

Overview of SMR projects worldwide, Market Potential for Near Term Deployment

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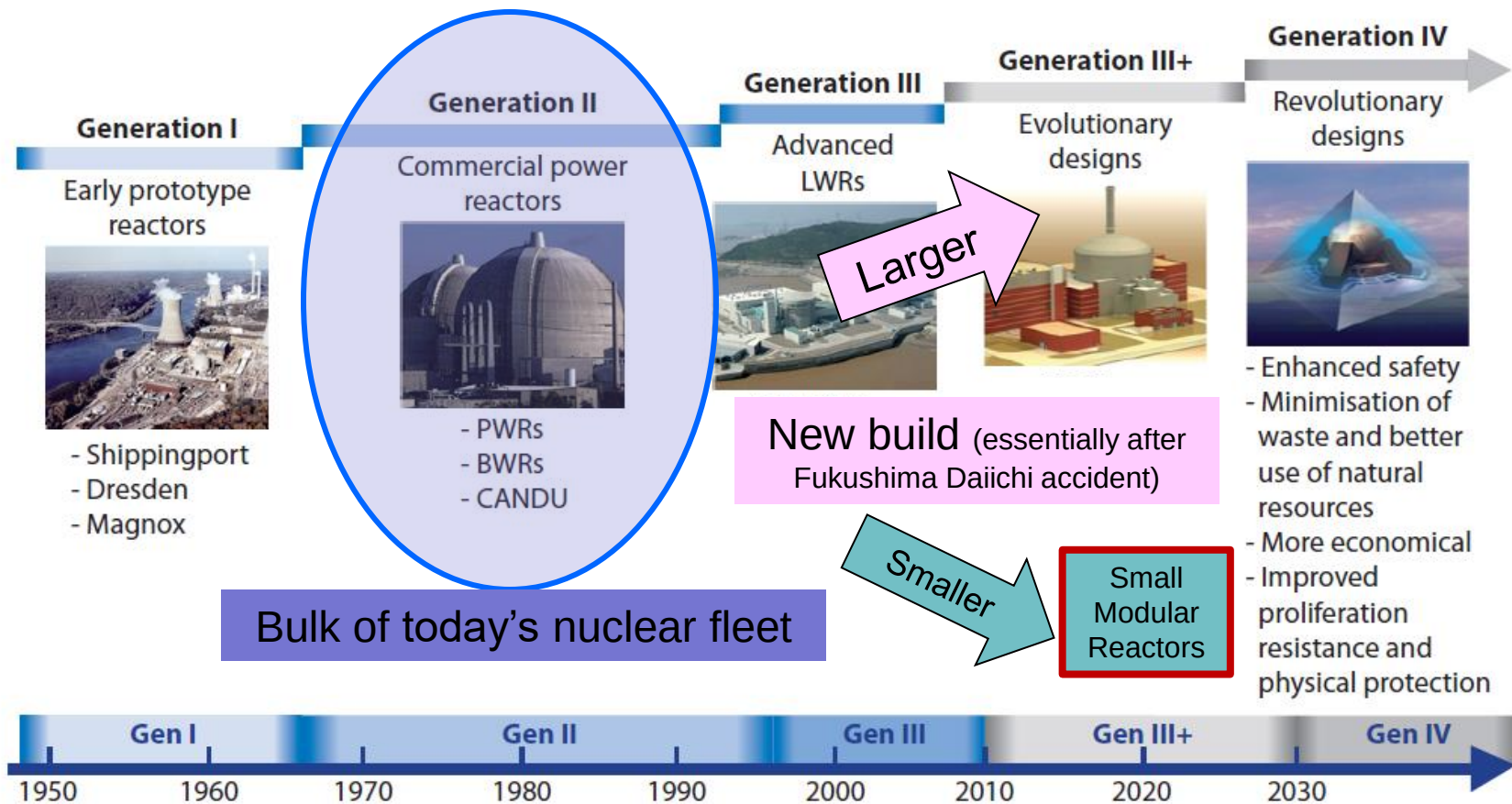
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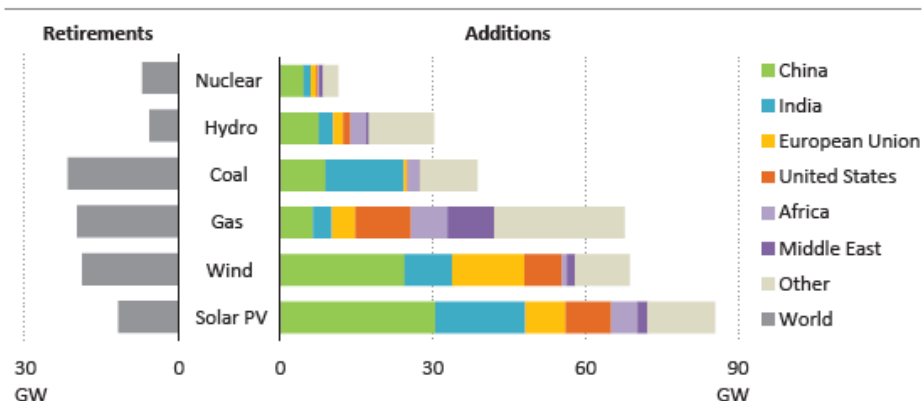
IAEA – TWG-SMR, 25 April 2018 – Vienna

Nuclear Reactors: Generations I to IV

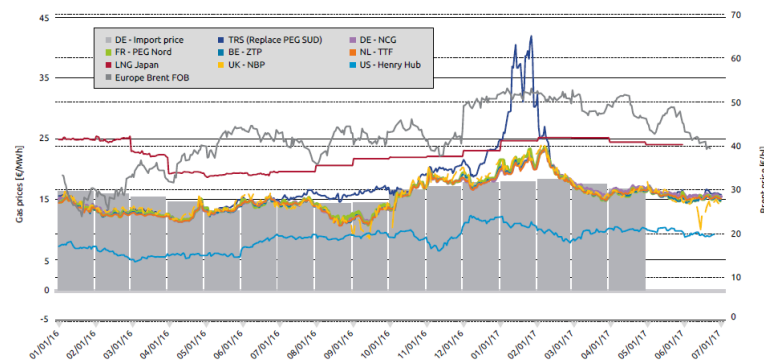
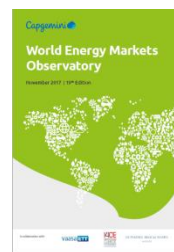


What is role of nuclear power in the future energy scenario ?

