

Advanced Reactor Systems and Future Energy Market Needs

what role for nuclear energy in the future?

Dr. Henri PAILLÈRE

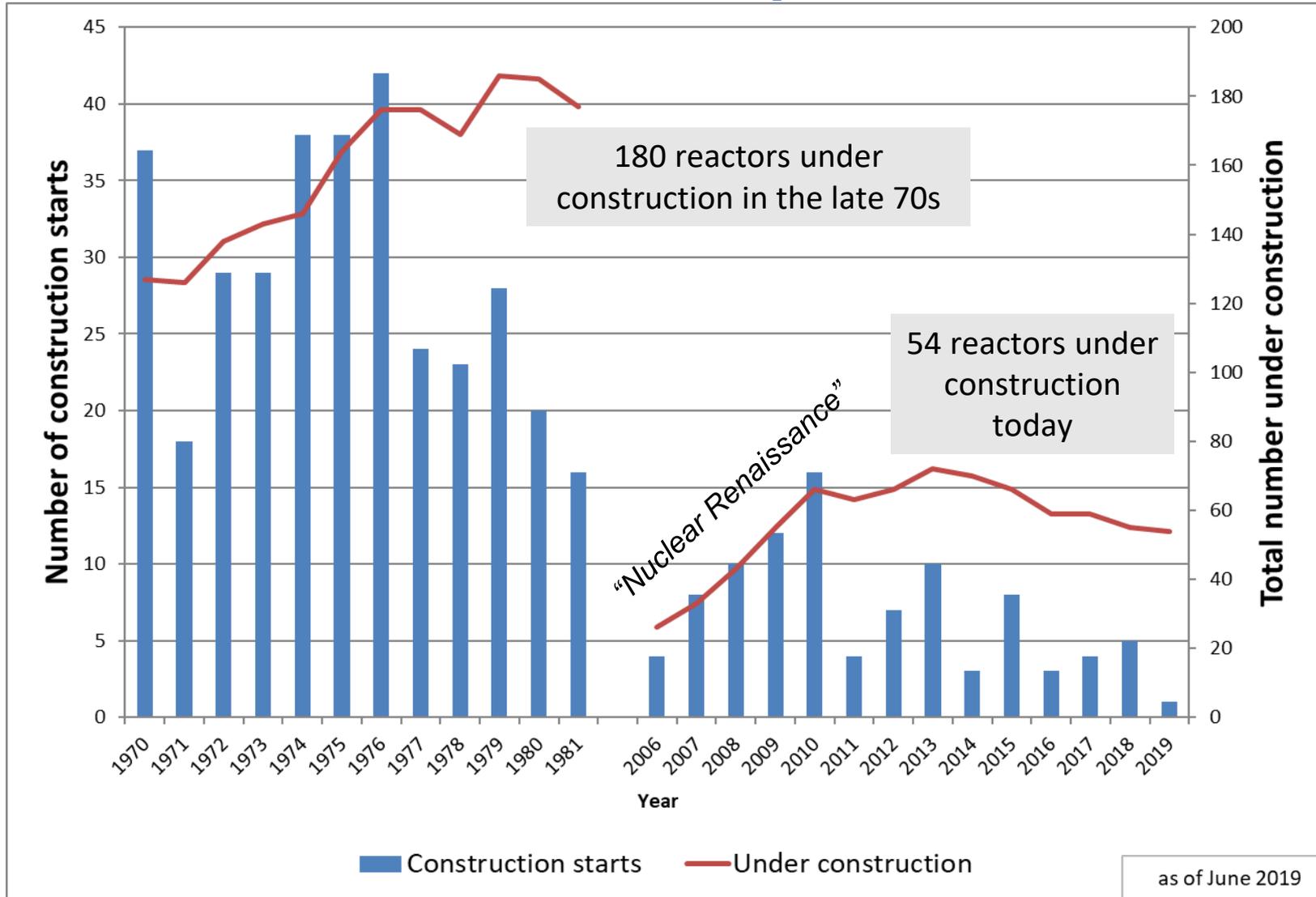
Deputy Head,

Division of Nuclear Technology Development and Economics

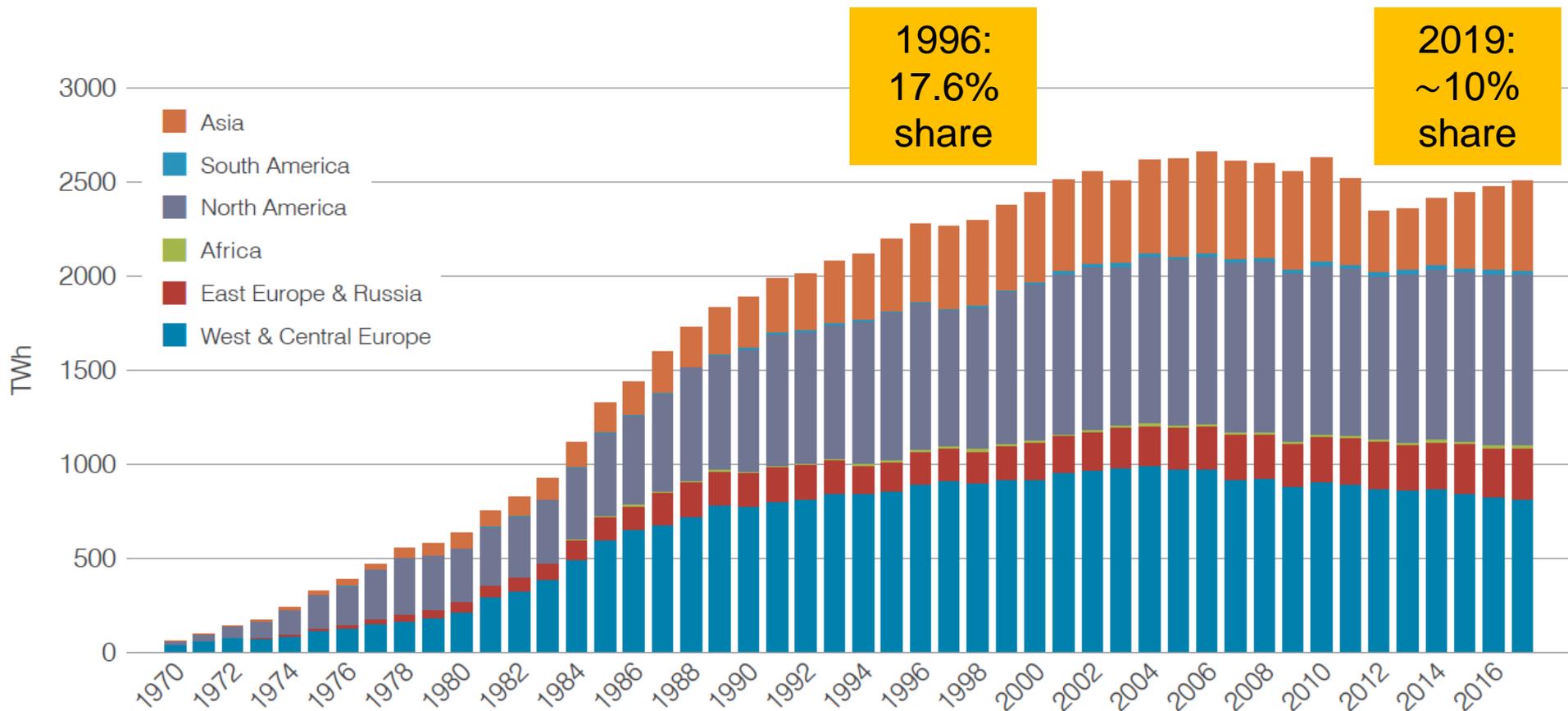
henri.paillere@oecd-nea.org

71st NDC Meeting, 10-11 July 2019

Reactor Construction – Comparison with the Past



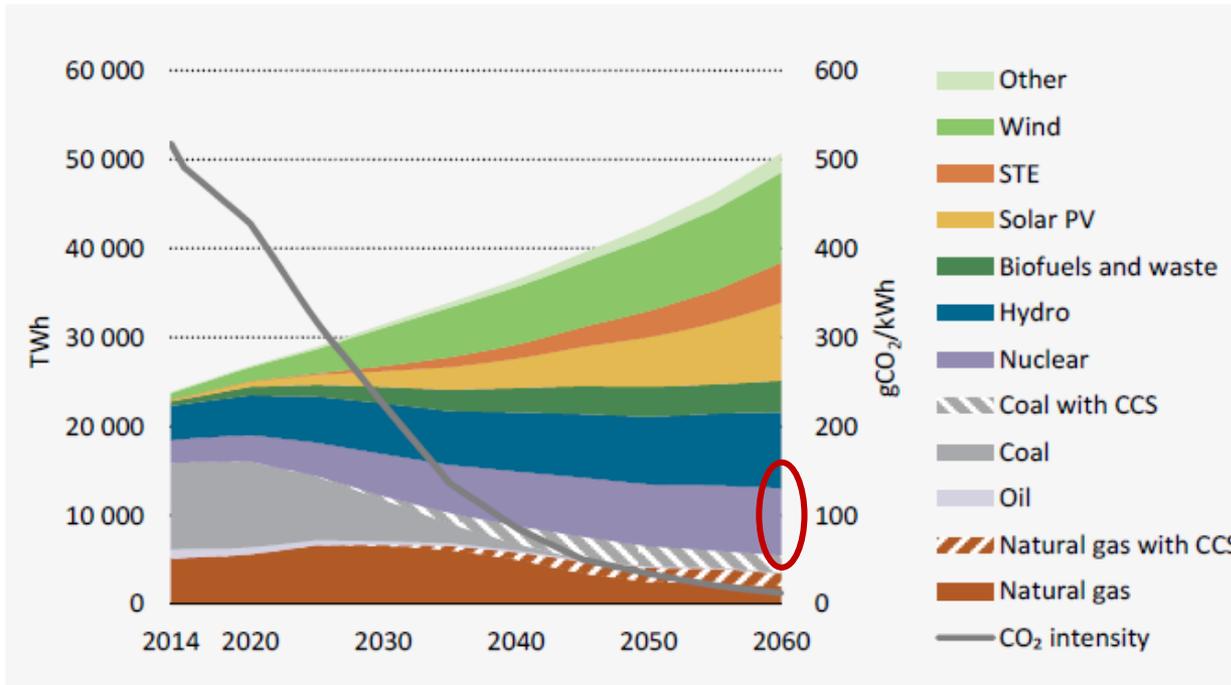
Nuclear electricity production



Source: World Nuclear Association and IAEA Power Reactor Information Service (PRIS)

Future low carbon electricity systems?

IEA projects an increase in the share of nuclear electricity (from 10% to 16%), as well as a massive increase in renewables, together with a *complete phase-out* of coal and oil, a drastic decrease of gas & the deployment of CCS, to meet “ 2°C or less” objectives.



Nuclear (and other “baseload” generators) will need to co-exist with large shares of variable renewables.

