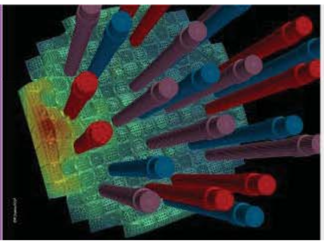


FISA 2022

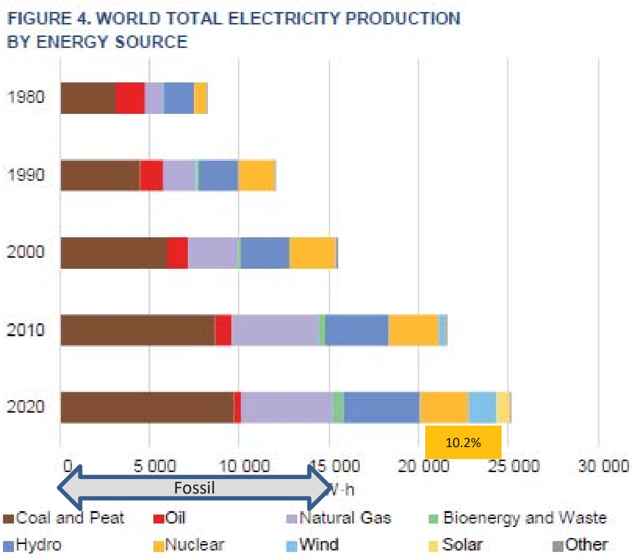
30 May - 3 June 2022
Lyon, France

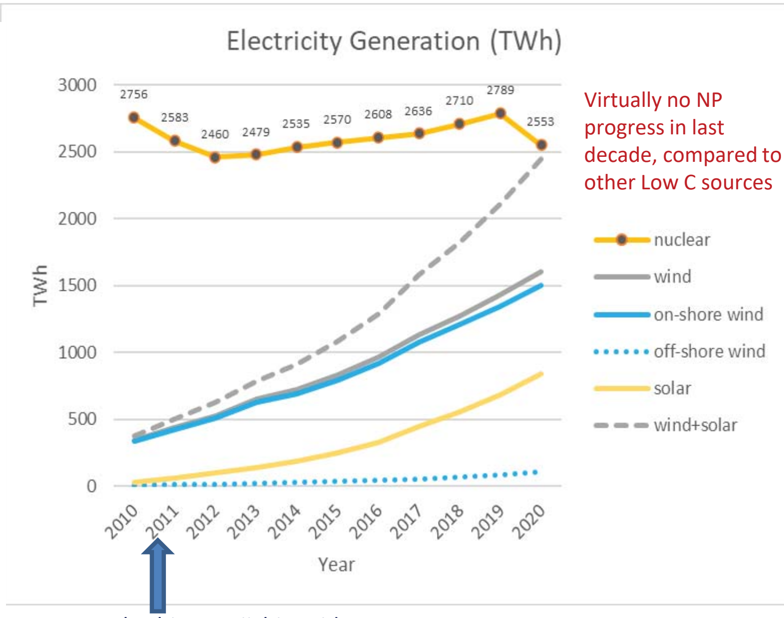
Global Trends in Nuclear Power:

Advanced Reactors Including SMRs: Challenges and Opportunities for Increased Sustainability

Stefano MONTI
Head of Nuclear Power Technology Development Section
International Atomic Energy Agency

Electricity generation still dominated by fossil fuels (>60%)



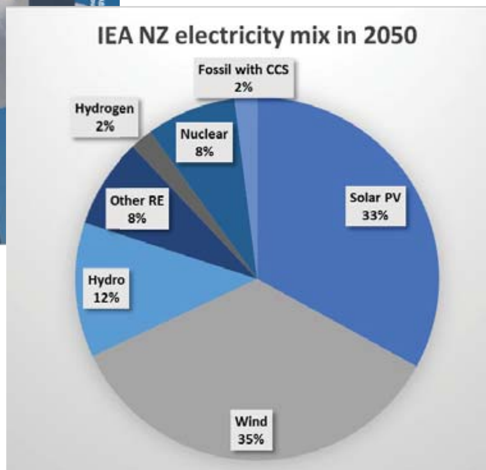


Fukushima Daiichi accident,
11 March 2011

IAEA and IEA data

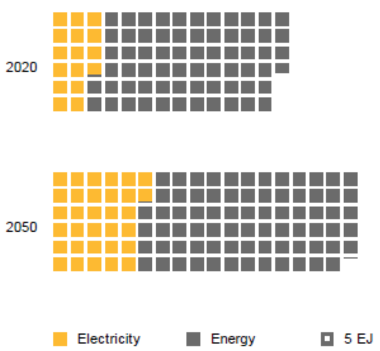
IEA Roadmap to Net Zero (May 2021)

