Cambridge Judge Business School

BIEE 2016

Economics of new nuclear in the UK

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Agenda

Review of how we got to where we are

Process and policy review

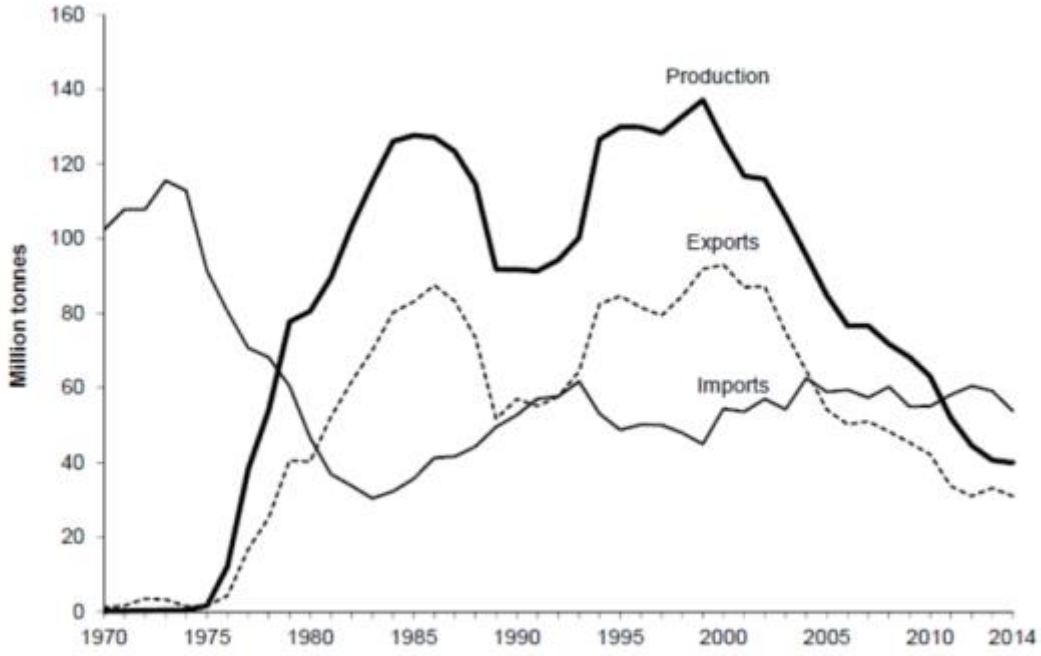
Is nuclear a case of market failure?

Future of nuclear depends on China

SMRs

Motivation for reviving new nuclear 1: North Sea depletion

Chart 3.1.1: Production, exports and imports of oil[(1)] 1970 to 2014



(1) Includes crude oil, natural gas liquids and process oils.

Source: Directory of UK Energy Statistics 2015

Motivation for reviving new nuclear 2: climate change

Climate Change Act 2008

CHAPTER 27

British nuclear stations in 2016: most close to closure

*Shut-down site known as Calder Hall

Source: DECC

2008: new nuclear is decriminalised

HM Government

dti

MEETING THE ENERGY CHALLENGE

A White Paper on Energy

MAY 2007

Alongside this White Paper, we are publishing a consultation document on nuclear power so that we can take a decision before the end of the year on whether it is in the public interest for companies to have this option available when making their investment decisions.