Source: IEA Energy Technology Perspectives, 2017 – (2 degree scenario (2DS))

67% renewables incl. 30% wind/solar
16% nuclear

Is nuclear on track to meet climate objectives?

<https://www.iea.org/tcep/power/nuclearpower/>

Nuclear power

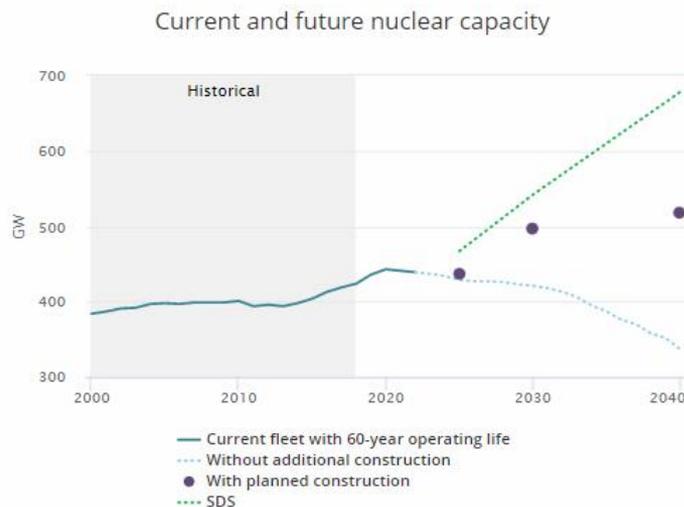
Tracking Clean Energy Progress

● More efforts needed

In 2018, 11.2 GW of additional nuclear capacity were connected to the grid, the largest increase since 1989. New projects were launched representing over 6 GW, and refurbishment projects are under way in many countries to ensure long-term operation of the existing fleet. Nevertheless, more efforts in terms of policies, financing and cost reductions are needed to maintain existing capacity and bring new reactors online. Under current trends, nuclear capacity in 2030 would amount to 497 GW, compared with 542 GW under the SDS. At least a doubling of the annual rate of capacity additions is therefore required.