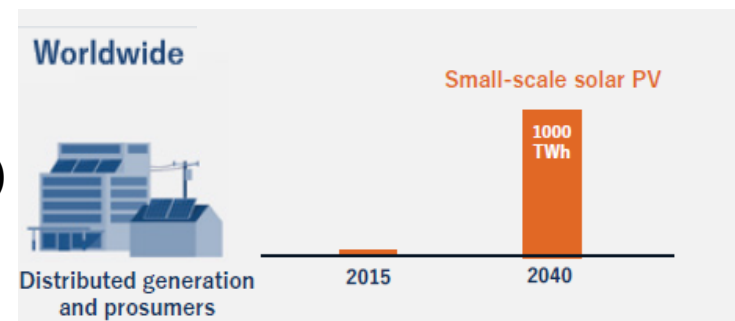
Some market trends....



After a century of dominance, fossil-fuelled power plants no longer lead, as renewables account for more than 60% of total capacity additions to 2040



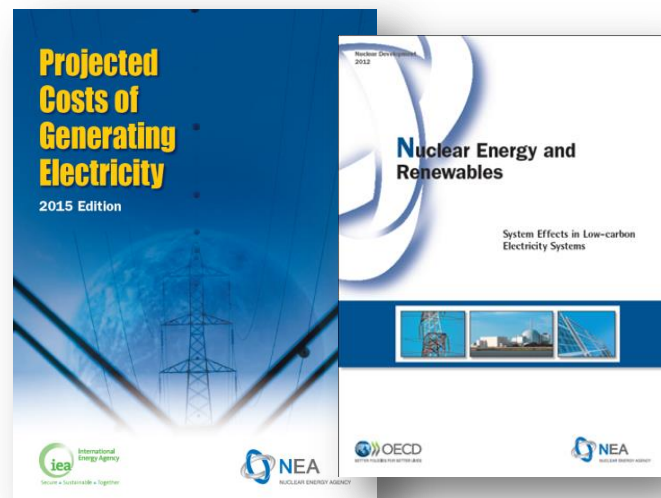
- The future electricity generation system might be:
 - More decarbonised
 - More decentralised (less base-load capacity)
 - More “liberalised”



What is role of nuclear power in the future energy scenario?

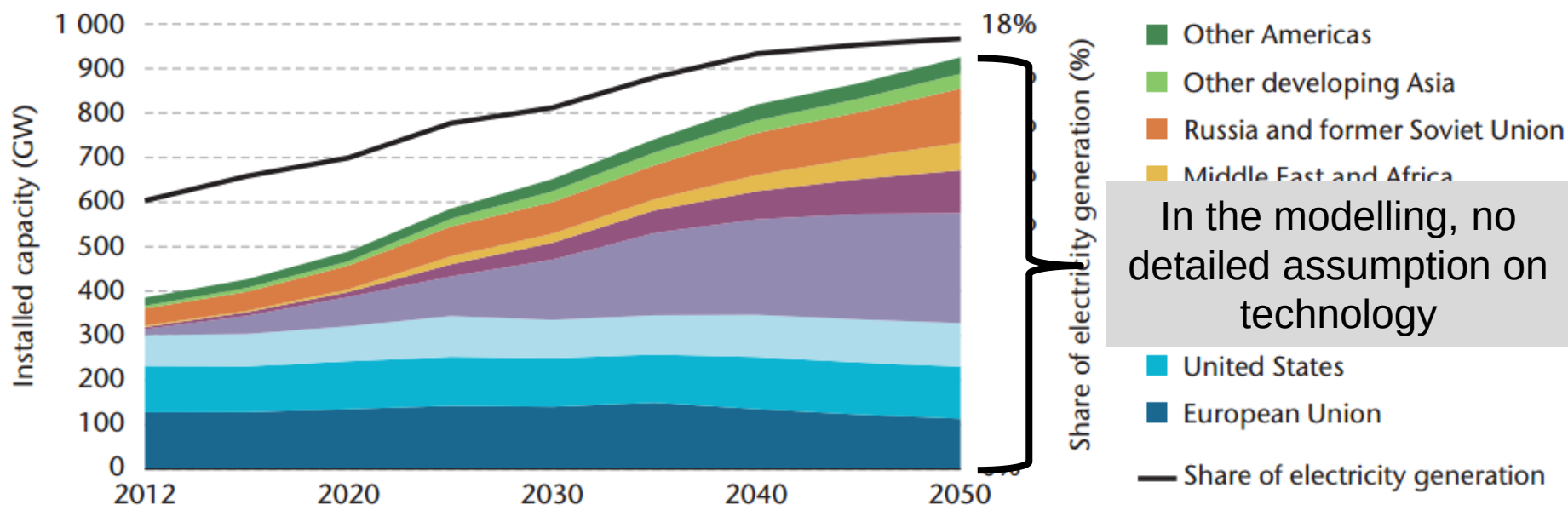
Nuclear technology strengths...

- Large scale power production, stable production costs
- Can be deployed quickly (eg. France in the 70s-90s, Sweden (70s-80s))
- “competitive” (Existing nuclear but new build?) against many other generation technologies – fossil (with C tax) / renewables (but the costs of these have decreased significantly over past years)
- Security of supply
- Decarbonisation – nuclear as one of the key low C generation technologies – will COP21 and the Paris Treaty lead to policies favouring nuclear?
 - For low C electricity
 - For low C heat?



2°C Scenario – Role of Nuclear

- IEA's 2°C Scenario (2DS) projects current nuclear capacity of 390 GW to more than double by 2050 to reach over 900 GW (gross capacity)
- Share of nuclear electricity would increase from **11%** to 17% (**16%** in ETP2016)
- China would see the largest increase in installed capacity and would be the largest nuclear power producer.
- Assumptions on LTO: 60 years in US / 55 years elsewhere.

