Nuclear Energy Innovation:

Meeting the Challenges of the Future

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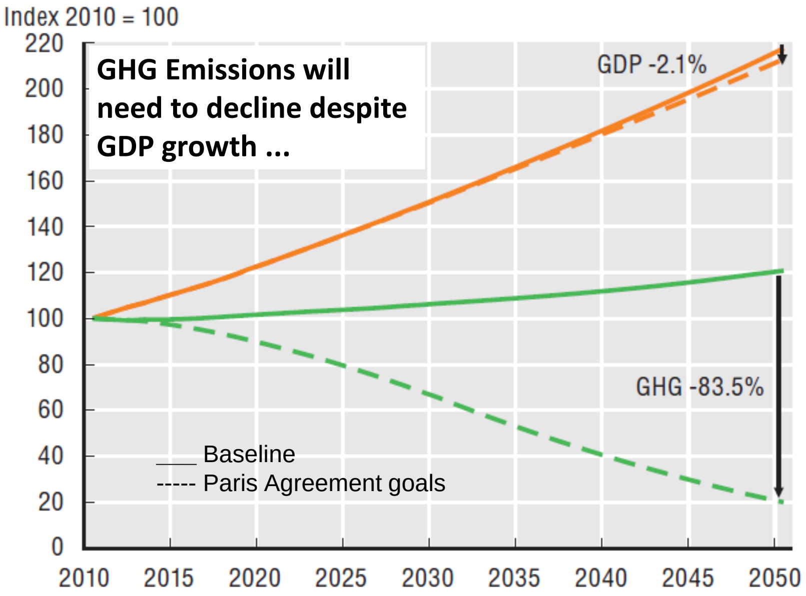
The NEA: 33 Countries Seeking Excellence in Nuclear Safety, Technology, and Policy

- 33 member countries + strategic partners (e.g., China, India, etc.)
- 8 standing technical committees of government leaders and over 80 working parties and expert groups
- 23 international joint projects

Paris Agreement Implies a 50 gCO2/kWh Target

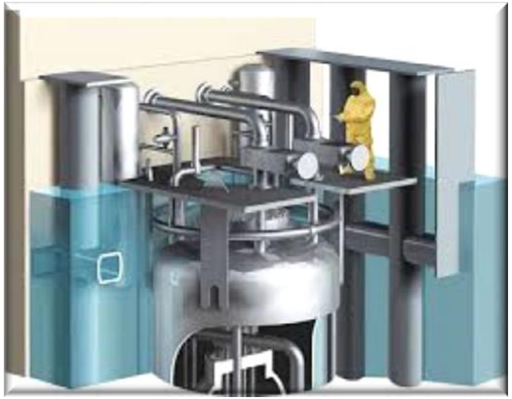


Source: OECD Environmental Outlook

- Paris Agreement is intended to hold "increase in global average temperature to well below 2°C".
- Current emission intensity is **570 gCO2/kWh** - target is **50 gCO2/kWh**
- Electricity contributes 40% of global CO2 emissions and will play key role. Annual emissions from electricity will need to decline 73% (global) and 85% (OECD countries).