This section was authored by the Nuclear Energy Agency, Division of Nuclear Technology Development and Economics (NTE)

 **Henri Paillere, Malisol Ohirko**
 Lead author

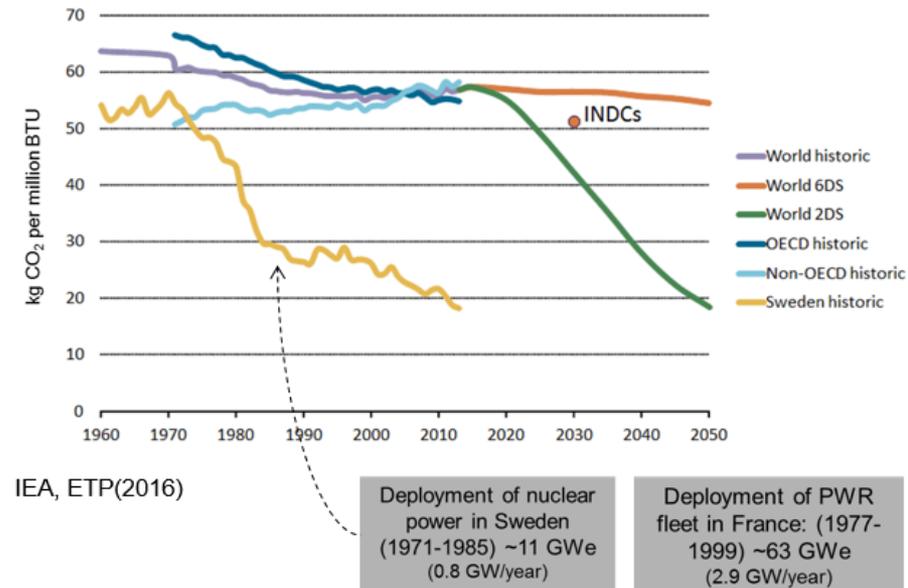


IEA. All rights reserved.

At least a doubling of new annual capacity additions is needed!

Policies supporting decarbonisation?

- In many countries, policies are more often directed at achieving deployment targets of selected technologies than at GHG reduction targets.
 - “technological neutrality” of policies in question → effectiveness of current policies?
- Very few support mechanisms for nuclear (LTO or new build).
 - EU Parliament voted to exclude nuclear from “green credits”.
 - US ‘Green New Deal’ & nuclear
- Eventhough, historically, nuclear has proven to be a **very effective technology** at reducing carbon intensity.



IEA report, May 2019: calling for a policy change

Steep decline in nuclear power would threaten energy security and climate goals

28 May 2019

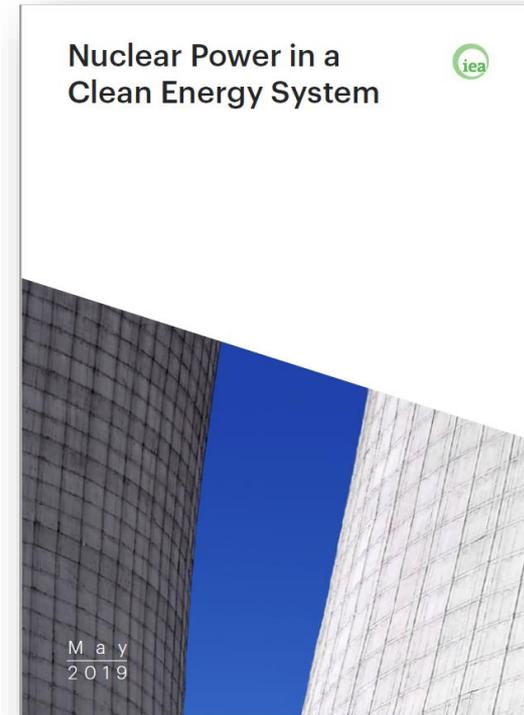


A new IEA report finds nuclear power capacity in advanced economies could fall sharply, making the global energy transition harder and more costly.



VANCOUVER – With nuclear power facing an uncertain future in many countries, the world risks a steep decline in its use in advanced economies that could result in billions of tonnes of additional carbon emissions, according to a new report by the International Energy Agency.

Nuclear is the second-largest low-carbon power source in the world today, accounting for 10% of global electricity generation. It is second only to hydropower at 16%. For advanced economies – including the United States, Canada, the European Union and Japan – nuclear has been the biggest low-carbon source of electricity for more than 30 years and remains so today. It plays an important role in electricity security in several countries.



F. Birol: “Despite the impressive growth of solar and wind power, the overall share of clean energy sources in total electricity supply in 2018, at 36%, was the same as it was 20 years earlier because of the decline in nuclear”

IEA policy recommendations vs. NEA/NDC studies

- **Keep the option open:** Authorise lifetime extensions of existing nuclear plants for as long as safely possible.
 - NDC 9.4 Maintaining Low Carbon Generation Capacity through LTO of NPPs: Economic, Technical & Policy Aspects
- **Support new construction:** Ensure that licensing processes do not lead to project delays and cost increases that are not justified by safety requirements. Support standardisation and enable learning-by-doing across the industry.
 - NDC 9.5 Reducing the costs of Nuclear Power Generation
- **Value dispatchability:** Design the electricity market in a way that properly values the system services needed to maintain electricity security, including capacity availability and frequency control services. Make sure that the providers of these services, including nuclear power plants, are compensated in a competitive and non-discriminatory manner.
- **Value non-market benefits:** Establish a level playing field for nuclear power with other low-carbon energy sources in recognition of its environmental and energy security benefits and remunerate it accordingly.
- **Support innovative new reactor designs:** Accelerate innovation in new reactor designs, such as small modular reactors (SMRs), with lower capital costs and shorter lead times and technologies that improve the operating flexibility of nuclear power plants to facilitate the integration of growing wind and solar capacity into the electricity system.
 - NDC 8.4 Nuclear Innovation 2050
 - NDC 8.5 Advanced Reactor Systems and Future Energy Market Needs
 - + other studies related to integration of nuclear & var. renewables (system costs), full costs, etc

Nuclear energy will have a place in tomorrow's energy markets if:

- *High level waste management implemented (long term storage, deep geological repositories for final disposal) + safety and non-proliferation maintained at highest levels + public support.*
- It can compete with alternative low carbon electricity generating technologies (costs on a €/kWh basis, financing, ...)
- Its attributes (CO₂-free, security, reliability, dispatchability – and contribution to grid stability/quality) can be appropriately valued.
- It can operate flexibly in electricity systems with large shares of var. renewables (without compromising its economics).
- Its “product flexibility” (i.e. possibility to generate electricity but also non-electric products – process heat, hydrogen, desalinated water, ...) can be recognised and marketed appropriately.
- There is a wide range of technologies, (large) LWR – (small) LWR (SMR) – other advanced reactors (non LWR SMRs / Gen IV).