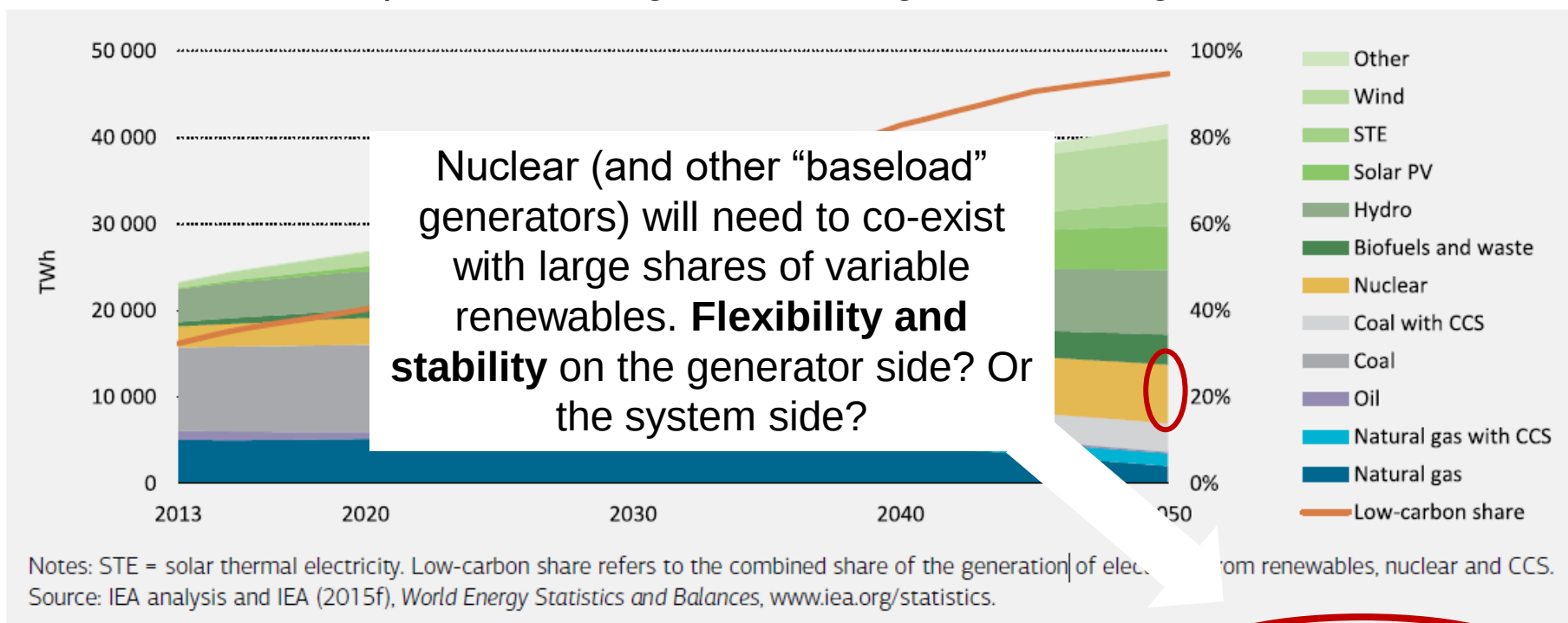


Source: IEA/NEA Nuclear Technology Roadmap Update (2015),
IEA (2016)

Future low carbon electricity systems?

In order to reach the 2°C scenario, the rise of nuclear would need to be accompanied by a *complete phase-out* of coal and oil, a drastic decrease of gas, the deployment of CCS and a massive increase of renewable energies.

Note that at COP21, parties have agreed to limit global warming to **well below 2°C**



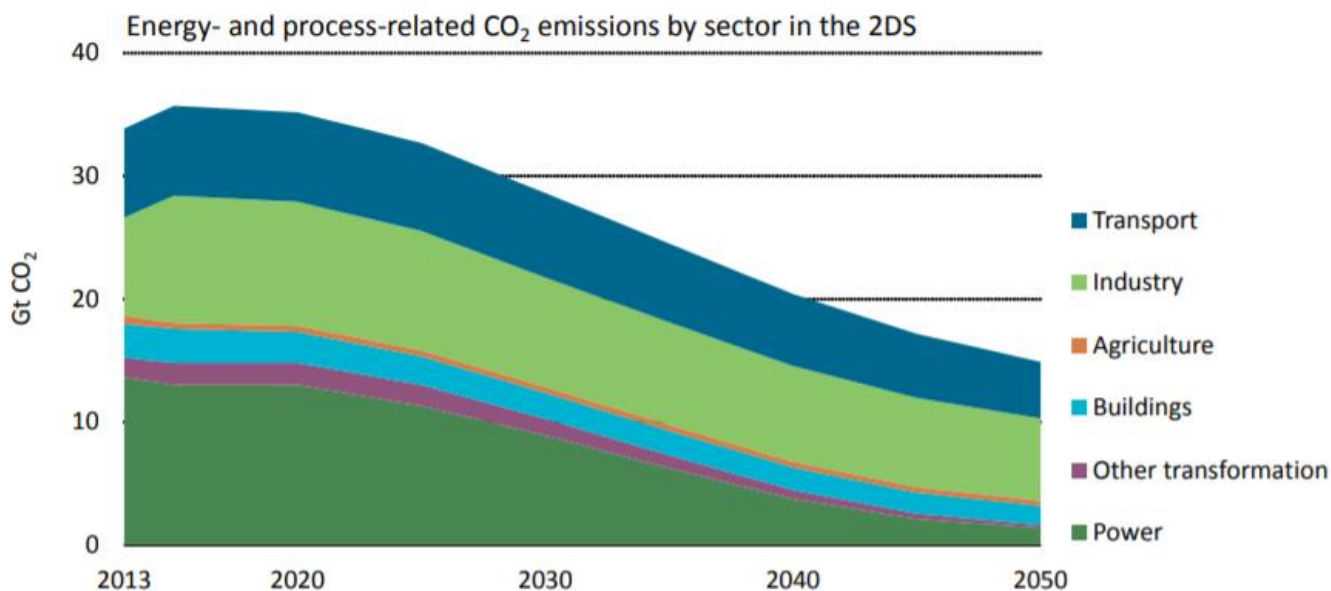
Source: IEA, ETP2016

IEA/Energy Technology Perspectives 2017 to be released June 2017

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

Future low carbon **heat** systems?