HM Government

BERR | Department for Business Enterprise & Regulatory Reform

MEETING THE ENERGY CHALLENGE

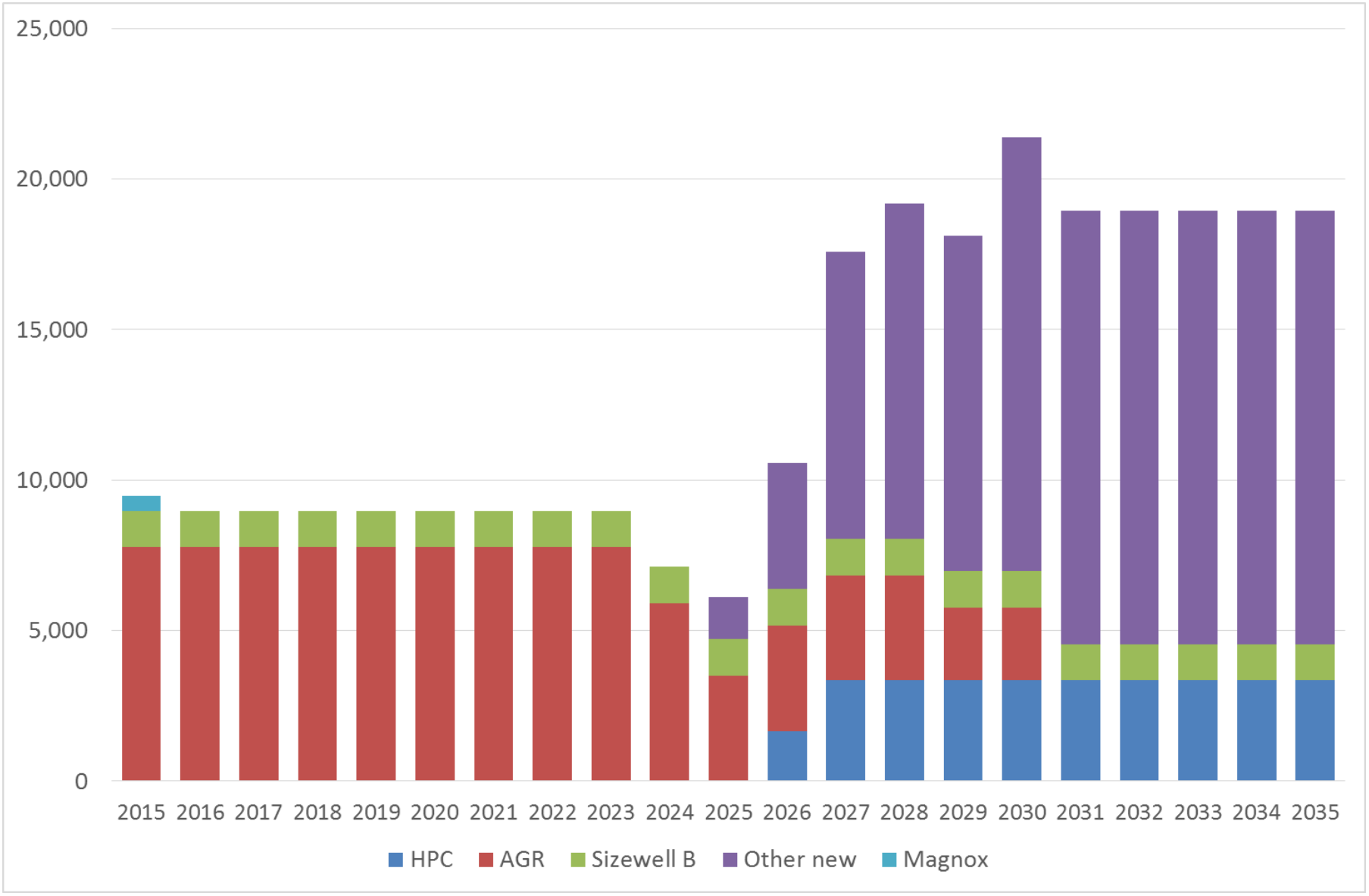
A White Paper on Nuclear Power

JANUARY 2008

Proposed new reactors in UK

Station	Sponsor	Reactor type	Gross GW capacity	Projected commissioning (first unit)
Hinkley Point C	EDF/CGN	EPR	3.2	2026
Moorside	NuGen (Hitachi + ENGIE + Kepco)	AP1000	3.8	2026
Oldbury C	Horizon (Toshiba)	ABWR	3.2	2028
Sizewell C	EDF/CGN	EPR	3.2	2028
Wylfa Newydd	Horizon	ABWR	2.8	2024
Bradwell B	CGN/EDF	Hualong 1	1.4	2028

Outlook for UK nuclear capacity (MW)



Hinkley Point C: to produce 7% of UK power by 2026

Source: EDF

Economic policy approaches to new nuclear

1. Textbook: price the externalities (GHG emissions and energy import dependency) then leave it to the market
2. Central decision on capacity, then auction
3. Central decision on capacity then individually negotiated contracts

The troubled history of Hinkley Point C

1990 Planning permission given for PWR at Hinkley Point

2006 Hinkley Point C project revived with an EPR

2007 EDF Energy CEO says British families will be cooking their Christmas turkey with nuclear energy from HPC in 2017

Oct 2008 EDF starts public consultations on Hinkley Point

Oct 2010 Protest against EDF's plan to move badger colony

Feb 2011 EDF now says HPC will be finished by 2018

Mar 2011 Fukushima disaster

Dec 2011 HPC to produce power by 2019

Aug 2012 Rumours of Chinese investment

Oct 2013 Project (including Chinese investment) gets full government approval; completion seen in 2023

Oct 2014 European Commission gives state aid approval

Oct 2015 Chinese President Xi Jinping state visit to UK; completion seen in 2025

Feb 2016 French trade union urges delay or cancellation; completion seen in 2026

Mar 2016 EDF Chief Financial Officer resigns over HPC threat to EDF's financial stability

