XIX^{ème} ANNUAL FORUM

Les SMRs: un nouveau type de réacteurs nucléaires adaptés à la production d’hydrogène

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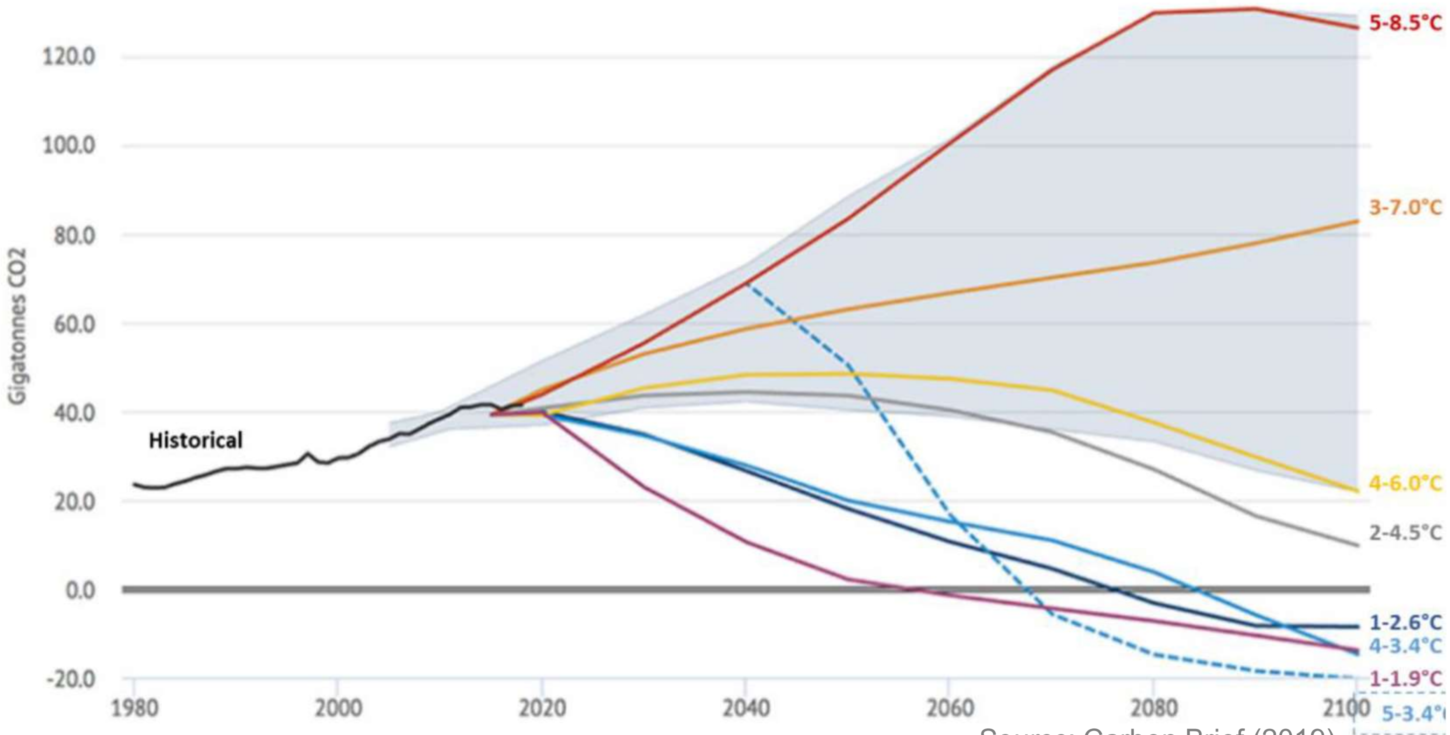
Sommaire

- Problématique changement climatique - énergie
- Intérêt du nucléaire
- Les SMRs
  - Caractéristiques
  - Technologies
  - Applications
  - Constructeurs
- Quelques exemples
- Conclusions

Changement climatique: il y a urgence

The magnitude of the challenge should not be underestimated

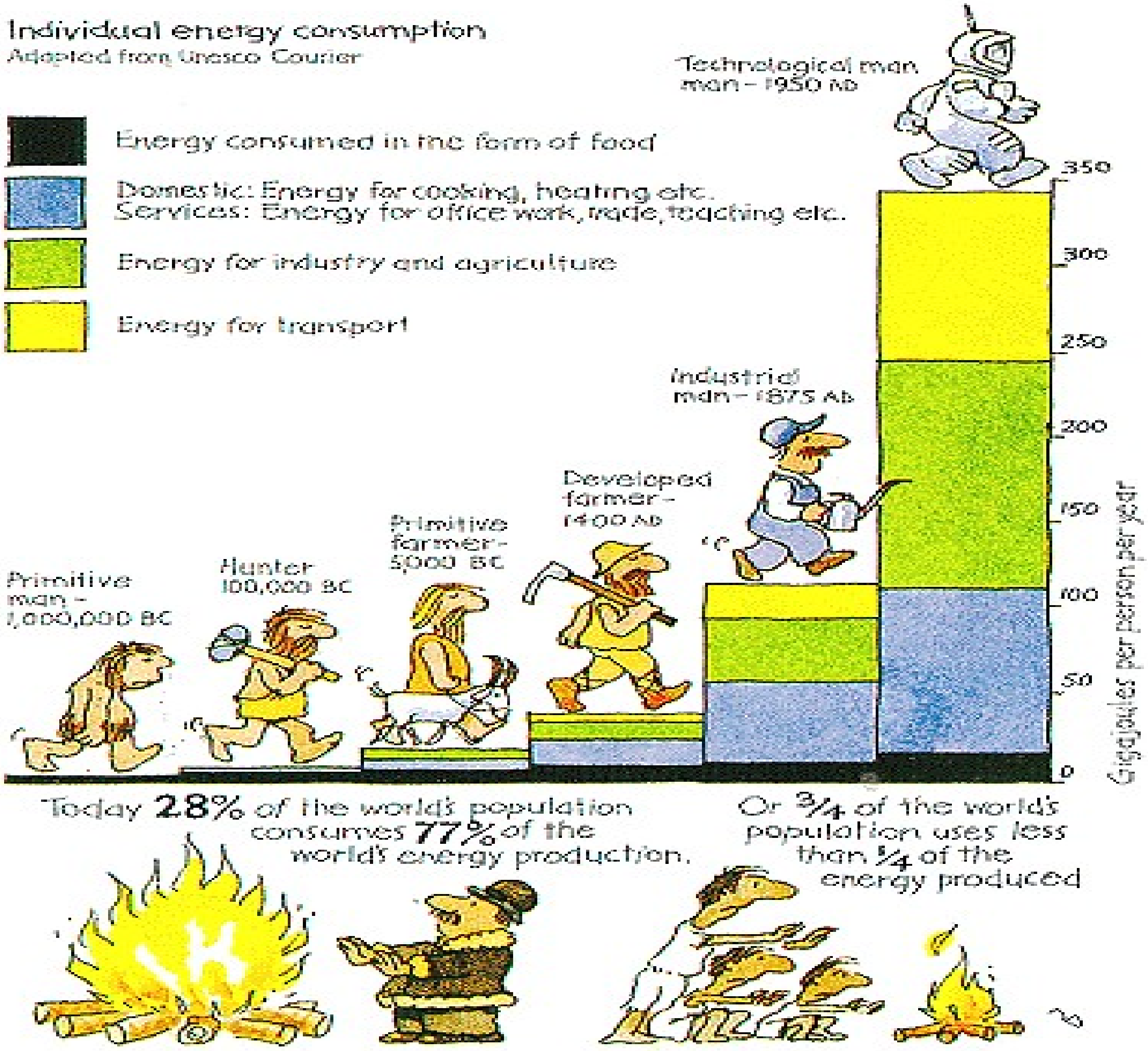
- The planet has a **"carbon budget" of 420 gigatons of carbon dioxide emissions for the 1.5°C** scenario
- At current levels of emissions, the entire carbon budget would be consumed within **8 years**
- Emissions must go to net zero, but the world is not on track