From 2 degrees to "well-below 2 degrees"



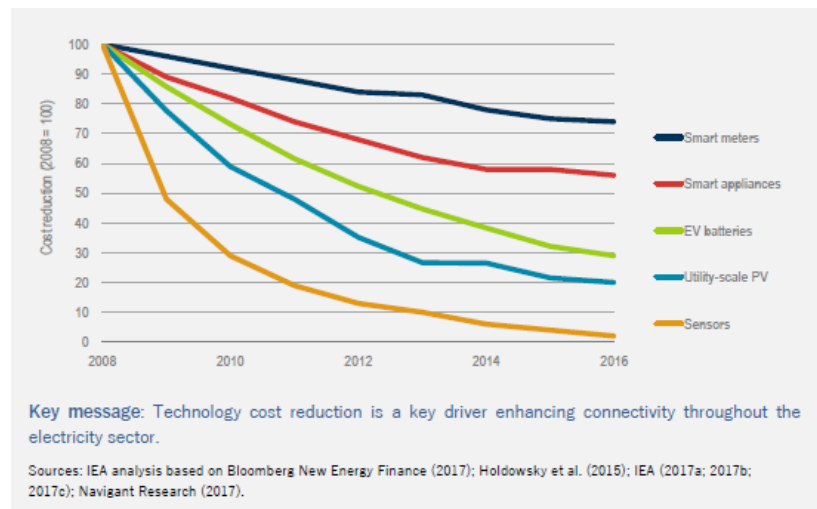
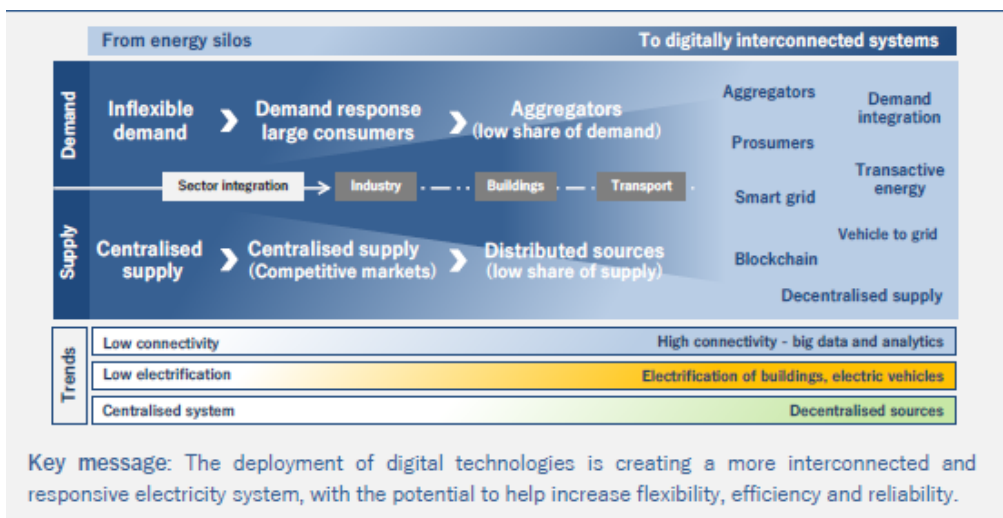
Industry and transport accounted for 45% of direct CO₂ emissions in 2013, but they are responsible for 75% of the remaining emissions in the 2DS in 2050.

2

Source: Energy Technology Perspectives, 2016 © OECD/IEA 2016

Future **decentralised** electricity generation system?

- Falling costs of digital devices and RES are accelerating decentralisation of the electricity production system



Source: IEA, Energy & Digitalization 2017

Future **liberalised** electricity market?

- Most modern economies have abandoned the vertically integrated model and progressively introduced wholesale market pricing
- New markets reforms in China, Mexico, Japan and South Korea
- Under these conditions technologies with high upfront fixed costs like nuclear may suffer
- Renewables are becoming more and more competitive and attract more investment
- Final investment decisions for nuclear in 2017 occurred at regulated tariff and by state-owned companies

Figure 2.3 Levelized cost of electricity (LCOE) comparison of selected power generation sources in Europe starting production in 2016-2017

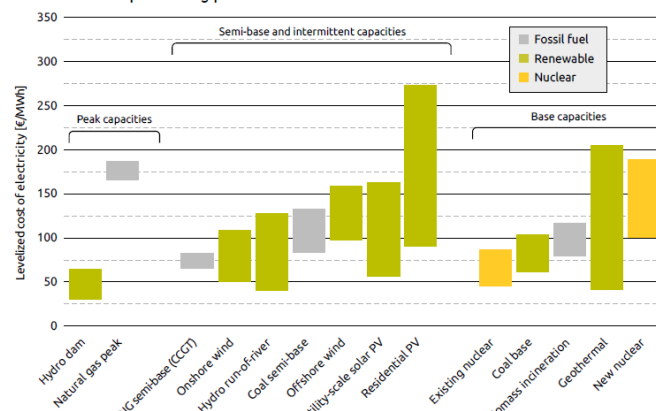
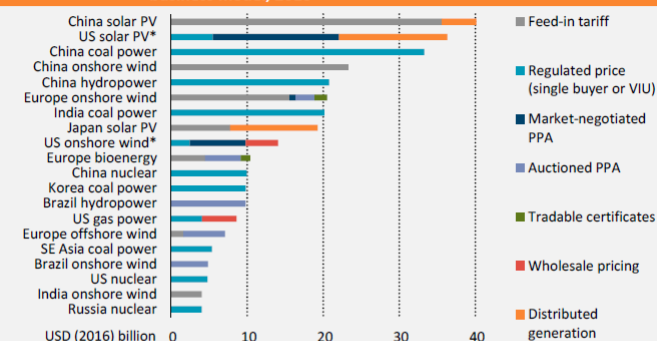


Figure 2.13 Investment in the top-20 power-generation sectors by main business model, 2016



The top-20 destinations for power-generation investment, which accounted for two-thirds of the world total in 2016, mostly have contracted pricing that allows for long-term cost recovery of assets.

*Renewables in the United States benefit as well from federal tax credits and market-negotiated PPAs are often struck to satisfy utility purchase obligations.

Note: Distributed generation breakdowns are only available for solar PV; VIU = vertically integrated utility; PPA = power purchase agreement.

Source: IEA, World Energy Investment 2017

Source: Capgemini, World Energy Market Observatory 2017

Challenges: new build (Gen III/III+)

	Nuclear	Coal steam	Gas CCGT	Wind onshore and solar PV
Investment cost	Very High	Moderate	Low	Moderate - high
Construction time	4-10 years	4-5 years		
Operational cost	Low	Low-moderate		
Operational characteristics	Mid to large scale production, baseload, limited flexibility	Baseload, moderate flexibility	Mid to large scale production, baseload, limited flexibility	
CO₂ emissions	Negligible	High- very high		
Key risks	Regulatory (policy changes), public acceptance, market	Regulatory (CO ₂ and pollution*), public acceptance, market	Regulatory (policy changes), public acceptance, market	
Other features	Low sensitivity to fuel prices (stable production costs), contributes to security of energy supply	Sensitivity to fuel prices	Very low sensitivity to fuel prices	

The future energy market needs and these challenges can be better addressed by advanced reactor technologies – in particular **SMRs**?