July 2016 EDF board approves project but UK government launches review

Sep 2016 UK government gives (slightly modified)approval

The even more troubled EPR

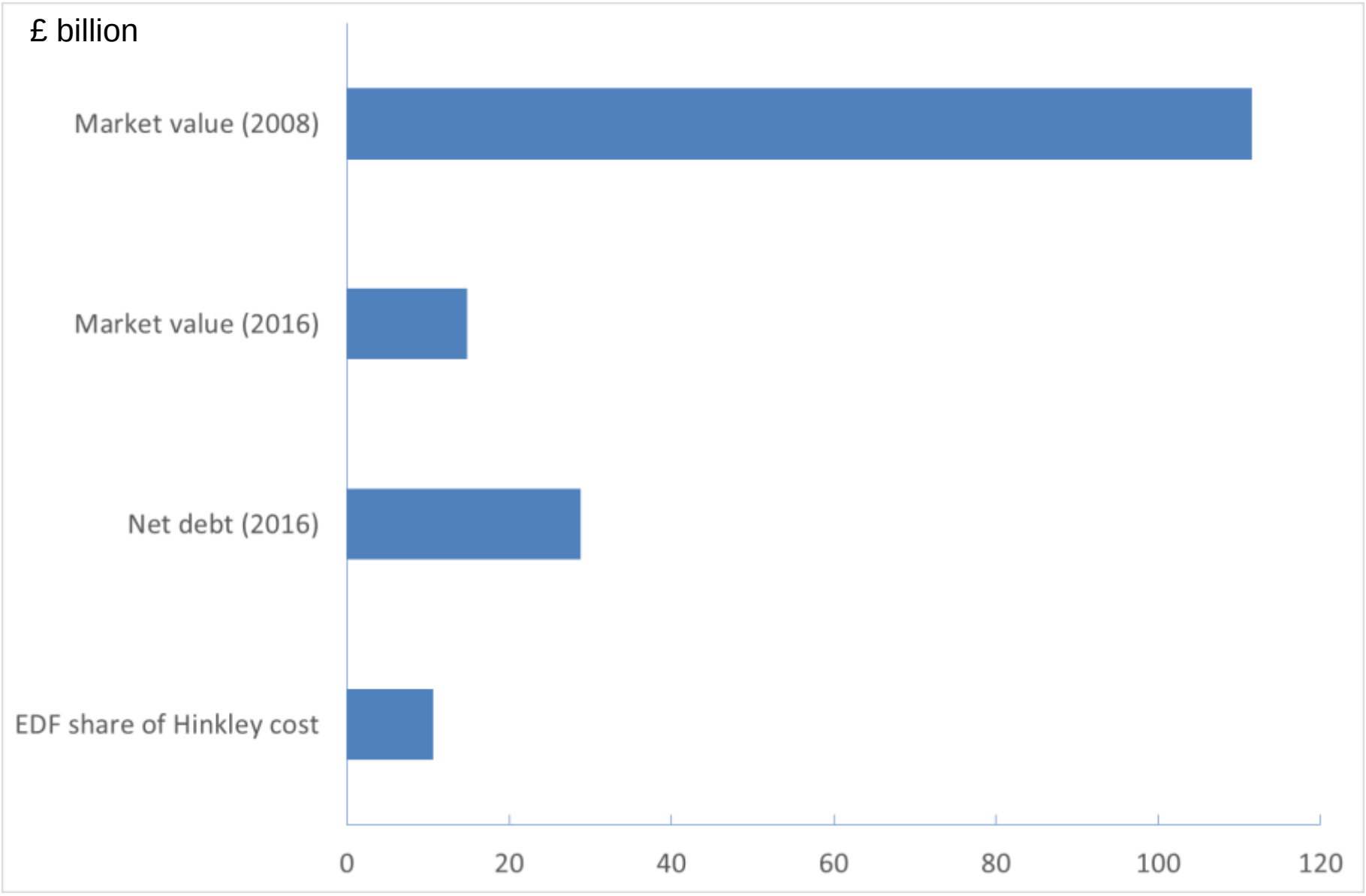
Olkiluoto 3 – Finland
Original scheduled operation – 2009
Latest estimate – 2018
Original cost – €3.2 bn
Latest estimate - €8.5 bn

Flamanville 3 - France
Original scheduled operation – 2012
Original cost - €3.6bn
Latest estimate €10.5 bn
Expected operation 2018 Q4

Taishan 1 & 2 – China
Unit 1 original scheduled operation – 2014
Construction finished December 2015
Testing in 2016

Source: EDF

French lessons



Could model 2 have worked?

UAE

2009 chose Kepco-led consortium, after shortlisting Areva/Suez/Total (EPR) and Hitachi-GE (ABWR)

4 x 1,400MW APR1400 3rd-gen reactors, $20 billion, most of contract is fixed price

State funded

UK

EDF far ahead of other possible bidders, partly owing to sites

Goal to get competition between consortia, but over time

Repeating 1960s error: different reactors, no standardisation?

Time pressure from Climate Change Act

UK is only advanced economy planning major nuclear expansion: bargaining power not used?

Country	% nuclear power (2015)	Policy
France	77	Stable – one EPR under construction
Belgium	47	Stable – no new stations planned
Sweden	41	Stable – no new stations planned
Switzerland	38	Stable – no new stations planned
Finland	35	Stable – one EPR close to finish; Russian reactor on order
Spain	20	Stable – no new stations planned
US	19	Intense competition from gas
UK	17	Major expansion/replacement planned
Germany	16	Planned phase out
Canada	17	Stable – no new stations planned
Japan	0	Planned restart but controversial
Italy	0	Shut down after Chernobyl disaster, 1986

Source: World Nuclear Association http://www.world-nuclear.org/info/Facts-and-Figures/Nuclear-generation-by-country/

Concepts of cost

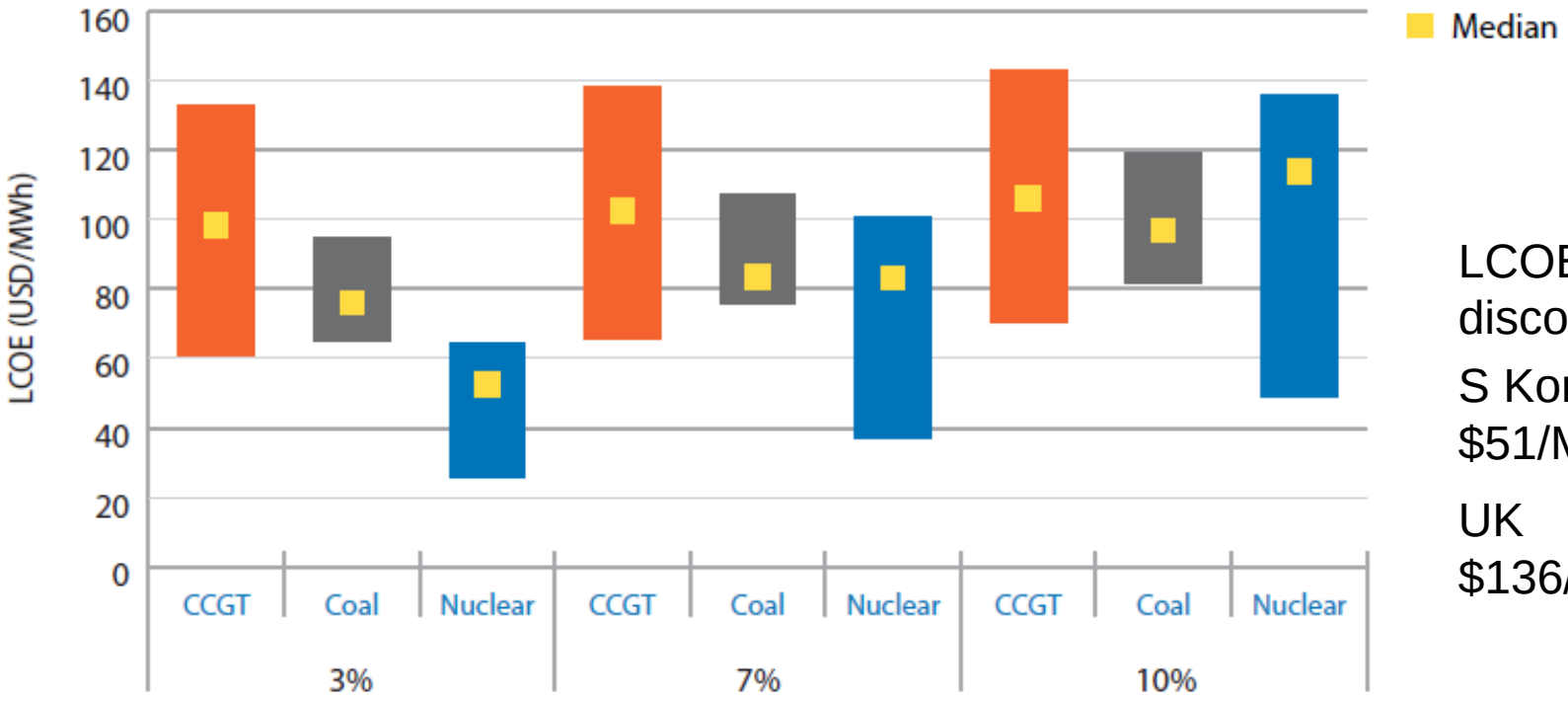
Overnight construction cost (no financing)