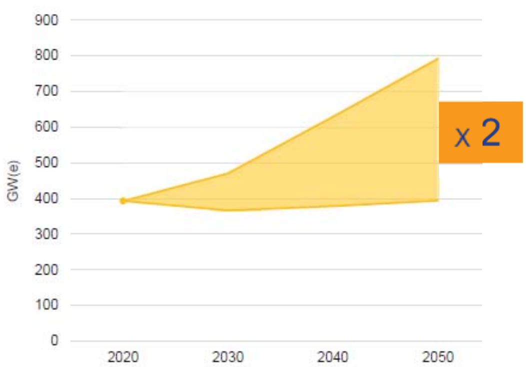
- Very little fossil in the mix → roadmap is massive deployment of renewables + **doubling of nuclear generation by 2050**
- High level of electrification (demand x 2.5)
- Nuclear generation (x 2) – share in electricity mix 10% to 8%
- Share of nuclear in heat 4%

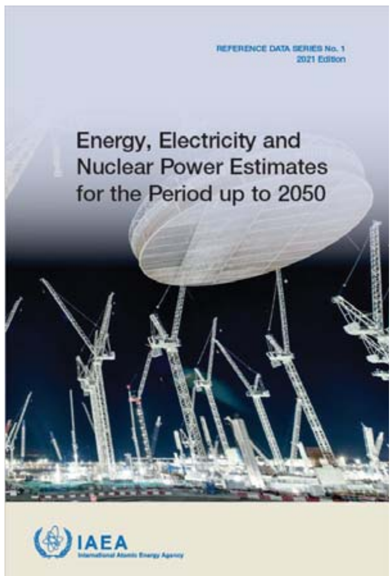


IAEA projections to 2050

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







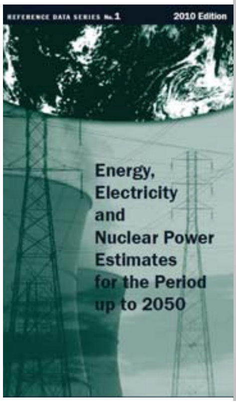
- Electricity consumption expected to double
- Share of electricity in energy consumption increases by 10 pts

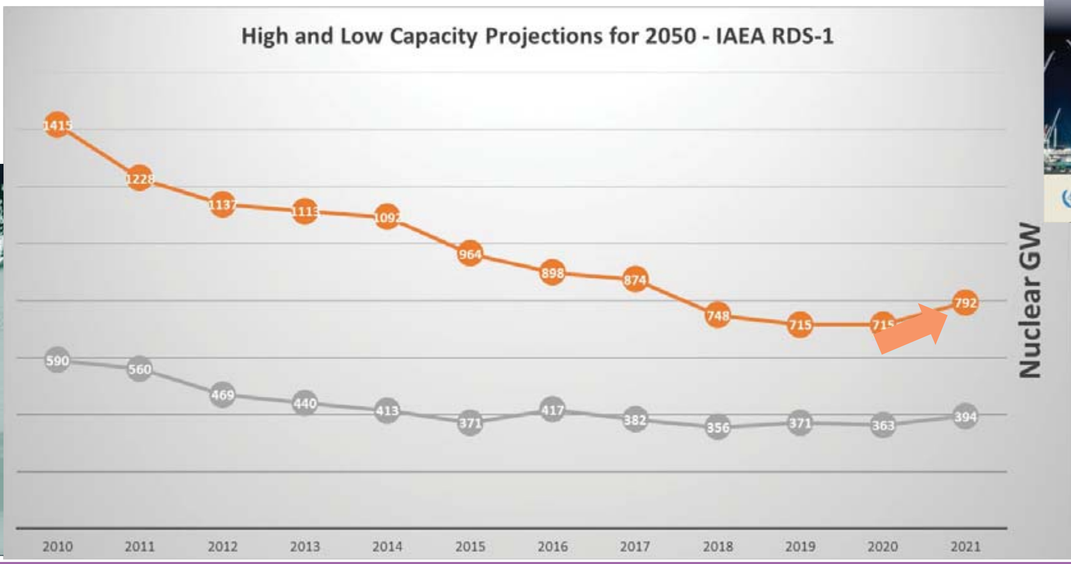
- High case: **More than doubling of nuclear capacity**, share slightly lower than 10%
- Low case: capacity by 2050 equal to 2020, share ~7.5%

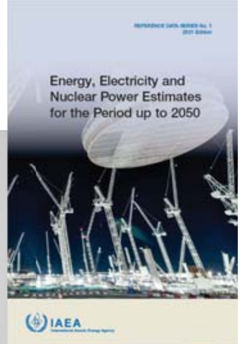
Released Sept. 2021

History of projections: 2021, one-off or the start of a trend?