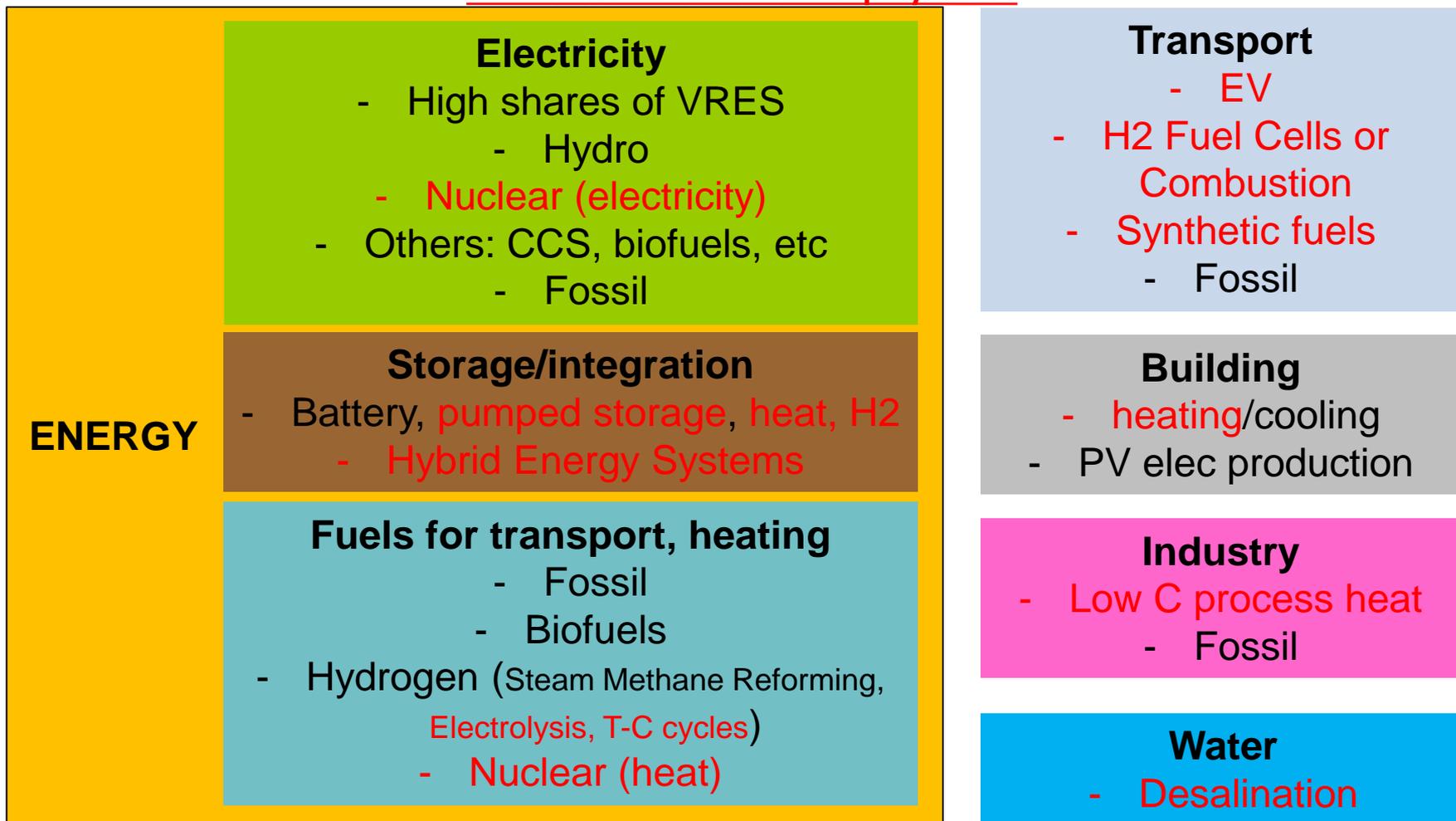
DESIGN / TECHNOLOGY

ECONOMICS

POLICIES

Tomorrow's energy markets & other sectors?

Sectors where nuclear can play a role



ARFEM – answering these questions

What is the role of nuclear energy in future low C systems?
Can a cost-effective, reliable & resilient system exist without nuclear?



Nuclear-Renewables
(Integration-Resilience-Security of Supply-Affordability)



