HOW TO REDUCE THE COSTS OF NEW NUCLEAR?

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&

*Chair, OECD/NEA Expert Group on the reduction of nuclear construction costs*

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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

Primary focus on near term (2030s) costs reductions for Gen-III as we move from FOAK to NOAK
… Follows 1988 Expert Group study on the “Means to Reduce the Capital Cost of Nuclear Power Stations”

Key areas covered:

- Increased plant size
- Improved construction methods
- Reduced construction schedule
- Design improvement
- Improved procurement, organisation and contractual aspects
- Standardisation and construction in series
- Multiple unit construction
- Regulation and policy measures
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 vs. Indirect costs

Direct costs
- Equipment
- Labor
- Construction tools and equipment
- Additional plant materials
- Buildings

Indirect costs
- Capitalized pre-construction costs
- Capitalized direct costs
- Capitalized indirect costs
- Capitalized owner's costs
- Capitalized supplementary costs
- Capitalized financial costs

Direct v. indirect construction costs (source: ETI, 2018)
Rapid reduction in the costs of renewables, but **nuclear expected to remain in competitiveness range in many parts of the world** on a LCOE basis

Role of the **cost of capital** (nuclear, solar PV and wind are all capital intensive)

International trend in levelized costs for Nuclear, Solar PV & onshore wind, 10% discount factor
(Source: IEA/NEA, 2010 & 2015 + projections for 2030)
## Construction Time of Recent FOAK Gen-III Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Type</th>
<th>Design Year</th>
<th>Decision Year</th>
<th>Construction Start</th>
<th>Initial Delay</th>
<th>Delay</th>
<th>Final Completion</th>
<th>Construction Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>OL3</td>
<td>EPR</td>
<td>2003</td>
<td>août-05</td>
<td>4</td>
<td>11</td>
<td>15</td>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>FLA 3</td>
<td>EPR</td>
<td>2005</td>
<td>déc-07</td>
<td>5</td>
<td>7</td>
<td>12</td>
<td>2019</td>
<td></td>
</tr>
<tr>
<td>NovoV 2.1</td>
<td>VVER1200</td>
<td>2006</td>
<td>juin-08</td>
<td>7</td>
<td>1</td>
<td>8</td>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>Leningr 2.1</td>
<td>VVER1200</td>
<td>2006</td>
<td>oct-08</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>2018</td>
<td></td>
</tr>
<tr>
<td>Sanmen 1</td>
<td>AP1000</td>
<td>2007</td>
<td>avr-09</td>
<td>6</td>
<td>3</td>
<td>9</td>
<td>2018</td>
<td></td>
</tr>
<tr>
<td>Hayiang 1</td>
<td>AP1000</td>
<td>2007</td>
<td>sept-09</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>2018</td>
<td></td>
</tr>
<tr>
<td>Shin Kori 3</td>
<td>APR1400</td>
<td>2007</td>
<td>oct-08</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>Taishan1</td>
<td>EPR</td>
<td>2007</td>
<td>oct-09</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>2018</td>
<td></td>
</tr>
<tr>
<td>Vogtle 3</td>
<td>AP1000</td>
<td>2008</td>
<td>mars-13</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>2019</td>
<td></td>
</tr>
<tr>
<td>Fuqing 5,6</td>
<td>HUALONG 1</td>
<td>2014</td>
<td>mai-15</td>
<td>5</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td></td>
</tr>
</tbody>
</table>

Source: SFEN, 2018
<table>
<thead>
<tr>
<th>Country</th>
<th>Reactor</th>
<th>Start</th>
<th>MWe</th>
<th>Ex-ante construction cost USD/kWe</th>
<th>Ex-post construction costs USD/kWe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olkiluoto 3</td>
<td>Finland</td>
<td>EPR</td>
<td>2005</td>
<td>1 x 1630</td>
<td>2430</td>
</tr>
<tr>
<td>Flamanville 3</td>
<td>France</td>
<td>EPR</td>
<td>2007</td>
<td>1 x 1600</td>
<td>2475</td>
</tr>
<tr>
<td>Leningrad 2</td>
<td>Russia</td>
<td>VVER1200</td>
<td>2008</td>
<td>2 x 1085</td>
<td>2673</td>
</tr>
<tr>
<td>Sanmen 1,2</td>
<td>China</td>
<td>AP 1000</td>
<td>2009</td>
<td>2 x 1000</td>
<td>2650</td>
</tr>
<tr>
<td>Taishan 1,2</td>
<td>China</td>
<td>EPR</td>
<td>2009</td>
<td>2 x 1660</td>
<td>1960</td>
</tr>
<tr>
<td>Shin Hanul 1,2</td>
<td>South Korea</td>
<td>APR1400</td>
<td>2012</td>
<td>2 x 1325</td>
<td>2300(** )</td>
</tr>
<tr>
<td>Vogtle 3,4</td>
<td>United States</td>
<td>AP 1000</td>
<td>2013</td>
<td>2 x 1117</td>
<td>5565</td>
</tr>
<tr>
<td>Fuqing 5,6</td>
<td>China</td>
<td>HUALONG 1</td>
<td>2015</td>
<td>2 x 1090</td>
<td>2800</td>
</tr>
</tbody>
</table>