[IAEA Increases Projections for Nuclear Power Use in 2050 | IAEA]



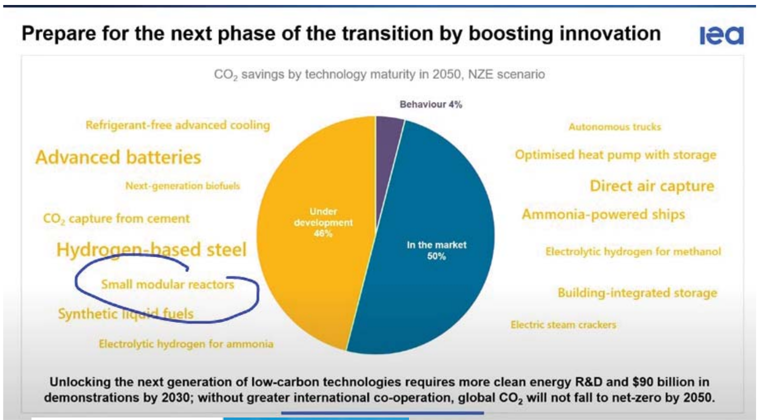


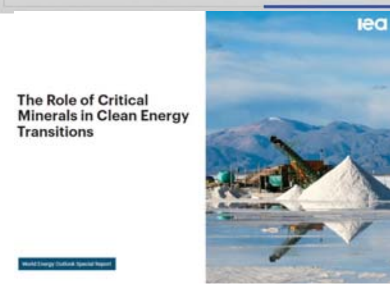


IEA Roadmap to Net Zero

2 important caveats:

1. Nearly half of the emissions reductions to 2050 come from **technologies that are not yet commercialized** → need to accelerate demonstration → market
   - For nuclear, this means the **demonstration & commercialisation of advanced reactor technologies (and fuel cycles)**
2. Issue of **supply of critical minerals**
   - More an issue for renewables (wind, solar) and grid and battery technologies than for nuclear power

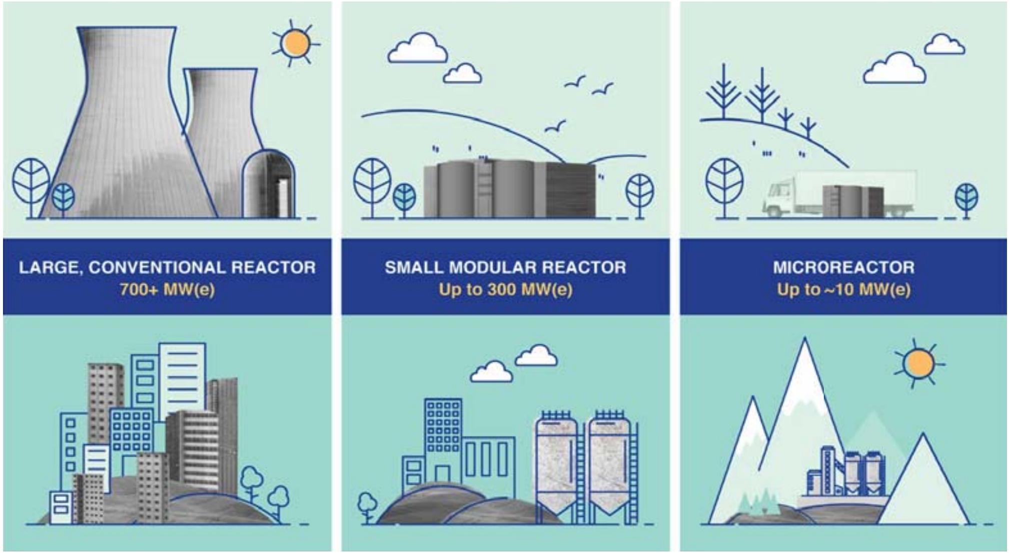




Nuclear energy is one of the low-C technologies with the lowest (critical) mineral intensity

Small Modular Reactor (SMR) Technology

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



- Modular construction
- Ability to fabricate major components of the nuclear steam supply system in a factory environment and ship to the point of use
- Limited on-site preparation
- Substantially reduce the lengthy construction times
- Multi- module as per energy demand

SMR – Deployment Horizon by 2030

SMRs at advanced stage:

1 in commercial operation
1 connected to grid
2 under construction
1 received SDA from U.S. NRC

HTR-PM first unit connected to grid on 20 Dec. 2021, commercial operation expected in **2022**

CAREM-25 construction halted in 2019, then restarted in 2019, expected to start **operation in 2023**