Flexibility



Non-electric Applications

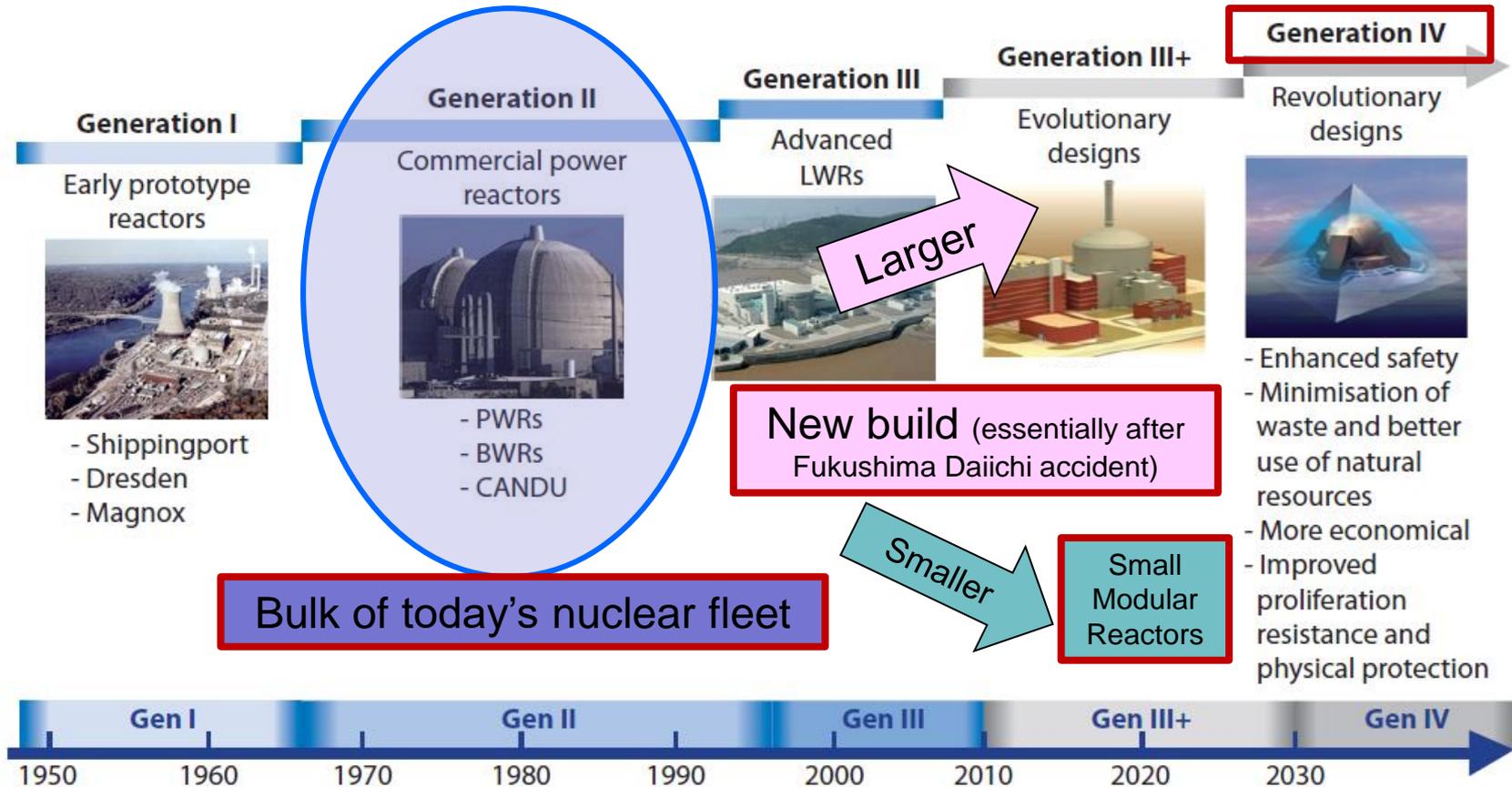


Hybrid Systems (storage)



**Higher Efficiency, Better Use of Energy, increased Flexibility
and lesser Environmental Impacts**

Nuclear Reactors: Generations I to IV



Evolutionary Gen III/III+ ... cost overruns, delays, ...

Westinghouse Files for Bankruptcy, in Blow to Nuclear Power

By DIANE CARDWELL and JONATHAN SOBIE MARCH 29, 2017



RELATED COVERAGE
Corpor
Spree.

The New York Times

CLIMATE

U.S. Nuclear Comeback Stalls as Two Reactors Are Abandoned

By BRAD PLUMER JULY 31, 2017



w n n
world nuclear news

Energy & Environment | New Nuclear | Regulation & Safety | Nuclear Policies | **Corporate** | Uranium & Fuel | W

Court approves Westinghouse reorganisation plan

28 March 2018

Westinghouse Electric Company's reorganisation plan - including its sale to Brookfield - has been approved by the US Bankruptcy Court. Westinghouse said the court's approval of the plan is a "significant milestone in the company's strategic restructuring".

Hinkley Point C is £1.5bn over budget and a year behind schedule, EDF admits

Cost of controversial nuclear power plant in Somerset has risen to £20.3bn and delayed by 15 months, says French energy firm



Flamanville: EDF annonce un nouveau retard dans la construction de l'EPR

Par Nicolas Orliac | Mis à jour le 25/07/2018 à 14:35 / Publié le 25/07/2018 à 11:34



EPR de Flamanville : la cuve obtient la validation de l'ASN

BERONIQUE LE BILLON | ANNE FEYZE | Le 26/06 à 09:00 | Mis à jour à 12:01



le sûreté nucléaire demande le ent du couvercle d'ici à 2024. fichait sa « grande », salue « une très bonne



EDF board approves buying 75.5 percent of Areva NP by end 2017 - sources

Geert De Clercq

3 MIN READ



PARIS (Reuters) - The board of French state-owned utility EDF has given final approval for the acquisition of a 75.5 percent stake in Areva NP, the nuclear reactor construction unit of fellow state-owned nuclear group Areva, by year-end, three sources said.

Cost overruns & delays for some FOAKs – restructuring of the nuclear industry

Evolutionary Gen III/III+... positive developments in 2018

Energy & Environment | **New Nuclear** | Regulation & Safety | Nuclear Policies | Corporate | Uranium & Fuel

First AP1000 unit begins generating power

02 July 2018

Unit 1 of the Sanmen nuclear power plant in China has been connected to the grid, becoming the world's first AP1000 to achieve grid connection and power generation. The milestone came just one day after Taishan 1, also in China, became the first EPR to reach the same milestone.



Sanmen units 1 and 2 (Image: CNNC)

More progress for China's Hualong One technology

2 February 2018

"Sanmen 1" grid and ha

[Print](#) [Email](#)



The reactor pressure vessel has been installed at China's demonstration Hualong One nuclear reactor, Fuqing 5, under construction at in Fujian province.

China National Nuclear Corporation (CNNC) said Fuqing 5 is expected to start up and begin commercial operation in 2019 or 2020. Installation of the RPV marks the completion of the installation of the unit's main components, CNNC said.

The Hualong One reactor pressure vessel was designed by China Nuclear Power Research and Design Institute and manufactured by China First Heavy Machinery.

The three steam generators and pump casings were installed earlier in January. Two demonstration Hualong One units are being built at Fuqing 5&6. The

Hualong One (HPR1000), an indigenous 1100MWe, three-loop pressurised water reactor, incorporates elements of CNNC's ACP1000 and China General Nuclear's (CGN's) reactor designs. Construction of two Hualong One units is also underway at CGN's Fangchenggang in Guangxi province. Those units, based on CGN's ACP1000+ design, are also expected to start up in 2019 and 2020.

Related Stories

- China's Taishan 1 reactor connected to grid
- Chinese AP1000s pass commissioning milestones
- Fuel loading under way at Chinese AP1000
- Hot testing of Sanmen 2 AP1000 completed

WNA Links

- Sanmen 1
- Advanced Nuclear Power Reactors
- Nuclear Power in China

Related Links

U.A.E. Completes First of Four Korean-Built Nuclear Reactors

By Bruce Stanley and Heesu Lee

March 26, 2018, 4:14 PM GMT+2 Updated on March 27,



- Barakah Unit 1 to load fuel in May: Korean energy ministry
- Reactor is Arab world's first; Saudis also want atomic plants



Energy & Environment | **New Nuclear** | Regulation & Safety | Nuclear Policies

Leningrad II-1 starts pilot operation

09 March 2018

Russia has today connected unit 1 of the Leningrad Phase II nuclear power plant to the grid and it has started producing its first power, state nuclear corporation Rosatom has announced. The VVER 1200 reactor was brought to the minimum controllable power level on 6 February.



Leningrad-II unit 1 (Image: Rosatom)

Chinese EPR connected

2 July 2018

[Print](#) [Email](#)



[Hinkley Point C] project as a whole," he said.

Unit 1 of China's Taishan nuclear plant in Guangdong province was connected to the on 29 June, becoming the world's first EPR to achieve grid connection and power generation, China General Nuclear International (CGN) and EDF Group announced. Taishan 1 is expected to enter commercial operation later this year.

