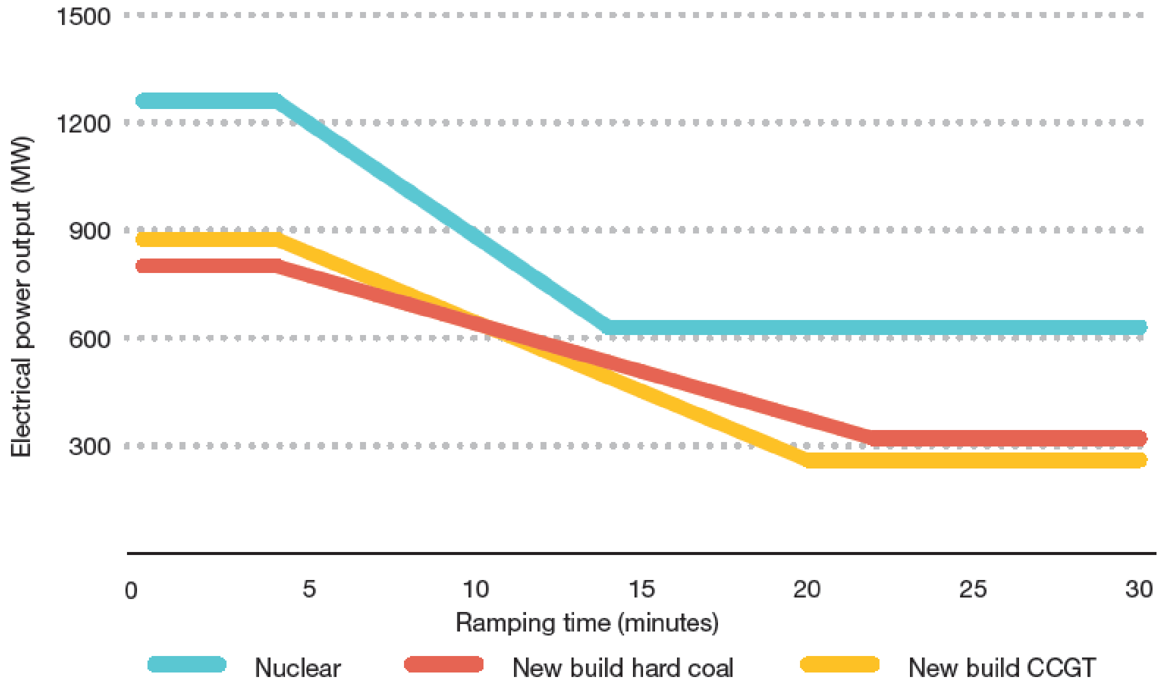
Global CO2 emissions from the electricity generation, estimated emissions avoided by low carbon technologies (upper panel) and share of low carbon electricity (lower panel),1971–2018. Source: IAEA calculations based on Refs [8, 9, 12]. Note: Gt CO2 — gigatons of carbon dioxide.

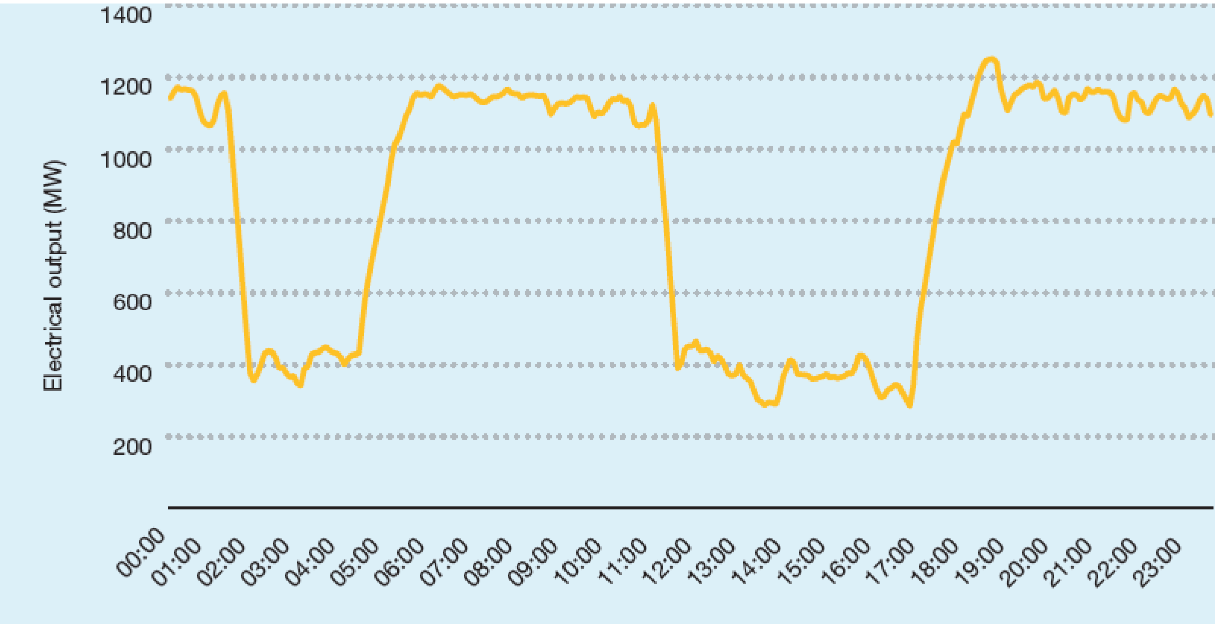


Contribution of material related emissions to total emissions per unit of output for low carbon energy sources. Source: Ref. [48]. Note: Upstream — production and transport of all necessary ancillary substances for operation (e.g. fuels, oils, lubricants etc); core infrastructure — from the extraction of the raw materials needed to build the power plant, until its dismantling and corresponding end of life material treatment; downstream infrastructure — construction and decommissioning of the electrical grid; downstream process — electrical losses; core process — operation and maintenance impacts.

Dispatchable and flexible source

- *Flexibility is at the heart of future low carbon electricity system with high penetration of VRE.*
- *Nuclear power has had decades' experience for flexible operation.*



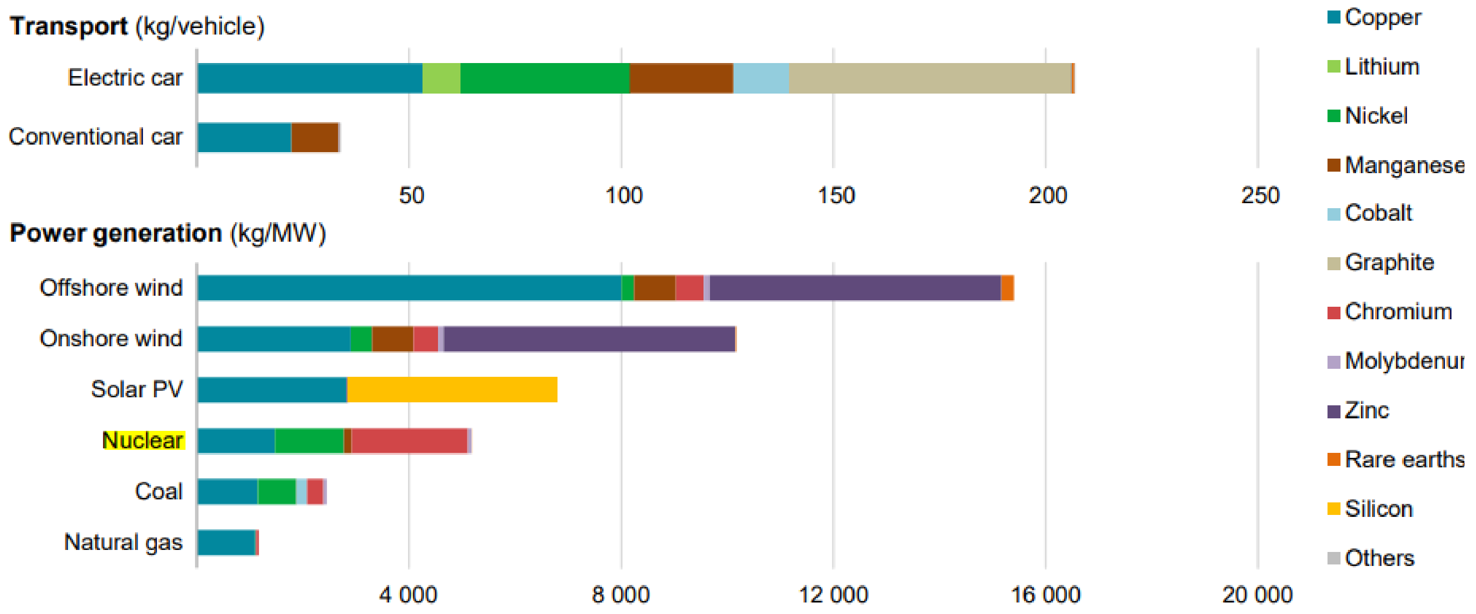


Power output of a French nuclear power plant in one day (courtesy of EDF).

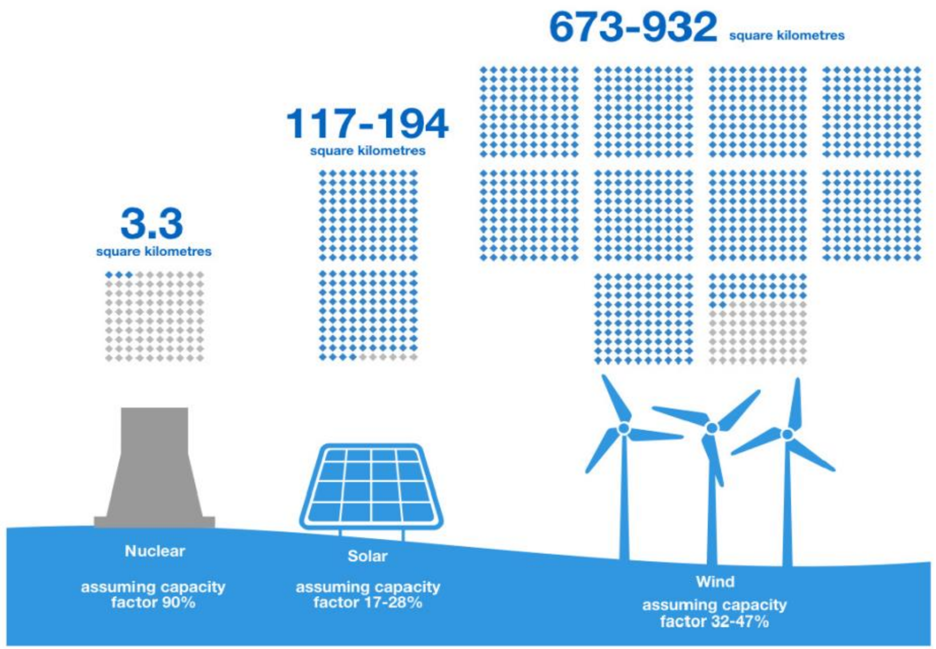
Patel, S. Flexible operation of nuclear power plants ramps up, POWER Magazine

Less mineral resource and smaller land footprint

Nuclear energy is one of the low-C technologies with the lowest (critical) mineral intensity and land footprint



The role of Critical material in Clean Energy Transition, IEA , 2021



Land requirement for NPP, wind and solar technologies per 1000 MW of capacity

Land Requirements for Carbon-free Technologies, NEI, 2015

Economic competitiveness

All low carbon technologies are characterized by a high proportion of overnight investment and financing costs

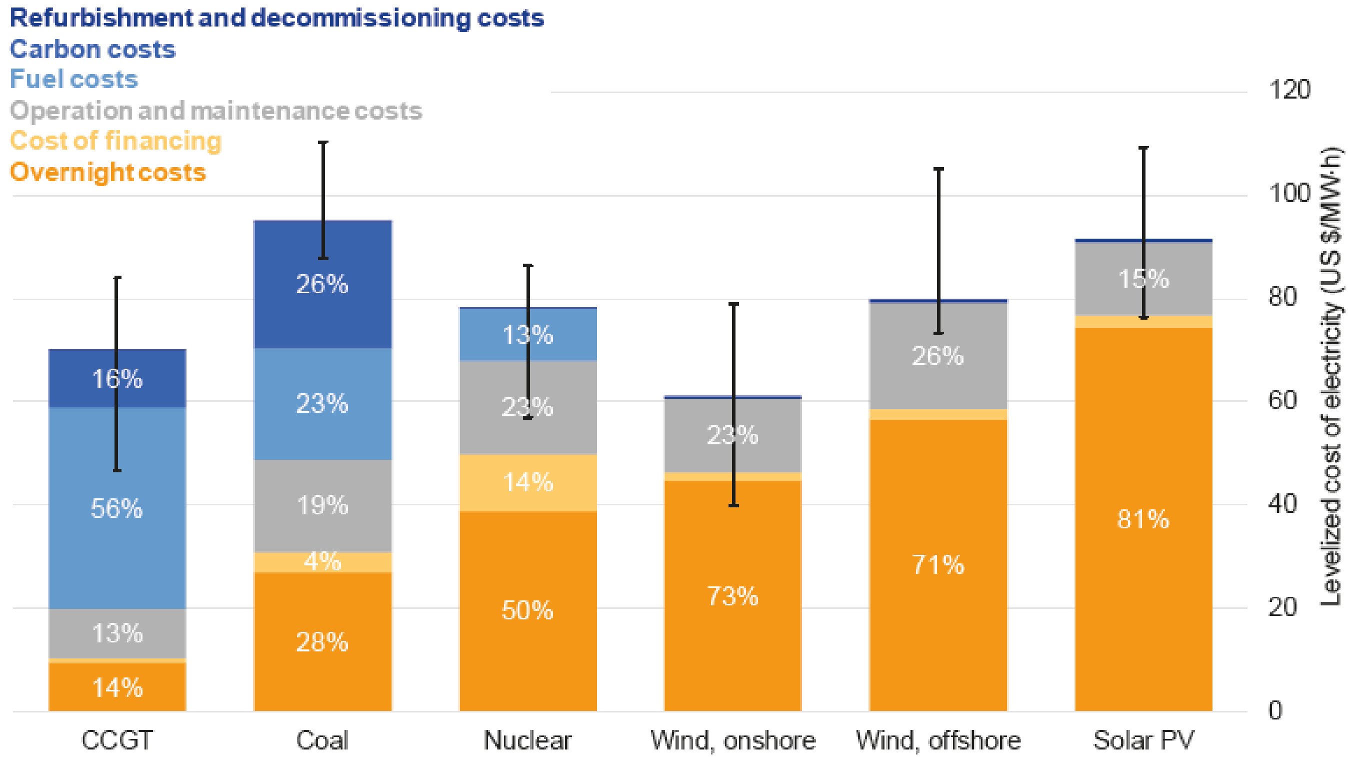


FIG. 8. Median values for the LCOE generation for different technologies, assuming a discount rate of 7% and carbon cost of US $30/tonne, with error bars representing the first and third quartiles for the lower and upper bounds, respectively. Source: Ref. [53]. Note: MW·h — megawatt-hour.