KLT-40S connected to the grid in Dec. 2019, started **commercial operation** at the end of **May 2020**

ACP100 construction officially started on 13 July 2021, at Changjiang NPP in Hainan province, scheduled commercial operation by the end of **2026**

NuScale received SDA issued by U.S.NRC in Sept. 2020. The first module is expected to be operational by **mid-2029**

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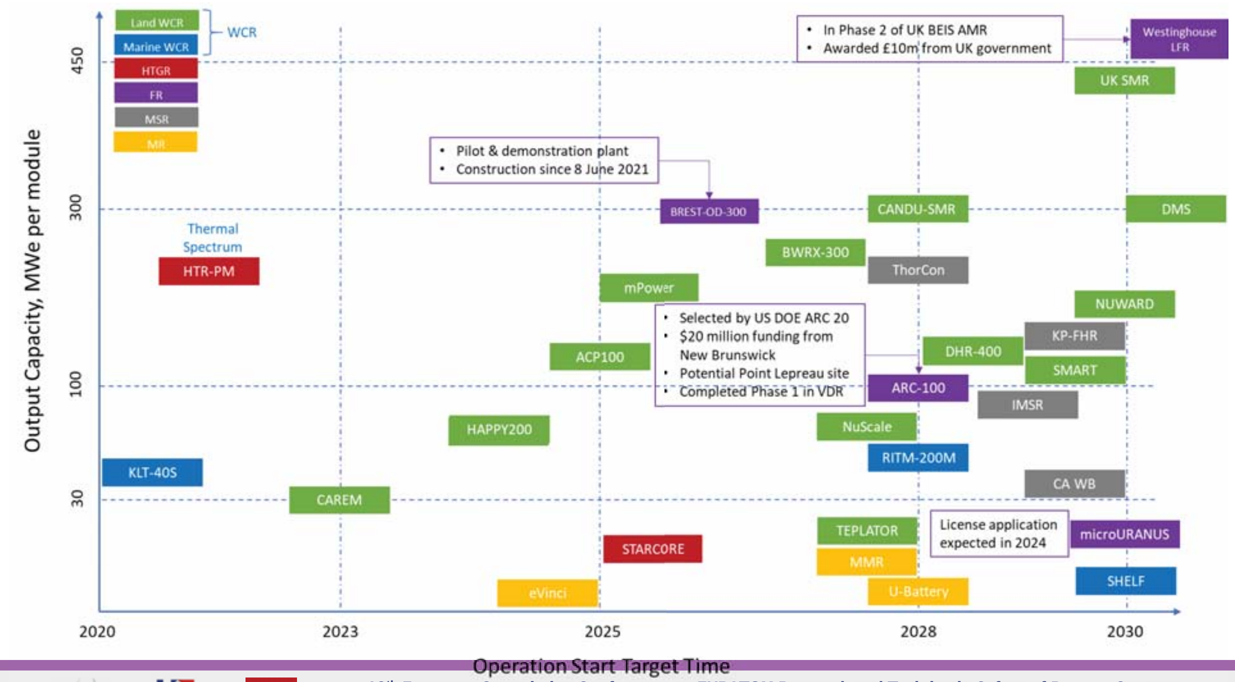
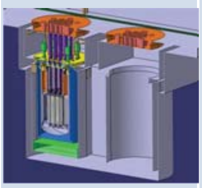
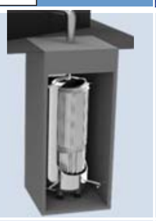
SMR – Deployment Horizon by 2030



Microreactor – Designs

Six designs included in the IAEA SMR ARIS Booklet (2020 edition)

