DE LA RECHERCHE À L'INDUSTRIE

www.cea.fr

THE ECONOMIC FUTURE OF NUCLEAR POWER:

THE POTENTIAL FOR CONSTRUCTION COSTS REDUCTION AND THE ROLE OF NUCLEAR FLEXIBILITY

Dr. Michel BERTHELEMY

CEA/I-tésé

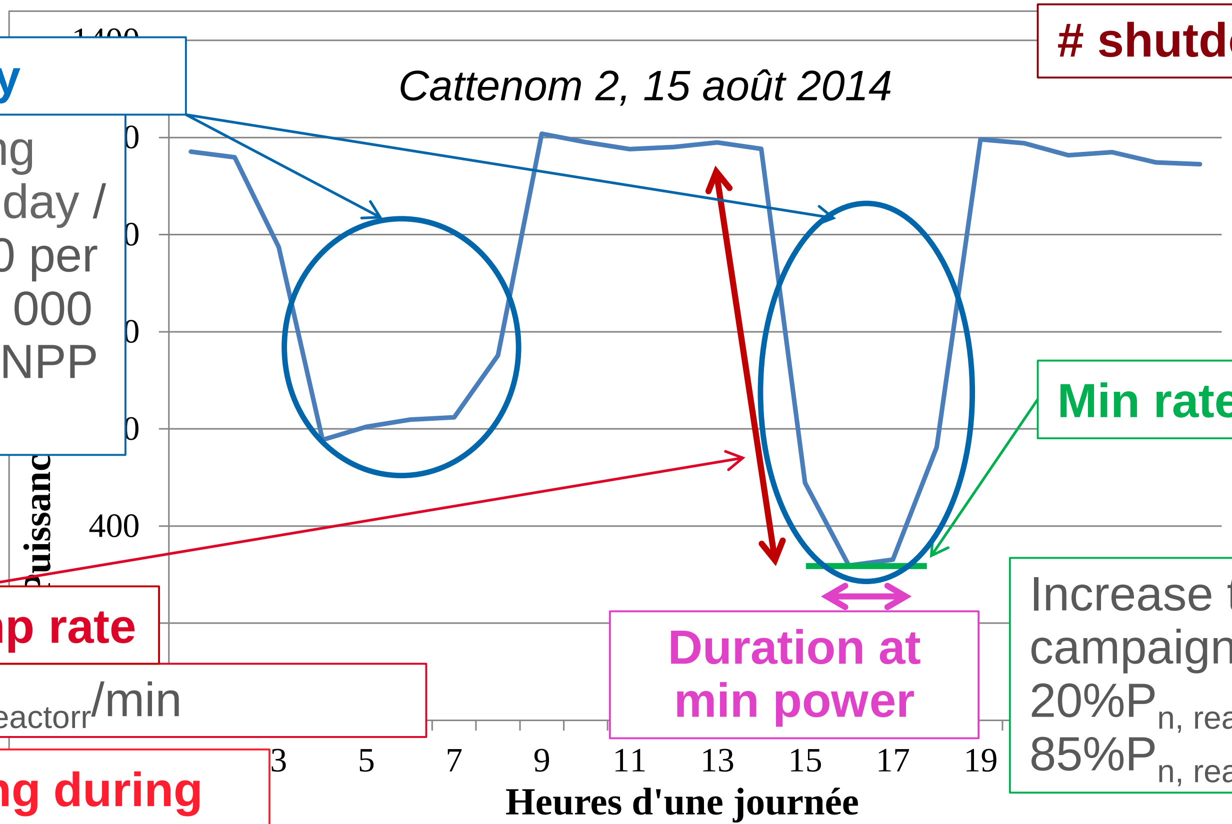
CEEM NUCLEAR CONFERENCE | PARIS DAUPHINE | 18 DECEMBER 2018

THE ROLE OF NUCLEAR FLEXIBILITY IN LOW CARBON ENERGY SYSTEMS

NEAR-TERM PROSPECTS FOR CONSTRUCTION COSTS REDUCTION

THE FLEXIBILITY OF THE FRENCH NUCLEAR FLEET TODAY: REACTOR LEVEL

French nuclear reactors are highly flexible (~ performance of a CCGT), with no impact on safety



 # ramping / day

2 load following operation per day / more than 200 per fuel cycle / 20 000 during Gen-II NPP lifetime