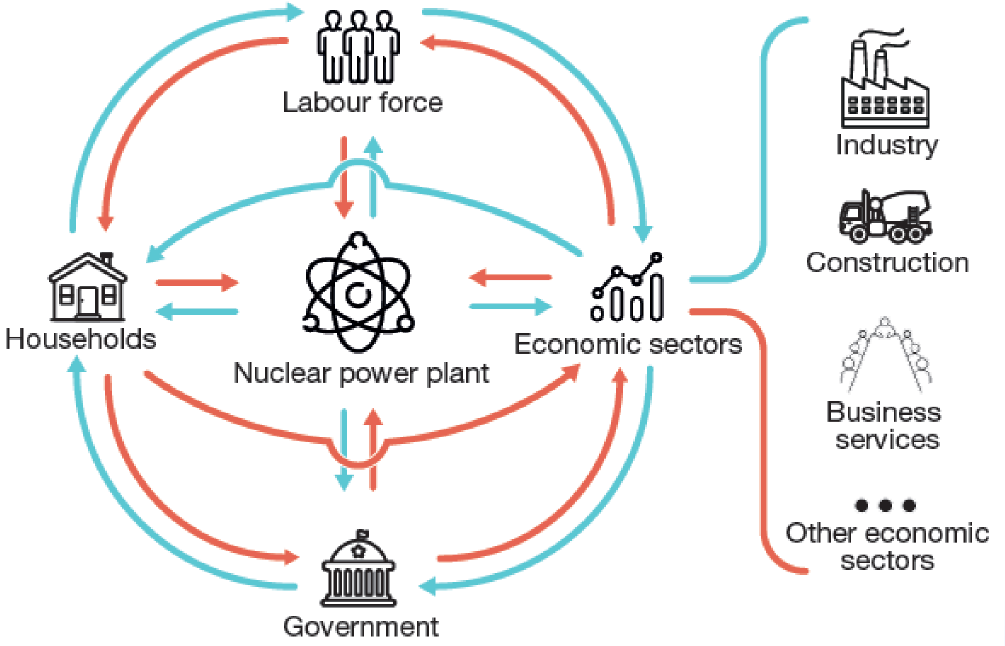
- *At lower discount rates, the LCOE for nuclear compares favourably with other technologies.*
- *The cost here is internalized direct cost, excluding system integration and environmental cost.*
- *Innovative financial mechanisms are available to address high upfront overnight cost , de-risk investment and secure revenue.*

- *At **3%** discount rate, nuclear power is estimated to be the cheapest generation technology across all regions, followed by VRE.*
- *At **10%** discount rate, all low carbon technologies lose competitiveness*

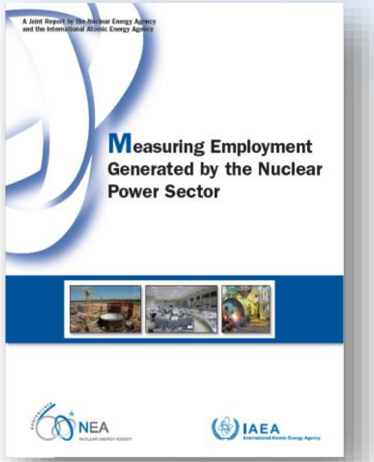
Valuable economic benefits

- *Jobs*
- *Economic Growth*

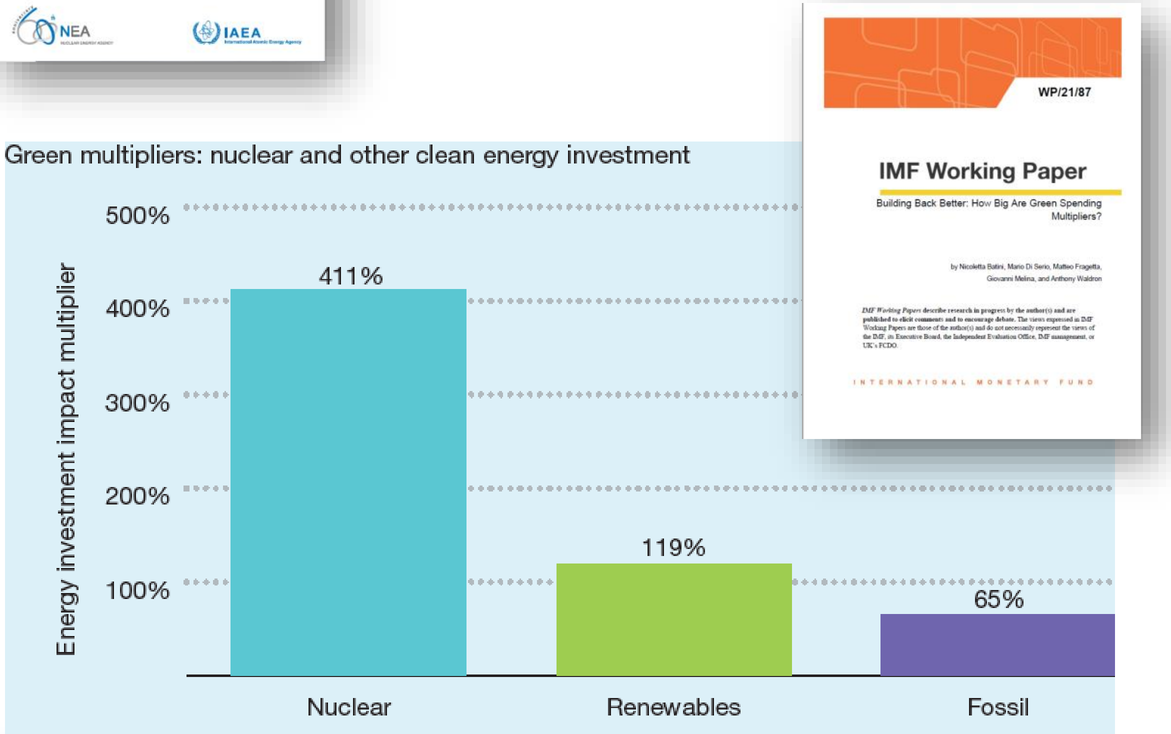
Importance for the “Just Transition” away from coal to mitigate the socio-economic costs of fossil activities.



Direct and indirect social economic benefit



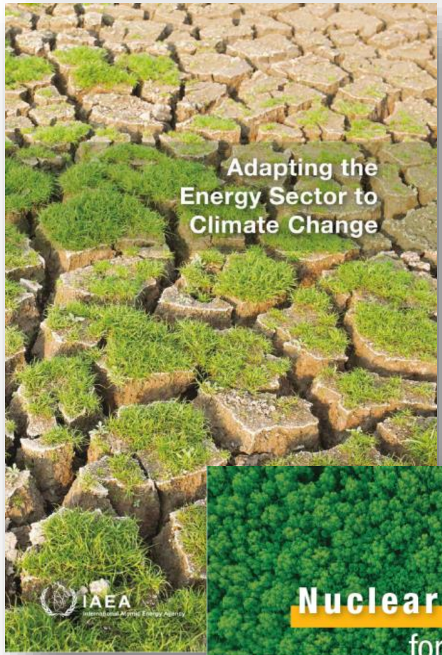
Total employment in the nuclear power sector of a given national economy is therefore roughly 200 000 labour years over the life cycle of a gigawatt of nuclear generating capacity

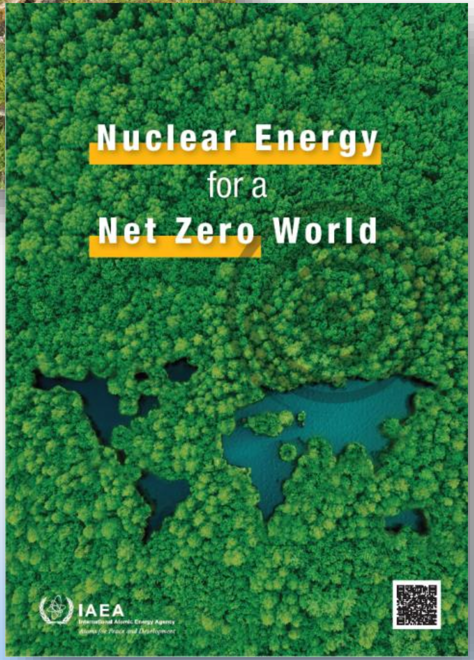


Energy investment impact multipliers (i.e. change in GDP per unit of investment spending) [67].

Climate resilience – adaptation case of nuclear

Nuclear power plants, like other energy infrastructures, are affected by CC and extreme weather events. But IAEA data (PRIS operational data) shows that even if the #reported events are on the rise, the production loss are not: adaption measures can be deployed to ensure robust and reliable power generation. (weak point is more often the grid – need for resilient "systems")





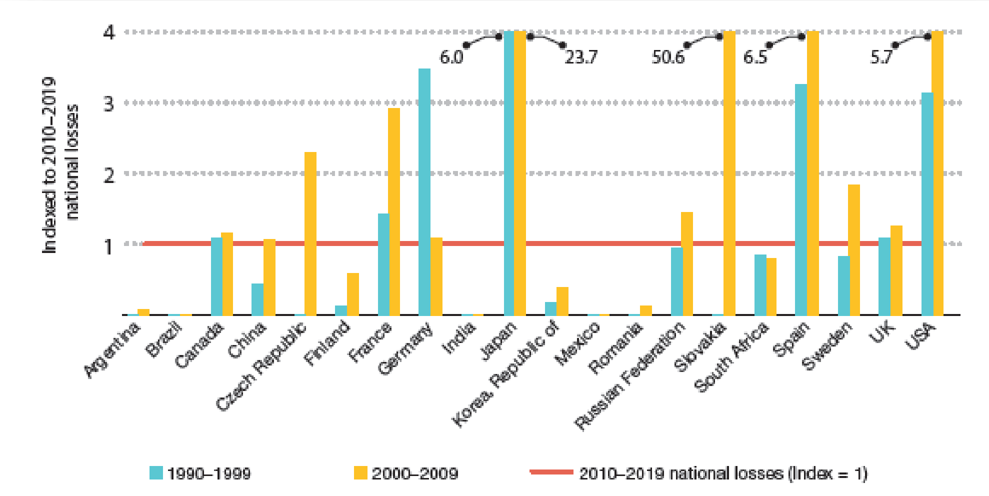
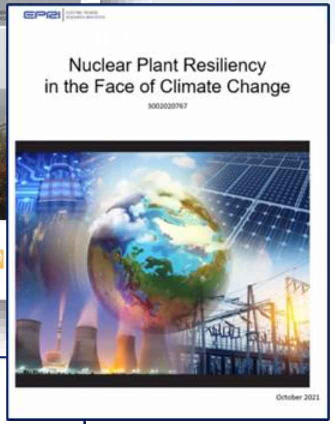
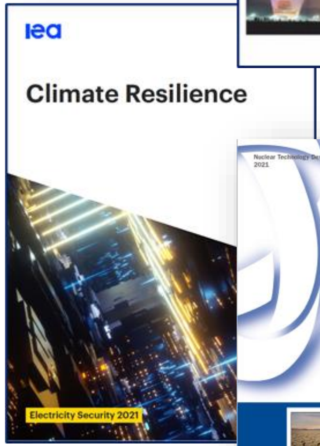
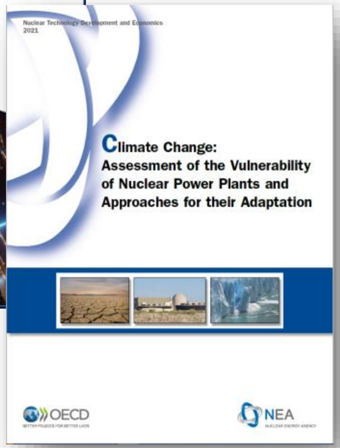


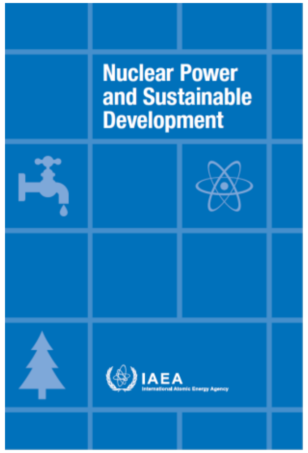
Figure 14. Decadal production losses due to extreme weather events relative to period 2010–2019. Note: Limited data reported for some countries.