Energy Well	MoveluX	U-Battery	AURORA	eVinci	MMR
					
Design Status: Pre-conceptual design, neutronics, thermohydraulic and materials studies done	Design Status: Conceptual design, complete test without fuel, FOAK demo after 2030	Design Status: Conceptual design, VDR with CNSC	Design Status: Accepted combined license application by the US NRC	Design Status: Conceptual Design, vendor design review with CNSC	Design Status: Preliminary Design, vendor design review with CNSC
• Centrum výzkumu Řež, Czech Republic • Fluoride HTR, Pool type • Molten Salt FLiBe coolant • 20 MWt / 8 MWe • Forced circulation • TRISO fuel • Enrichment: ~ 15% • No onsite refueling • Refueling cycle: 84 months	• Toshiba, Japan • Heat-Pipe cooled • Calcium-hydride moderated reactor • 10 MWt / 4 MWe • Natural circulation • Silicide fuel, Hexagonal • Enrichment: < 5% • Continuous operation • 100 m² plant footprint	• URENCO, UK • HTGR • 10 MWt / 4 MWe • Forced helium circulation • TRISO fuel (17-20% U235) • Hexagonal FAs • Enrichment: < 20% • 5 EPFYs core life • 30 year design life	• OKLO Inc., USA • Liquid Metal Fast Reactor • Liquid metal coolant, no moderator • 4 MWt / 1.5 MWe • UZr metal fuel (<20% U235) • Refueling cycle: up to 20 years • Design life: 20 years per deployment	• Westinghouse, USA • Heat Pipe cooled • Metal hydride moderator • TRISO or another encapsulation • 7-12 MWt / 2-3.5 MWe per module • Enrichment: 5-19.75% • Refuel interval: 36+ months • No onsite refuelling, Replace reactor approach • Design life: 40 years	• USNC, USA, Canada • HTGR / micro-reactor / nuclear battery • 15 MWt / 5 MWe • Core Outlet Temp: 630°C • FCM TRISO graphite, Hexagonal fuel block • Enrichment: HALEU 19.75% • Refuel interval: fuelled once during lifetime

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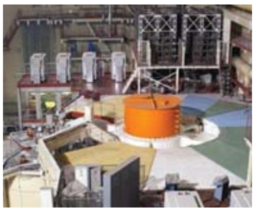
Fast Reactors in Operation & under Commissioning

Country	Name	Coolant	Purpose	Power (th/e) MW	Year (Op.)	Status
Russia	BOR-60	sodium	experimental	**60/10**	1969	operating
	BN-600	sodium	prototype	**1470/600**	1980	operating
	BN-800	sodium	commercial	**2100/880**	2015	operating
China	CEFR	sodium	experimental	**65/20**	2011	operating
India	FBTR	sodium	experimental	**40/13**	1985	operating
	PFBR	sodium	prototype	**1250/500**	(Est.) 2022	commissioning
Japan	JOYO	sodium	experimental	**150/--**	1978	license renew


BN-600
Russia, 1980


BN-800
Russia, 2015

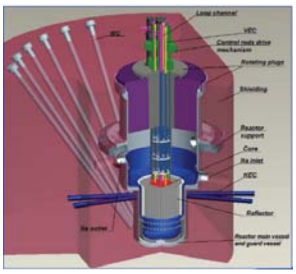

CEFR, 20 MW(e)
China, 2011


FBTR, 13 MW(e)
India, 1985

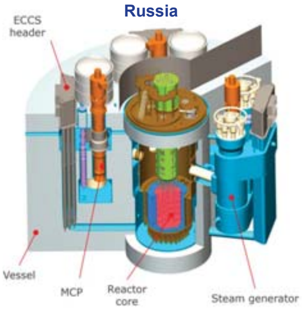

PFBR, 500 MW(e)
India, 2022

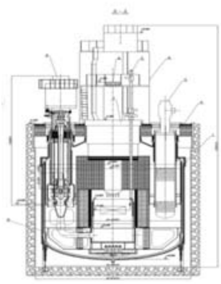
Fast Reactors under Construction

Country	Name	Coolant	Purpose	Power (th/e) MW	Year (Op.)	Status
Russia	MBIR	sodium	Experimental/MTR	**150/50**	~2028	construction
	BREST-OD-300	lead	demonstrator	**700/300**	~2026	construction
China	CFR600 x2	sodium	prototype	**1500/600**	~2023	construction (2 units)