- Shorter construction times
- Lower investment costs
- Increased learning rates
- Higher flexibility
- Reduced EPZ (emergency planning zone)

* Around 18 000 people die each day as a result of air pollution from fossil fuel combustion (heating, transport, power) ((IEA, 2016)

Source: IEA WEO (2014), NEA analysis

2011

Nuclear Development
June 2011



Current Status, Technical Feasibility and Economics of Small Nuclear Reactors



NUCLEAR ENERGY AGENCY

2015



Technology Roadmap

Nuclear Energy

2015 edition



2016

Nuclear Development
2016

Small Modular Reactors: Nuclear Energy Market Potential for Near-term Deployment

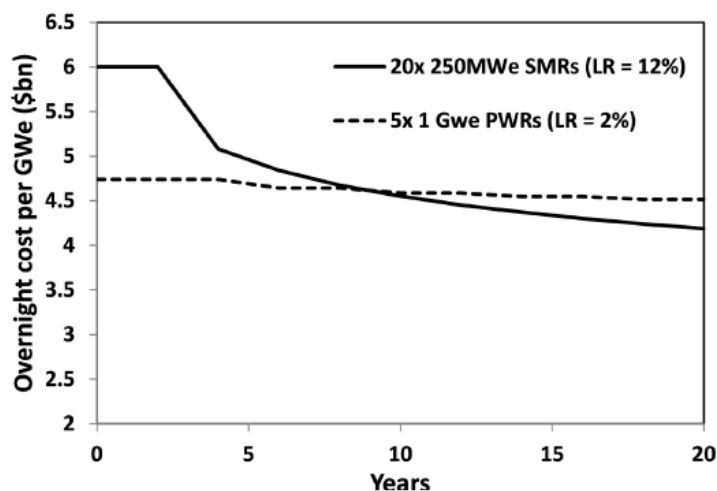
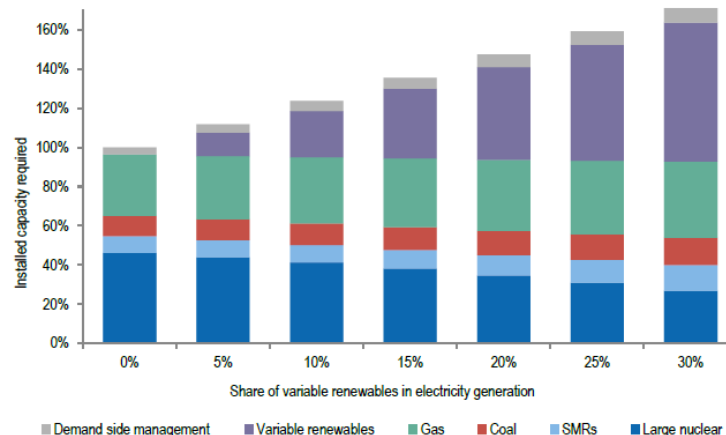
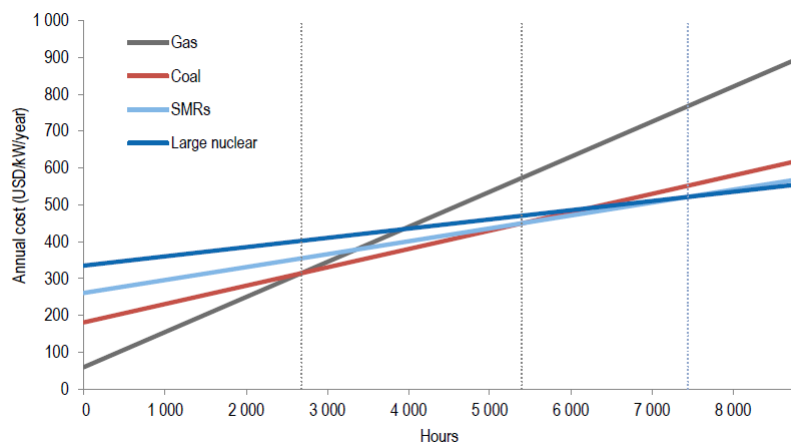


SMR features (1/2)

Economics and real prospects for SMRs are not yet proven... **vendors promote SMRs** with the following arguments:

- Enhanced safety due to lower total power/core and passive safety systems (also reduced EPZ)
- Simplified « system », structures and components, and in-factory modules fabrication (... is supply chain ready? Licensing issues?)
- Smaller upfront overnight capital investment and financing costs (... total vs per kW? Can increasing learning rates balance diseconomies of scale?)
- Economy of scale for multi-units sites (ia. human resources, operation/maintenance and optimization of outages)
- Increased flexibility (ia. multi-units) in case of high penetration of RES (a low carbon solution to replace coal plants in a long term energy mix?)
- Suitable for smaller grids or remote locations (descentralised energy system)
- High potential for non-electric uses and cogeneration (eg. Desalination, hydrogen production, process heat for industry, etc...)

SMR features (2/2)



Technology	Years covered by study	Range of learning rates (%)
Coal (PC)	1902–2006	5.6 to 12
Natural gas	1980–1998	-11 to 34
Nuclear	1975–1993	0 to 6
Wind (onshore)	1980–2010	-3 to 32
Solar PV	1959–2001	10 to 53
Bioenergy	1976–2005	0 to 24
Hydropower	1980–2001	0.48 to 11.4

Source: OECD-NEA, Small modular reactors: Nuclear Energy market potential for near-term development (2016)

Source: Policy Exchange, Small Modular Reactor: The next big thing in energy (2018)

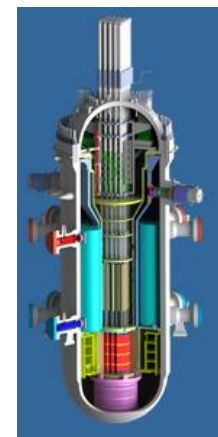
Small Modular Reactors, more than a niche market?