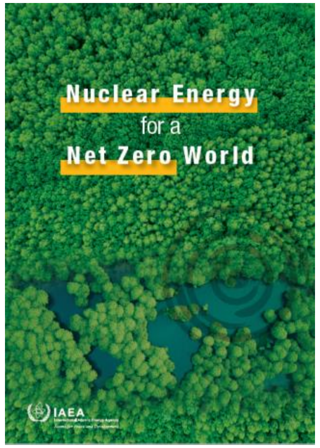




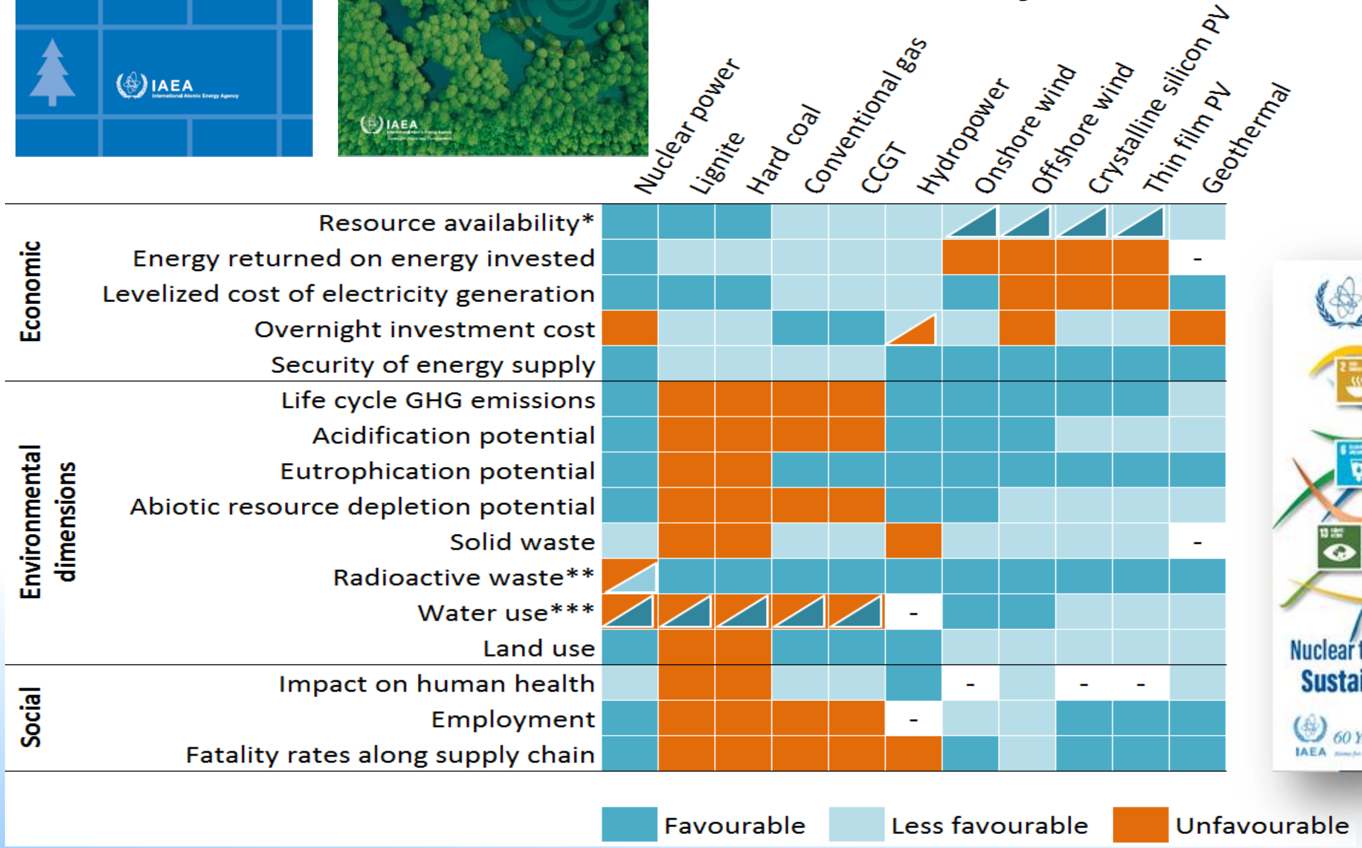


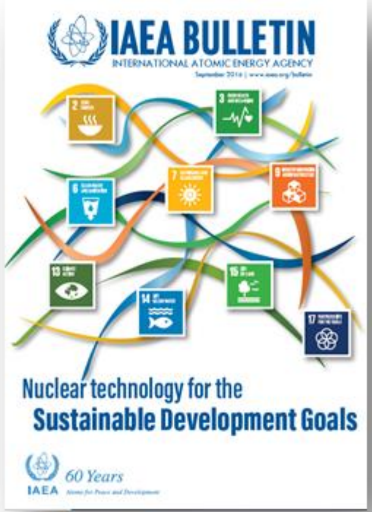
Nuclear power vs SDGs

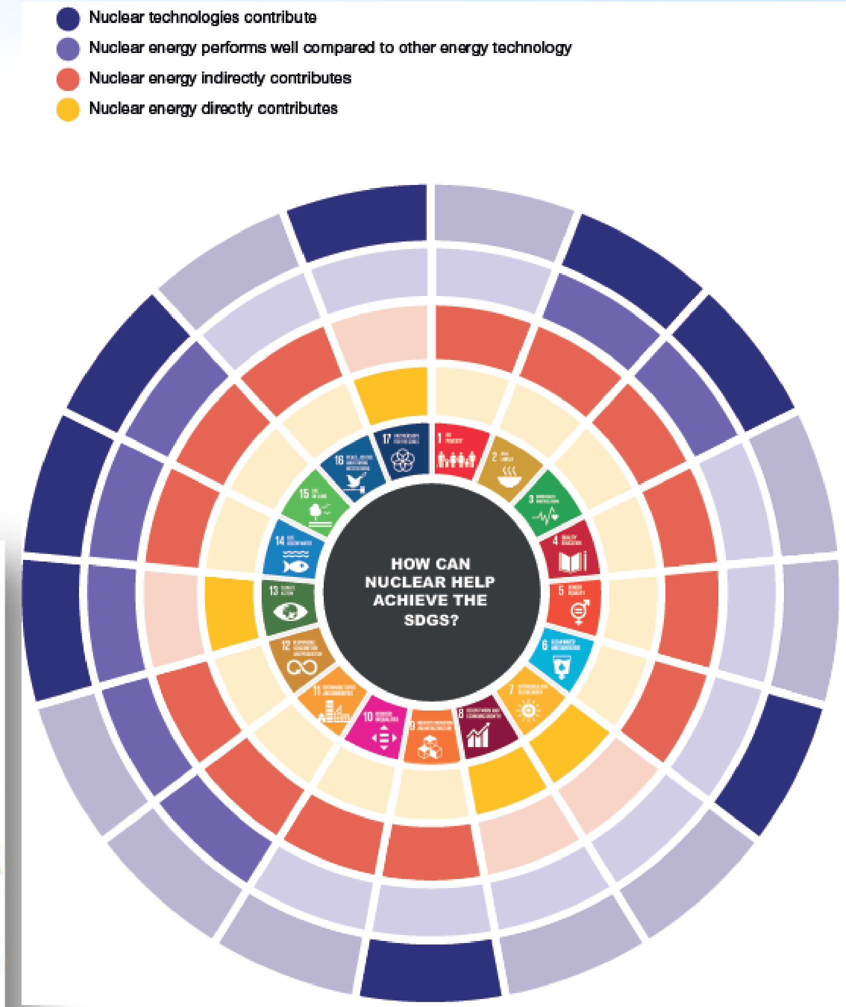




- *Favorable in many sustainable indicators*
- *Contribute to many SDGs directly and indirectly*

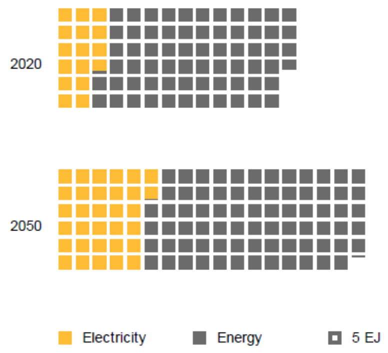




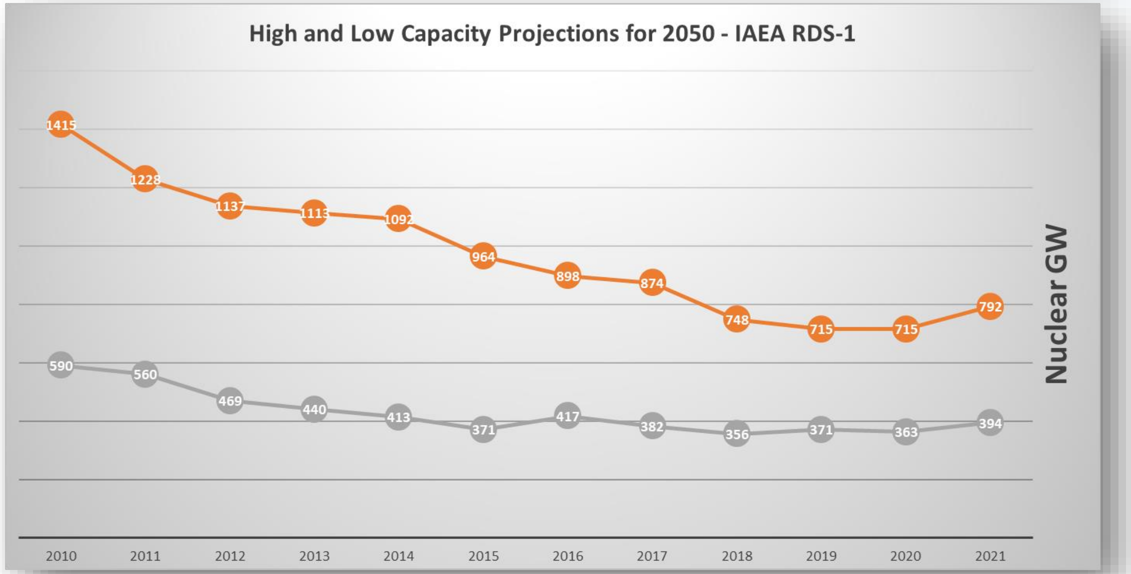


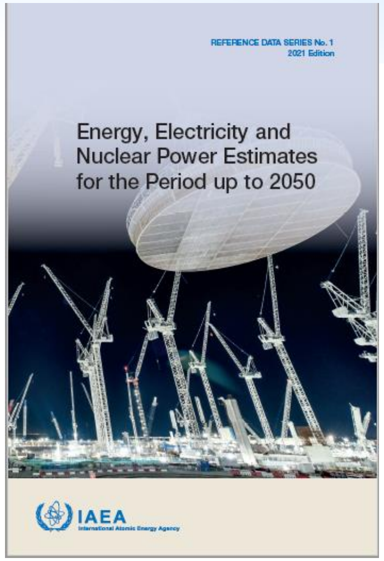
Projecting the future

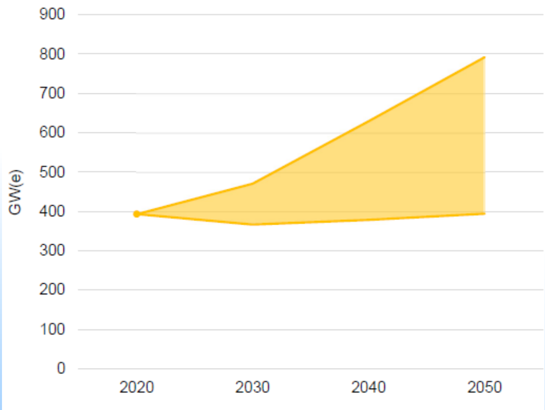
Energy, Electricity and Nuclear Power Estimates for the Period Up to 2050



- *Electricity consumption expected to double in 2050*
- *Share of electricity in energy consumption increases by 8 pts*