 # shutdowns

Min rated power

Max ramp rate

5%$P_{n,\ reactorr}$/min

Duration at min power

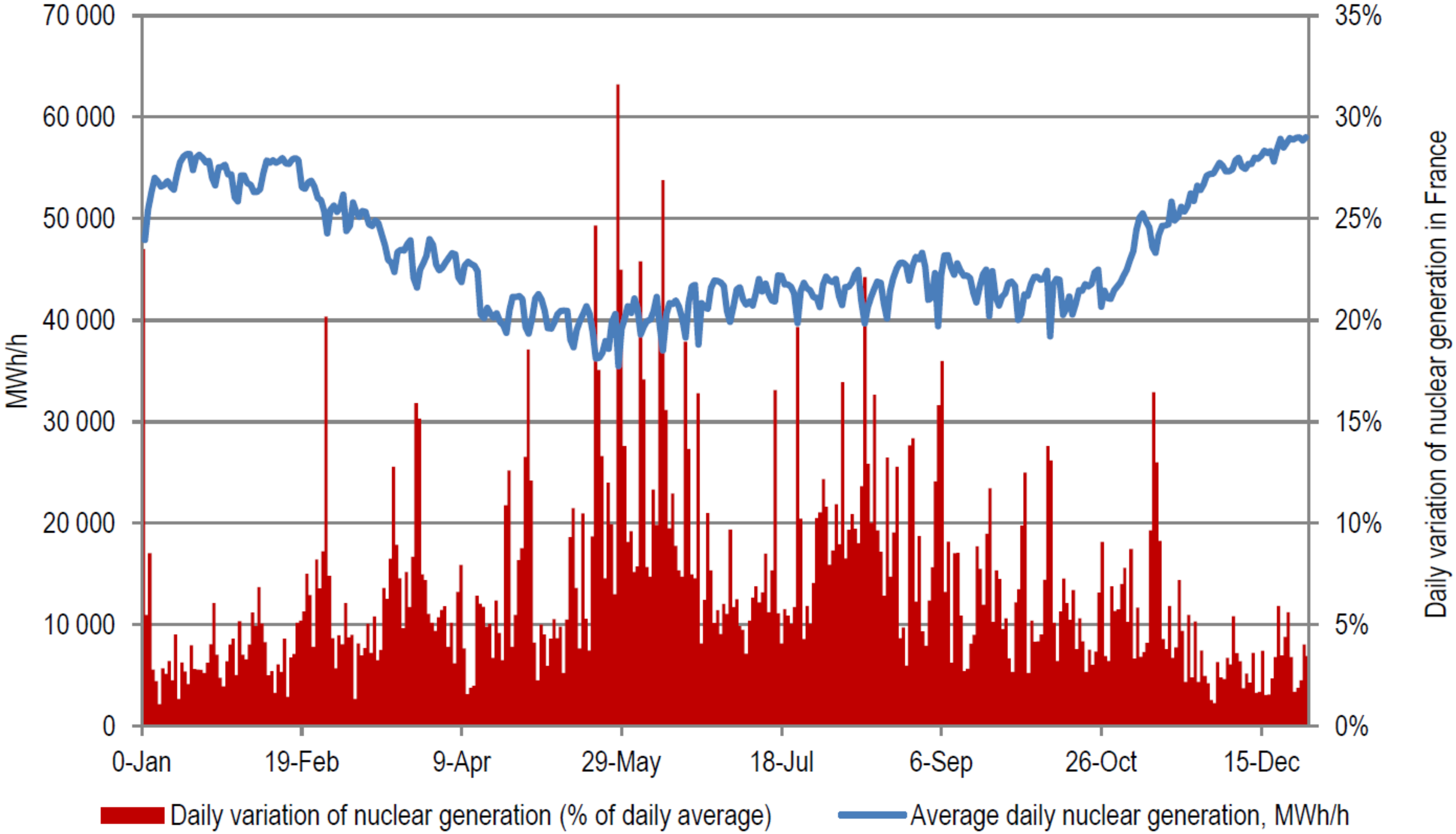
Increase the fuel cycle campaign : from 20%$P_{n,\ reactor}$ to 85%$P_{n,\ reactor}$

Load-following during fuel cycle campaign

RTE data

THE FLEXIBILITY OF THE FRENCH NUCLEAR FLEET TODAY: FLEET LEVEL

Today's French nuclear fleet meets most of the seasonal flexibility needs of the power mix



Source: OECD/NEA, 2011

FLEXIBILITY OF THE FRENCH NUCLEAR FLEET ALREADY SUPPORTS RENEWABLES INTEGRATION (1/2)

Since the 1980s, 75% of French nuclear power comes from nuclear
➔ Nuclear cannot always produce as baseload

Nuclear supports flexibility needs at 3 levels:

- Frequency regulation (network stability)
- Consumption variability (night, weekend, summer...)
- Renewable integration (wind, solar PV)

NEW

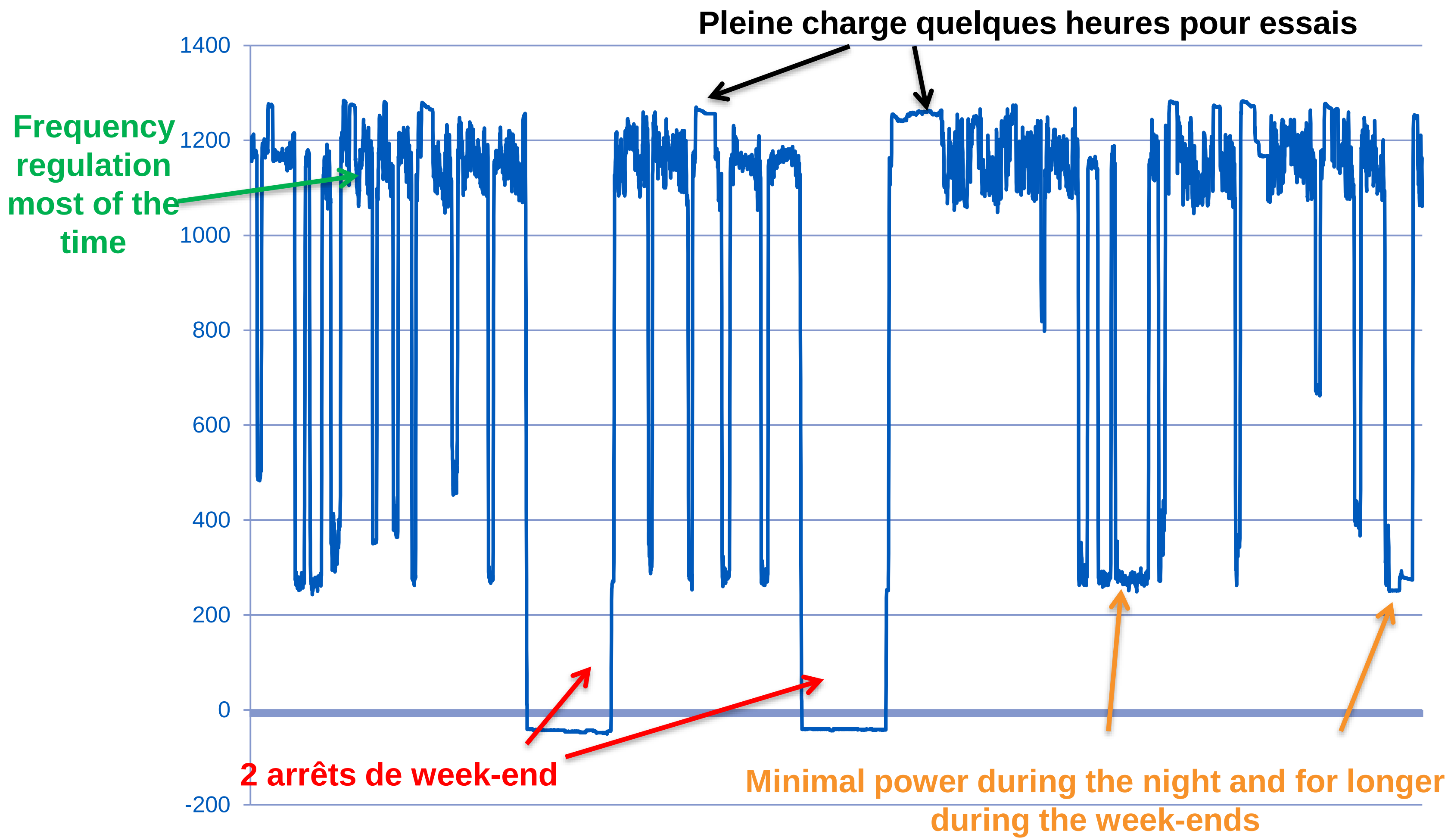
Non-produced power available later ➔ impact on outages planning