Zheng Dongshan, CEO of CGN UK described the grid connection of the new Taishan 1 reactor as "a major step forward in China," but also noted the significance for the UK, where EPR technology will be used at both Hinkley Point C and Sizewell C.

"The fact that an EPR power station has been linked to the electricity network for the first time reinforces our strong confidence in this reactor technology and in the

Evolutionary Gen III/III+ (large LWR): Situation in June 2019

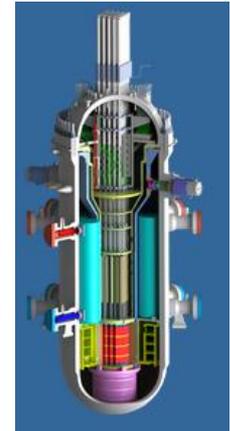
- **AP1000** (~1100MW)
 - 4 in operation (China)
 - 2 under construction (US)
- **APR1400** (~1340MW)
 - 2 in operation (Korea)
 - 8 under construction (Korea, UAE)
- **EPR** (~1630MW)
 - 1 in operation, 2nd one started (China)
 - 3 under construction (Finland, France, UK)
- **Hualong 1** (~1000MW)
 - 4 under construction (China)
- **VVER1200** (~1110MW)
 - 3 in operation (Russia)
 - 9 under construction (Bangladesh, Belarus, Russia, Turkey)

Majority of new
build today
consists of
large Gen
III/III+ LWR

- *Improved safety*
- *Improved performance*
- *Improved economics (for Nth Of A Kind – NOAK) [but not for the FOAKs]*

Small Modular Reactors, more than a niche market?

Vendor	Country	Design	Type	Net capacity (MW)	In operation*	Under construction*
Babcock & Wilcox	United States	mPower	PWR	180	0	0 
CNEA	Argentina	CAREM-25	PWR	25	0	1
CNEC	China	HTR-PM	HTR	210	0	Twin units
CNNC	China	ACP-100	PWR	100	0	0
KAERI	Korea	SMART	PWR	110	0	0
NuScale	United States	NuScale SMR	PWR	45	0	0
OKBM	Russia	KLT-40S	Floating PWR	2x35	0	Twin units (one barge)



*: As of 31 December 2014.

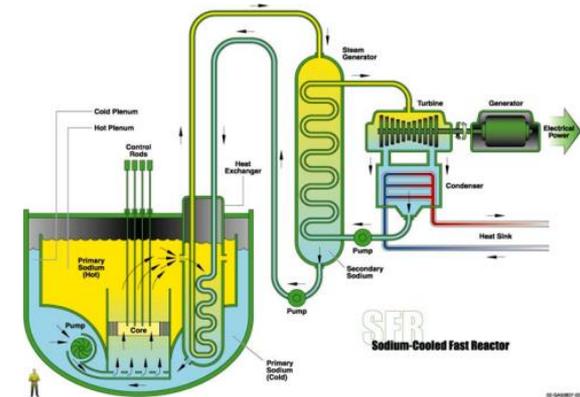
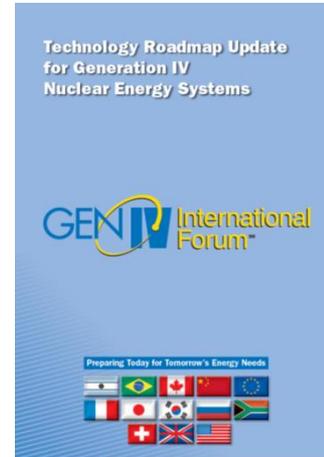
Design certification of US NuScale on-going at NRC

Licence to operate granted in June 2019, grid connection expected end year

Global First Power 5MW microreactor licence application in Canada



Generation IV technologies



6 designs developed in an international collaborative framework

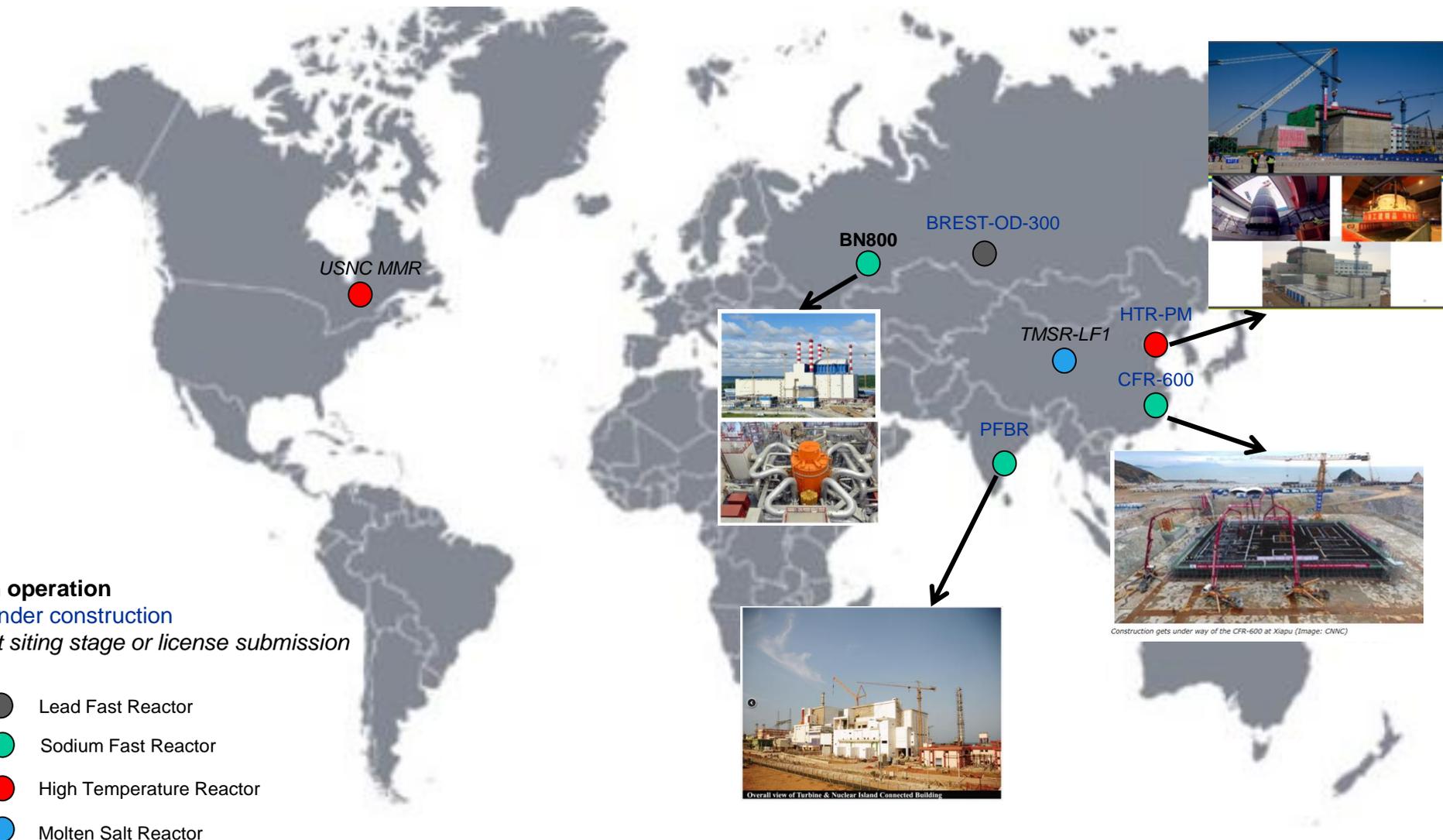
- “Fast Reactors”:
 - Sodium-cooled fast reactor (SFR)
 - Lead-cooled fast reactor (LFR)
 - Gas-cooled fast reactor (GFR)
- “Thermal Reactors”:
 - Super-critical water-cooled reactor (SCWR)
 - Very high temperature reactor (VHTR)
- “Thermal/Fast Reactor”:
 - Molten Salt Reactor (MSR)