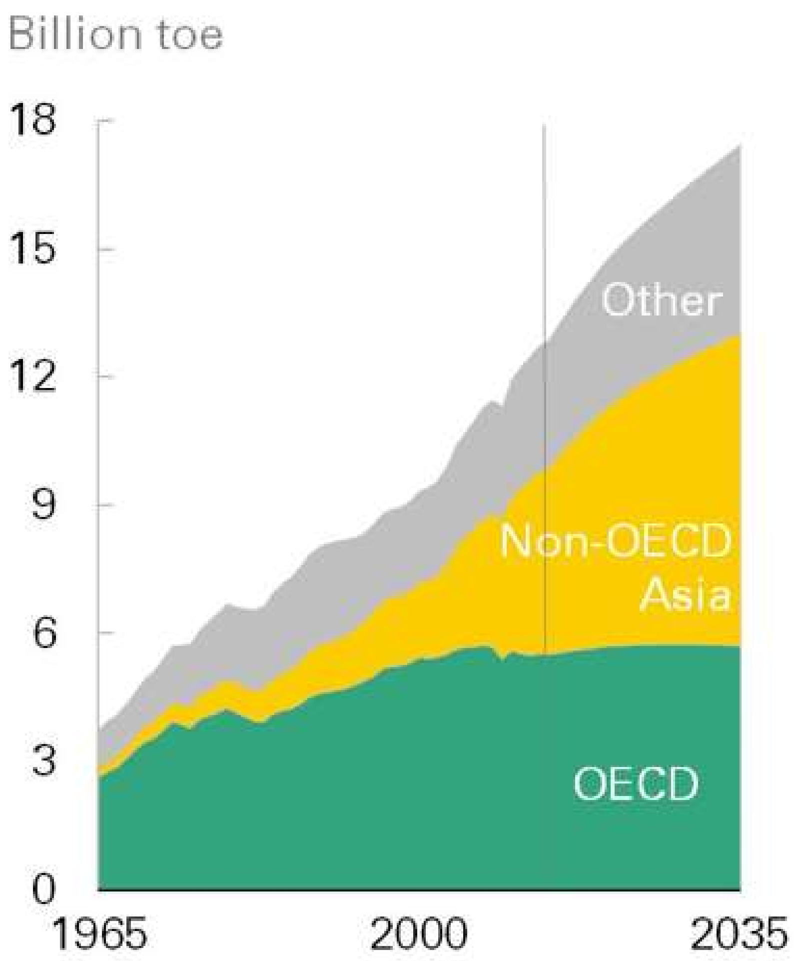
Source: Carbon Brief (2019).

Problématique de l'énergie:

En 2000: 6 milliards de personnes, **Environ 9 milliards en 2050**

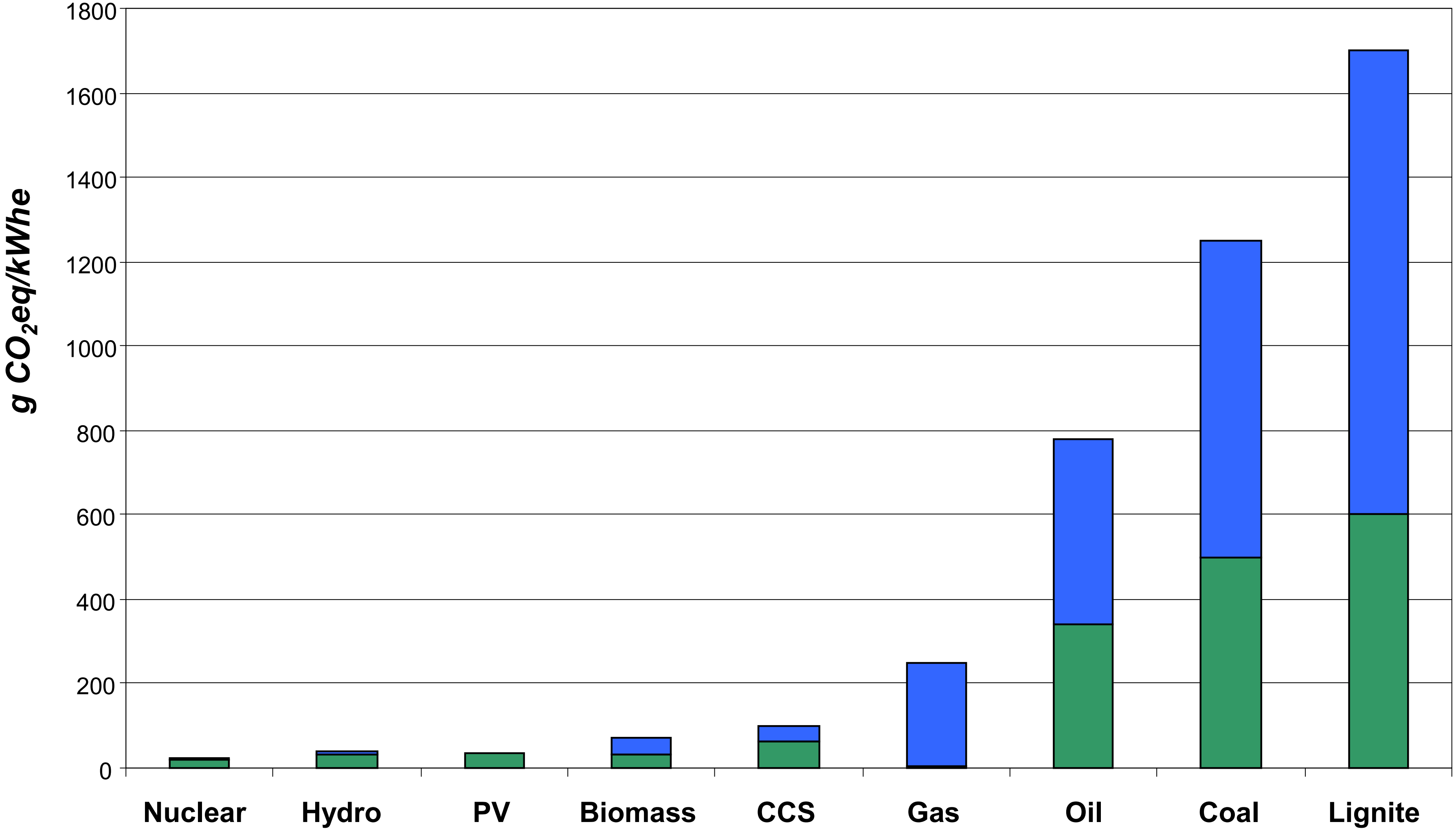


Consommation d'énergie primaire



Source: BP Energy Outlook 2035

Emissions de CO2 emissions : comparaison entre sources d'énergies

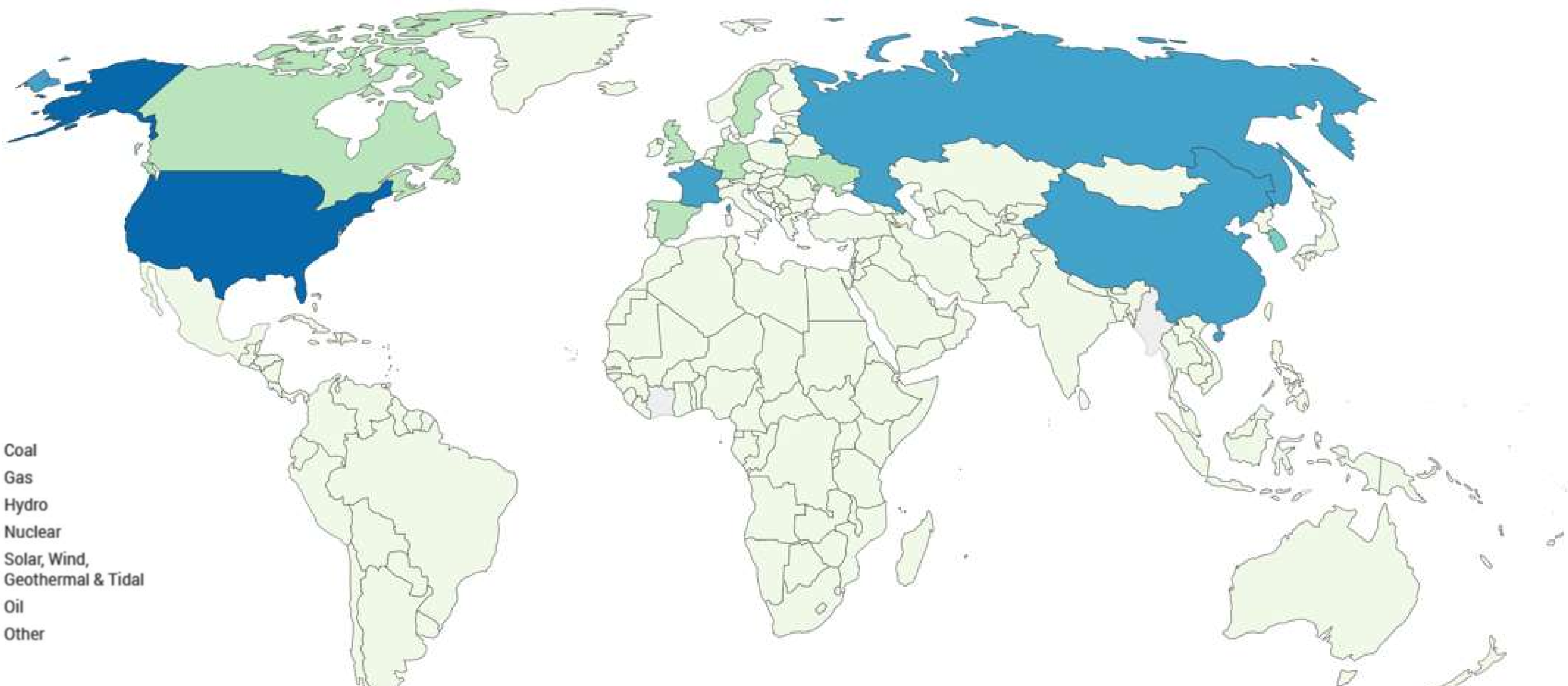


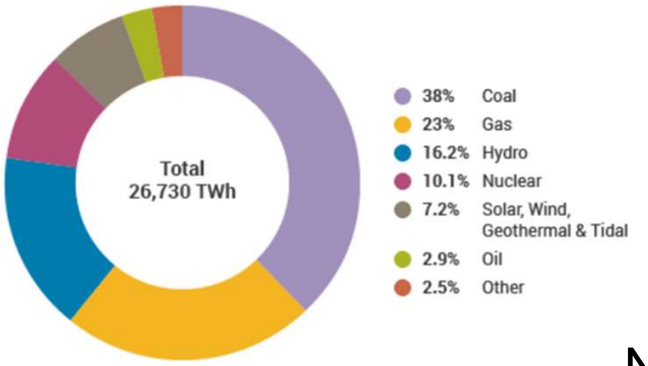
Ranges reflect differences in assessment technology, conversion efficiency, etc …

Source : D. Weisser IAEA May 2006

L’énergie nucléaire aujourd’hui

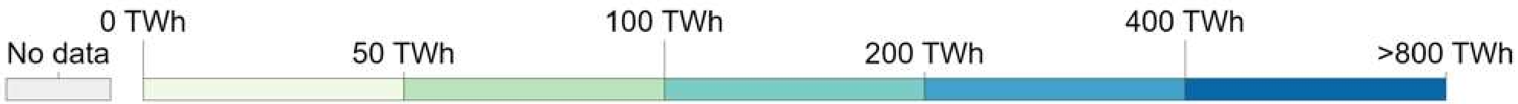
Nuclear energy generation by country - 2020





World electricity production by source 2018 *(source: IEA)*

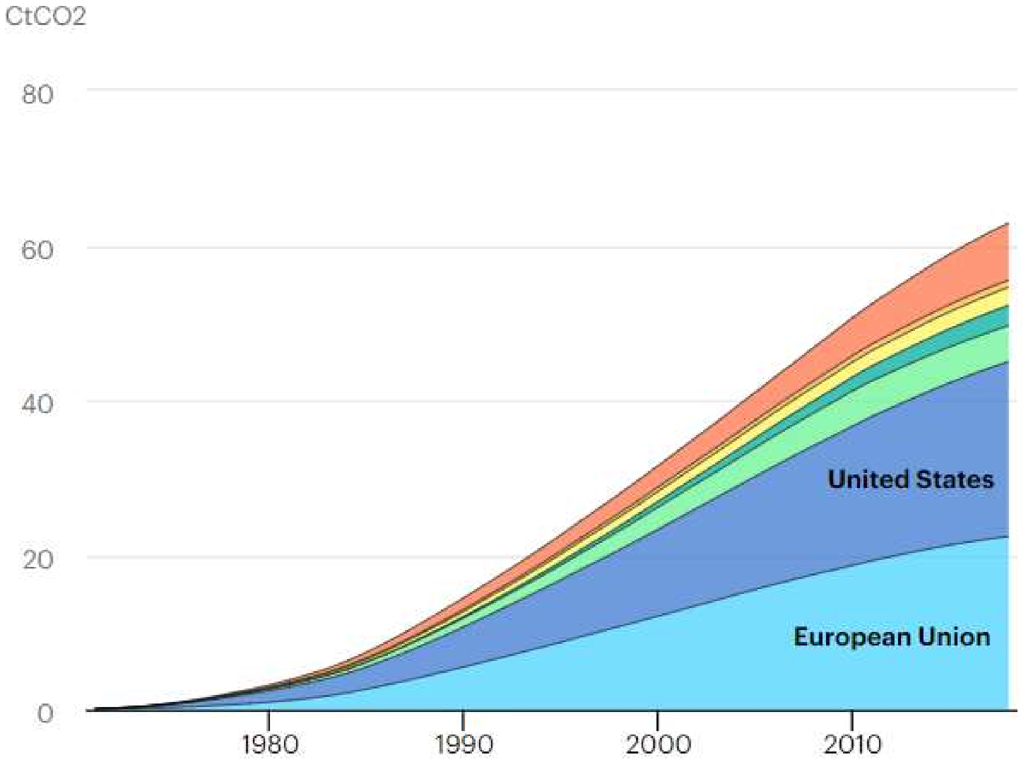
Nuclear power is the second-largest source of low-carbon electricity today, with 452 operating reactors providing 2700 TWh of electricity in 2018, or 10% of global electricity supply.

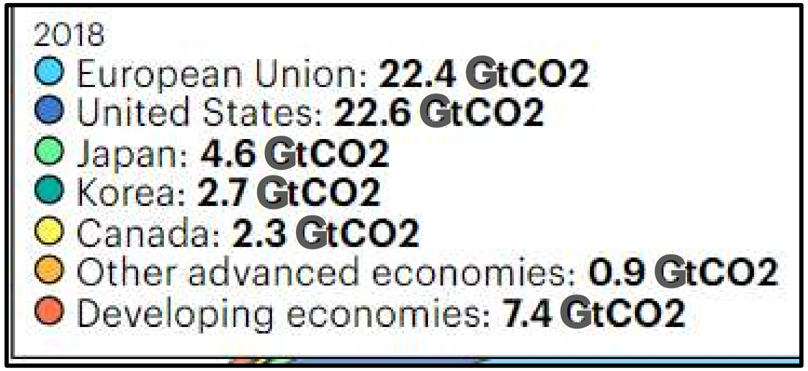


Source: BP Statistical Review of World Energy & Ember

Emission de CO2 évitées par le nucléaire

Cumulative CO2 emissions avoided by global nuclear power in selected countries, 1971-2018





(source: IEA, 2019)

Nuclear power has avoided about 63 Gt of CO2 emissions over the past 50 years, nearly equal to 2 years of global energy-related CO2 emissions.