Today, about **1 TWh of nuclear power due to renewables** (i.e. less than 7%)

Source: EDF

FLEXIBILITY OF THE FRENCH NUCLEAR FLEET ALREADY SUPPORTS RENEWABLES INTEGRATION (2/2)

Production – Golfech 2 – June 2013 – KU 65 %



Up to 5% nominal power / min!

Source: EDF

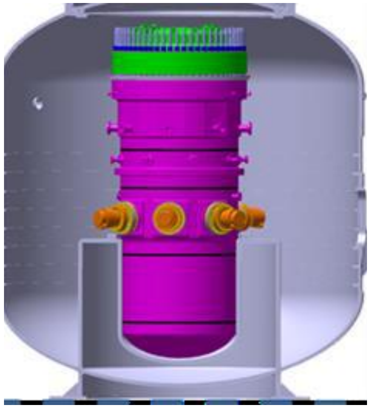
R&D TO SUPPORT THE FLEXIBILITY OF NUCLEAR POWER

A range of R&D activities support the load-following capabilities of the existing nuclear fleet:

- *Preventative maintenance program for Balance of Plant*
- *Improved water chemistry monitoring*
- *New generation of digital tools for control room operator*
- *….*

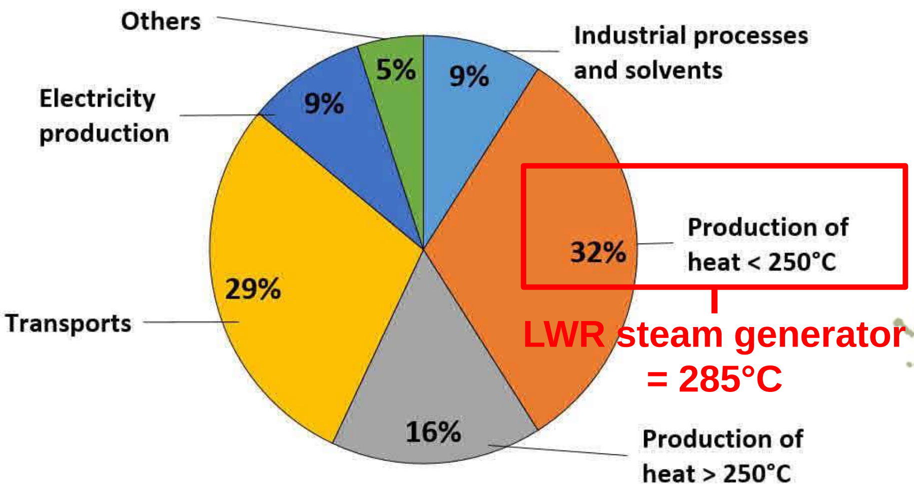
Future Gen-III NPP (EPR2 in France) to integrate flexibility needs from renewables at design stage

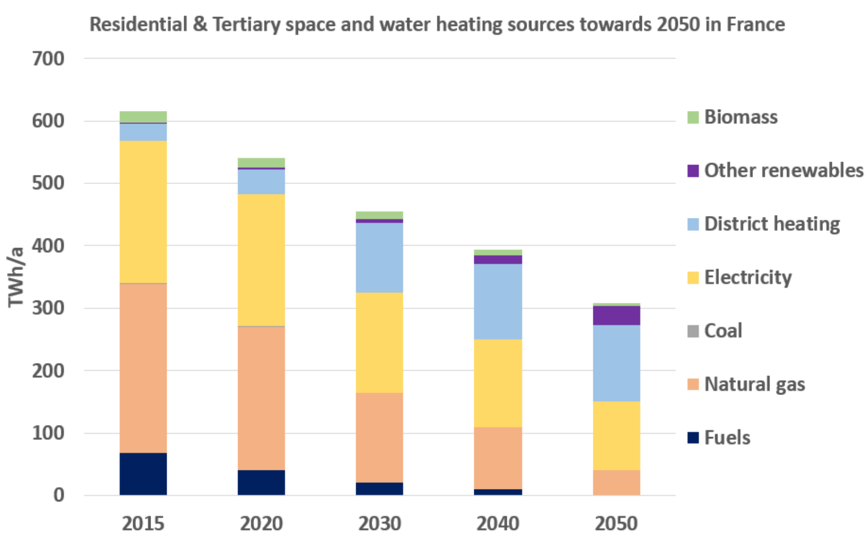
Enhanced load-following opportunities with LWR-SMR (e.g. design without boric acid) **but also Gen-IV reactor concepts** (e.g. no Xenon effect in SFR)

