Economics of new nuclear in the UK

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Director, Master of Finance
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
Motivation for reviving new nuclear 2: climate change

Is the Government doing enough about 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
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.
### Proposed new reactors in UK

<table>
<thead>
<tr>
<th>Station</th>
<th>Sponsor</th>
<th>Reactor type</th>
<th>Gross GW capacity</th>
<th>Projected commissioning (first unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hinkley Point C</td>
<td>EDF/CGN</td>
<td>EPR</td>
<td>3.2</td>
<td>2026</td>
</tr>
<tr>
<td>Moorside</td>
<td>NuGen (Hitachi + ENGIE + Kepco)</td>
<td>AP1000</td>
<td>3.8</td>
<td>2026</td>
</tr>
<tr>
<td>Oldbury C</td>
<td>Horizon (Toshiba)</td>
<td>ABWR</td>
<td>3.2</td>
<td>2028</td>
</tr>
<tr>
<td>Sizewell C</td>
<td>EDF/CGN</td>
<td>EPR</td>
<td>3.2</td>
<td>2028</td>
</tr>
<tr>
<td>Wylfa Newydd</td>
<td>Horizon</td>
<td>ABWR</td>
<td>2.8</td>
<td>2024</td>
</tr>
<tr>
<td>Bradwell B</td>
<td>CGN/EDF</td>
<td>Hualong 1</td>
<td>1.4</td>
<td>2028</td>
</tr>
</tbody>
</table>
Outlook for UK nuclear capacity (MW)
Hinkley Point C: to produce 7% of UK power by 2026
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

- Market value (2008)
- Market value (2016)
- Net debt (2016)
- EDF share of Hinkley cost
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?

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

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

LCOE at 10% discount rate:
- S Korea: $51/MWh
- UK: $136/MWh

IEA estimated overnight cost ($/kW)

- Europe: 5,500
- US: 4,900
- China: 3,500
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>
<thead>
<tr>
<th>Financial input</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual inflation</td>
<td>2%</td>
</tr>
<tr>
<td>Average operating cost (£/MWh)</td>
<td>15.3</td>
</tr>
<tr>
<td>Construction cost (£m)</td>
<td>16,000</td>
</tr>
<tr>
<td>Availability</td>
<td>91%</td>
</tr>
<tr>
<td>No of years to build</td>
<td>9</td>
</tr>
<tr>
<td>Corporate tax rate</td>
<td>20%</td>
</tr>
<tr>
<td>Price fall in year 36</td>
<td>50%</td>
</tr>
</tbody>
</table>
Comparisons of risk bearing among current and likely new nuclear projects

<table>
<thead>
<tr>
<th>Reactor</th>
<th>Country</th>
<th>Status</th>
<th>Construction risk</th>
<th>Power price risk</th>
<th>Debt guarantee?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olkiloto 3</td>
<td>Finland</td>
<td>Under construction</td>
<td>Contractor (Areva)</td>
<td>Customers</td>
<td>None</td>
</tr>
<tr>
<td>Flamanville 3</td>
<td>France</td>
<td>Under construction</td>
<td>Sponsor (EDF)</td>
<td>Customers (via regulation)</td>
<td>No</td>
</tr>
<tr>
<td>Vogtle</td>
<td>USA</td>
<td>Under construction</td>
<td>Customers</td>
<td>Customers (via regulation)</td>
<td>Federal US government</td>
</tr>
<tr>
<td>Hinkley Point C</td>
<td>UK</td>
<td>Final approval given</td>
<td>Sponsor (EDF and CGN)</td>
<td>Customers (mediated by government)</td>
<td>UK government</td>
</tr>
</tbody>
</table>

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

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

- Economy wide cost advantage
- Civil infrastructure expertise
- Nuclear specific expertise
  - Regulation/planning process
  - Learning by doing
  - Lower cost of capital
Small Modular Reactors

“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).