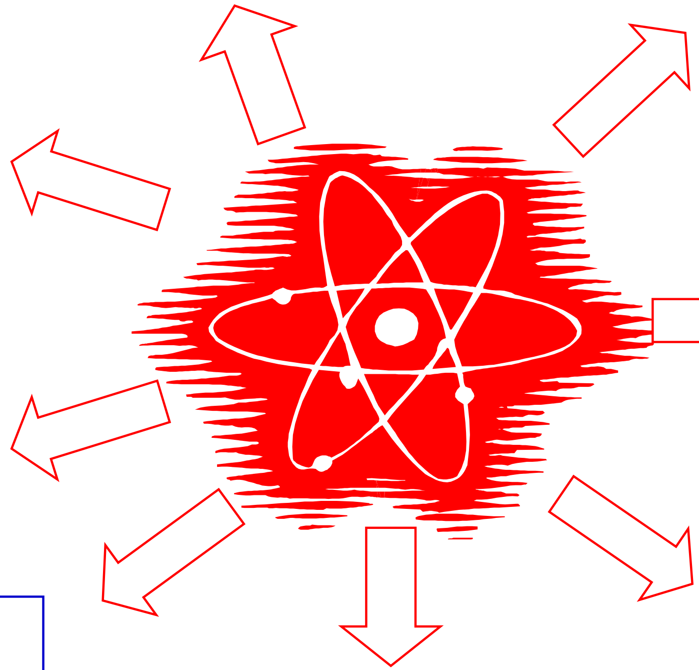
European Union · United States · Japan · Korea · Canada · Other advanced economies · Developing economies

Autres applications possibles de l'énergie nucléaire

Paper manufacture
- ***Paper Mill***
- ***Heating***

Oil-producing
- ***Refining***
- ***De-sulfurisation of crude oil***
- ***Gas production***
- ***Coal gasification***
- ***Extraction of bitumen***

Cement works
- ***Production of cement***



Iron industries
- ***Steel Production***

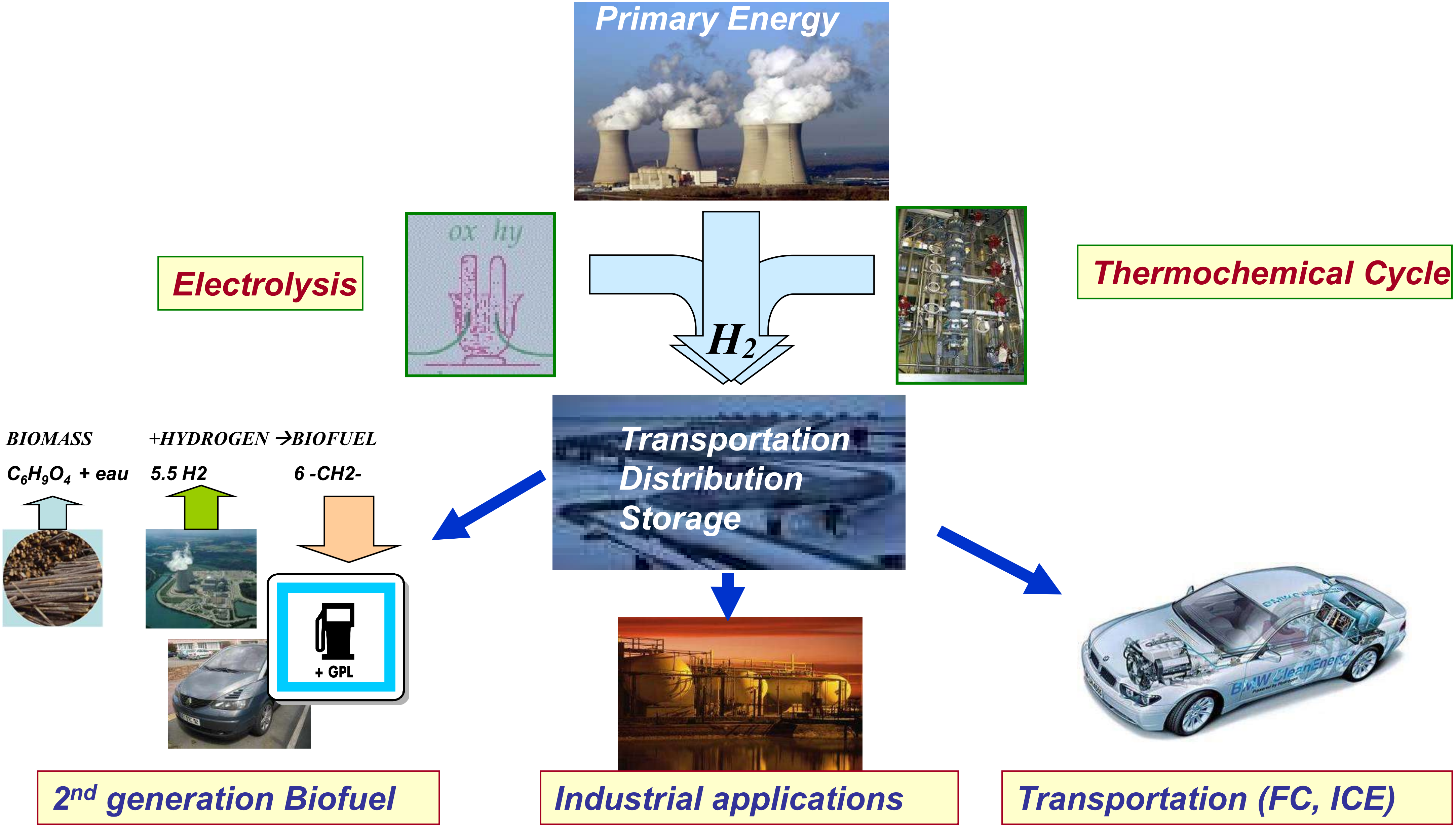
Electricity
- ***Production of electricity***

Chemical industries
- ***Production of hydrogen***
- ***Production of ethylen***
- ***Production of styren***
- ***…***

Other industries
- ***Production of other metals (aluminium, …)***
- ***Glass manufacturing***

Others
- ***Sea water desalination***
- ***District Heating***

Nuclear Hydrogen for Transportation Fuels & Industrial Processes



Le monde se convertit !

Tout le monde en parle, à commencer par ceux qui font l'économie …

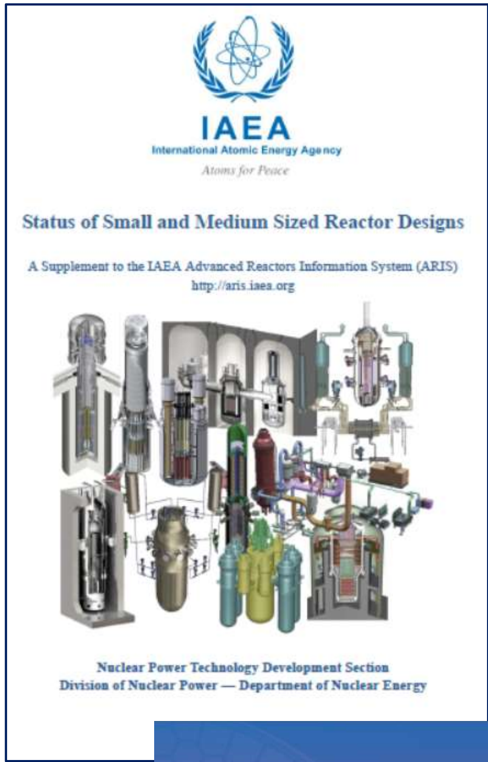
En France aussi !

Le président Emmanuel Macron a annoncé le 12 octobre 2021 allouer 1 milliard d'euros pour des innovations de rupture dans le nucléaire

Les SMRs, qu'est-ce que c'est ?