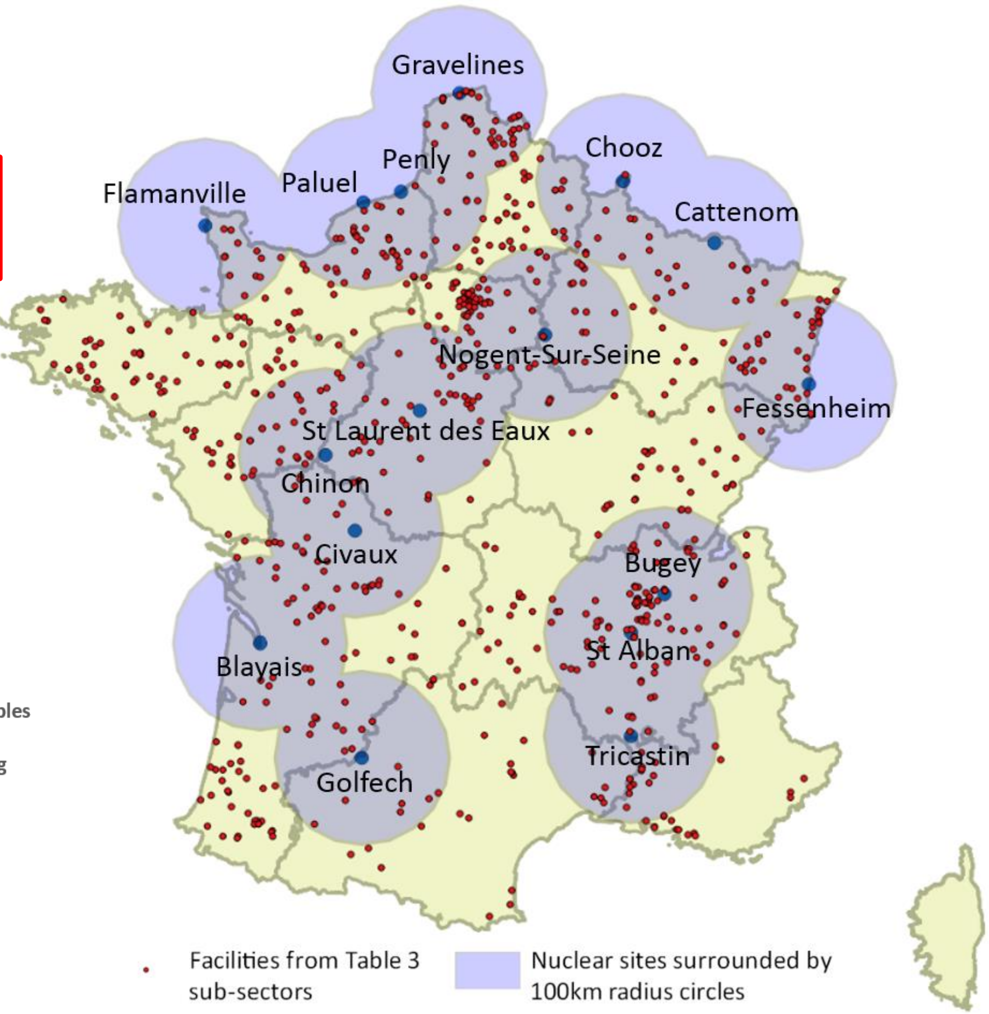


Non-electric applications to support the decarbonisation of the energy sector
(e.g. nuclear cogeneration, see next slide**)**

NUCLEAR COGENERATION : A LONG TERM OPPORTUNITY TO DECARBONIZE THE HEAT SECTOR







TAKE-AWAY MESSAGES

Nuclear power flexibility is a reality <u>today</u> and already contributes to the integration of variable renewables

Understanding flexibility needs in high renewable scenarios remains a complex issue: **need for a system approach in energy economics research to better assess the value of nuclear power as part of the « flexibility mix »**

Role of R&D to further increase nuclear flexibility, primarily for Gen-III nuclear technologies and (potentially) advanced reactors concepts looking both at flexible generation and output

➡ **Central role of long term electricity market reforms** in order to better reflect the value of flexible power generation

THE ROLE OF NUCLEAR FLEXIBILITY IN LOW CARBON ENERGY SYSTEMS

NEAR-TERM PROSPECTS FOR CONSTRUCTION COSTS REDUCTION

NUCLEAR CONSTRUCTION COSTS IN TODAY'S ENERGY POLICY DEBATES

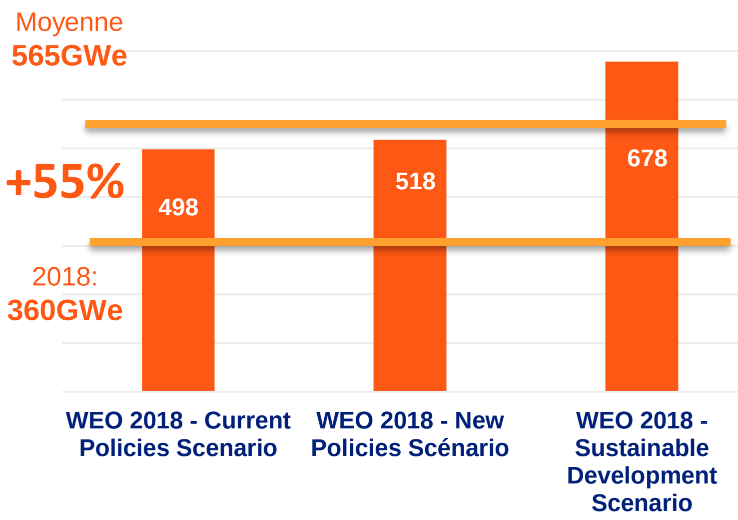
Not a new topic …

- OECD/NEA (2000) already looked at construction costs reduction
- OECD/NEA (2015) focused on supply chain issues
- Recurrent projects costs studies (CGE) with IEA

.. But important time to revisit the issue

- Many FOAK reactors commissioned in 2018/2019
- LCOE challenges with reduction of levelized costs of renewables
- Need to ramp-up nuclear new build to meet role in decarbonisation scenarios