<i>Vendor</i>	<i>Country</i>	<i>Design</i>	<i>Type</i>	<i>Net capacity (MW)</i>	<i>In operation*</i>	<i>Under construction*</i>
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.

eVinci Westinghouse micro-reactor

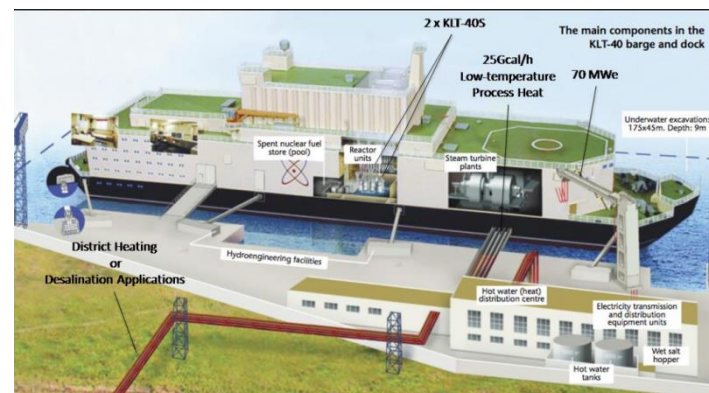
Source: IEA/NEA Nuclear Technology Roadmap (2015)



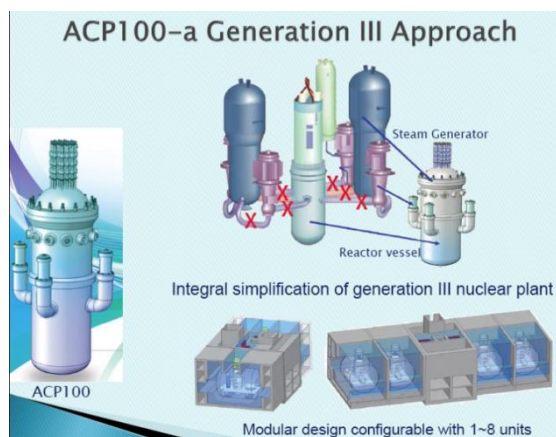
Some ongoing developments... (1/3)



CAREM (Argentina, 25MWe): under construction, commercial operation > 2019



KLT40s (Russia/OKBM, 2x35 MWe): under construction, commercial operation > 2019



ACP100 “Linglong One” (China/CNNC, 100MWe): under development



ACPR50s (China/CGN, 60MWe): under construction, commercial operation > 2020

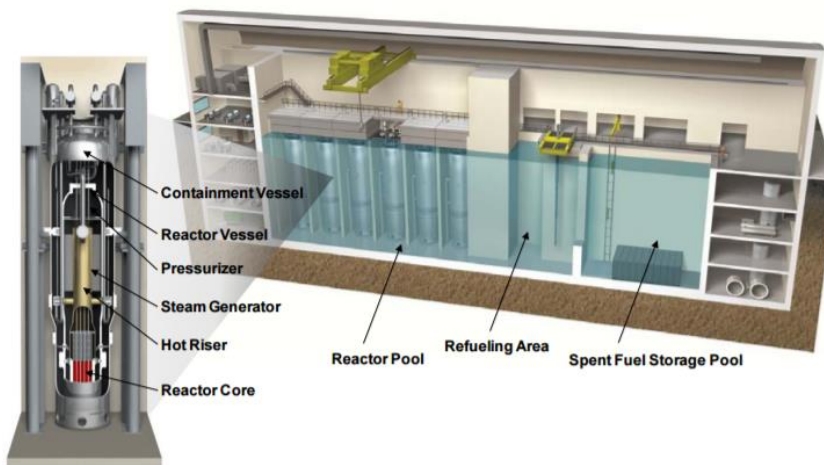
Some ongoing developments... (2/3)



SMART (Korea/KAERI): under development,
MoU with Saudi Arabia – desalination,
deployment > 2024



HTR-PM (China/CNEC – 2 units/210 MWe):
under construction, operation > 2017



NuScale (US, 50MWe
– up to 12 modules)
March 2017: Design
Certification Application
accepted by NRC. First
foreseen project at INL,
operation > 2027

Some ongoing developments... (3/3)

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Canada Mapping a Strategy for the Next Generation of Nuclear Reactor Technology

News Release
From [Natural Resources Canada](#)

February 22, 2018 Ottawa Natural Resources Canada

Canada has been a world leader in nuclear energy for over 60 years. The nuclear industry in Canada is a vital source of innovation, job creation and low-carbon energy. The next generation in nuclear technology will help Canadians build a cleaner, safer world while meeting our energy needs in a low-carbon economy.

Prime Minister Justin Trudeau, today announced a road mapping process to assess the potential for small modular reactor (SMR) technology in Canada.

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Canada launches roadmap to assess SMR potential

5 March 2018

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

Canada's Parliamentary Secretary Kim Rudd, on behalf of the Minister of Natural Resources, the Honourable Jim Carr, on 22 February announced a road mapping process under the Energy Innovation Program to explore the potential for on- and off-grid applications for small modular reactor (SMR) technology in Canada. "The next generation in nuclear technology will help Canadians build a cleaner, safer world while meeting our energy needs in a low-carbon economy," Natural Resources Canada (NRC) said in a press release.

Canada

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Department for Business, Energy & Industrial Strategy

Policy paper

Advanced Nuclear Technologies

Updated 5 February 2018

Contents

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The advanced nuclear sector has the potential to deliver a range of benefits, including: [Industrial Strategy](#) building on our existing economic advantages in nuclear while shaping new advantages to tackle the [Clean Growth Grand Challenge](#).

Rolls-Royce **UK SMR: A National Endeavour**



The infographic illustrates the UK's commitment to Small Modular Reactors (SMRs) as a national endeavour. It features a central timeline with key milestones: 'First SMR in the UK' (2025), 'First SMR in the world' (2028), and 'First SMR in the UK' (2030). The timeline is flanked by icons representing various aspects of the project, including 'Design', 'Construction', 'Operation', and 'Decommissioning'. The bottom of the infographic shows a city skyline with a large SMR reactor integrated into the urban landscape, symbolizing the reactor's role in providing clean energy for the future.

UK



THU MAR 15, 2018 / 1:42 PM EDT

France considers developing mini nuclear reactors, eyes cost

Reuters Staff

(Reuters) - The French nuclear industry is considering developing Small Modular Reactors (SMRs), but will have to ensure these miniaturised generators are not only technically feasible but also financially viable, executives said.