Levelised cost of energy (LCOE) over lifetime, discounted

Ex ante price charged to customer to justify investment

OECD: levelised cost of nuclear is high at realistic discount rate

Figure ES.1: LCOE ranges for baseload technologies (at each discount rate)



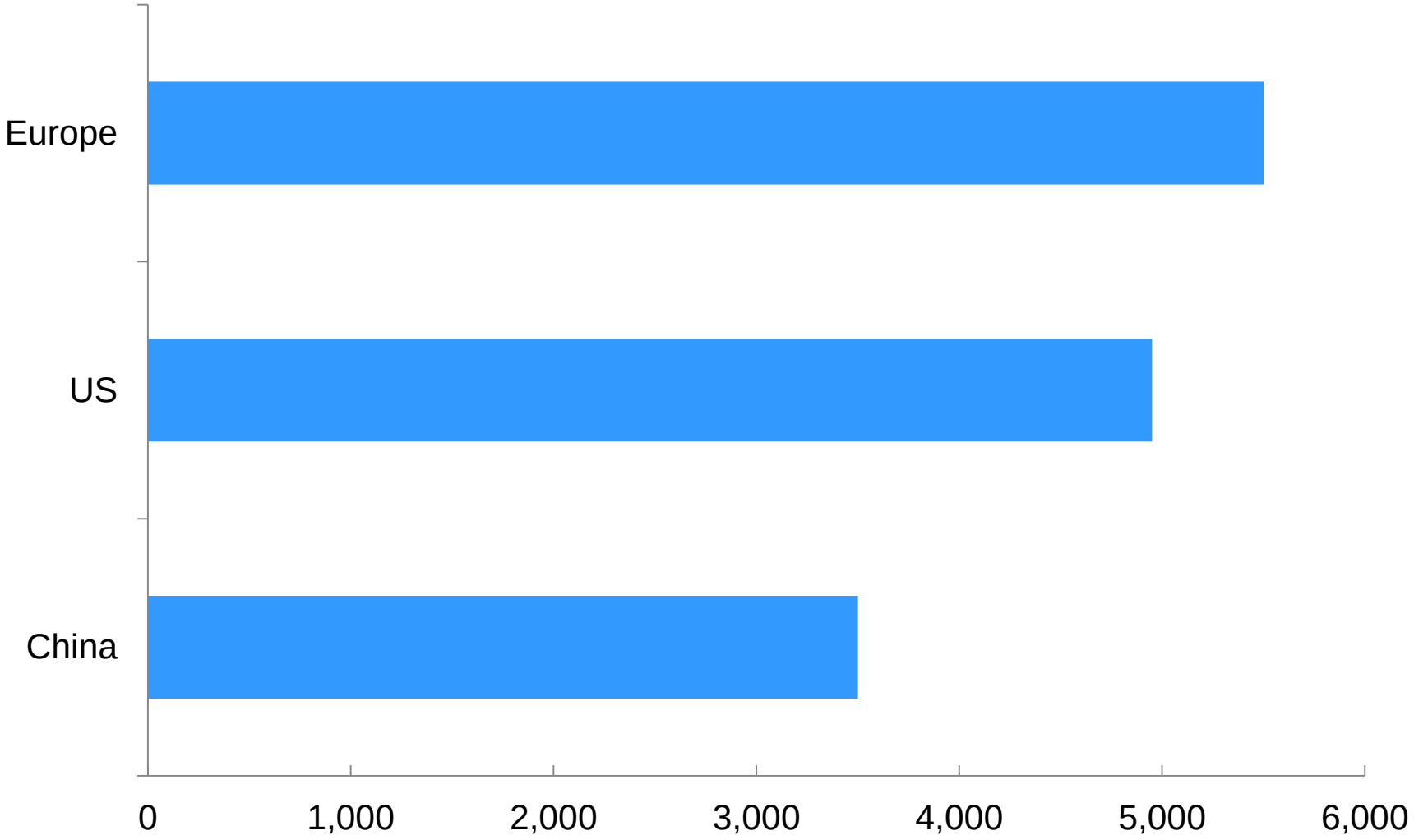
LCOE at 10% discount rate:

S Korea $51/MWh

UK $136/MWh

Source: OECD ***Projected Costs of Generating Electricity* – 2015 Edition** http://www.oecd-nea.org/ndd/pubs/2015/7279-proj-costs-electricity-2015-es.pdf

IEA estimated overnight cost ($/kW)



Model 3: Hinkley Point C (and probably other projects)

Sponsors bear construction risk

Partial state debt guarantee (fee of 2.95%)

35 year fixed (real) price revenue contract (de facto sovereign counterparty)

“Gain-share” mechanism to adjust price depending on i) construction out-turn; ii) achieved rate of return

Fixed price contract is inefficient form of risk protection

Figure xx Indicative cashflows for Hinkley Point C (£ million)

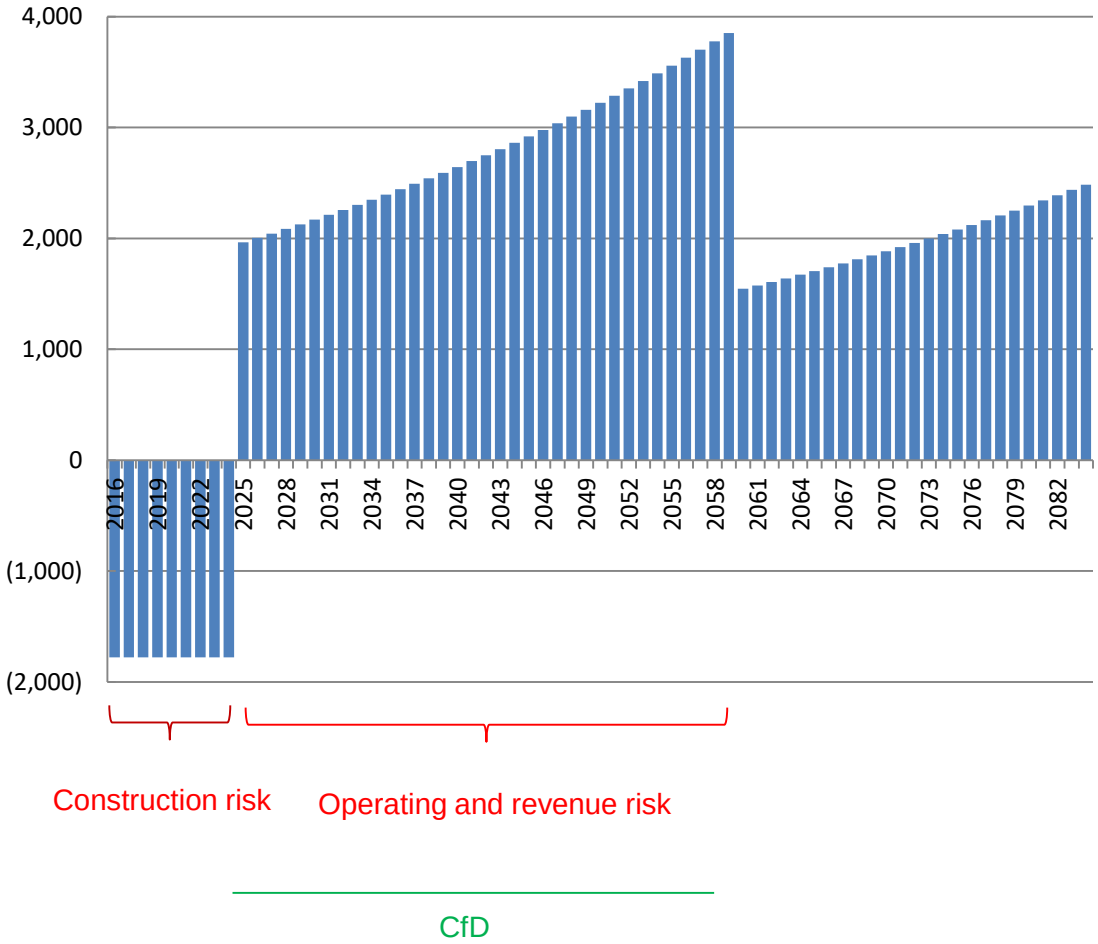


Table xx Assumptions on Hinkley Point C financial model

Financial input	Assumption
Annual inflation	2%
Average operating cost (£/MWh)	15.3
Construction cost (£m)	16,000
Availability	91%
No of years to build	9
Corporate tax rate	20%
Price fall in year 36	50%