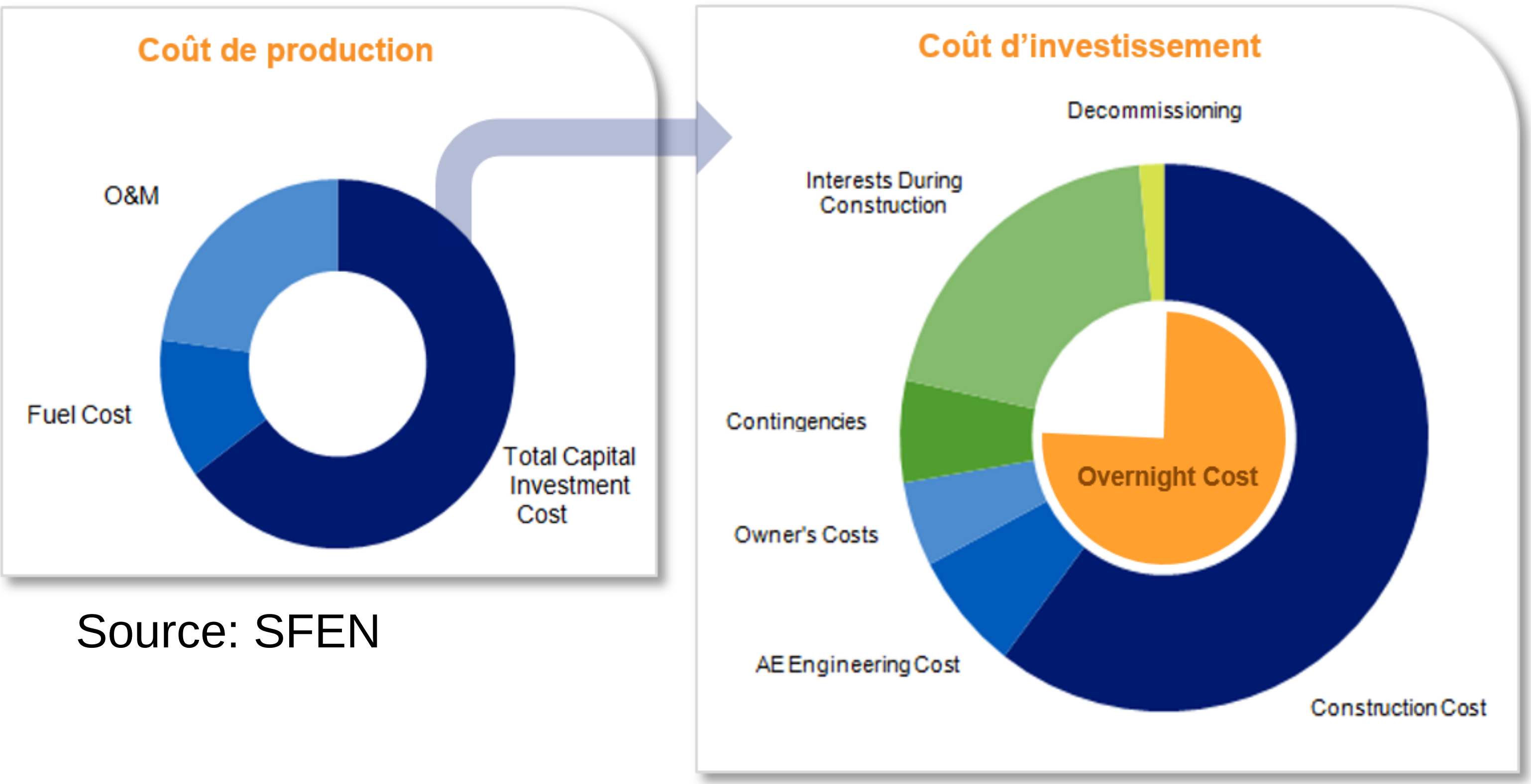
Installed nuclear capacity in 2040 (GWe)



Core issue = near term (2030s) costs reductions for Gen-III as we move from FOAK to NOAK

© 2018 Organisation for Economic Co-operation and Development

BACK TO BASICS: NUCLEAR PRODUCTION COSTS BREAKDOWN



Source: SFEN

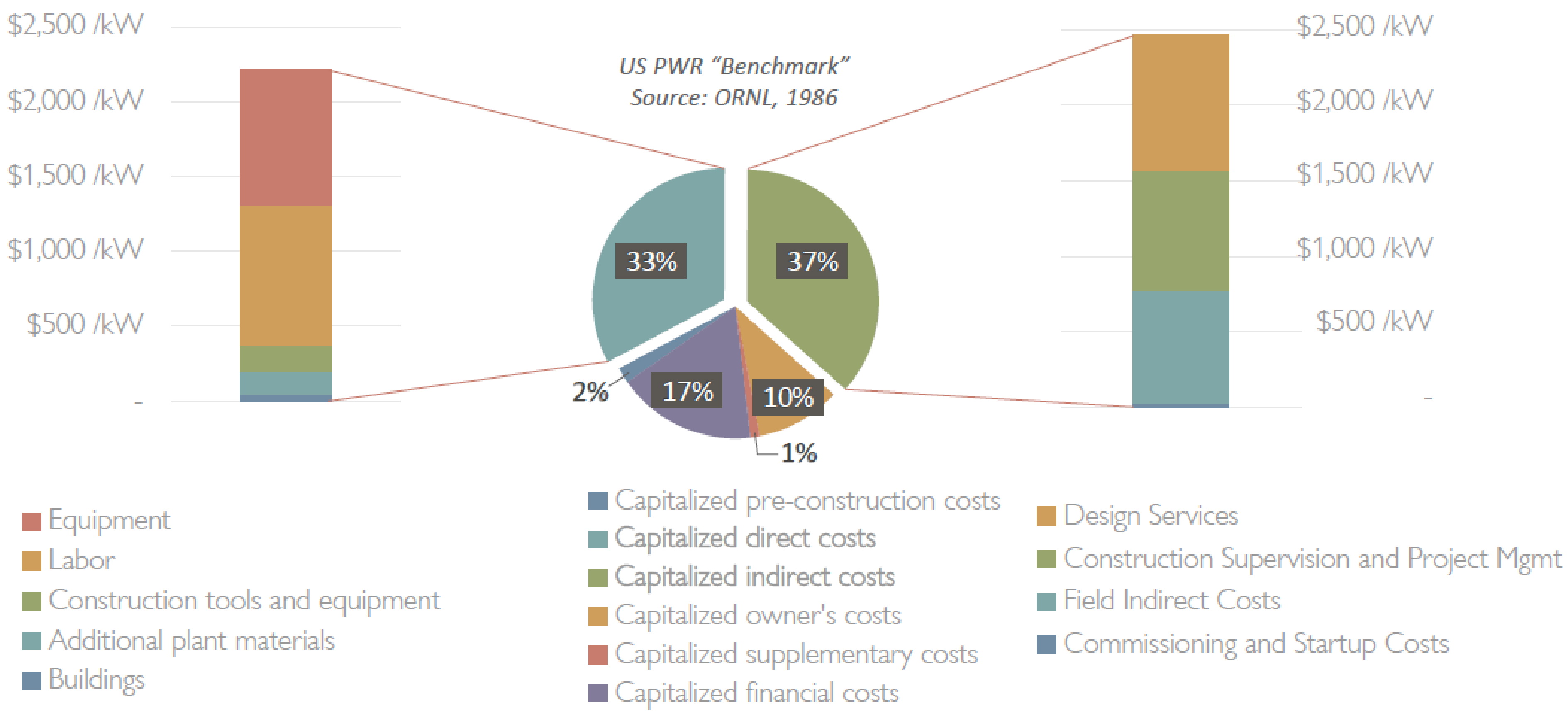
At a 7% discount rate → investment costs = about 2/3rd of the levelized costs of nuclear power