EDF-owned Framatome, formerly called Areva, builds the world's largest nuclear reactor model - the 1,650-megawatt EPR - but is now also conducting research into small 150- to 170-MW reactors with state nuclear agency CEA.

"In France we have always preferred big-capacity reactors ... but we need to also consider smaller models," said Xavier Ursat, EDF's head of new nuclear, at an innovation seminar organised by French nuclear industry lobby SFEN.

France?

SMRs for nuclear heat?

- Some countries are assessing SMRs potential for decarbonized district heating (also important to reduce air pollution)

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China plans demonstration nuclear heating project

12 February 2018

A feasibility study on constructing China's first nuclear plant for district heating is being carried out by China General Nuclear (CGN) and Tsinghua University. The plant would use the domestically-developed NHR200-II low-temperature heating reactor technology.



An artist's impression of a plant based on the NHR200-II reactor (Image: CGN)

China's National Energy Administration (NEA) recently organised a meeting to discuss nuclear energy heating in northern China. The meeting agreed that CGN and Tsinghua University should conduct preliminary work on the construction of a demonstration project in China. The work is to include planning and site selection, land and water use, emergency plans, communication with the public and actively promoting the project.

Related Stories

- Finnish cities might consider SMRs for district heating
- Czech reactors could supply heat

WNA Links

- Nuclear Power in China
- Nuclear Process Heat for Industry

Related Links

- China General Nuclear Power Group (CGNPC)
- National Energy Administration
- Tsinghua

Energy & Environment New Nuclear Regulation & Safety Nuclear Policies Corporate Uranium &

Finnish cities might consider SMRs for district heating

15 December 2017

A number of Finnish cities have received political initiatives to evaluate the feasibility of using small modular reactors (SMRs) instead of fossil fuels to provide district heating, according to Energy for Humanity. A recent study looked at completely decarbonising electricity, transport and heating in Helsinki through the use of small, advanced reactors.

Most of the district heating in Finland is produced by burning gas, wood fuels and peat, said the non-profit organisation, by philanthropic donations and advocates for climate action access. It noted that while many Finnish cities have progressive policies and goals, they have struggled to decarbonise heating.

"More than half of the greenhouse emissions of all of Helsinki district heating, mainly run by fossil fuels," said Petrus Pen city council member and vice chair of the Finnish Pirate Party. "We are serious about decarbonising Helsinki, we need to at least take a look at these upcoming reactors."

Atte Harjanne, a climate change researcher at the Finnish Environment Institute and a Green Party representative at the Helsinki City Council, agrees. "Nuclear has proven – despite the early fears – that the movement grew up with – to be a safe, fast and cost-effective way to decarbonise the energy sector. It deserves a look at a level."

WNA Links

- Nuclear Power in Finland

RAULI PARTANEN

DECARBONIZING CITIES:

HELSINKI
METROPOLITAN
AREA

Providing district heating, power and transportation fuels with advanced nuclear reactors

ECOMODERNIST
SOCIETY OF
FINLAND

ENERGY FOR
HUMANITY

2017



SMRs for newcomer countries?

- Several “newcomer” countries are expressing interest in SMR technology:
 - Indonesia – interest for High Temperature Reactors
 - Saudi Arabia – interest in desalination applications (SMART) and Chinese-design HTRs
 - Jordan – interest in HTR (X-Energy) and LWR-based SMRs (Rolls Royce), as well as with Rosatom-designed SMRs.
 - Poland, HTR roadmap ...
 - **Could SMRs help the introduction of nuclear energy, a first step towards the deployment of large LWRs ?**

Rolls-Royce to conduct SMR study for Jordan

09 November 2017

Rolls-Royce said today it has signed a memorandum of understanding with state-owned Jordan Atomic Energy Commission (JAEC) to conduct a technical feasibility study for the construction of a Rolls-Royce SMR in Jordan. The signing ceremony took place in Paris between Alan Rickman, Chairman of Rolls-Royce, and Alan Rickman, Chairman of JAEC.

Energy & Environment New Nuclear Regulation & Safety Nuclear Policies Corporate

Jordan to consider deployment of X-energy SMR

29 November 2017

The Jordan Atomic Energy Commission (JAEC) has signed a memorandum of understanding (MoU) with X-energy to assess the potential deployment of X-energy's Xe-100 high temperature gas-cooled pebble bed modular reactor in Jordan.

Related Stories

Advanced agreement signed

China, Saudi Arabia begin HTGR feasibility study

17 May 2017

China and Saudi Arabia have signed a memorandum of understanding (MoU) to begin a feasibility study for the construction of high-temperature gas-cooled reactors (HTGRs) in the Middle East.



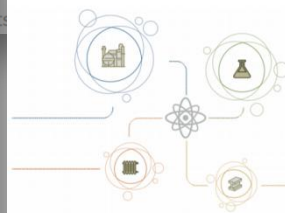
Experimental Power Reactor (I-EPR)

Location	: PUSPIPTK SERPONG
Power	: 10 MWe
Technology	: HTGR
Construction	: 2018-2022
Commissioning / Operation	: 2022/2023
Project Status	: Completion of pre-project

- Development of the experimental power reactor of I-EPR is an innovative way and one of the entry points in the utilization of nuclear energy in Indonesia
- In line with the regulation in which BATAN has an authority to build and operate non-commercial NPP
- Development of I-EPR is also a strategic effort for mastering nuclear energy project management, engineering capacity building and human resource development to strengthen the role of Technical Supporting Organization (TSO).
- I-EPR will be a FOAK (First of a Kind) for future Indonesia's commercial NPPs



Possibilities for deployment of high-temperature nuclear reactors in Poland



Report of the Committee for Analysis and Preparation of Conditions for Deployment of High-Temperature Nuclear Reactors

Some takeaway points

- Meeting 2DS targets will demand **massive structural change in the electricity sector**. Nuclear, hydro and renewables main sources of low C electricity gen. by 2050. Due to the intermittency of variable renewables, **flexibility and stability** will be needed (generation, system) and nuclear power is the only low-carbon dispatchable technology ready to be deployed massively to meet these concerns.
- **Challenges for new nuclear build:**
 - **Competitiveness in electricity market, public acceptance, policy stability**
- **Nuclear is also a low carbon source of heat** → potential to displace fossil-based processes in the heat market too (desalination, district heating, process heat, H₂)
- **SMR can potentially play an important role** in future energy markets:
 - Public acceptance (enhanced safety)
 - Electricity & heat (cogeneration) – flexibility, new market opportunities
 - Improved financing and competitiveness – need a high build rates to get economics right
 - Facilitate the introduction of nuclear energy in newcomer countries