MBIR, Russia

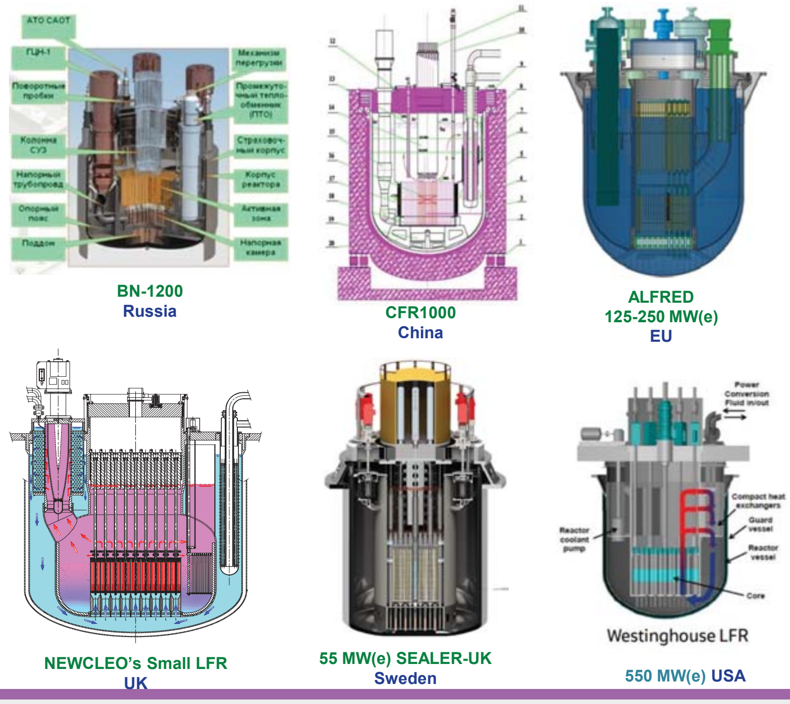
BREST-OD-300
Russia



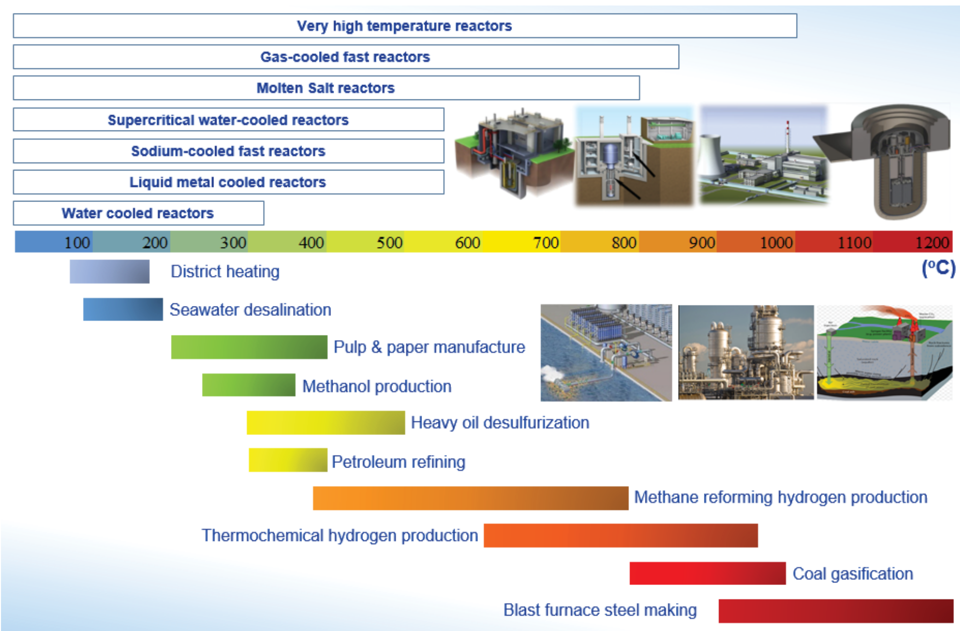

CFR600, China

Fast Reactors under Development and Design

Country	Name	Type - Coolant
Russia	BN-1200	SFR sodium
	SVBR-100	LFR LBE
	MOSART	MSR molten salt
China	CFR1000	SFR sodium
	CLFR-300	LFR LBE/lead
	CLEAR-M10A	LFR LBE
	CLEAR-I	LFR LBE
	CLEAR-M10D	LFR lead
India	FBR1 & 2	SFR sodium
EU	ESFR	SFR sodium
	ALFRED	LFR lead
	ALLEGRO	GFR helium
	MSFR	MSR molten salt
Belgium	MYRRHA	LFR-ADS LBE
France	ASTRID	SFR sodium (suspended)
R. of Korea	KALIMER-600	SFR sodium
	PGSFR	SFR sodium (suspended)
UK/Italy	LFR-AS-200	LFR - Lead
UK/Sweden	SEALER-UK	LFR lead
USA	Westinghouse LFR	LFR lead
	NATRIUM	SFR sodium
	VTR (PRISM)	SFR sodium
	SSTAR	LFR lead (suspended)
	MCSFR	MSR chloride salt
	EM2	GFR helium
	KP-FHR	MSR fluoride salt
	LLC ARC-100	SFR sodium



Reactor Technologies for Non-electric Applications



Heat and H2: Prospects of using current fleet of NPPs

USA

US DOE commits $20M to create clean hydrogen from NP with Palo Verde project

China

Haiyang becomes first Chinese city to enjoy ‘zero-carbon’ heating with nuclear power

Russia

Kola nuclear power plant is building a hydrogen test facility

Canada

Bruce Power is exploring feasibility of using excess energy for hydrogen production

United Kingdom

UK Strategy lays out plans to use existing nuclear plants this decade for clean hydrogen production

India

Approved Nuclear Desalination Project at Madras Atomic Power Station (PHWR), Kalpakkam

Heat and H2: Prospects of using advanced reactor technologies

Canada

- SMR Developers Focus on Process Heat
- Alberta’s oil sands producer considers capitalizing heat from SMRs