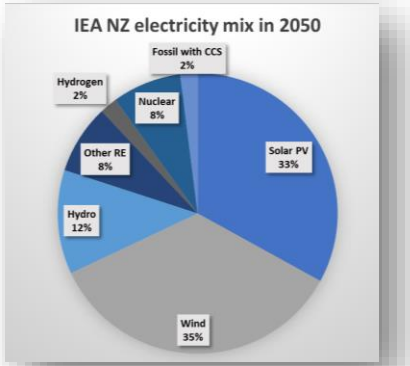


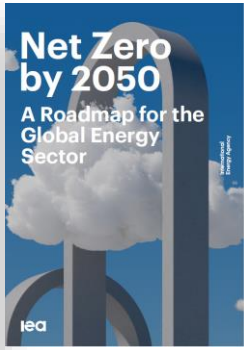




IAEA Projection up to 2050

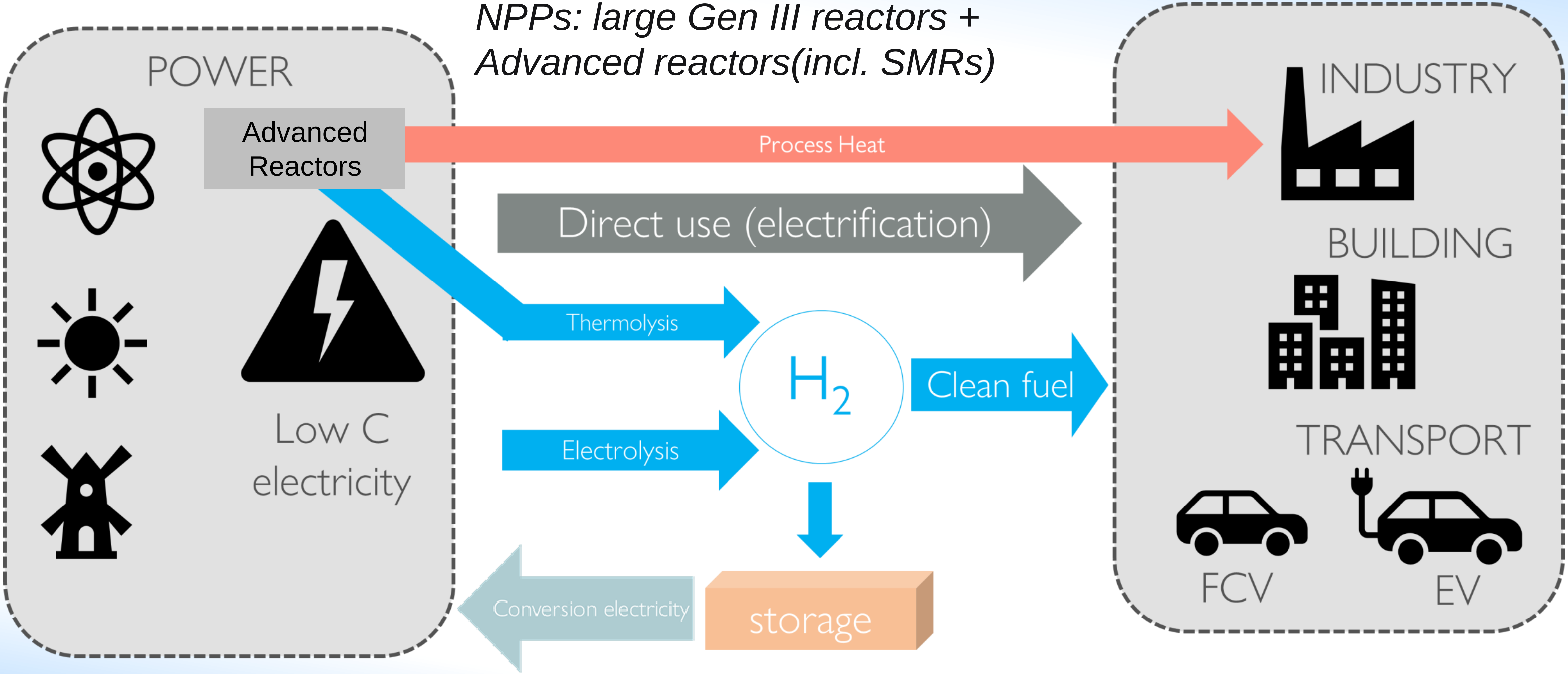
- *High case: installed capacity increases 20 % (470GWe) by 2030 and 80% (792 GWe) by 2050, close to IEA NZ scenario. First time revised up since Fukushima.*
- *Low case: decrease by 7%(366 GWe) by 2030 and rebound back (394 GWe) to 2020 level.*





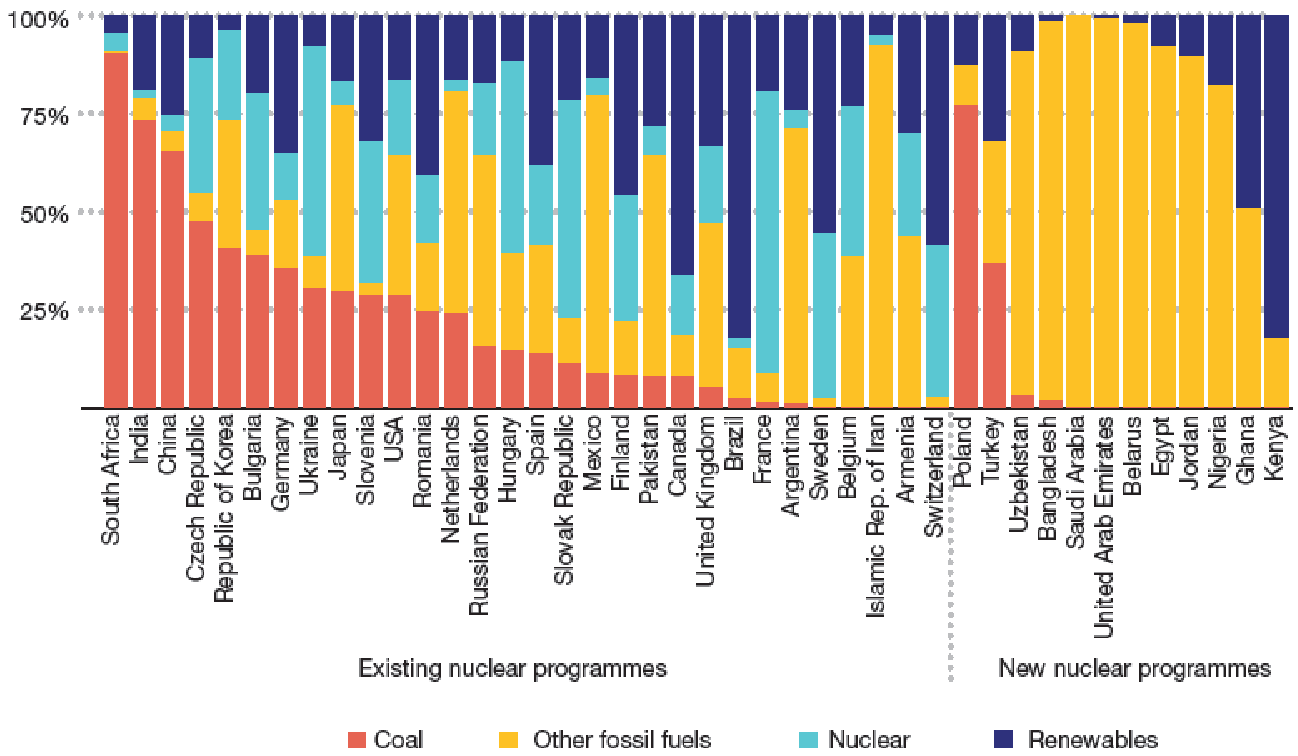
Nuclear beyond electricity

NPPs: large Gen III reactors + Advanced reactors(incl. SMRs)



3 low-carbon energy vectors: electricity, heat, hydrogen

Coal Replacement by nuclear



Electricity generation mix (2018) in countries with or planning nuclear power programmes

Several countries operating NPP or planning to operate NPP account for 85% of the world's coal generation

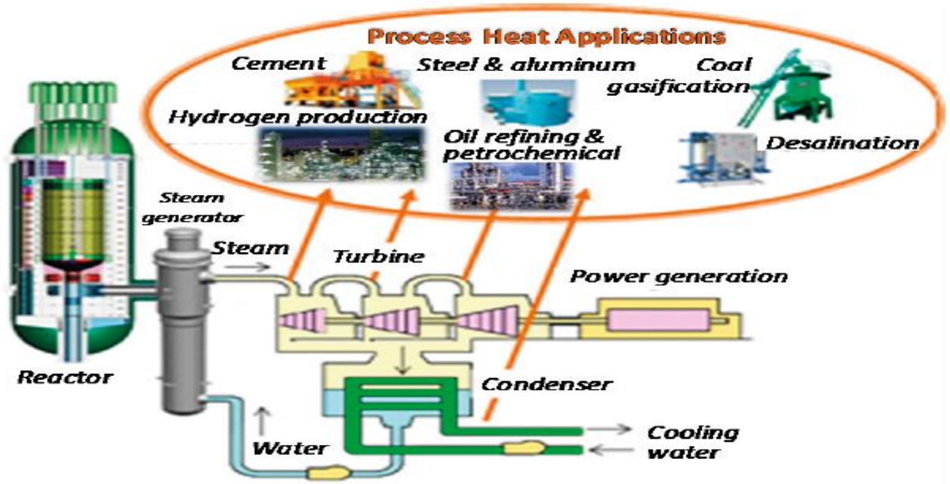
Single nuclear reactor could replace multiple coal units. Various SMR designs in different stages of development could be well suited to replace smaller coal fired units across a wider range of applications.

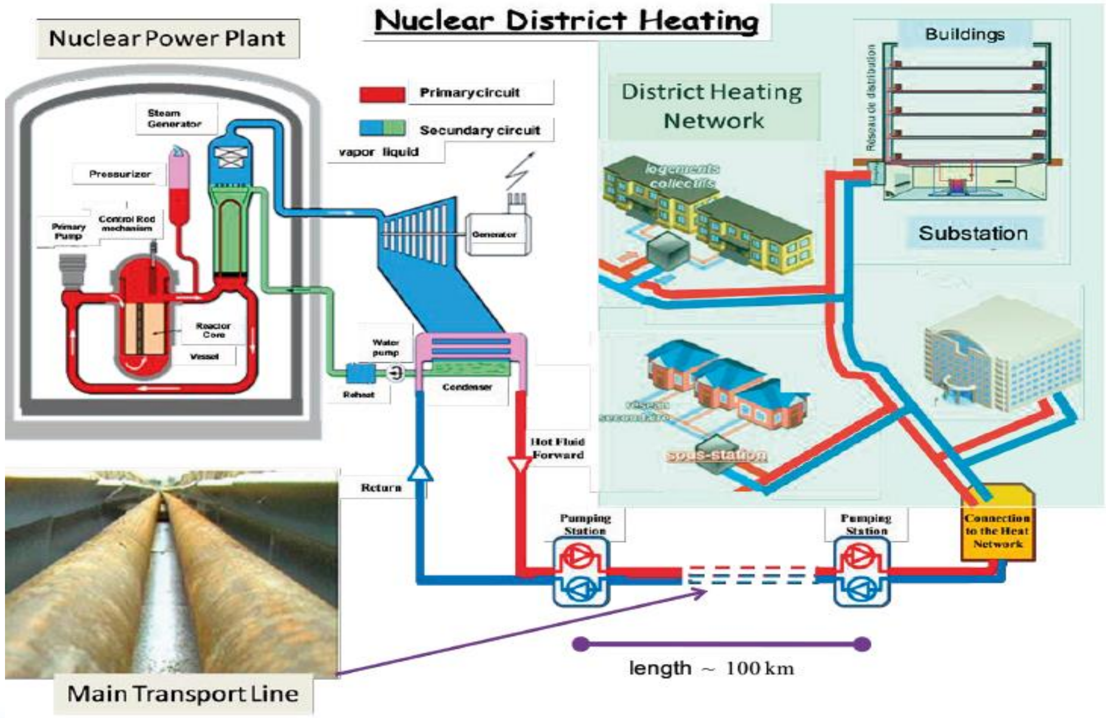
		Plant output			Coal replacement applications	Technological and commercial maturity
		Electricity	Low temperature heat (300°C) (district heat, industry, H_2)	High temperature heat (600-700°C) (industry, H_2)		
Nuclear reactor design	Large water cooled	✓	✓		Multi-unit power plant	Mature; more than 300 units in operation
	SMR, water cooled	✓	✓		Single unit, power or CHP	Demonstration; pre-commercial; conventional nuclear licensing process widely applicable
	SMR, advanced (gas/sodium cooled)	✓	✓	✓	Single unit, power, CHP, industrial boiler, H_2	Design phase; demonstrated technology; pre-commercial
	SMR, advanced (salt or lead cooling; micro-reactors)	✓	✓	✓	Single unit, power, CHP, industrial boiler, H_2	Research, development and demonstration

Categorizing selected nuclear technologies suitable for replacing coal.

Heat supply by nuclear

- *About 15% of the currently operating NPPs are used to supply heat in form of steam and/or hot water, along with power production.*
- *Decades of experience of nuclear-fuelled district heating has been accumulated in Switzerland, Sweden, Russia, Hungary, China and other European countries and heat from nuclear power plants has also been sent to industrial sites in several countries.*



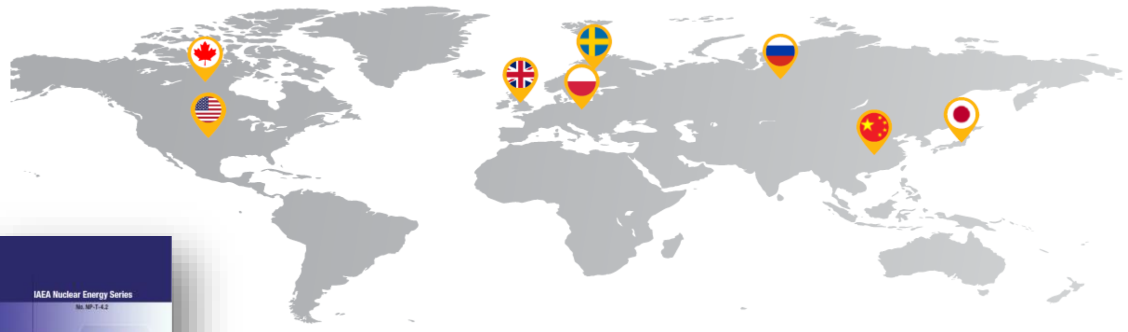


IAEA Guidance on Nuclear Energy Cogeneration,2019

Hydrogen production by nuclear

IAEA

Interest in hydrogen production using nuclear energy is growing internationally due to the potential to deliver electricity and heat for hydrogen synthesis in a sustainable, low carbon and cost effective manner.