- According to the IAEA, small reactors are reactors with an equivalent electric power of about or less than 300 MWe

- Numerous innovative concepts are under development for various applications:
  - ✓ electricity generation,
  - ✓ heat production (district heating, industries, …),
  - ✓ desalination,
  - ✓ coal power plant replacement,
  - ✓ alternative to diesel generation in remote communities,
  - ✓ decarbonization of hard-to-abate sectors (transportation, …)
  - ✓ hydrogen generation and some other …



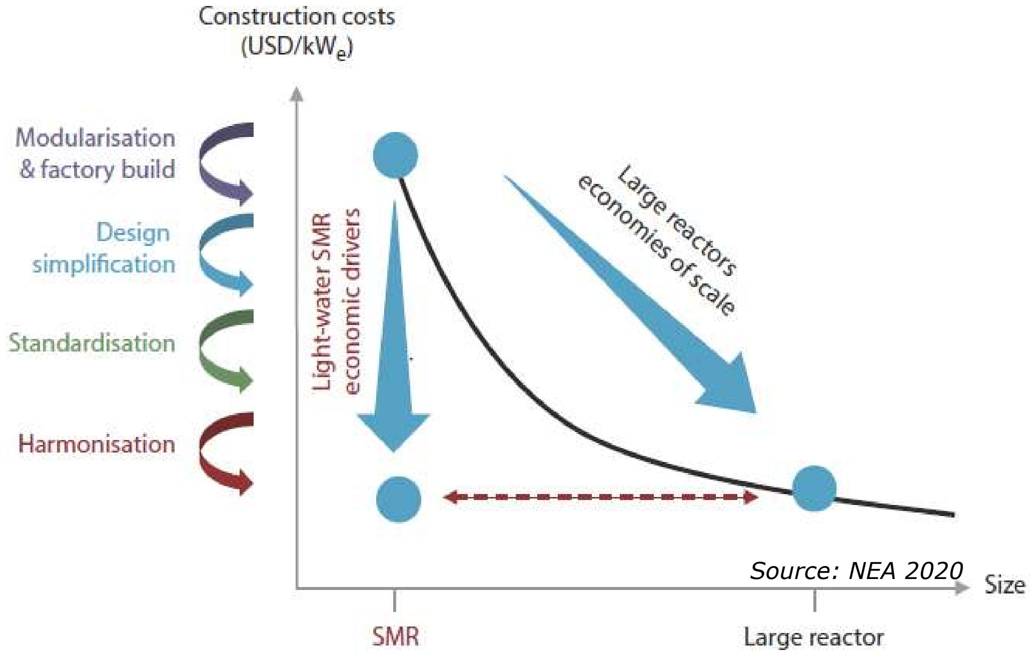
Les SMRs ont-ils un avenir ?

- The SMR concept has been around for decades, but it did not materialize as an industry
- Why is it different this time?
  - Growing climate pressure: exiting fossil sources is an imperative but how ?
  - Scientific consensus about the need of nuclear energy to combat climate change and therefore contribute to a deep decarbonization of the economy. This could result in growing public support and funding (long-term policy support, R&D, regulatory development, public-private partnerships, financial support to FOAK demonstrators, etc.)
  - Technological progress: material science, digital tools, advanced fabrication methods
  - Visionary private investors and venture capitalists support breakthrough innovations and both evolutive and disruptive reactor concepts – multiple competing start-ups
  - Increasing political support for nuclear energy although, in several countries, it is not stated openly
  - Geopolitics: several large economies invest heavily in the development of SMRs, the others, initially more reluctant, don’t want to stay behind. It is a kind of renewed competition for global leadership in nuclear technology.

SMRs: principaux moteurs économiques

- The main economic drivers that should allow SMRs to beat the diseconomy of scale are intimately linked with **their potential for higher intrinsic safety compared to current generation of large reactors**:

    1. Modularization & factory build
    2. Design simplification
    3. Standardization
    4. Harmonization



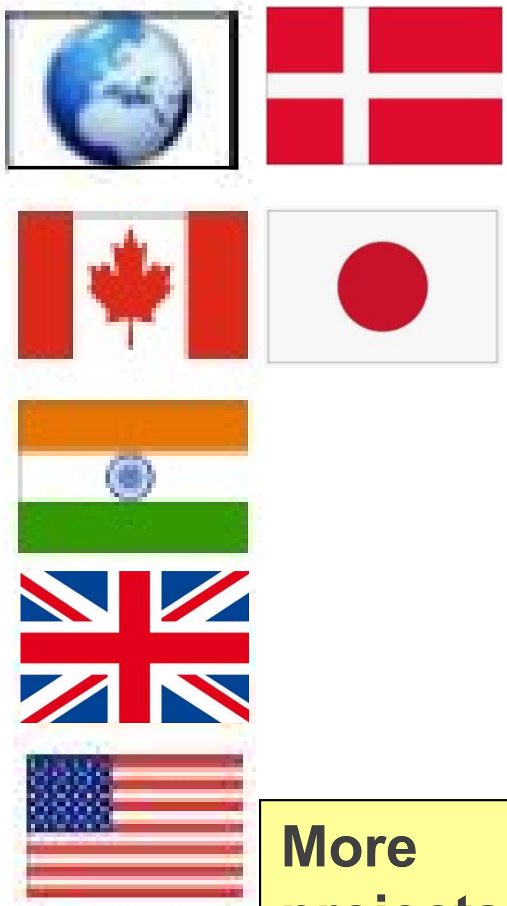
- Moreover, as regards investment, SMRs present a-priori some attractive features compared to large reactors: **lower capital costs, smaller upfront investment**, possibility of sequencing, lower risks in terms of construction time overruns, ...