(source: SFEN, 2018)

NUCLEAR INVESTMENT COSTS BREAKDOWN

Direct costs

Indirect costs



Direct v. indirect construction costs (source: ETI, 2018)

CONSTRUCTION TIME OF RECENT FOAK GEN-III PROJECTS

				Construction time (years)			
	Design	Decision	Construction start	Initial	Delay	Final	Construction completed
OL3	EPR	2003	août-05	4	11	15	2020
FLA 3	EPR	2005	déc-07	5	7	12	2019
NovoV 2.1	VVER1200	2006	juin-08	7	1	8	2016
Leningr 2.1	VVER1200	2006	oct-08	5	3	8	2018
Sanmen 1	AP1000	2007	avr-09	6	3	9	2018
Hayiang 1	AP1000	2007	sept-09	5	4	9	2018
Shin Kori 3	APR1400	2007	oct-08	5	3	8	2016
Taishan1	EPR	2007	oct-09	5	4	9	2018
Vogtle 3	AP1000	2008	mars-13	4	2	6	2019
Fuqing 5,6	HUALONG 1	2014	mai-15	5	?	?	?

Source: SFEN, 2018

CONSTRUCTION COSTS OF RECENT FOAK GEN-III PROJECTS

	Country	Reactor	Start	MWe	Ex-ante construction cost USD/kWe	Ex-post construction costs USD/kWe
Olkiluoto 3	Finland	EPR	2005	1 x 1630	2430	> 6260 (*)
Flamanville 3	France	EPR	2007	1 x 1600	2475	7800 (*)
Leningrad 2	Russia	VVER1200	2008	2 x 1085	2673	3040
Sanmen 1,2	China	AP 1000	2009	2 x 1000	2650	2800
Taishan 1,2	China	EPR	2009	2 x 1660	1960	3150
Shin Hanul 1,2	South Korea	APR1400	2012	2 x 1325	2300(**)	2645
Vogtle 3,4	United States	AP 1000	2013	2 x 1117	5565	6800
Fuqing 5,6	China	HUALONG 1	2015	2 x 1090	2800	3500

Source: SFEN, 2018

(*) 1€ =1,2 USD (**) = Shin Kori 3,4

WHY "MEGA" PROJECTS (SOMETIMES) FAIL? PARALLEL WITH OTHER INDUSTRIES

McKinsey, "A risk-management approach to a successful infrastructure project"

https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/a-risk-management-approach-to-a-successful-infrastructure-project

- Large, complex, long-term projects.
- Involve a large number of stakeholders (e.g. contractors) entering the project at different stages with different roles and responsibilities.
- Significant interface risks.
- Poor project structuring and risk management.

Planned
Actual

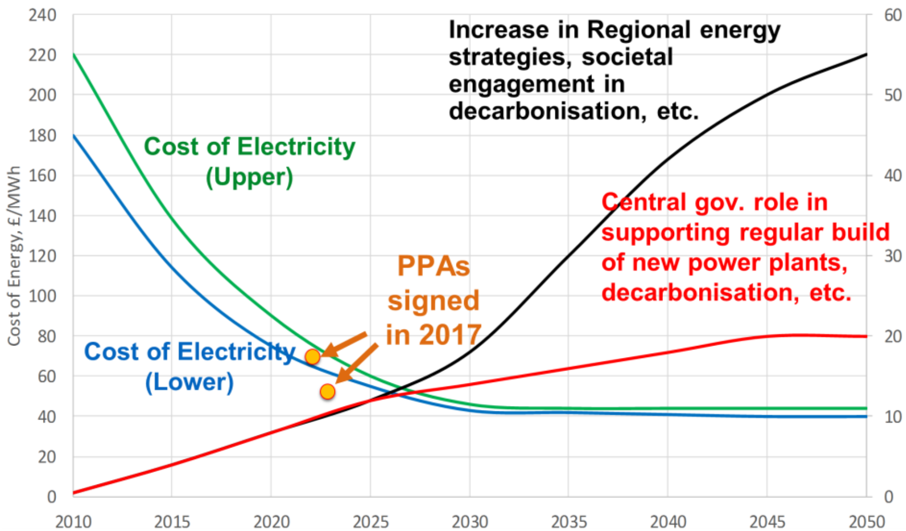
Example	Budget vs actual, € billion	Delays and start-up problems	Incorrect capacity and revenue plans	Total value lost vs plan, € billion
Eurotunnel	7.5 / 15.0	• 6-month delay • 18 months of unreliable service after opening	• Overestimated market-share gain in freight and passengers by 200%	~7.5
High-speed rail Frankfurt-Cologne	4.5 / 6.0	• 1-year delay of construction • Legal and technical issues	• Unforeseen capped government funding	~1.5
Betuwe Line NL (cargo rail)	2.3 / >5.0	• 1.5-year[1] delay of construction • Technology choices still not finalized	• Annual revenue shortfall of €20 million	~3.0
Kuala Lumpur Airport	2.0 / 3.5	• Initial issues with connectivity to downtown area • Complaints about facility hygiene levels	• Handles only ~60% of current capacity • Losing market share to Singapore	~1.5

[1]Project still not finalized and costs could go even higher.