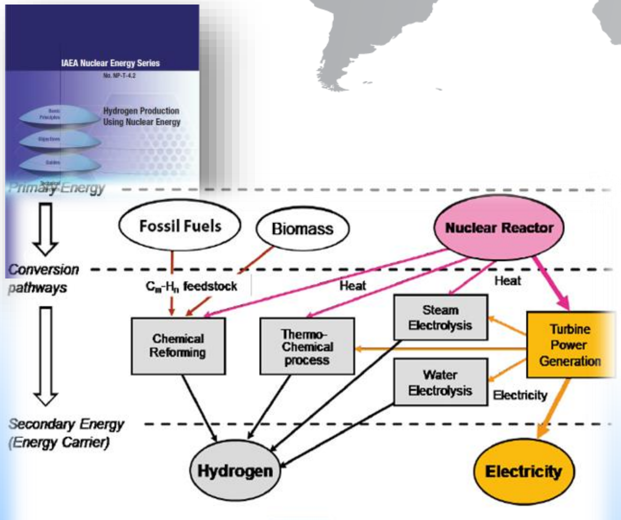


FIG. 8. Nuclear hydrogen cogeneration routes.

Hydrogen production using existing LWRs with electrolysers

USA

- DOE H2@Scale: public-private partnerships to advance flexible operation of LWRs with integrated H_2 production.
- Davis Besse NPP pilot using a 2 MW PEM electrolyser.
- Palo Verde NPP studying the potential of a reversible PEM electrolyser, producing electricity at peak demand and H_2 during periods of low demand.
- Exelon conducting demonstration of a 1 MW PEM electrolyser for H_2 production.

UK

- EDF confirmed the technical feasibility of low carbon hydrogen production at the Heysham NPP, but the project has not advanced to the demonstration phase.
- EDF is considering large scale hydrogen production powered by its UK nuclear plants, starting with a 2 MW demonstration electrolyser supplying H_2 to decarbonize construction at the Sizewell C project.

Russian Fed.

- Rosatom is launching a pilot project to produce hydrogen at the Kola NPP using matrix-alkaline electrolysis and will also develop hydrogen liquefaction units and liquid hydrogen transport equipment.

Canada

- The utility Bruce Power is exploring the technical feasibility and business case for nuclear hydrogen production at the Bruce Nuclear Generating Station to support the goal to achieve net zero emissions on site by 2027.

Sweden

- Vattenfall has been producing hydrogen at Ringhals NPP since 1997.
- Vattenfall, together with a steel producer (SSAB) and mining company (LKAB), has launched a new initiative to decarbonize steel production using low carbon electricity and hydrogen, with plans to produce 1 million tons of fossil-free steel per year by 2026.

R&D activities focused on hydrogen production with advanced reactors and SMRs

USA

- Under the Next-Generation Nuclear Plant (NGNP) project, DOE, the Idaho National Laboratory (INL) and industry partners are investigating two HTGRs with demonstrated potential for providing heat for hydrogen production.
- An evaluation by INL shows NuScale's 250 MW_{th} SMR could economically produce almost 50 t H_2/day, avoiding 168 kt CO_2 per year compared to H_2 from natural gas. A twelve-module plant could support a mid-

UK

- The Department of Business, Energy and Industrial Strategy (BEIS) is supporting several Advanced Modular Reactor technology projects, including U-Battery, a developer of HTGRs.

Russian Fed.

- Rosatom plans to commission an HTGR to produce hydrogen via the adiabatic conversion of methane with utilization of carbon dioxide by 2030.
- Thermochemical hydrogen production from water is also envisaged in the Russian Federation.

China

- The demonstration High Temperature Reactor Prototype Module, with a design temperature of 750°C, is expected to start operating at end of 2021, after successful cold tests in 2020.

Japan

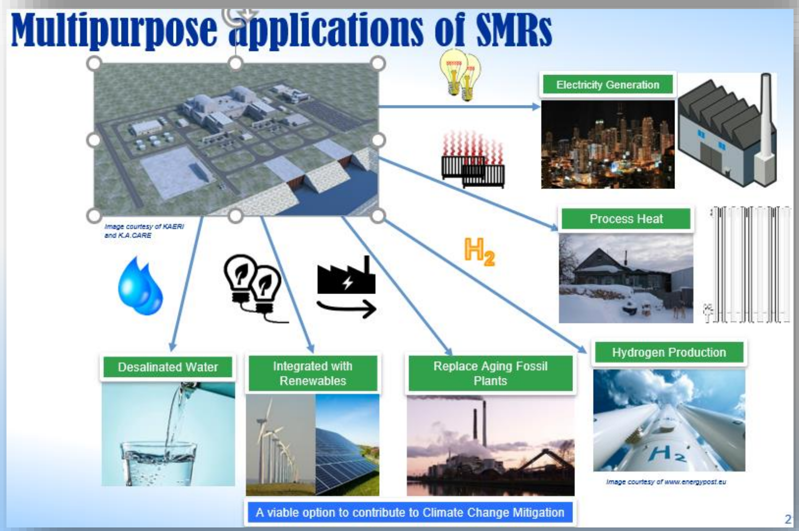
- Hydrogen production was demonstrated at the High Temperature Test Reactor using the iodine-sulphur thermochemical process in 2019.

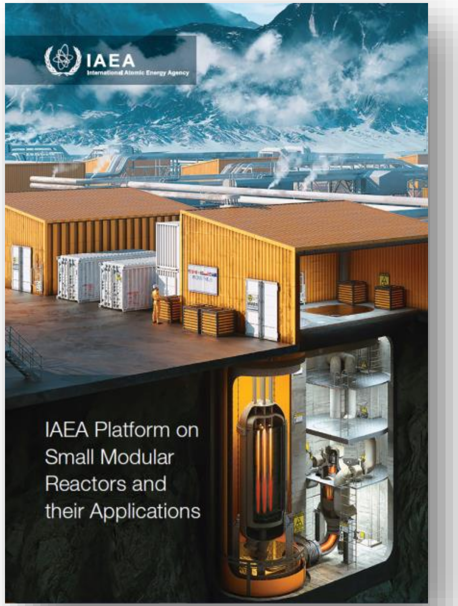
Poland

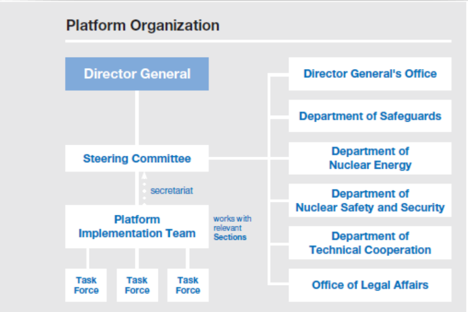
- The Polish National Center for Nuclear Research initiated a project to develop the HTGR reactor in cooperation with Japan.

IAEA and climate change

More climate change related programmatic activities, e.g., innovation for nuclear power and fuel cycle including SMR , techno-economic studies of energy system, case studies of nuclear hydrogen production, co-generation, hybrid system, stakeholder engagement, etc.





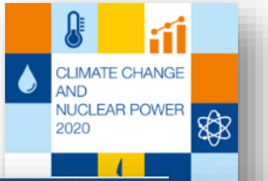


- *SMR platform on enabling factors of its deployment.*
- *One Initiative on harmonization and standardization aiming at facilitating SMR deployment.*
- *New Technical Working Group on nuclear power in low carbon energy system.*
- *Requests from MS to model transitions to net zero (energy supply MESSAGE tool)*
- *……*

IAEA and climate change (Con't)

"There is an increased recognition that nuclear is part of the solution and it will be part of the solution." ***IAEA DG Grossi at COP 26***

United Nations | HIGH-LEVEL DIALOGUE ON ENERGY
UNITED NATIONS, NEW YORK, SEPTEMBER 2021



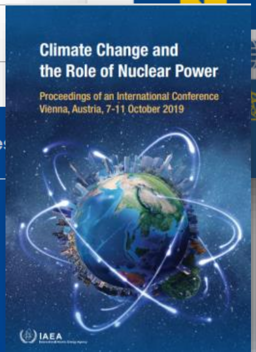
European Commission

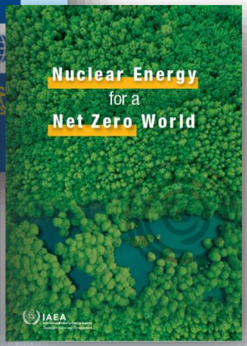
VIENNA ENERGY FORUM 2021

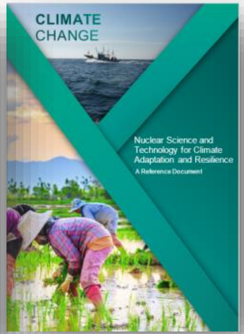
Home › Business, Economy, Euro › Banking and finance › Sustainable finance › EU taxonomy for sustainable activities

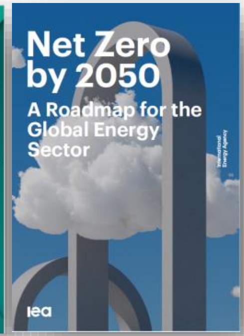
EU taxonomy for sustainable activities

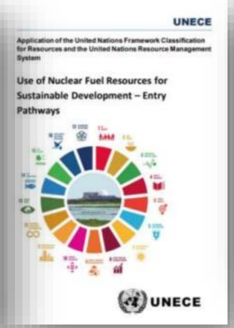
What the EU is doing to create an EU-wide classification system for sustainable activities

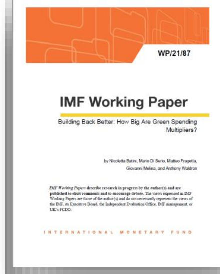












Take-aways

- *Ambitious decarbonization pathways to ensure net zero target achieved the Paris Agreement needs all stakeholders on board and all low carbon technologies at hand.*
- *Increasing recognition of nuclear energy not only as climate friendly low carbon energy option, but also as an enabler of broader, more resilient transformation.*
- *Challenges need to be addressed to release nuclear energy 's potential in net zero transition, including favorable regulatory and policy frameworks, innovative technology advancement, improved economic competitiveness, strengthened stakeholder engagement, etc.*
- *International cooperation will help to transfer IAEA high case projection and IEA NEZ scenario into a reality.*

Nuclear energy is and must be part of the solution to climate change

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Thank you!

Meet the Presenters

Dr. Shannon Bragg-Sitton is the Director for the Integrated Energy & Storage Systems Division in the Energy & Environment Science & Technology Directorate at Idaho National Laboratory, which includes Power and Energy Systems, Energy Storage and Electric Transportation, and Hydrogen and Electrochemistry departments. She also serves as the National Technical Director for the DOE Office of Nuclear Energy Integrated Energy Systems program. Dr. Bragg-Sitton is currently serving as the Chair of the Gen-IV International Forum interim Task Force (iTF) on Non-electric Applications of Nuclear Heat (NEaNH).

Shannon.bragg-sitton@inl.gov

Non-Electric Applications of Generation IV Reactors

Accelerating Economy-Wide Decarbonization via Nuclear Energy

Dr. Shannon Bragg-Sitton
Idaho National Laboratory, USA
Chair, GIF Task Force on Non-Electric Applications of Nuclear Heat

19 April 2022

The bottom line up front

- Today, operating nuclear plants and nuclear new-build projects are mainly GWe-size units for electricity generation
- There is worldwide development of reactors that will be available at smaller scale (micro- and small modular reactors [SMRs]), with many being advanced, high temperature designs
- Ambitious goals have been set for economy-wide decarbonization – power grid, industry, and transportation
  - → These goals are driving significant activity (and funding) around electrification <u>and</u> provision of heat and H_2—without emissions—to support energy demands
  - → Dispatchable nuclear energy can be complementary to a grid with high variable renewable penetration, while simultaneously producing non-electric energy products
- Economics of advanced and SMRs are yet to be confirmed, but we must provide solid information on these paradigm shifting products and systems for industry adoption

Advanced nuclear technologies can deliver broader, more flexible services than electricity production only. Their high power density and dispatchability is a huge asset for decarbonization, especially in combination with variable renewable energy sources.