Un grand nombre de projets et plusieurs technologies

LWR

HTGR

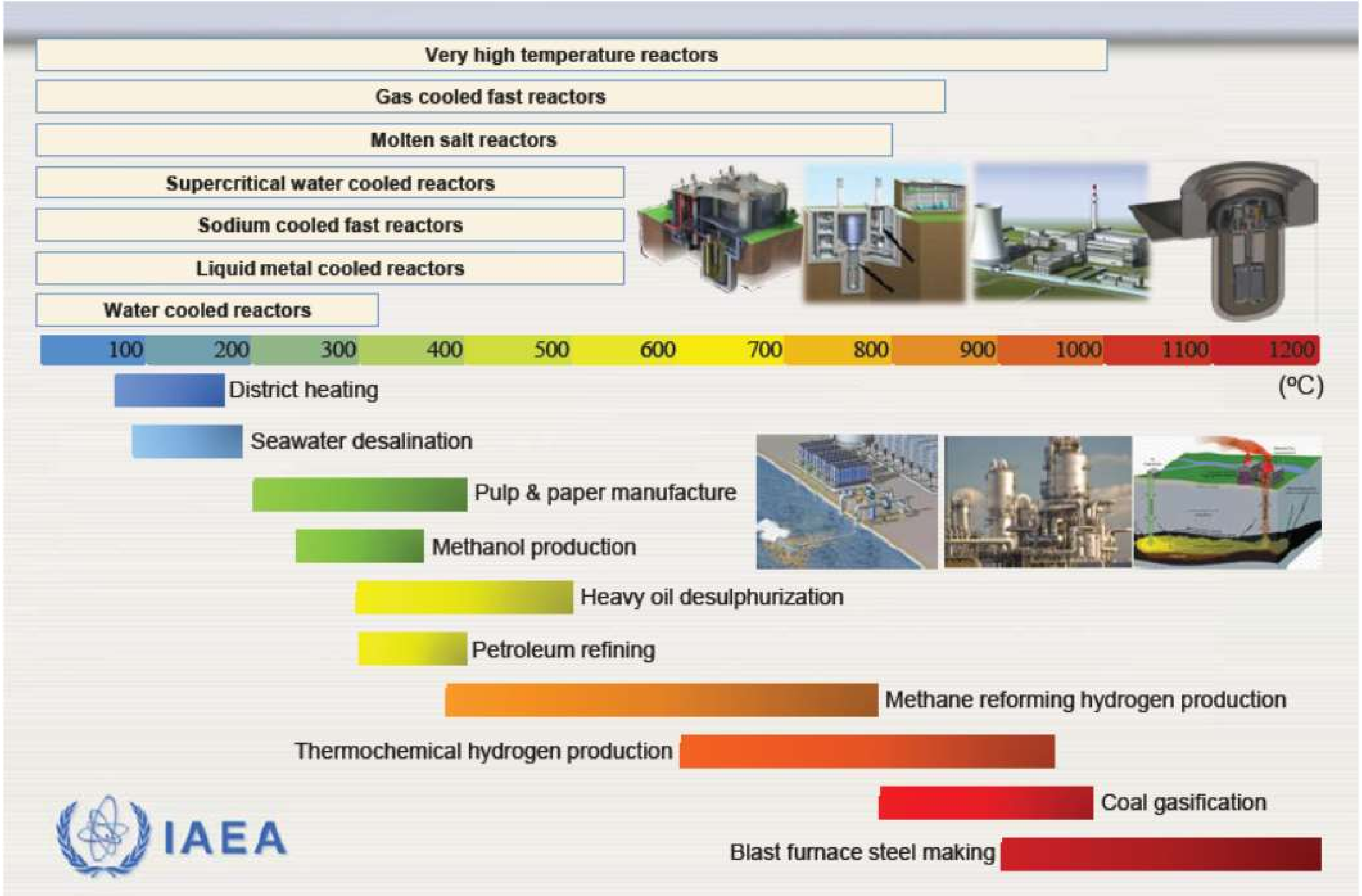
MSR



LMR

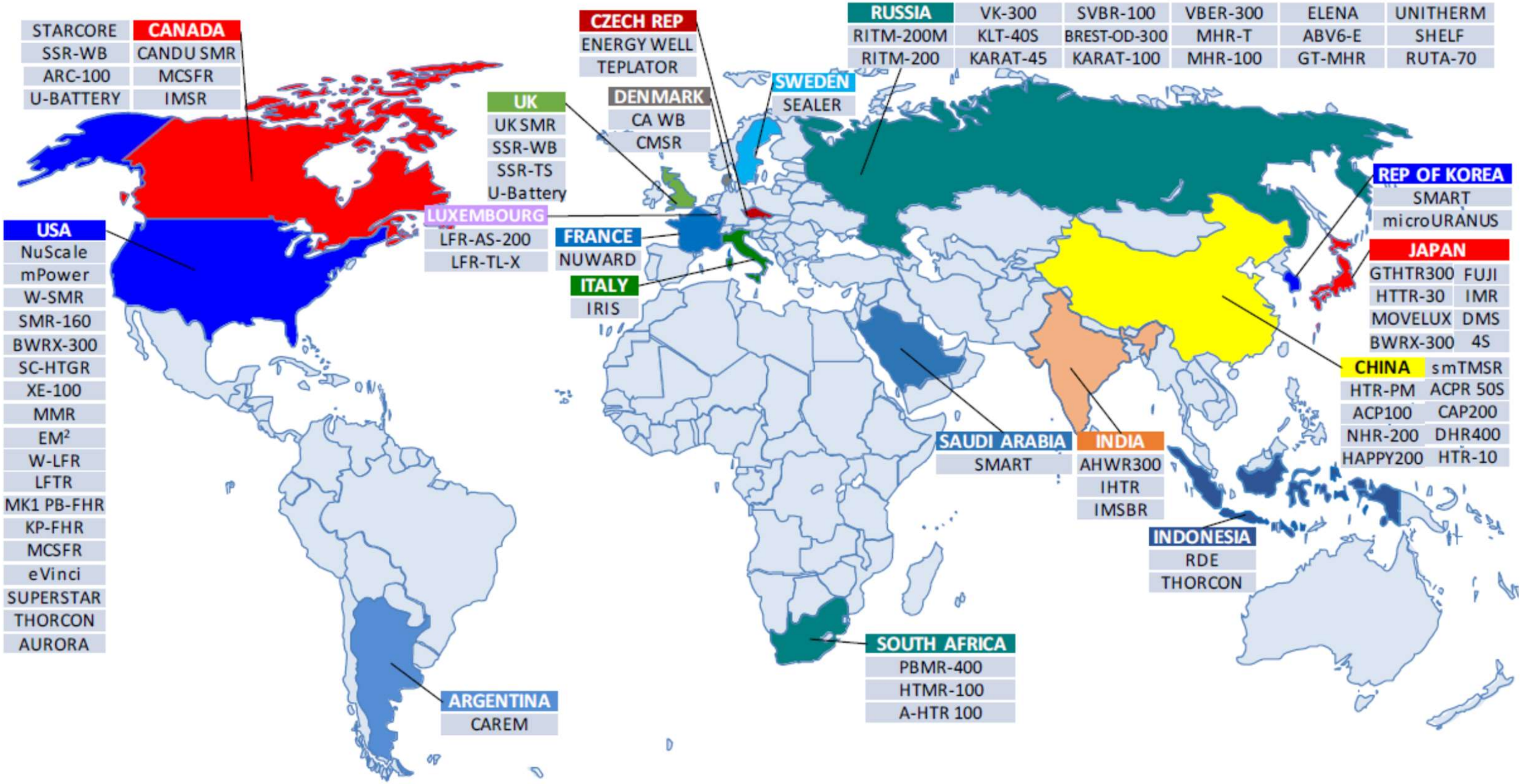
More than 70 projects listed by the IAEA in 2018

Des technologies adaptées aux marchés



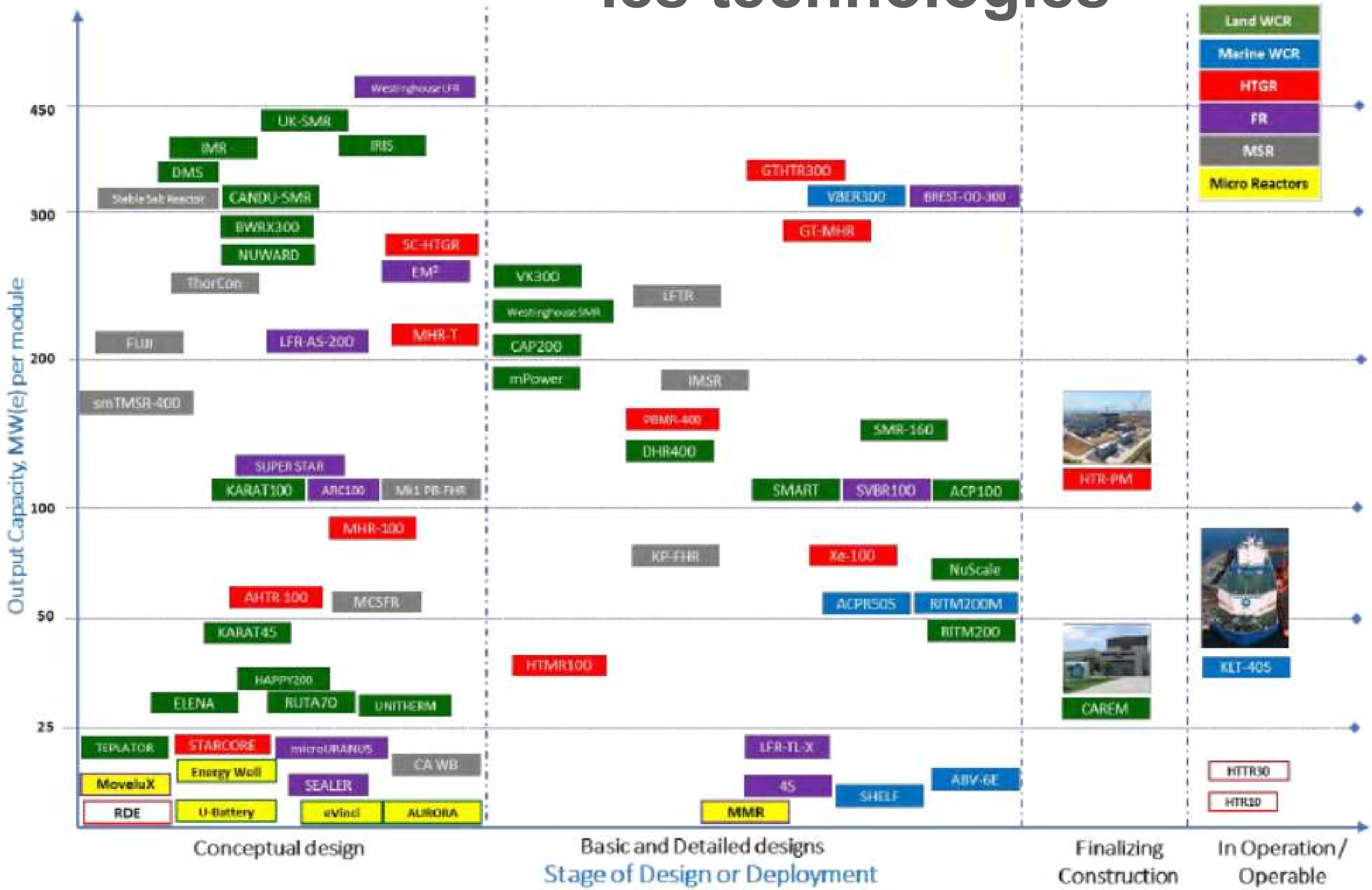
SMR designs for non-electrical applications according to system temperature