Source: Annual reports; Jane's Airport Review; McKinsey analysis; Reuters

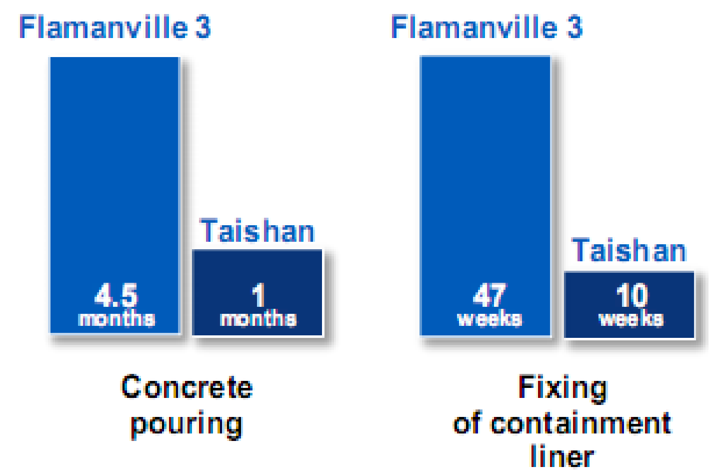
ENGINEERING THE LEARNING CURVE: PARALLEL WITH THE WIND INDUSTRY

Fast learning in the UK offshore wind industry



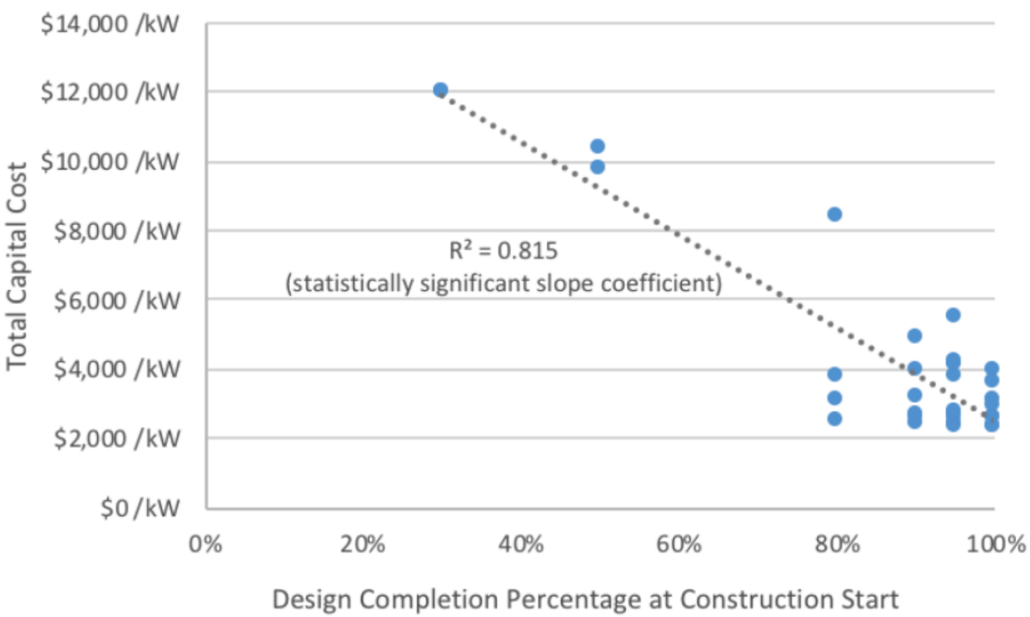
* The CFDs were half the price of contracts awarded in the last UK offshore wind tender in February 2015.

Significant improvement for key construction stages between Flamanville v. Taishan EPRs



CONSTRUCTION COSTS DRIVERS: LESSONS FROM RECENT GEN-III FOAK (1/2)

Figure 6. Design Completion Percentage and Total Capital Cost

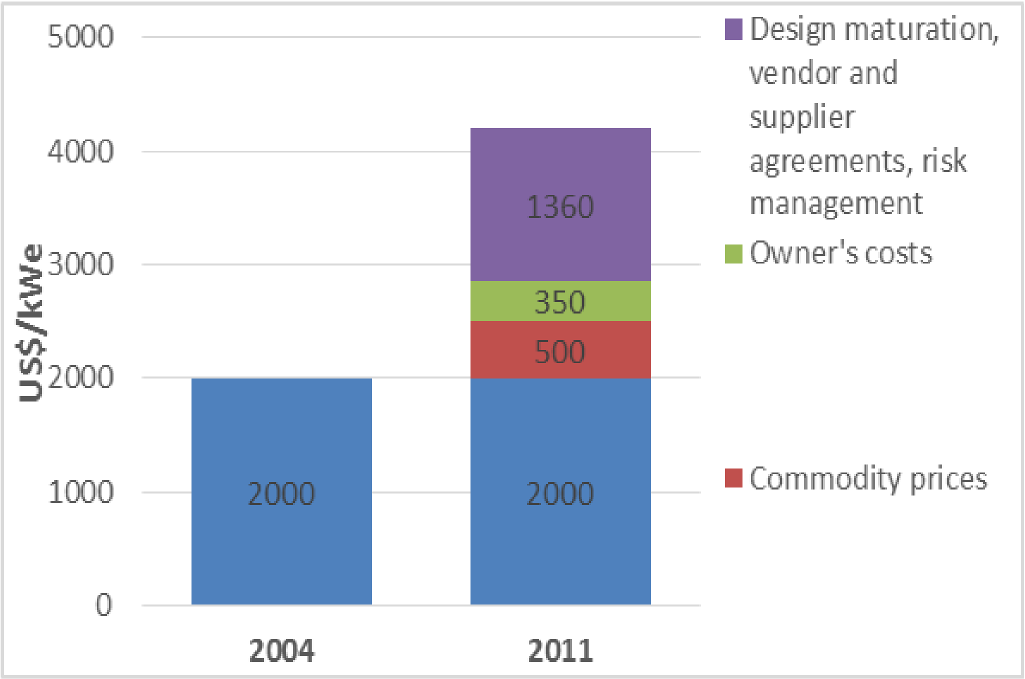


Source: ETI (2018)

Key role of **design maturity**

- Partly to do with optimistic bias to benefit from first-mover advantage
- Misalignment of incentives (e.g. push construction start in order to secure funding at Vogtle)

CONSTRUCTION COSTS DRIVERS: LESSONS FROM RECENT GEN-III FOAK (2/2)