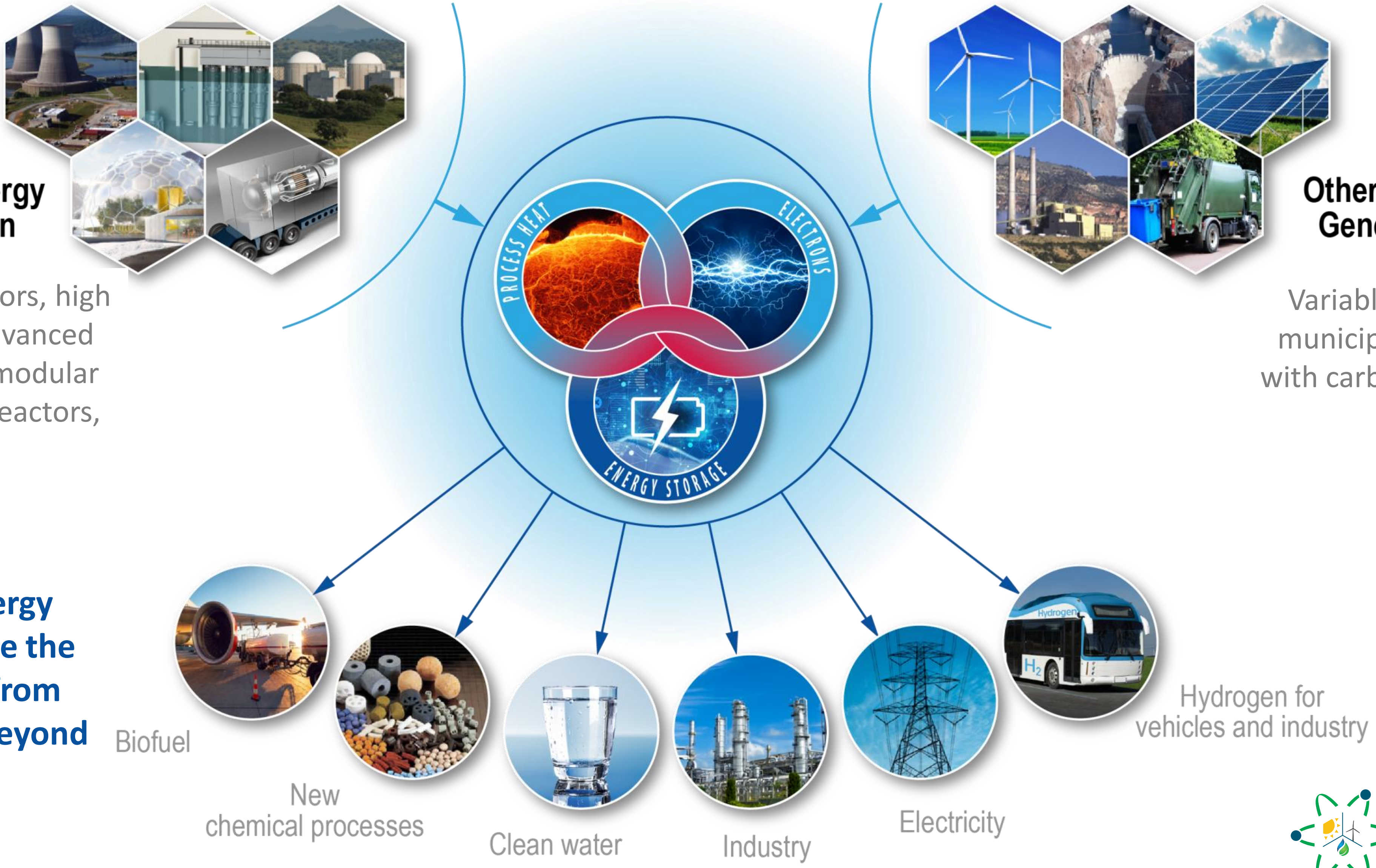
Future clean energy systems – transforming the energy paradigm

Nuclear Energy Generation

Light water reactors, high temperature advanced reactors, small modular reactors, microreactors, etc.

Other Energy Generation

Variable renewables, municipal waste, fossil with carbon capture, etc.

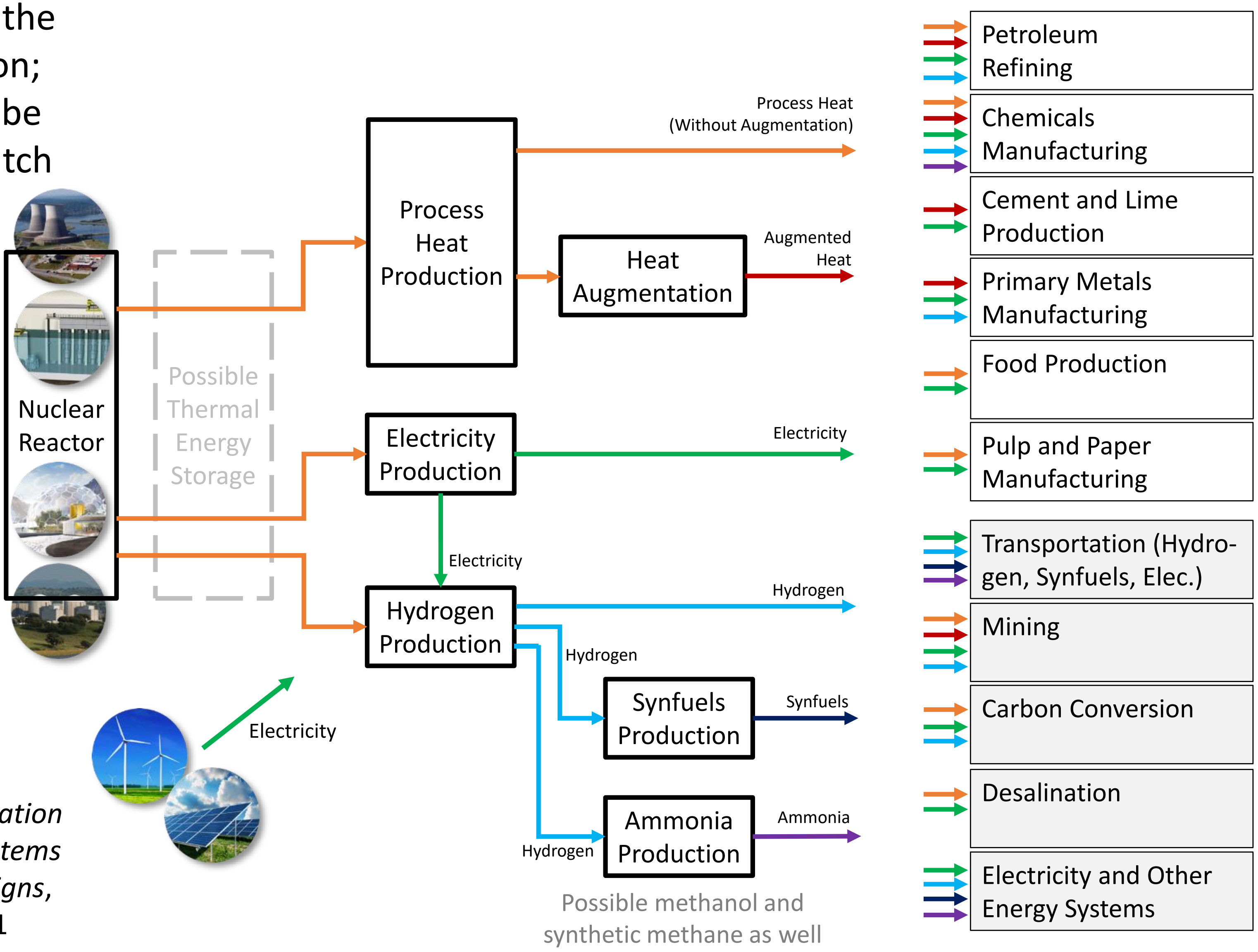


Integrated energy systems leverage the contributions from nuclear fission beyond electricity

IES Integrated Energy Systems

Summary of potential nuclear-driven IES opportunities

Reactor sizes align with the needs of each application; heat augmentation can be applied if needed to match process temperature demands.

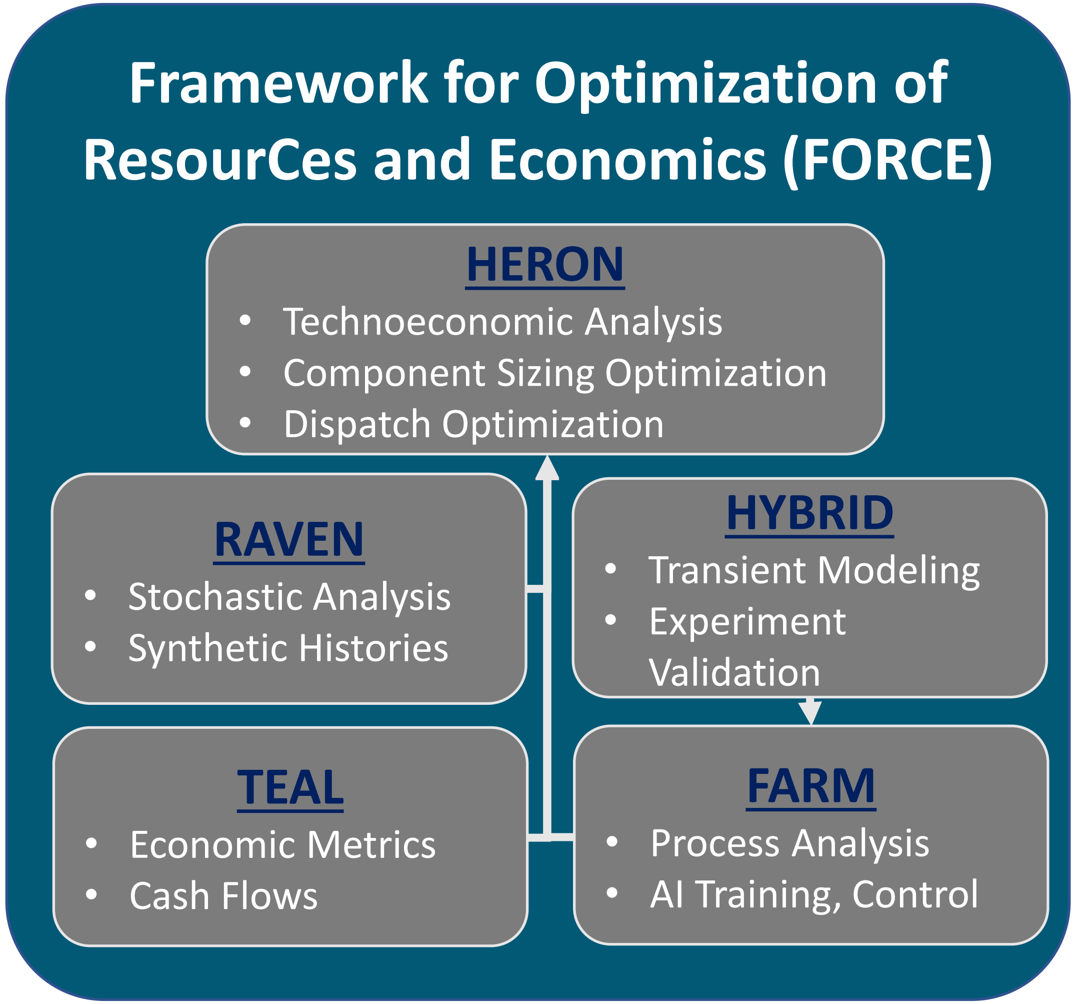


Source: INL, *National Reactor Innovation Center (NRIC) Integrated Energy Systems Demonstration Pre-Conceptual Designs*, INL EXT-21-61413, Rev. 1, April 2021

Integrated energy systems analysis and optimization

Technoeconomic Assessment

- Portfolio Optimization
- Dispatch Optimization
- Process Model Simulation
- Economic Analysis
- Supervisory Control
- Stochastic Analysis
- Workflow Automation

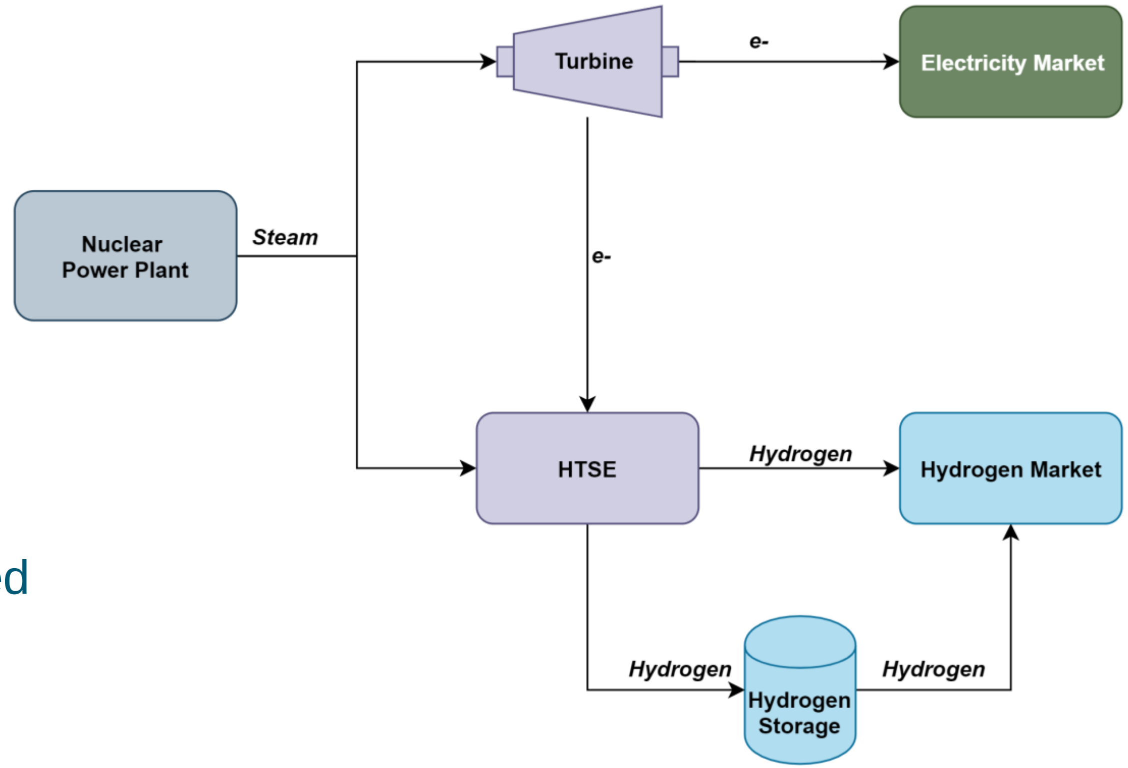


For more information and to access opensource tools, see https://ies.inl.gov/SitePages/System_Simulation.aspx.