Key Observations

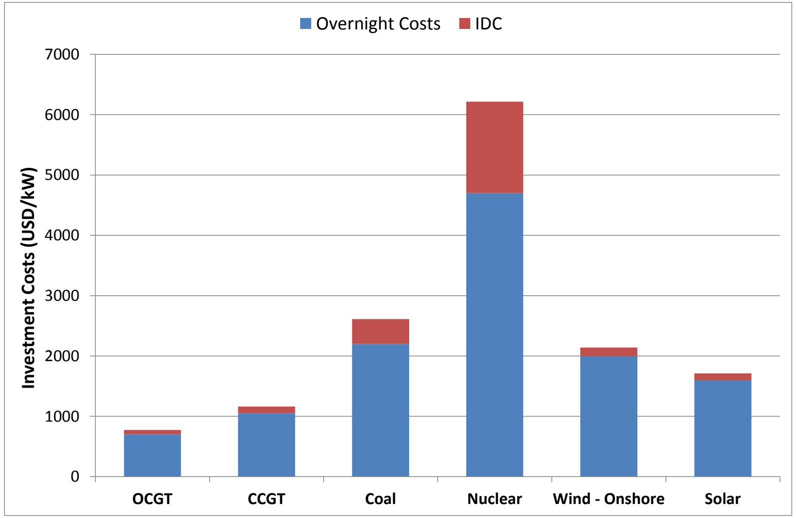
- Large deployment of VRE will occur around the world and provide important benefits.
- According to Eurostat, CO_2 emissions in the EU increased **1.8 percent in 2017** despite a 25 percent increase in wind power and 6 percent growth in solar.
- The IEA reports energy-related CO_2 emissions reached a new high of 33.1 Gt in 2018, up 1.7% from 2017.
- Finding the right approach to long-term, economic and reliable electricity supply is be the central challenge to the decarbonization the future global economy.



Recent NEA Work: *Broad Conclusions*

- To meet global energy and environmental requirements, all low-carbon technologies must be optimally applied—with all costs accurately allocated.
- The electricity markets must be modernized. Existing market structures make investment in any unsubsidised low-carbon technology very difficult.
- Large deployment of VRE will occur around the world – but the contribution of VRE in each country will depend on the cost of available resources.
- To the degree dispatchable capacity is needed, nuclear can serve a large role—if it is economically compatible with evolving markets.

Nuclear Competitiveness Depends on Capital Costs



Overnight Construction Costs for Plants Built in 2020

Source: NEA

- In today's market, the capital cost of nuclear power is a major issue—LCOE is NOT driving decisions.
- Lack of construction experience in Western countries and weak supply chains make cost and schedules uncertain.
- As the costs of alternatives drop, these high costs become unsustainable.

New Technologies May Provide Solutions

- ***Small Single-unit and Modular LWRs***
  - **Low cost modules can be installed as needed**
  - **Higher flexibility**
  - **Manufacturability increases quality and reduces cost and risk**
  - **Safety characteristics may dispense with need for offsite EP**
- ***Mobile SMRs***
- ***Micro Modular Reactors (MMRs)***
- ***Generation IV reactors***
  - **Next generation technologies beyond LWR**

GROWING GLOBAL INTEREST IN SMRS

- **First technologies now nearing regulatory approval**
- **Major technology projects underway in US, France, UK, Russia, and other countries**
- **High interest in both OECD countries and emerging economies**

NuScale Conceptual Design

Design	Net output per module (MWe)	Number of modules (if applicable)	Type	Designer	Country	Status
Single Unit LWRs						
CAREM	30	1	PWR	CNEA	Argentina	Under construction
SMART	100	1	PWR	KAERI	Korea	Certified design
ACP100	125	1	PWR	CNNC	China	Construction start planned for end of 2019
SMR-160	160	1	PWR	Holtec International	United States	Conceptual design
BWRX-300	300	1	BWR	GE Hitachi	United States-Japan	Conceptual design
UK SMR	450	1	PWR	Rolls Royce	United Kingdom	Conceptual design

SMR Categories: *Single Unit LWRs*

- **Lowest risks to deployment**
- **Some provide game-changing safety performance**
- **Cost-effectiveness remains to be verified**

Adapted from Oct 2019 Background Note to the Steering Committee on Nuclear Energy and IAEA Analyses

SMR Categories: *Multi-module LWRs*

Design	Net output per module (MWe)	Number of modules (if applicable)	Type	Designer	Country	Status
Multi-module LWR SMRs						
NuScale	70	12	PWR	NuScale Power	United States	Detailed design and ongoing licensing process, FOAK planned in mid-2020s
RITM-200	50	2	PWR	OKBM Afrikantov	Russia	Land-based NPP under conceptual design
Nuward	170	2 to 4	PWR	CEA/EDF/ Naval Group/ TechnicAtome	France	Conceptual Design