China

- HTR-PM: Feasibility study on the application and design of nuclear hydrogen and cogeneration in industrial sector
- Various SMRs designs (e.g. ACP100 SMR) for electricity production, heating, steam production or seawater

Finland

- Low-temperature District Heating and Desalination Reactor

Japan

- HTGR cogeneration plant for hydrogen production

Poland

- HTGR for district heating; MMR for hydrogen production

Republic of Korea

- SMR for desalination/ district heating

Russia

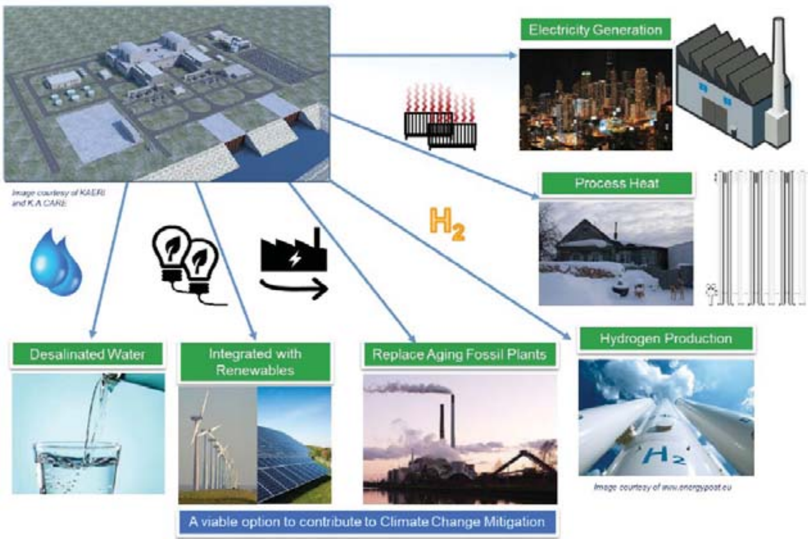
- Floating SMRs for cogeneration, HTGR for hydrogen production

United Kingdom

- SMRs, AMRs for cogeneration and hydrogen production

United States

- Various SMR designs for hydrogen production, water desalination, district heating



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Challenges Facing Successful Deployment of SMR & Innovative Reactor Technologies

- **Demonstration of Safety and Performance**
  - Above all as far as the most “revolutionary” designs
- **Demonstration of Economic Competitiveness**
  - Modularization
  - Economies of Serial Production
  - Integration with other clean energy sources
- **Harmonization and Standardization** *to enable the effective global deployment of standardized fleets of safe and secure advanced reactors*:
  - Common industrial approaches (e.g. codes & standards, supply chain, etc.) by technology holders and users’ requirements and criteria by operators
  - Harmonized regulatory approaches between national regulatory bodies, including a common set of internationally recognized requirements (*while maintaining national responsibilities*)
- **Development of nuclear infrastructure for deployment**
  - Embarking and expanding countries

IAEA Platform on SMRs and their Applications

Objective: Provide national governments, experts and regulators with integrated Agency-wide support on all aspects of SMR development, deployment and oversight

What?

- IAEA’s internal governance to coordinate activities consistently with MSs needs and requests
- Single access point for MSs and stakeholders