IES
Integrated Energy Systems

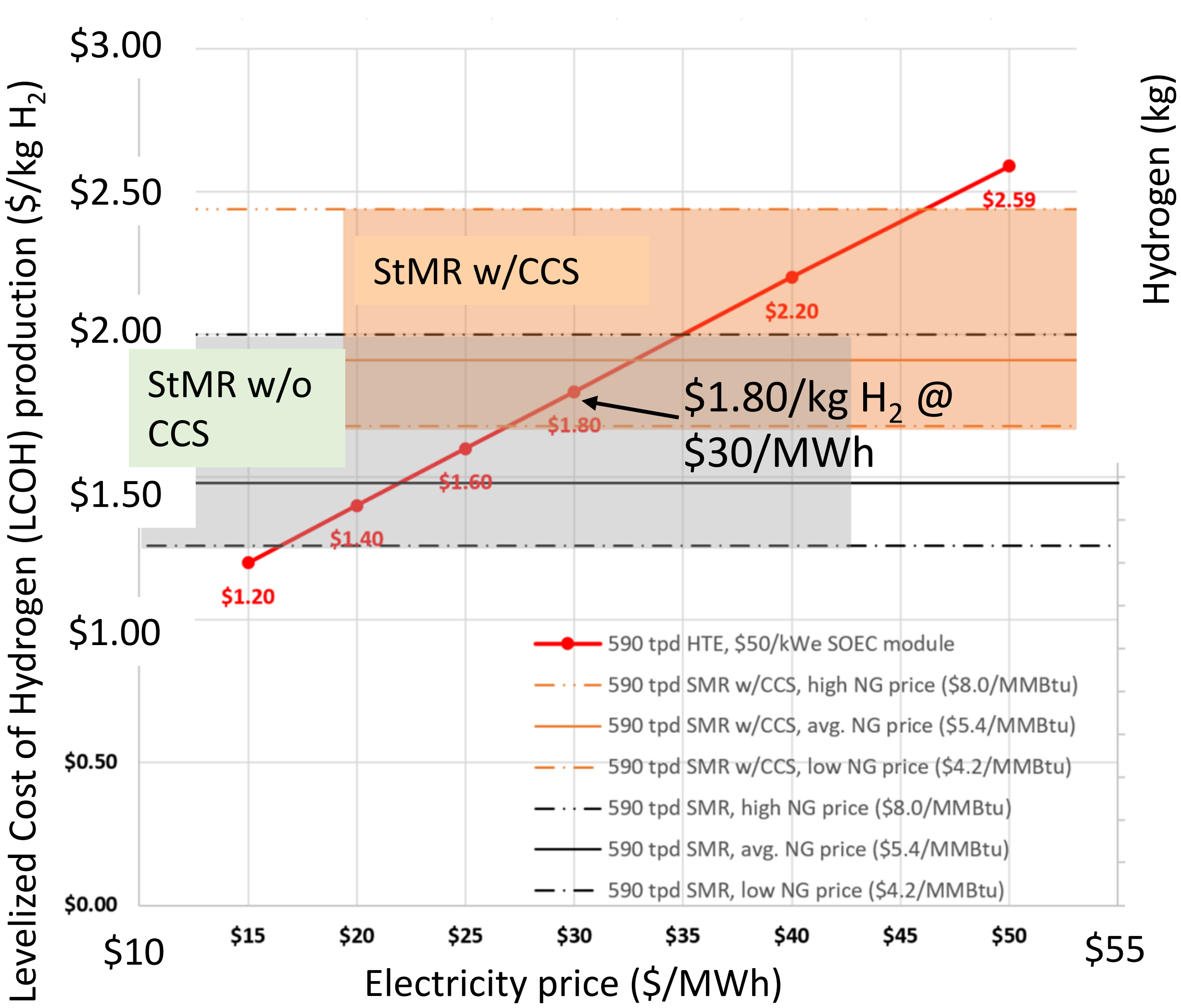
Example: Disruptive potential of nuclear produced H_2

- Collaboration between INL, ANL, NREL, Exelon, and Fuel Cell Energy
- **Goal:** Evaluate the potential of using existing nuclear plants to make hydrogen via high temperature steam electrolysis (HTSE) in parallel to grid electricity to enhance LWR economics
- **Approach:** Techno-economic analysis of HTSE process in selected operating modes and market conditions
  - Electricity only (business as usual)
  - Dynamic H_2 production (with H_2 storage to enable variable electricity and H_2 dispatch)
- **Assumptions**
  - HTSE does not thermally cycle
  - Dedicated H_2 transport pipelines
  - No subsidies for avoided emissions
  - Ancillary services market not considered
  - H_2 demand must always be met

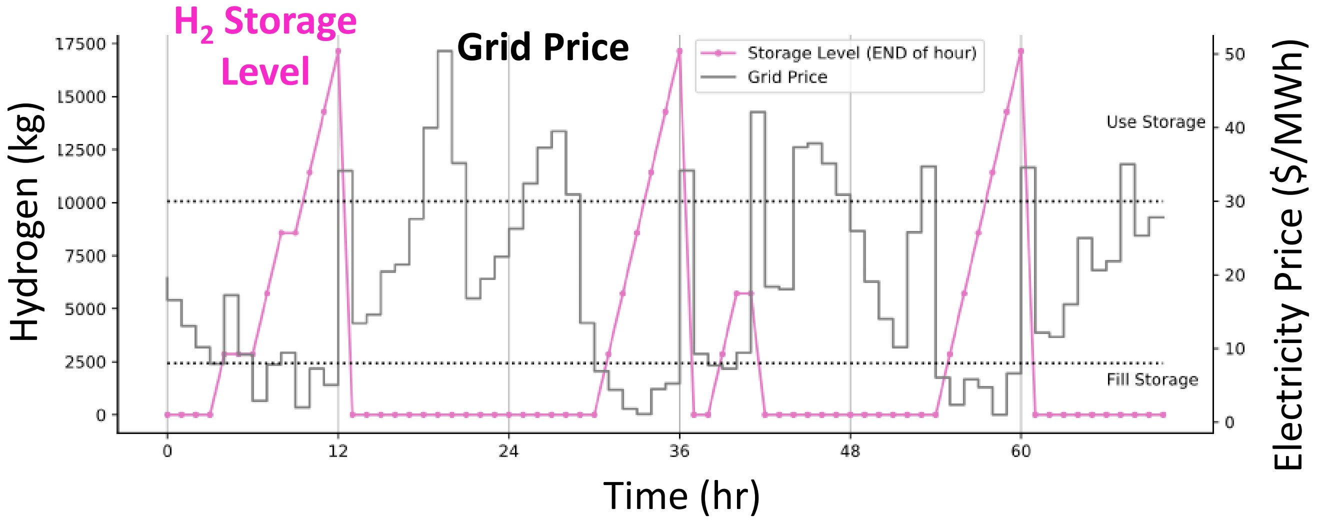


IES Integrated Energy Systems

Example: Disruptive potential of nuclear produced H_2



LWR-HTSE LCOH as a function of electricity price compared to the Steam Methane Reforming (StMR) plant (with and without carbon capture and sequestration [CCS]) LCOH with low, baseline, and high natural gas pricing.



- Analysis tools used to determine optimal dispatch of electricity to meet grid demand (high grid prices) or to produce H2 (low grid prices)
- H_2 is alternately stored or dispatched from storage to ensure the H_2 market demand is also met at all times

IES
Integrated Energy Systems

Example: Disruptive potential of nuclear produced H_2

- **Results**
  - Low grid pricing → hydrogen is more profitable
  - High grid pricing → sale to the grid is more profitable
  - H_2 storage provides flexibility in plant operations, ensures that all demands are met
  - H_2 off-take satisfies demand across steel manufacturing, ammonia and fertilizer production, and fuel cells for transportation
- Analysis results suggest a possible revenue increase of $**1.2 billion ($2019)** over a 17-year span

Nine Mile Point
Nuclear Power Plant
LTE/PEM Vendor

- **Outcome:** Award from the DOE EERE Hydrogen & Fuel Cell Technologies Office with joint Nuclear Energy funding for follow-on work and low temperature electrolysis demonstration at the Constellation Nine-Mile Point plant; anticipate hydrogen production ~Fall 2022
- **Full report:** Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest (INL/EXT-19-55395)

IES Integrated Energy Systems

Nuclear-H_2 demonstration projects

Four projects have been selected for demonstration of hydrogen production at U.S. nuclear power plants (NPP)

- H_2 production using direct electrical power offtake
- Develop monitoring and controls procedures for scaleup to large commercial-scale H_2 plants
- Evaluate power offtake dynamics on NPP power transmission stations to avoid NPP flexible operations
- Produce H_2 for captive use by NPPs and clean hydrogen markets

Projects

- **Constellation:** Nine-Mile Point NPP (~1 MWe LTE/PEM)
- **Energy Harbor:** Davis-Besse NPP (~1-2MWe LTE/PEM)
- **Xcel Energy:** Prairie Island or Monticello NPP (~150 kWe HTSE)
- **APS/Pinnacle West Hydrogen:** Palo Verde Generating Station (~15-20 MWe LTE/PEM)
- **Fuel Cell Energy:** Demonstration at INL (250 kWe)

Nine Mile Point NPP LTE/PEM

Davis-Besse NPP LTE-PEM

Thermal & Electrical Integration at an Xcel Energy NPP HTSE/SOEC

Prairie Island

Monticello

Palo Verde Generating Station, H_2 Production for Combustion and Synthetic Fuels

Progress in flexible thermal and electrical power dispatch

- The INL Human Systems Simulation Laboratory was used to test concepts for dispatching thermal and electrical power from nuclear reactors to a hydrogen electrolysis plant
  - Two formerly licensed operators tested 15 scenarios
  - A modified full-scope generic Pressurized Water Reactor was used to emulate the nuclear power plant
  - A prototype human-system interface was developed and displayed in tandem with the virtual analog panels
  - An interdisciplinary team of operations experts, nuclear engineers, and human factors experts observed the operators performing the scenarios
- This exercise emphasized the need to support the adoption of thermal power dispatch through
  - Leveraging automation to augment any additional operator tasking
  - Monitoring energy dispatch to a second user

LWRS LIGHT WATER REACTOR SUSTAINABILITY

IES Integrated Energy Systems

PRA for thermal integration of steam electrolysis: Summary conclusions

- Generic probabilistic risk assessment (PRA) investigation into licensing considerations
- Identified top hazards
  - Internal: Steam line break, loss of offsite power
  - External: HTE H_2 leak or H_2 detonation
- Key conclusions
  - Licensing criteria is met for a large-scale HTE facility sited 1 km from a generic PWR and BWR
  - Safety case for less than 1 km distance is achievable
- Other insights
  - Individual site NPP and geographical features can affect the results of the generic PRA positively or negatively
  - Generic PRAs in the study are examples for official site studies for use in licensing

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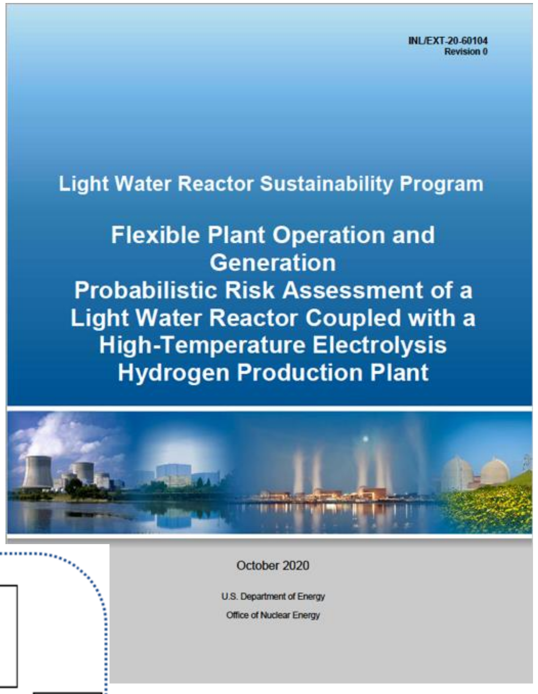
OSTI link: https://www.osti.gov/biblio/1691486


INL/EXT-20-60104
Revision 0

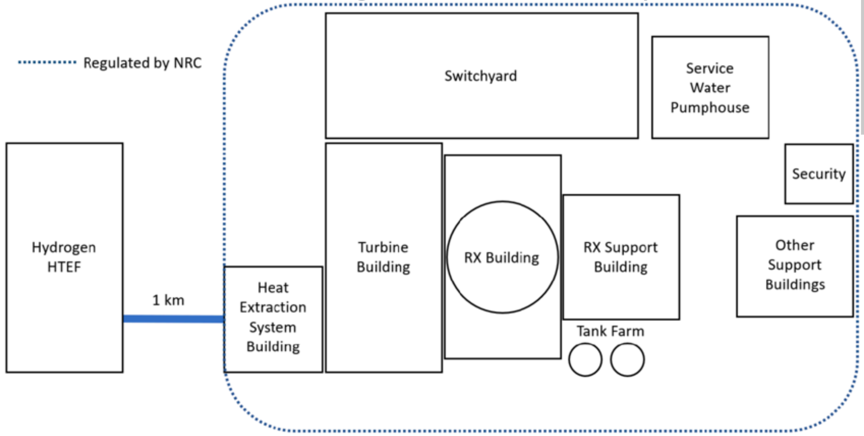
Light Water Reactor Sustainability Program

Flexible Plant Operation and Generation
Probabilistic Risk Assessment of a Light Water Reactor Coupled with a High-Temperature Electrolysis Hydrogen Production Plant

October 2020

U.S. Department of Energy
Office of Nuclear Energy

NRC jurisdictional boundary for LWR servicing an HTE facility



Advanced reactor IES case studies (FY22)

- **Thermal energy storage:** Utilization of thermal energy storage to support electrical markets and/or industrial integration
- **Synthetic fuel production:** Nuclear heat and steam to produce hydrogen; then, as a feedstock, the hydrogen is used in conjunction with a CO2 source to produce various high value synthetic fuels via the Fischer-Tropsch process
- **Carbon conversion:** Nuclear heat and steam to convert coal, as a feedstock, into valuable products for a variety of carbon markets