Market failure? State involvement in current projects

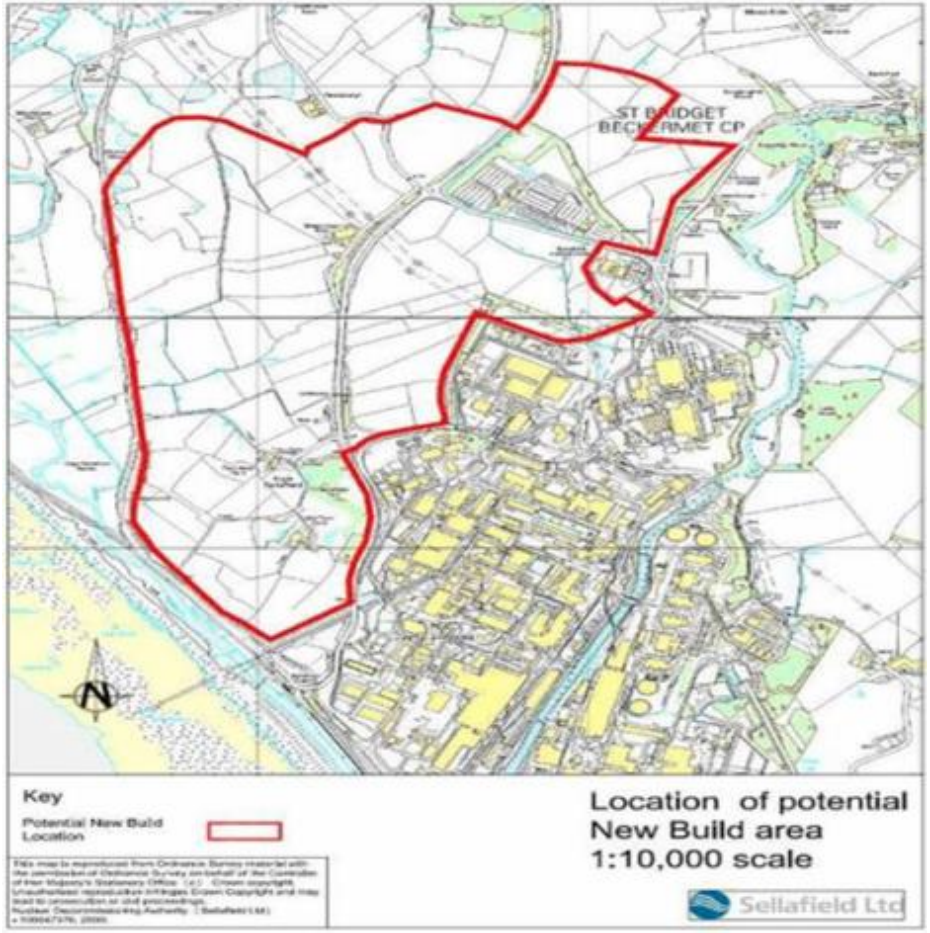
Comparisons of risk bearing among current and likely new nuclear projects

Reactor	Country	Status	Construction risk	Power price risk	Debt guarantee?
Olkilotuo 3	Finland	Under construction	Contractor (Areva)	Customers	None
Flamanville 3	France	Under construction	Sponsor (EDF)	Customers (via regulation)	No
Vogtle	USA	Under construction	Customers	Customers (via regulation)	Federal US government
Hinkley Point C	UK	Final approval given	Sponsor (EDF and CGN)	Customers (mediated by government)	UK government

Source: Taylor, S. in R. Heffron, G. Little (2016) *Delivering Energy Law and Policy in the EU and the US - A Reader*
https://edinburghuniversitypress.com/book-delivering-energy-law-and-policy-in-the-eu-and-the-us.html

Risk management in a “private project”