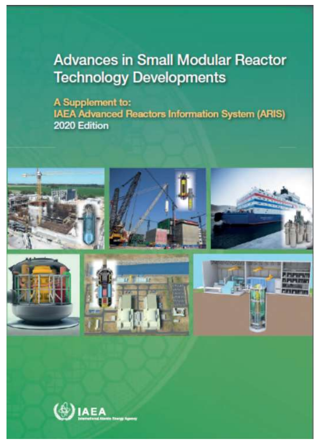
Les technologies SMRs en développement dans le monde



Source : AIEA -2020

Des niveaux de développement très différents suivant les technologies





Stage of Design or Deployment of SMRs in terms of their Output Capacity

Floating SMR: Akademik Lomonosov

KLT-40S nuclear reactors with 35x2 Mwe

- **Construction started in 2007**
- **Commerical operation since 2020**

MAJOR TECHNICAL PARAMETERS	
Parameter	**Value**
Technology developer, country of origin	JSC "Afrikantov OKBM", Rosatom, Russian Federation
Reactor type	PWR
Coolant/moderator	Light water / light water
Thermal/electrical capacity, MW(t)/MW(e)	150 / 35
Primary circulation	Forced circulation
NSSS Operating Pressure (primary/secondary), MPa	12.7
Core Inlet/Outlet Coolant Temperature (°C)	280 / 316
Fuel type/assembly array	UO_2 pellet in silumin matrix
Number of fuel assemblies in the core	121
Fuel enrichment (%)	18.6

TerraPower Natrium

TerraPower
A Nuclear Innovation Company

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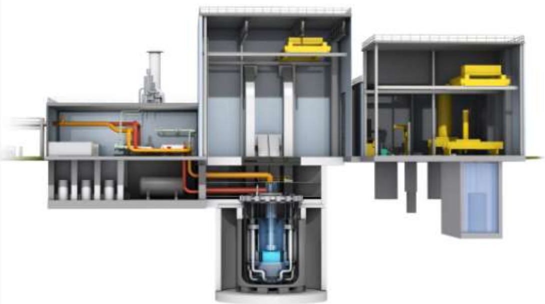
Bill Gates and like-minded visionaries determine the private sector must act to develop clean energy resources to halt climate change and to raise global living standards.

2006

Nuclear power is identified as an essential element of energy infrastructure.

The DOE awards TerraPower $80 million to demonstrate the Natrium™ reactor and integrated energy system with its technology co-developer GE Hitachi Nuclear Energy and engineering and construction partner Bechtel.

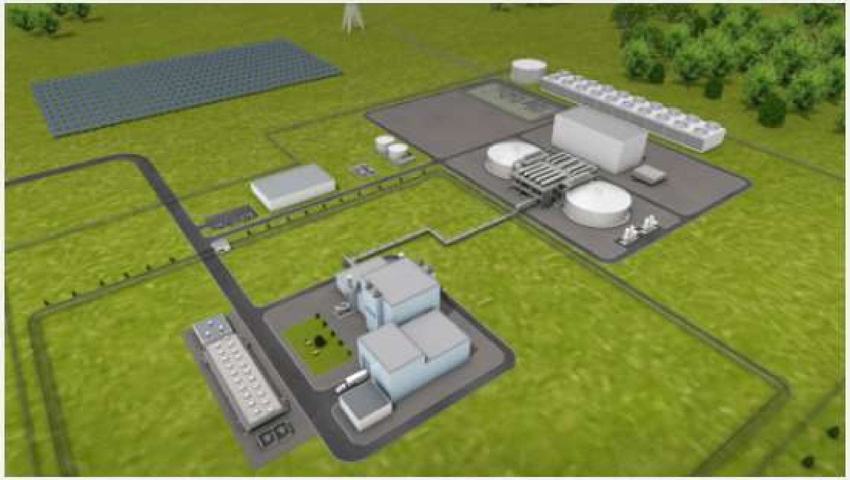
2020



« Make America Great Again »

TerraPower and PacifiCorp announce efforts to advance the Natrium™ reactor demonstration project at a retiring coal plant in Wyoming.

2021

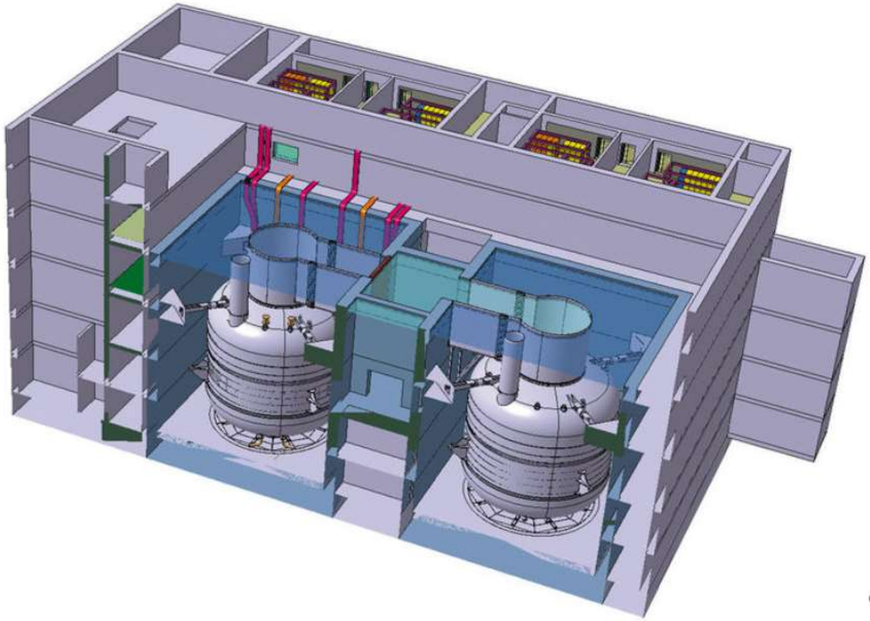


NuScale (NuScale Power, LLC)

Reactor type Integral PWR
Thermal / electrical capacity: 200 MW(th) / 60 MW(e) (gross)
Core Inlet / Outlet Coolant Temperature : 265°C / 321°C
Fuel type/assembly array UO2 pellet / 17x17 square