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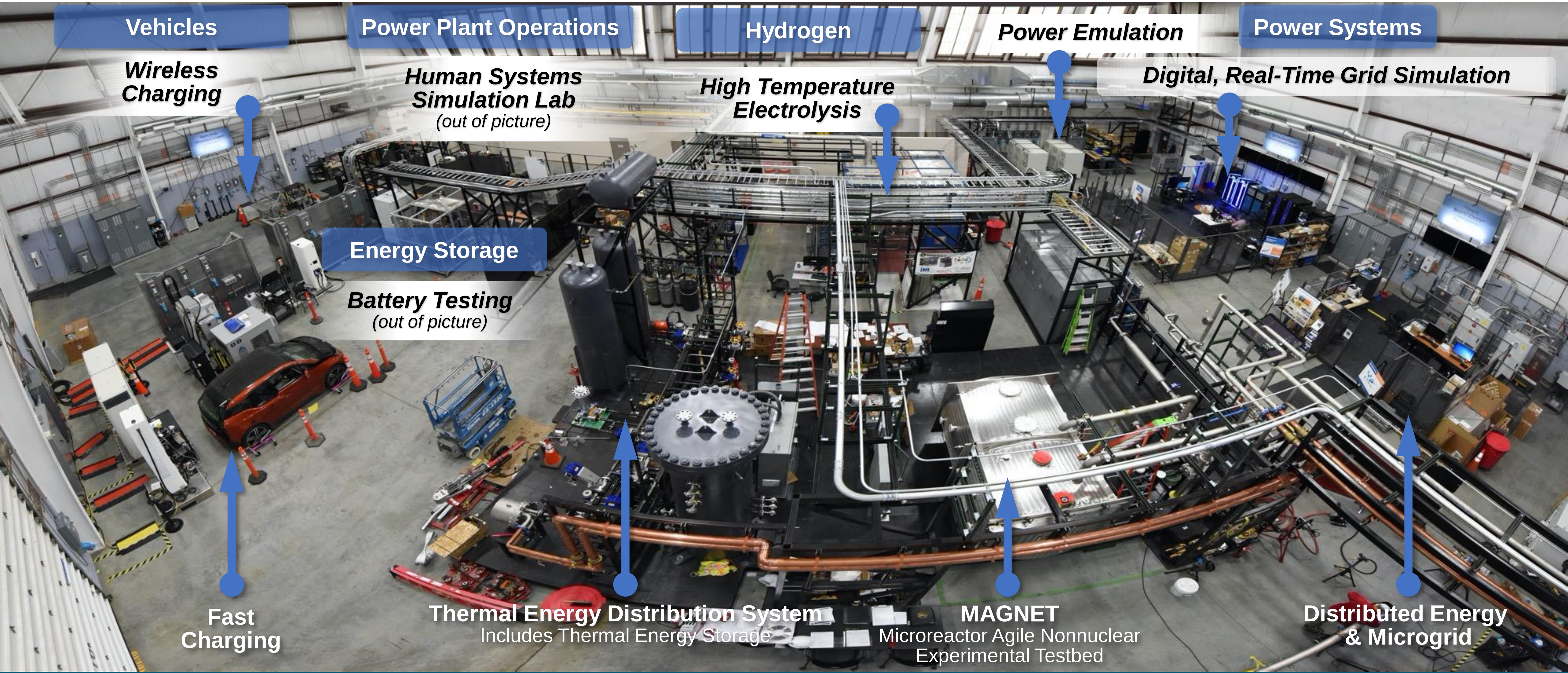
Experimental evaluation:

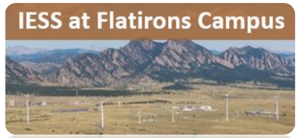
Model validation, technology demonstration, performance characterization, control system development

Dynamic Energy Transport and Integration Laboratory (DETAIL) for electrically heated testing of integrated systems



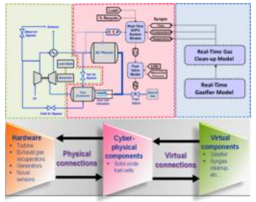
DETAIL enables cross-complex laboratory connections

ARIES



NREL
Transforming ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY



Power Hardware and Grid-in-the-Loop

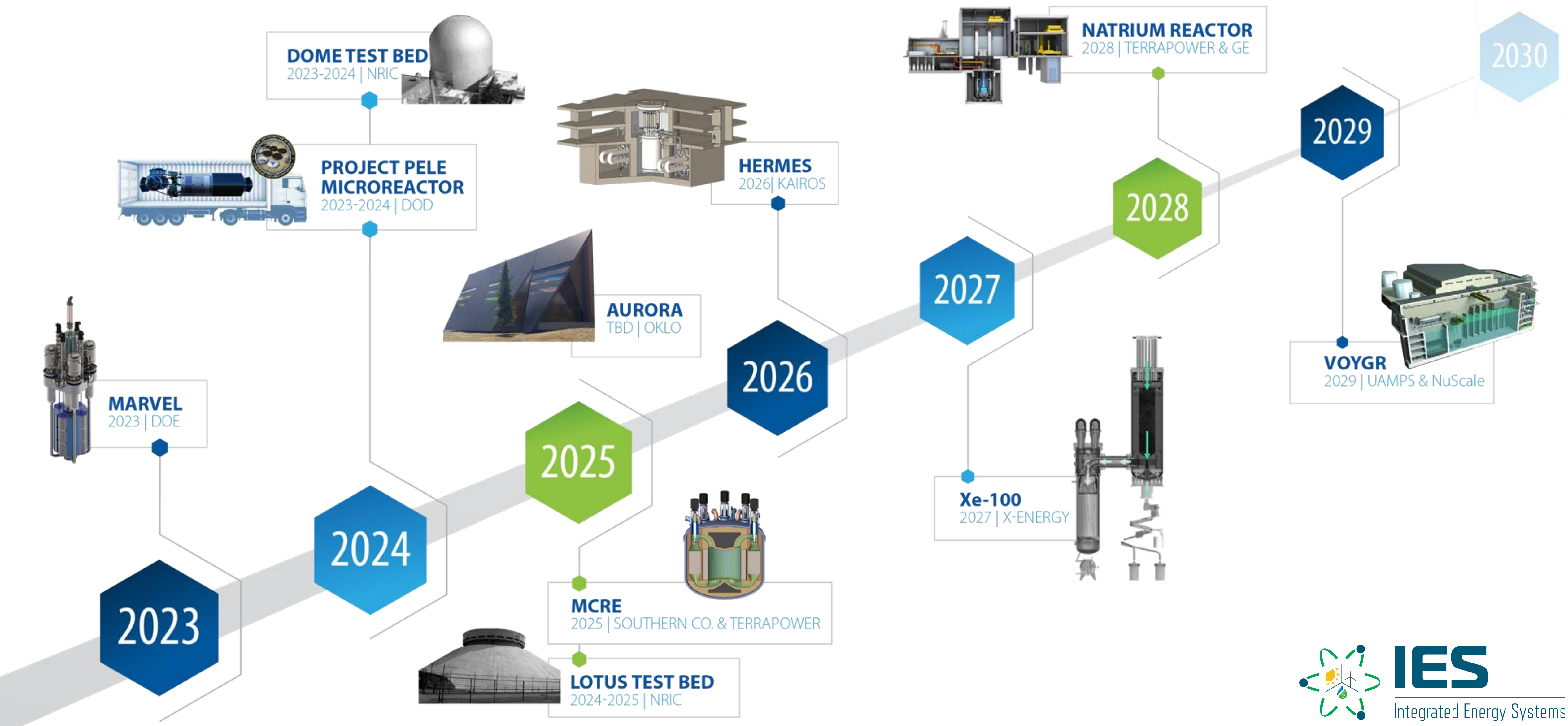
Human-in-the-Loop

Hydrogen and other Flexible Industrial Processes

Thermal Energy Generation and Transport

IES
Integrated Energy Systems

Accelerating advanced reactor demonstration & deployment



IES
Integrated Energy Systems

GIF Task Force on Non-Electric applications of Nuclear Heat (NEaNH-TF)

- Decarbonization of electricity is by far insufficient to meet GHG emission reduction targets
- Non-electric sectors in industry and transport can be weaned from fossil fuel by heat or low-carbon energy carriers (e.g., process steam, H_2, syngas, methanol etc.)

  → Cheap fossil fuel can no longer remain a competitor in these sectors
- GIF-type SMRs can be employed for cogeneration and integration in energy markets with high fractions of renewables; numerous concepts under development and available in literature
- NEANH TF will identify and review these systems, and develop key performance indicators, e.g.,
  - Technology Readiness Level (TRL)
  - Timeliness
  - Adaptability to geographical conditions
  - CO_2 emission reduction potential
  - Cost/Benefit ($/t CO_2 saved)
  - Boundary conditions for economic viability

Anticipated outcomes:

- Clarify challenges and constraints
- Provide guidance to the energy communities
- Propose R&D to accelerate development and deployment

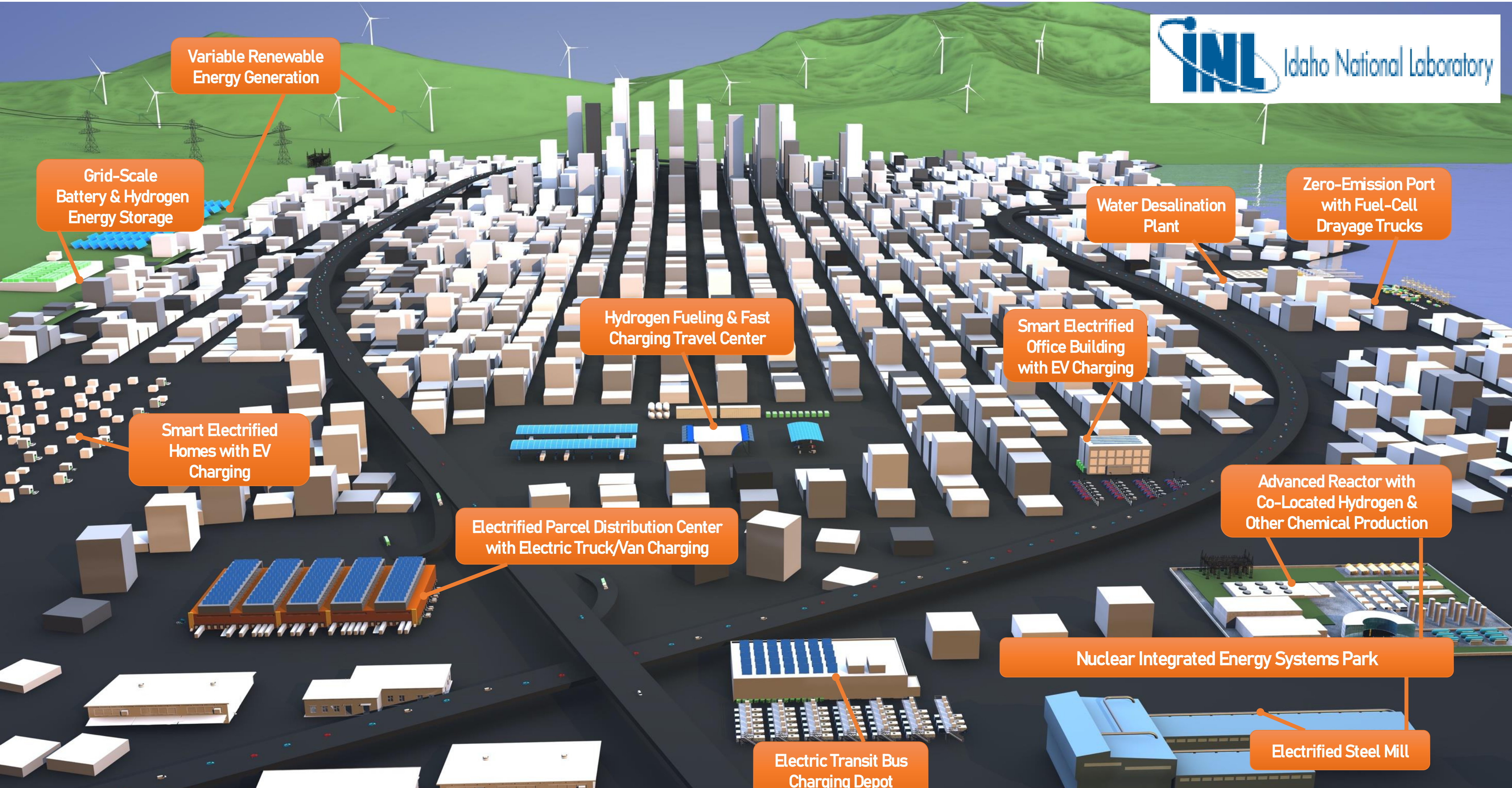
GEN IV International Forum
Expertise | Collaboration | Excellence

Key questions to be addressed by NEaNH

- What are the potential assets/benefits of integrated, multi-output systems (a.k.a. “hybrid” systems)?
- What are regionally optimal NEaNH solutions with GIF technology systems?
- What are “optimum” combinations, as a function of deployment location?
  - Reactor type, size
  - Energy applications
- How do the different advanced reactor technologies compare with regard to potential for supporting non-electric process applications?

Many different options under evaluation

Distributed energy systems for a net-zero future



Upcoming Webinars

Date	Title	Presenter
11 May 2022	Development of Nanosized Carbide Dispersed Advanced Radiation Resistant Austenitic Stainless Steel (ARES) for Generation IV Systems	Mr. Jiho Shin, KAIST, Republic of Korea
15 June 2022	Nuclear Waste Management Strategy for Molten Salt Reactor Systems	Dr. John Vienna & Dr. Brian Riley, PNNL, USA
27 July 2022	A Gas Cherenkov Muon Spectrometer for Nuclear Security Applications	Mr. Junghyun Bae, Purdue University, Winner of the 2021 ANS Pitch Your PhD Competition