Moorside, Cumbria

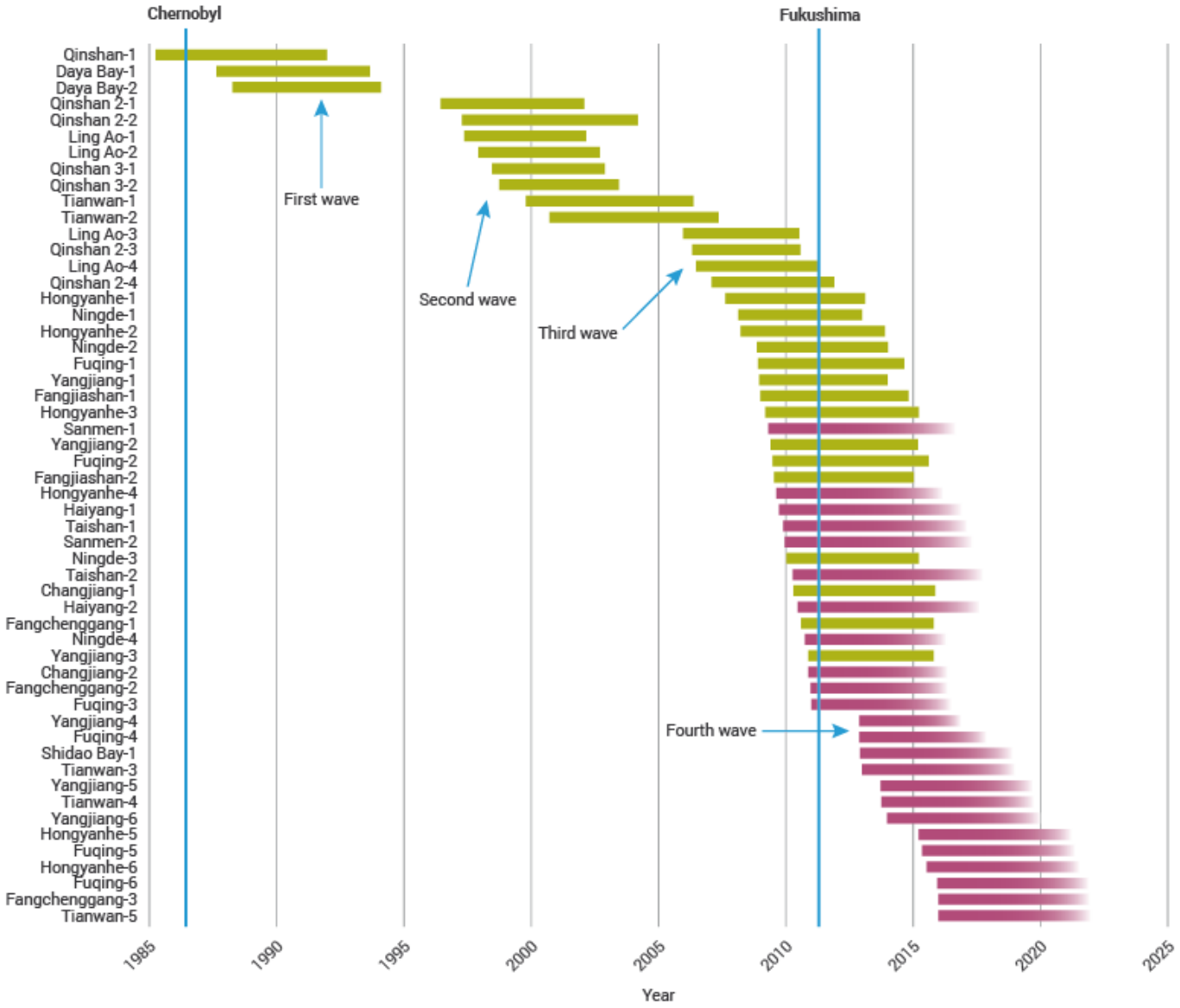


3.4-3.8GW AP1000 reactor
Toshiba (60%) and ENGIE (40%)
Projected sources of funding:
- *UK state debt guarantee*
- *Japanese Bank for International Cooperation*
- *US Ex-Im Bank*
- *Korea*

Source and ©: NuGen

China and nuclear

China’s nuclear surge

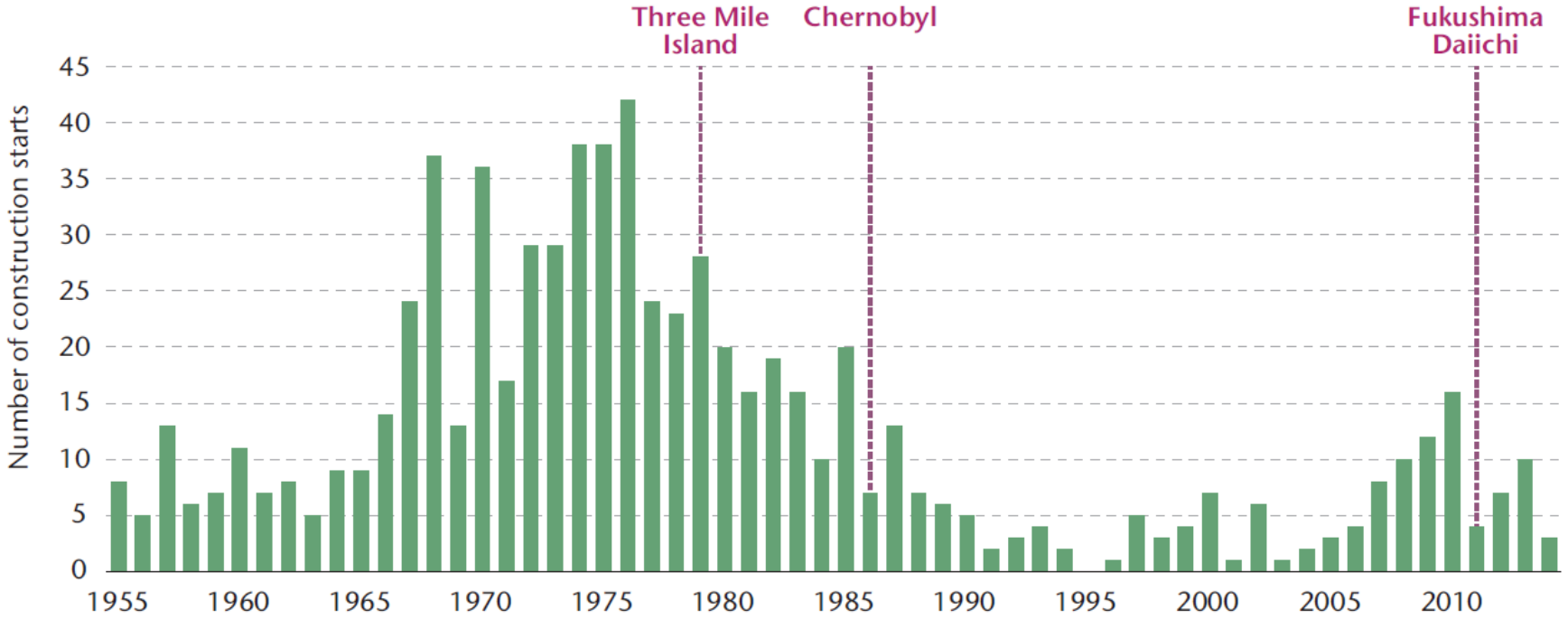


23GW under construction
47GW planned

Source: World Nuclear Association http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx

Nuclear renaissance: it's mostly China

Figure 1: Nuclear reactor construction starts, 1955 to 2014



Source: IAEA Power Reactor Information System (PRIS).