- **Lowest risks to deployment**
- **Some provide game-changing safety performance**
- **Cost-effectiveness remains to be verified**

Adapted from Oct 2019 Background Note to the Steering Committee on Nuclear Energy and IAEA Analyses

SMR Categories: *Mobile SMRs*

Design	Net output per module (MWe)	Number of modules (if applicable)	Type	Designer	Country	Status
Mobile SMRs						
ACPR50S	60	1	Floating PWR	CGN	China	Under construction
KLT-40S	70	2	Floating PWR	OKBM Afrikantov	Russia	Pre-commission-ing testing

Adapted from Oct 2019 Background Note to the Steering Committee on Nuclear Energy and IAEA Analyses

- **Thus far based on adapted LWR technologies (i.e., icebreaker reactors)**
- **Uncertainties regarding regulatory and legal approach**
- **Cost-effectiveness remains to be verified**

SMR Categories: *MMRs*

Design	Net output per module (MWe)	Number of modules (if applicable)	Type	Designer	Country	Status
Micro Modular Reactors (MMRs)						
eVinci	0.2-5	1	Heat pipe reactor	Westinghouse	United States	Basic design
Oklo	2	1	LMFR	Oklo	United States	Basic design
UBattery	4	1	HTGR	Urenco and partners	United Kingdom	Basic design
MMR	5-10	1	HTGR	USNC	United States	Basic design
LFR-TL-X	5-20	1	LMFR	Hydromine Nuclear Energy	Luxembourg	Conceptual design

Adapted from Oct 2019 Background Note to the Steering Committee on Nuclear Energy and IAEA Analyses

- **Many regulatory issues to be resolved**
- **Non-LWR technologies**
- **Uncertainties regarding acceptance by security officials**
- **Cost-effectiveness remains to be verified**

Design	Net output per module (MWe)	Number of modules (if applicable)	Type	Designer	Country	Status
Generation IV SMRs						
4S	10	1	LMFR	Toshiba	Japan	Detailed design
CA Waste Burner	20	1	MSR	Copenhagen atomics	Denmark	Conceptual design
Xe-100	35	1	HTGR	X-energy LLC	United States	Conceptual design
ARC-100	100	1	LMFR	Advanced Reactor Concepts LLC	Canada	Conceptual design
KP-FHR	140	1	MSR	Kairos Power	United States	Pre-conceptual design
IMSR	190	1	MSR	Terrestrial Energy	Canada	Basic design
HTR-PM	210	2	HTGR	China Huaneng / CNEC/Tsinghua University	China	Under construction
ThorCon	250	1	MSR	Martingale Inc	United States	Basic design
EM2	265	1	GMFR	General Atomics	United States	Conceptual design
SC-HTGR	272	1	HTGR	Framatome	United States	Conceptual design
Stable Salt reactor	300	1	MSR	Moltex Energy	United Kingdom	Pre-conceptual design
Westinghouse lead fast reactor	450	1	LMFR	Westinghouse	United States	Conceptual design

SMR Categories: *Generation IV*

- **Many regulatory issues to be resolved**
- **Most technologies still conceptual**
- **Non-LWR technologies**
- **Cost-effectiveness remains to be verified**

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Deploying Advanced SMRs is Global Challenge

- Development and licencing of most technologies will be very expensive; some development, testing, and licencing costs could be shared

- Strategies for global deployment are highly desirable:
  - *Success for small reactors requires significant production runs; good economies of sale are difficult if they are effectively limited to home markets*
  - *Like aircraft and other high-investment products, access to global markets is essential*

- Regulators can become a showstopper if requirements are different in each country

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

If action on climate is associated with limits to life, economic growth, and freedom, success will be difficult. Nuclear energy can be a vital part of a positive solution set – if it can succeed in 21st Century markets.

Thank you for your attention

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