Goals

- Sustainability
- Economics
- Safety and Reliability
- Proliferation Resistance & Physical Protection

At R&D level today (GIF). Prototypes of some of these technologies planned over the period 2030/2040. **Commercialisation beyond 2040**, alongside further evolutions of LWRs

Reactor systems with “Gen IV technologies”: in operation, under construction or at siting / license application stage



“Gen IV” SMRs: accelerated deployment?

License application
in Canada

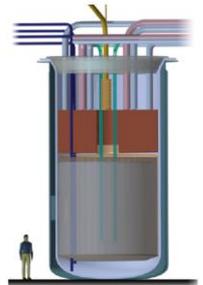


in partnership with

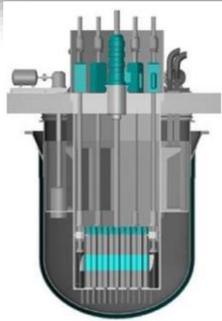



HTR MMR

Siting study in Canada
(Ontario/Chalk River)

MSR Thermal

LFR

Project in Poland




HTR

Technology selected for
development of Versatile
Test Reactor (US)



HITACHI



SFR

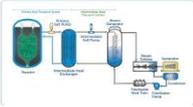


SFR

Opportunities in
Canada (New
Brunswick)



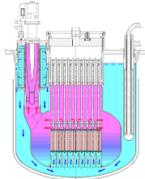

MSR

MSR Thermal




MSR Thermal

LFR

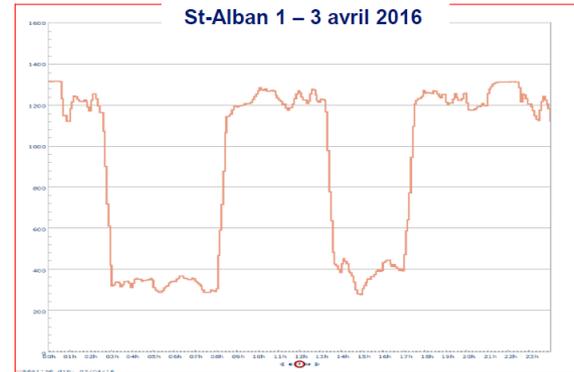



HTR

Flexibility: Role of Nuclear (1)

- IEA analyses show the need for flexibility of future generation systems including power plants, grids & energy storage.
- Gas often presented as “natural partner” of variable renewables. Gas is flexible but is *not* a low C source of power.
- Today’s **nuclear fleet already provides flexibility** (France, Germany, US too) “flexible operation”: load following, frequency response...

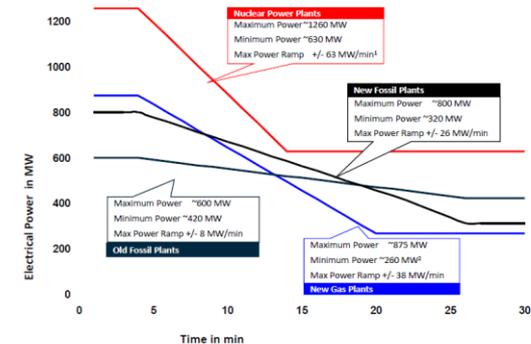
Designed and observed capacities for EDF reactors (900 MW CPY and 1300 MW)



- 2 variations per day
- Down to 20% of max power
- 30 minutes between minimum and maximum power
- Frequency regulation

Courtesy of EDF
(S. Feutry)

Comparison of power ramps

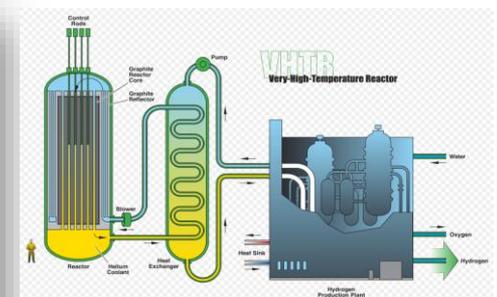
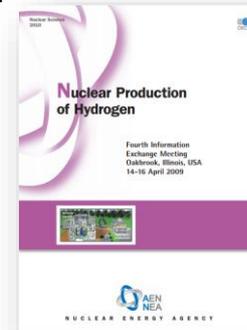


Nuclear Power Plants belong to the most flexible plants in the grid!