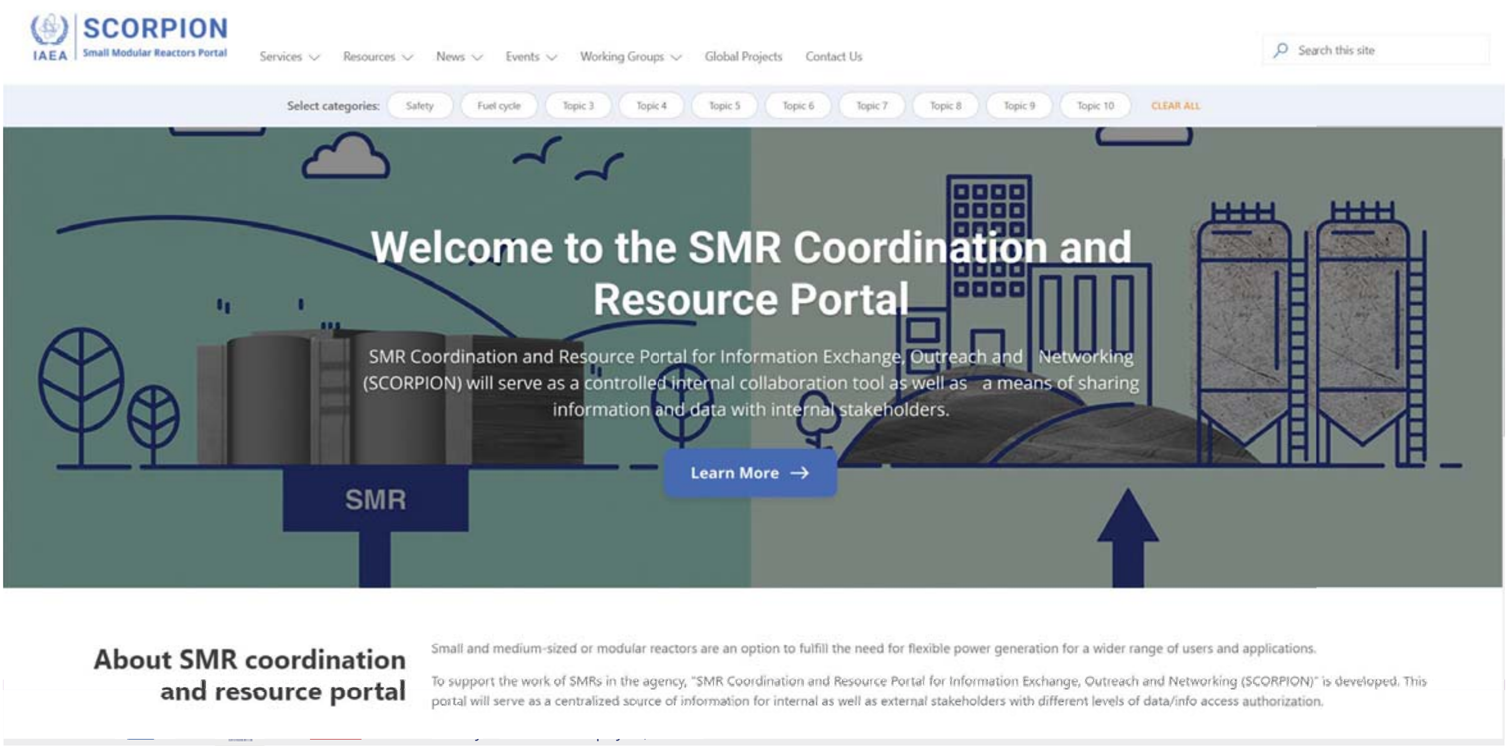
How?

- Develop medium-term strategy on SMR and its applications
- Create enabling environment and a portal to enhance internal as well as external communication

Why?

- Member Sates request for consistent, coordinated and optimized Agency support
- Effective and efficient support to Member States, International Organizations and stakeholders willing to cooperate with the IAEA

SCORPION: 1st Release in July



IAEA Nuclear Harmonization & Standardization Initiative - NHSI

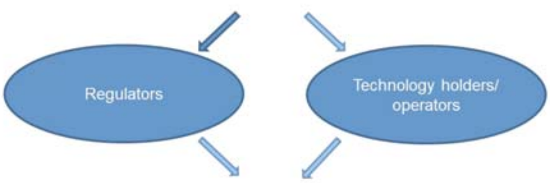
Regulatory Track

- Developing harmonized regulatory approaches between national regulatory bodies, including a common set of internationally recognized requirements, while maintaining national responsibilities for safety and security.

Industrial Track

- Developing common industrial approaches by technology holders and users' requirements and criteria by operators, consistent with fair global competition, intellectual property rights protection, and not hampering innovation and continuous improvement.

Two separate, complementary tracks



IAEA as facilitator and integrator

Take Aways

- Nuclear has unique attributes to play a major role in the **transition to Net Zero**:
  - Only technology that can provide **at scale low C electricity, heat and hydrogen**
  - **Reduced land footprint** and **use of critical minerals**, much **higher capacity factors**
- It can complement renewables – dispatchability, flexibility, **security of supply** - and support low carbon H_2 production.
  - It can **lower the costs of the transition** to carbon neutrality.
  - Offers a **less risky pathway** to net zero (*100% renewables would need extremely high deployment rates + massive storage capabilities + higher dependency on critical minerals*)
- For nuclear to fulfill its full role – *i.e. massive production of all major clean energy carriers* – consistently with net zero roadmap there is the **need to quickly advance design and demonstration of advanced reactor technologies, including SMRs and FRs**

Hotei-san: "focus on the moon and not on the finger pointing to the moon…"

IAEA intends to continue the conversation on nuclear energy's role in the energy transitions at the Ministerial Conference on Nuclear Power (October 2022) and COP27 (November 2022).

8 December 1953

1 to 23 October 1957

11 December 1957

1959

10 December 2005

1958 to 1979

Thank you for your attention!

23 August 1979

Contact:
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S.Monti@iaea.org

Atoms for Peace and Development…