To be noted, the US, Canada and Japan will launch at the **May 2018 Clean Energy Ministerial**, a “nuclear initiative” (Nuclear Innovation: Clean Energy Future – **NICE Future**) – which include the assessment of advanced reactor technologies (such as SMRs) as enablers of integration of nuclear & renewables (flexibility, non-electric applications)

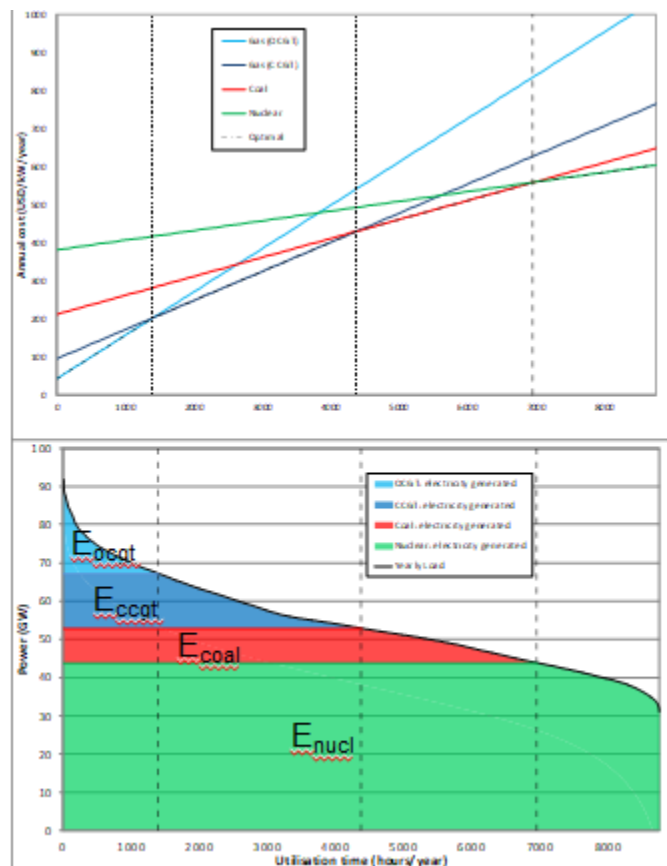
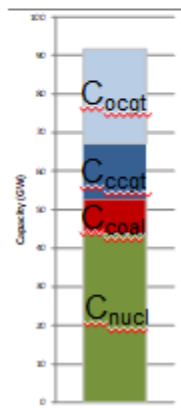
Thank you for your attention!

Appendix: Long term optimal mix

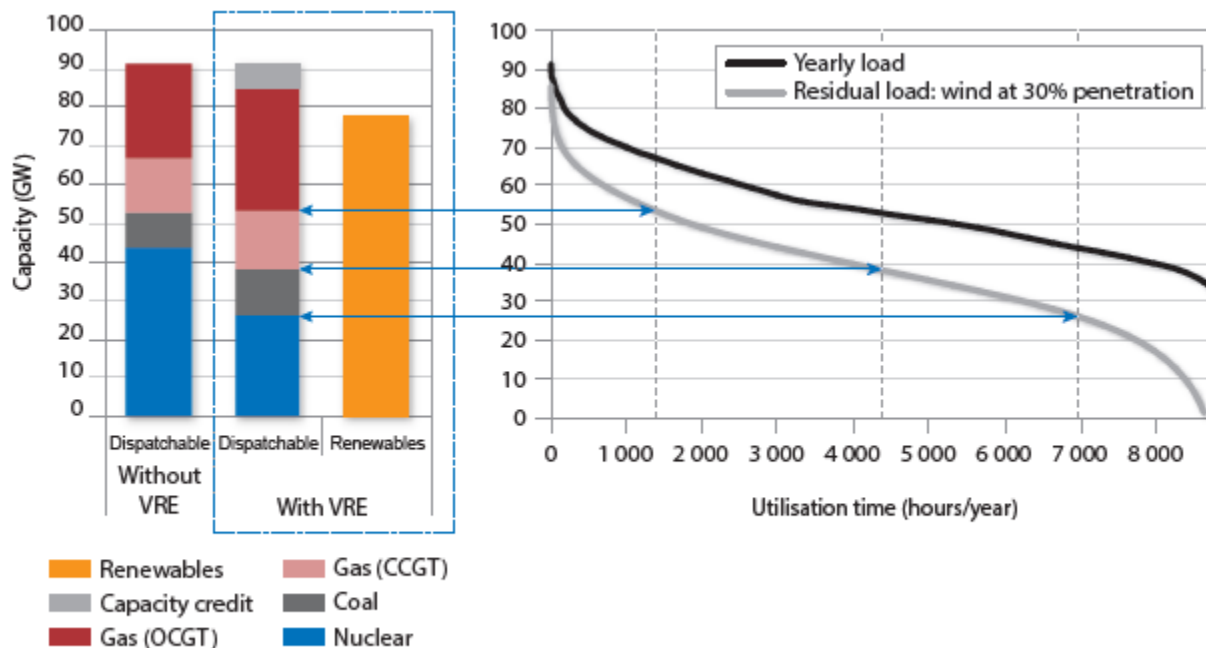
	Fixed costs USD/kW/year	Variable costs USD/MWh	LCOE USD/MWh
OCGT	43.5	113.8	118.7
CCGT	96.1	76.4	87.4
Coal	212.8	49.8	74.1
Nuclear	382.0	25.5	69.1

$$Gen_{Cost} = \sum_i (C_i \cdot FC_i + E_i \cdot VC_i)$$

- The optimal generation mix obtained is the one that minimises the generation cost for meeting a given yearly load duration curve.
- The cost/MWh depends upon the shape of the load duration curve.
- Methodology developed for dispatchable generators but can be applied also to VRE.
- Difficulty in modelling storage.



Appendix: Residual load curve analysis



Note: Figure based on load data and wind profile for France 2011. Wind generation scaled to a penetration of 30%; scaling may overestimate the impact of variability. For illustration only.

Source: IEA, Projecting costs of generating electricity 2015