Courtesy of PreussenElektra (D. Janin)

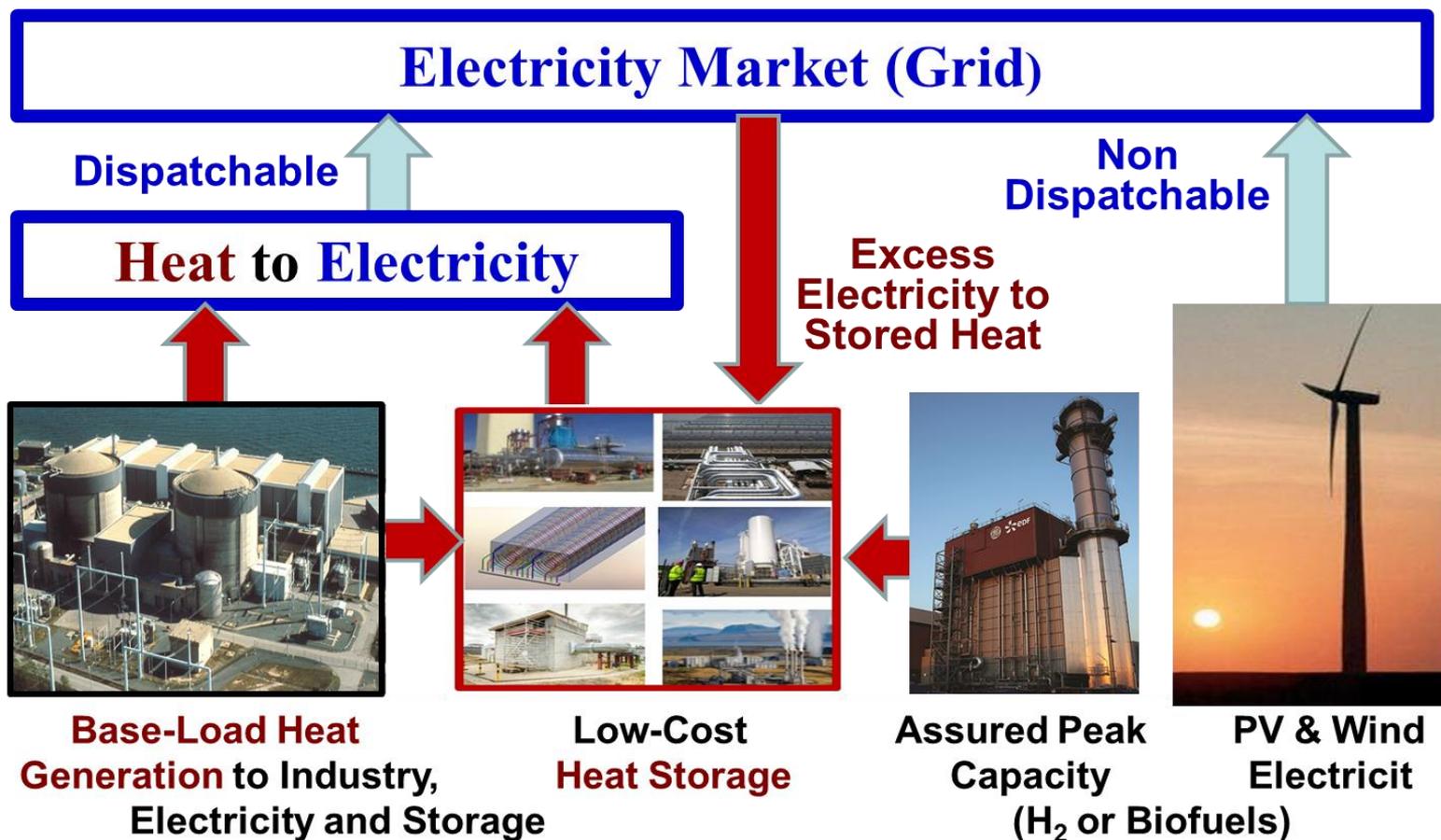
Flexibility: Role of Nuclear (2)

- Nuclear can contribute further to flexibility of energy systems:
 - Contribution to **energy storage**
 - Famous example of Swiss Hydro buying cheap nuclear electricity from France at night to pump water up, and sell hydro electricity during the day time (but this model challenged by current electricity market conditions)
 - Heat storage (see eg. Forsberg MIT work) [next slide]
 - Contribution to **non-electric applications** / decarbonise other sectors:
 - District heating: over 35 years of experience from Beznau NPP in Switzerland, supplying heat & hot water to local communities
 - Desalination: a very energy-intensive process which can use nuclear heat & electricity
 - Process heat for industry
 - Hydrogen production (fuel, storage)
 - **Hybrid Energy Systems**



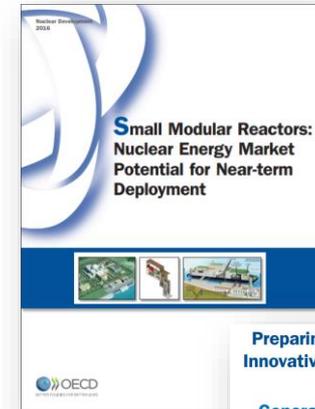
Flexibility: Role of Nuclear (3)

Energy Storage (Forberg, MIT)



Innovations

- **Future reactors:**
 - **Large LWR Reactors (Gen III/III+)**
 - Cost reduction, constructability
 - Improved manoeuvrability
 - **Small Modular Reactors:**
 - deployment flexibility (scalable, siting)
 - increased operational flexibility
 - **Gen IV reactors** (including non LWR-cooled SMRs)
 - Fuel flexibility (from open to closed fuel cycle, U, Th)
 - High temperatures, higher efficiency – product flexibility (heat, H₂)
 - Targeting both electric & non-electric markets. Nuclear: **low C source of electricity AND heat!!!** (and few competitors (CCS, biomass))
 - Flexibility key for future power & future energy systems



Nuclear Innovation Clean Energy Future - NICE Future



HOME ABOUT OUR WORK ▾ MINISTERIA

**NUCLEAR INNOVATION:
CLEAN ENERGY FUTURE
(NICE FUTURE)**



A CLEAN ENERGY MINISTERIAL INITIATIVE



Countries Launch a Nuclear Innovation Initiative under the Clean Energy Ministerial

24 May 2018

- Technology evaluations of innovative energy systems and uses
- Engagement of policy makers and stakeholders in future energy choices
- Valuation, market structure, and ability to finance
- Communicating nuclear energy's role in clean, integrated energy systems



Photos courtesy of Third Way

PARTICIPATING COUNTRIES



PARTNERS



<https://www.nice-future.org>

Some take-aways

- Current fleet provides ~10% of the world's electricity, the 2nd largest source of low carbon electricity. Ageing fleet – LTO major issue in coming years
- Replacing the existing fleet and deploying new build to produce 15-16% of global electricity will require major investments as well as stable and favourable policies, “good” products from industry, and public support
- A large portfolio of technologies (Gen III/III+, SMR & advanced reactors, Gen IV) exists today or under development. **ARFEM study to assess how well suited they are to future energy market needs & other lowC applications.**
- Innovations are needed:
 - To reduce the costs of Gen III/III+ reactors
 - To ensure the success (costs, manufacturability, flexibility) of SMRs and Gen IV reactors
 - To demonstrate at industrial scale the use of nuclear energy for non-electric applications (process heat, hydrogen, desalination, etc)
 - Need to communicate better on benefits of nuclear including the cost-benefits of a clean energy system that includes dispatchable/flexible nuclear
- Policy change needed to ensure success (see IEA report recommendations)