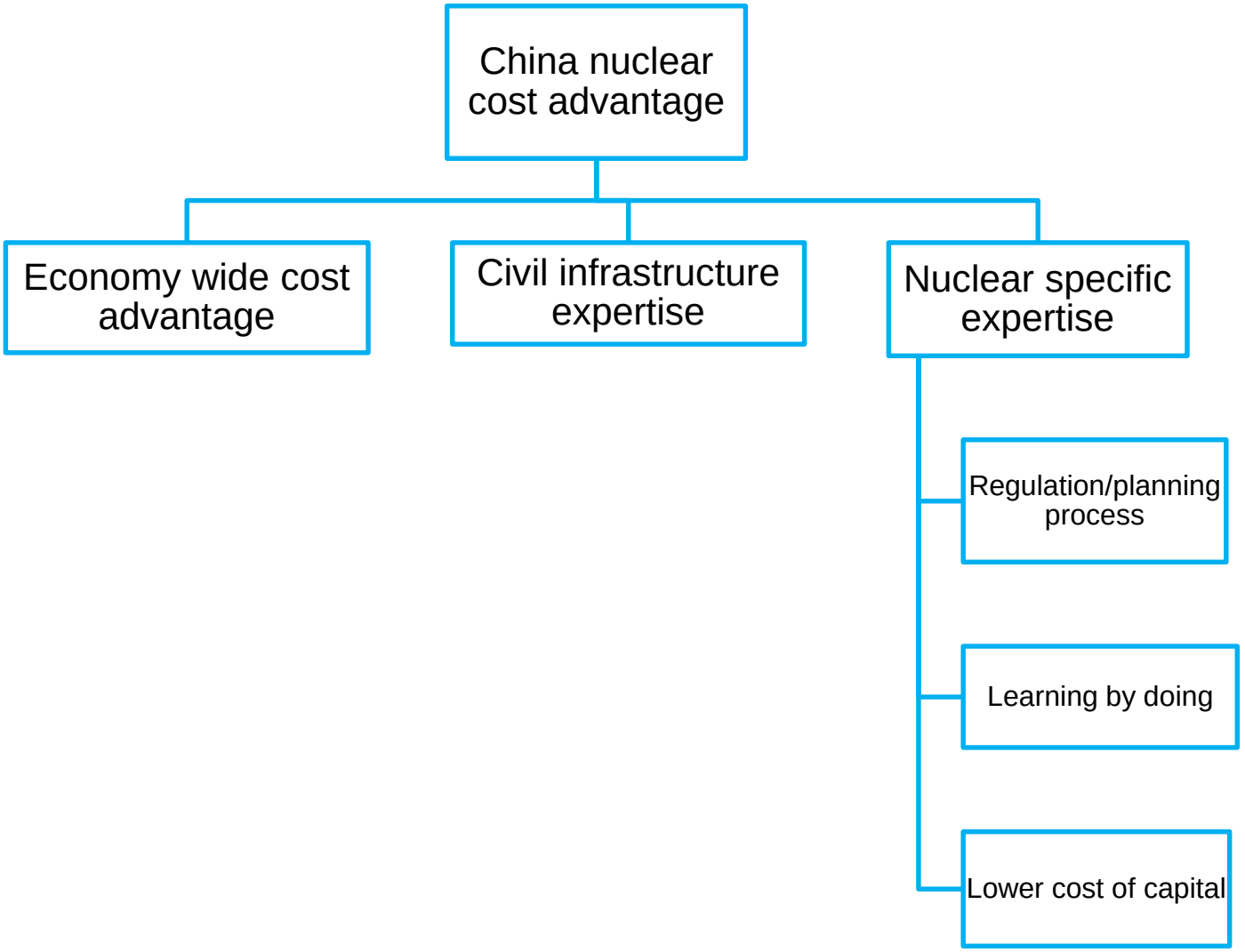
A brief history of Chinese nuclear

French PWR, Daya Bay, Guangdong

Russian PWR, Tianwan, Jiangsu

Chinese Hualong One PWR, Fengchenggang, Guangxi

Sources of China's nuclear cost advantage



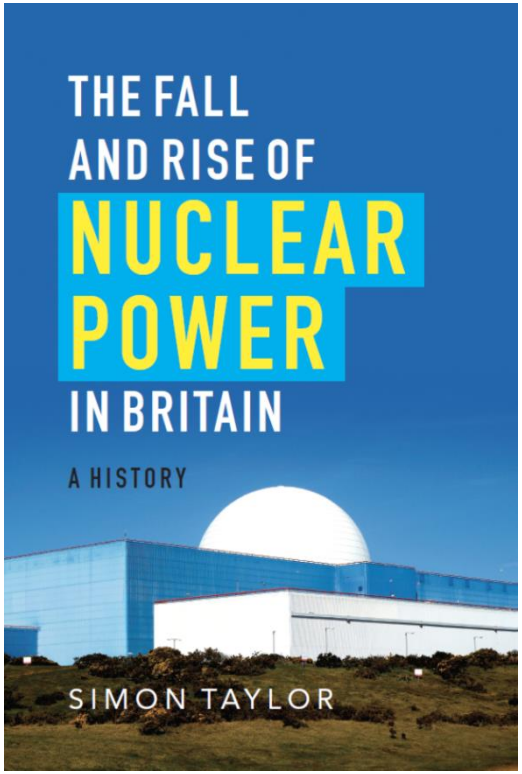
Small Modular Reactors

Table 4: Examples of small modular reactor designs (under construction or with near-term deployment potential)

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.

"However, the economics of SMRs have yet to be proven."



“hard hitting and authoritative”
- Sir Geoffrey Owen, Financial Times

“..Taylor’s cool and dispassionate financial and economic analysis of nuclear technology in the UK, especially over the past few years, is an excellent and even enthralling read.”
- Gordon Mackerron, Nature Energy

"A terrific piece of work ... far greater and more devastating detail than anything else so far in the public domain."
- Lord Howell, former Secretary of State for Energy

"An important and valuable analysis of one of the most important challenges of this century. The role of government and the market needs a fundamental reappraisal.”
- Tim Stone, Non-Executive Director of Horizon Nuclear Power; former Expert Chair of the Office For Nuclear Development in DECC

"Much can be learned from Britain's adventures in nuclear power. This engaging and authoritative account is essential reading for anyone who wants to reap the lessons of history."
- Professor Sir David J C MacKay FRS, Regius Professor of Engineering, University of Cambridge and author of Sustainable Energy – without the hot air. Chief Scientific Advisor to DECC (2009-2014).

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