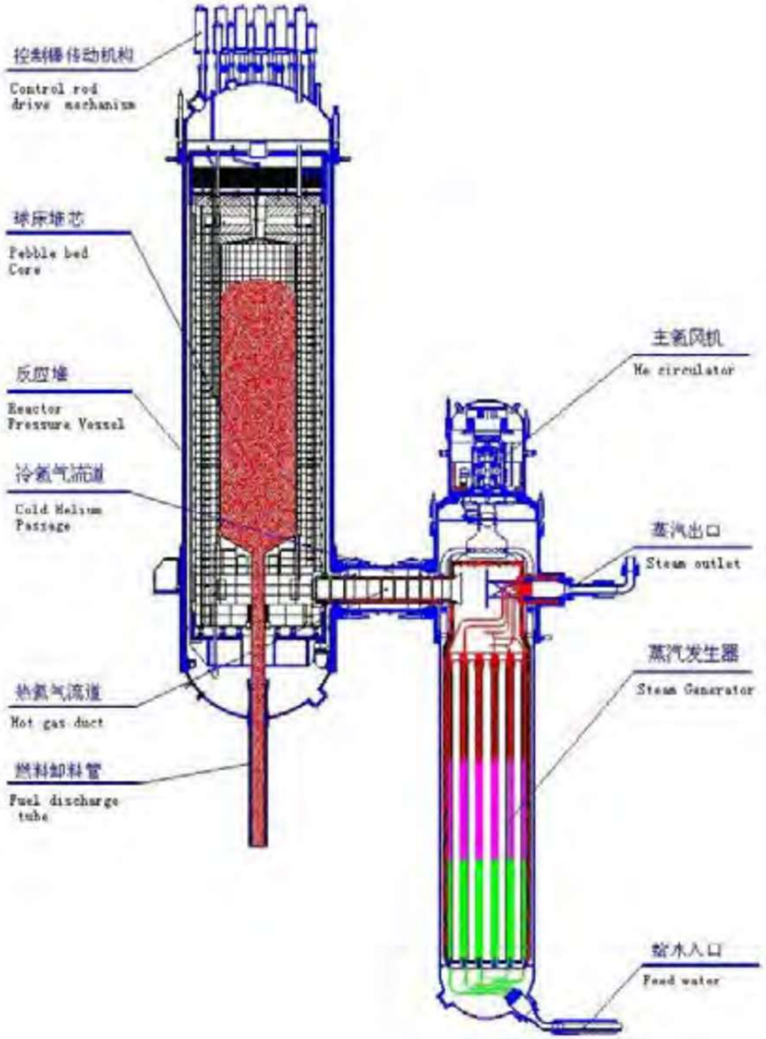
Vue d'artiste du projet de SMR de Nuscale Power (Les Echos 4 avril 2021)

NUWARD (EDF – CEA – TA - Naval Group)



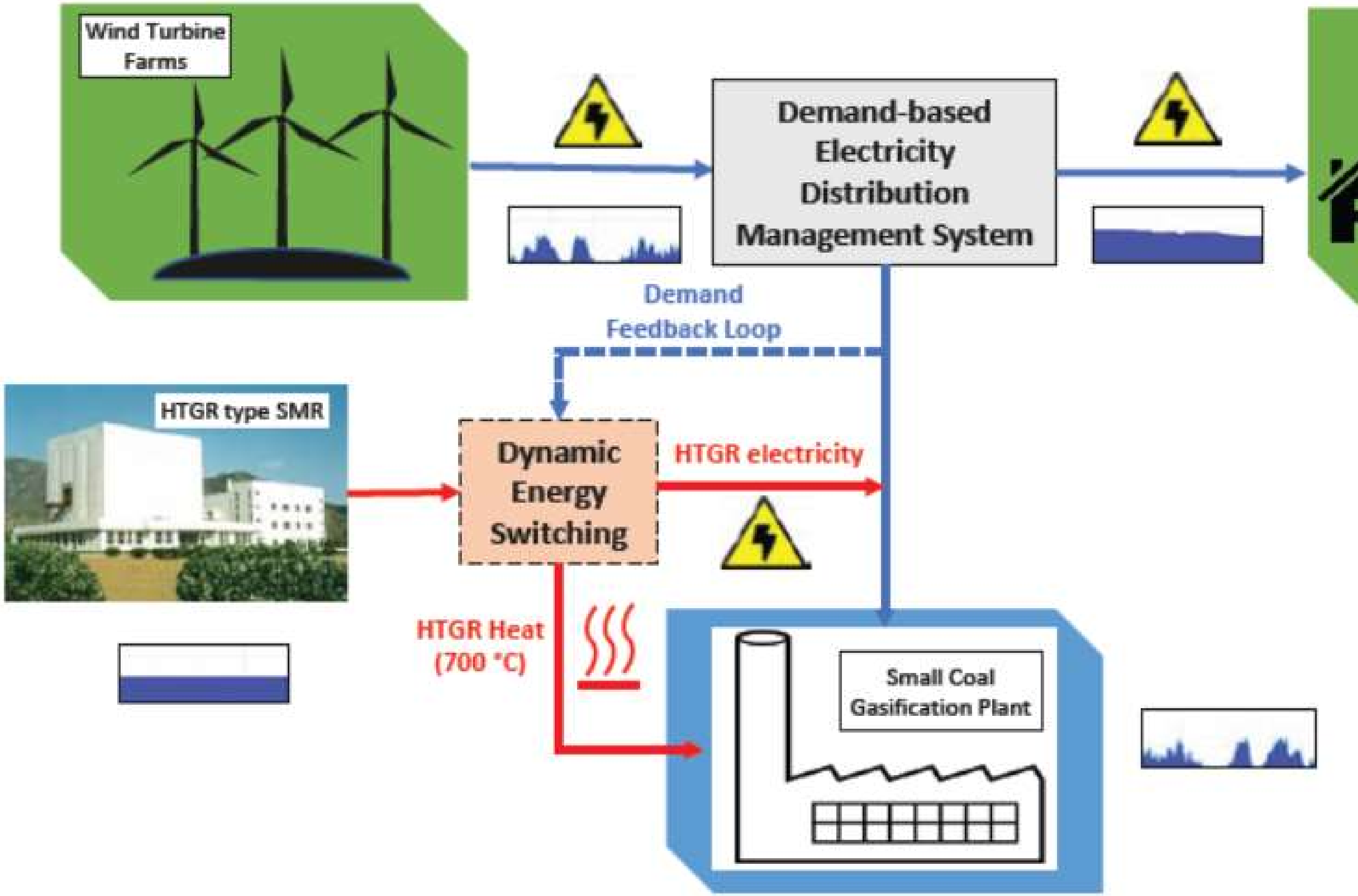
MAJOR TECHNICAL PARAMETERS	
Parameter	**Value**
Technology developer, country of origin	EDF-led consortium with CEA, Naval Group, and TechnicAtome, France
Reactor type	Integral PWR
Coolant/moderator	Light water / light water
Thermal/electrical capacity, MW(t)/MW(e)	2x540 / 2x170
Primary circulation	Forced circulation
Operating Pressure (primary/secondary), MPa	15 / 4.5
Core Inlet/Outlet Coolant Temperature (°C)	280 / 307
Fuel type/assembly array	UO_2 / 17x17 square pitch arrangement
Number of fuel assemblies in the core	76
Fuel enrichment (%)	<5
Core Discharge Burnup (GWd/ton)	-
Refuelling Cycle (months)	24
Reactivity control mechanism	Control rod drive mechanism (CRDM), solid burnable poisons
Approach to safety systems	Passive
Design life (years)	60
Plant footprint (m^2)	3500, nuclear island including fuel storage pool
RPV height/diameter (m)	13 / 4
RPV weight (metric tonnes)	310
Seismic Design (SSE)	0.25g
Distinguishing features	Highly compact NSSS and containment, boron-free design, load follow
Design status	Conceptual Design

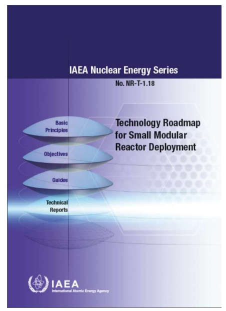
HTR-PM (Tsinghua University, China)



MAJOR TECHNICAL PARAMETERS	
Parameter	**Value**
Technology developer, country of origin	INET, Tsinghua University, People's Republic of China
Reactor type	Modular pebble bed high temperature gas-cooled reactor
Coolant/moderator	Helium/graphite
Thermal/electrical capacity, MW(t)/MW(e)	2x250 / 210
Primary circulation	Forced circulation
NSSS Operating Pressure (primary/secondary), MPa	7 / 13.25
Core Inlet/Outlet Coolant Temperature (°C)	250 / 750
Fuel type/assembly array	Spherical elements with coated particle fuel
Number of fuel assemblies in the core	420 000 (in each reactor module)
Fuel enrichment (%)	8.5

Les SMRs: un des piliers des écosystèmes énergétiques de demain





Hybrid system of wind power and HTGR connected to a coal gasification plant

Conclusions

- **Nuclear energy may have a key role in an energy mix aiming at a sustainable low-carbon future**

- **Nuclear and renewable energies are more than ever complementary**

- **Nuclear energy offers alternative solutions to fossil energies for several industries on the basis of electricity, H2 or heat production**

- **In this regard, SMRs are an asset**

Merci pour votre attention

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