Source: SFEN, 2018

(*) 1€ =1,2 USD  (** ) = Shin Kori 3,4
DIFFERENT WAYS TO LOOK AT THE POTENTIAL FOR COSTS REDUCTIONS

- Historical costs trends
- Evidence of learning by doing (econometrics)
- Lessons learnt from other industries
- Lessons learnt from recent FOAK projects
CONSTRUCTION COSTS TREND: HISTORICAL EVIDENCE FROM FRANCE

Difficulties for comparison of (international) construction costs data

- Eg. Choice of deflator

Case of France: limited construction costs increase overtime if control for economies of scale + learning using industrial price index

Construction costs data in France: defining and interpreting overnight costs...

Source: Cour des comptes, 2012 + own interpretation
Recent econometric studies (Berthelemy and Escobar, 2015; Escobar and Lévêque, 2016)

- Role of construction time
- Learning by doing conditional on standardization...
- ... but trade-off between reductions in costs enabled by standardization and potential gains from adopting new technologies
CONSTRUCTION COSTS DRIVERS: GETTING TO THE LEARNING CURVE

Fast learning in the UK offshore wind industry

- Increase in Regional energy strategies, societal engagement in decarbonisation, etc.
- PPAs signed in 2017
- Cost of Electricity (Upper)
- Cost of Electricity (Lower)

* 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

- Central gov. role in supporting regular build of new power plants, decarbonisation, etc.
- Concrete pouring: Flamanville 3 (4.5 months), Taishan (1 month)
- Fixing of containment liner: Flamanville 3 (47 weeks), Taishan (10 weeks)
CONSTRUCTION COSTS DRIVERS: PARALLEL WITH OTHER INDUSTRIES

McKinsey, “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.

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

\(^1\)Project still not finalized and costs could go even higher.
Source: Annual reports; Jane’s Airport Review; McKinsey analysis; Reuters
**Optimistic bias:** Early estimates of projects costs are underpredicted a majority of the time

Source: Rand (1981!!!)
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)

Source: ETI (2018)
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 (?)

Factor for increases in overnight construction costs in the US (Source: Univ. of Chicago, 2011)
Innovation to reduce costs, boost revenues and thermal efficiency

<table>
<thead>
<tr>
<th>Reduce Capital Cost</th>
<th>Reduce O&amp;M</th>
<th>Boost Revenues</th>
<th>Boost Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modular Construction</td>
<td>Advanced Concrete</td>
<td>Robotics</td>
<td>Hydro-phobic/hydrophilic Coatings</td>
</tr>
<tr>
<td>Seismic Isolation, Embeddment</td>
<td>Accident Tolerant Fuels</td>
<td>Advanced Informatics and I&amp;C (AI, machine learning)</td>
<td>Brayton Cycles</td>
</tr>
<tr>
<td>3D Printing</td>
<td>Advanced Decommissioning</td>
<td>Oxide Dispersion-Strengthened Alloys</td>
<td>Chemicals Production</td>
</tr>
</tbody>
</table>

Emphasis to be put on **cross-cutting technologies** that can reduce the **indirect costs**

THE ROLE OF PUBLIC INTERVENTION FOR REDUCING THE COST OF CAPITAL

KEY FACTORS FOR REDUCING CONSTRUCTION COSTS: CONCLUSIONS FROM SFEN STUDY

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

2) **Procurement & risk management** practices

3) **Policy framework**, in particular for reducing **financing** costs

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

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

Conclusion SFEN study: **- 30 % construction costs** reduction achievable for future 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)
- **Political 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
CONCLUDING REMARKS

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

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