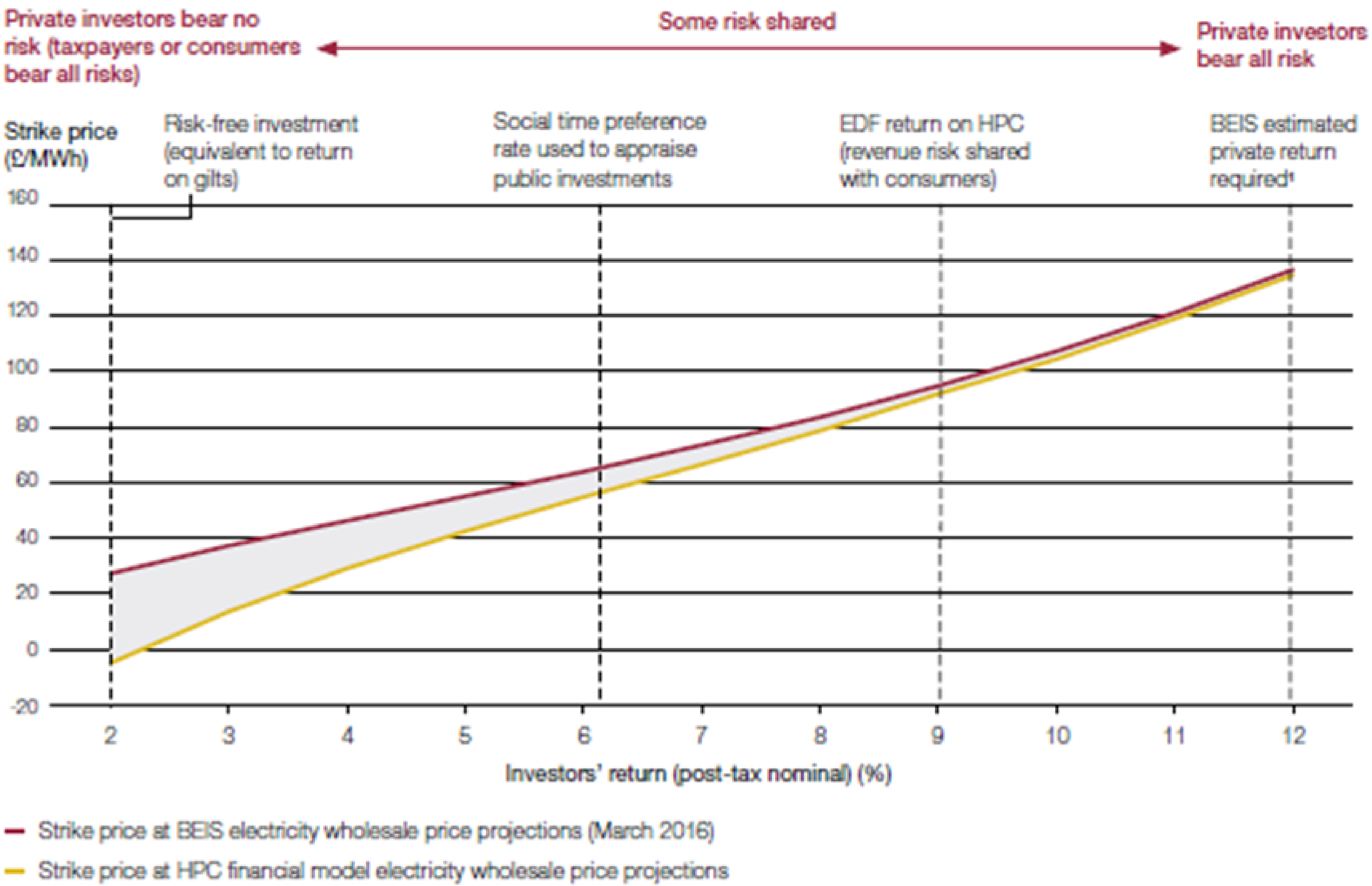
Factor for increases in overnight construction costs in the US *(Source: Univ. of Chicago, 2011)*

Importance of **regulatory framework and industrial policy on soft costs:**

- Regulatory uncertainty
- Issues with risk allocation
  → “margins on margins effect”
- Asymmetric information and transaction costs
  → “hold up” problem

Post-Fukushima safety regulations indirect impact on construction costs through delays (?)

THE ROLE OF PUBLIC INTERVENTION FOR REDUCING THE COST OF CAPITAL



Department for Business, Energy & Industrial Strategy, “Hinkley Point C”, National Audit Office, HC 40 SESSION 2017-18 23 JUNE 2017

DIFFERENT CATEGORIES OF RISK FOR NUCLEAR PROJECTS

A nuclear projects covers a range of risks in a single multi-billion project

- Market risks: In Europe, electricity prices divided by 2 over the last 10 years (60 to 30 €/MWh)
- Politicial risks: energy policy reversal with changes in political majority
- Technical risks: costs overruns & delays

➡ **Need to balance risks between investors, final consumer and the State**

Two keys energy policy enablers:

- Support low carbon investments → **credible & robust CO2 price**
- Some form of **long term contract** → RAB, CfD, ..

➡ Conclusion SFEN study: **up to -50 % financial costs** reduction achievable for future project

KEY FACTORS FOR REDUCING CONSTRUCTION COSTS: CONCLUSIONS FROM SFEN STUDY

1) **Design maturity** & **simplification** (EPR2 project)

2) **Risk management** practices (including procurement policies)

3) **Energy Policy framework** (in particular for reducing financing costs)

4) **New technologies** (digital, HP concrete, modular construction, …)

5) **Learning by doing** + **twin** effect through **standardization**

SFEN study: **- 30 % overnight construction costs** reduction achievable for future projects

TAKE-AWAY MESSAGES

New nuclear needed to meet our **2050 CO2 objectives** (IEA, EU, IPCC)

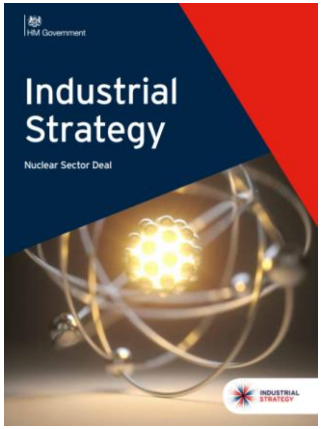
The nuclear industry is moving from FOAK and could deliver ‘rapidly’ more competitive Gen-III/III+ series reactors

- Important to capitalize on the **lessons learnt + supply chain competencies**

Need to consider together construction costs reduction and financing as key levers to reduce overall LCOE

- **Better risk allocation** between public and private stakeholders to mitigate project risks and avoid misalignment of incentives
- New nuclear = infrastructure project

(New) nuclear requires a concerted effort between the industry and policy makers



THANK YOU FOR YOUR ATTENTION

michel.berthelemy@cea.fr