Economics of HTR

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High Temperature Reactors for deep decarbonisation: the Polish example
From the Gemini+ research project towards demonstration

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Outline

• Relevant IAEA activities
  – PESS and NPTDS sections
  – Launch of CRP on Economics of SMRs (including HTRs)

• Decarbonising beyond power
  – Towards “Net Zero” goals
  – Non-power applications of nuclear energy

• Economics
  – nuclear cogeneration
  – H2 production

• Integrated Energy Systems (Hybrid Nuclear Renewables)
  – Coupling through electricity and hydrogen
  – Coupling through electricity, heat and hydrogen (HTR case)

• Macro-economic impacts of nuclear programmes
• Conclusions
Planning and Economic Studies Section

- Energy Planning support to Member States
- Nuclear power projections to 2050
- Technical and economic analysis of nuclear power and integrated nuclear/renewables systems
- Assessing contribution of nuclear energy to Climate Change mitigation
- Water-Energy Nexus, Resilience and adaptation to CC


Nuclear Power Technology Development Section

- Advanced reactors including SMRs
- Non-electric applications of nuclear energy
Small Modular Reactors

- **Economics based on “serial production”**, modular design with factory fabrication, etc

Latest IAEA Booklet on Advanced in SMR Technology Developments:

- Design description and main features of **72** SMR designs being updated (56 in 2018)
- SMRs are categorized in types based on coolant type/neutron spectrum:
  - Land Based Water-cooled Reactors
  - Marine Based Water-cooled Reactors
  - **High Temp gas cooled reactors**
  - Fast Reactors
  - Molten Salt Reactors
  - Micro reactors

Areas of investigation

- Market research
- Analysis of the competitive (non-nuclear) landscape
- Project planning, cost forecasting and analysis
- Project structuring, risk allocation and financial valuation
- Business planning and business case demonstration
- Economic cost-benefit analysis

Activities

- 75+ proposals received so far
- About 50 proposals selected
- First Meeting of the CRP to take place in Vienna on December 7-11, 2020

Expect data and analysis on economics of HTR (contribution from China, Japan, Indonesia, Poland, S. Africa, US)
Towards net-zero emissions

- Decarbonising the power sector will not be sufficient.
- Need to decarbonize other sectors, representing 60% of emissions today:
  - **Electrification** whenever possible (so increased demand for clean electricity)
  - Need for **low C heat sources** (e.g. fossil + CCS, nuclear heat, solar thermal)
  - Use of **low C fuels**, including hydrogen, produced from clean electricity

→ **Sector Coupling / integrated systems**

3 low-carbon energy vectors: electricity, heat, hydrogen
Non-electric applications: Process Heat, Desalination
Non-electric applications: District Heating

- Decades of experience, in Russia, Hungary, Switzerland, etc

- In June 2020, the new **Floating Nuclear Power Plant** Akademic Lomonosov, powered by two SMR units, provided 1st heat to Pevesk district (1st grid connection in Dec 2019)

- In November 2020, **Haiyang NPP** (AP1000) started delivering commercial DH
- **Considerations:**
  - Cost Allocation
  - Net Present Value
  - Exergy
  - Profitability analysis, etc
  - Proximity NPP – users (issue of cost of transport infrastructure)
  - **IAEA tools** for cost evaluation: HEEP (Hydrogen), DEEP (Desalination)

- Also issue of stability of production costs (favorable to nuclear vs. fossil fuel alternatives)

\[
C_H = (C' - C_0) + c_0 (E_0 - E') = \Delta C + c_0 \Delta E
\]

Co = LCOE, \( \Delta E \) = electricity loss

- Cost of cogenerated product (= LCOH x H produced)
- Cost of plant modification
Case of Hydrogen

Over 96% of world $H_2$ produced from fossil fuels. How to produce “clean” / Low Carbon Hydrogen:

- Low temperature electrolysis with low carbon electricity (renewables, nuclear)
- High temperature steam electrolysis (current or advanced reactors incl. HTR)
- Thermo-chemical splitting (advanced reactors incl. HTR)

Economics of hydrogen production depend on a wide variety of parameters such as scale and availability of the plant, cost of feedstock, efficiency of the technology employed, state of development (i.e. early stage or mature) and physical distance to end use markets

For $H_2$ produced from electrolysis to be competitive on a heating-value basis against fossil-fuel reforming would require very high CO2 prices (100-200 €/t)
### Comparison of different H2 production methods

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy source</th>
<th>Feedstock</th>
<th>Capital cost (M$)</th>
<th>Hydrogen cost ($/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMR with CCS</td>
<td>Standard fossil fuels</td>
<td>Natural gas</td>
<td>226.4</td>
<td>2.27</td>
</tr>
<tr>
<td>SMR without CCS</td>
<td>Standard fossil fuels</td>
<td>Natural gas</td>
<td>180.7</td>
<td>2.08</td>
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<tr>
<td>Solar PV electrolysis</td>
<td>Solar</td>
<td>Water</td>
<td>12–54.5</td>
<td>5.78–23.27</td>
</tr>
<tr>
<td>Solar thermal electrolysis</td>
<td>Solar</td>
<td>Water</td>
<td>421–22.1</td>
<td>5.10–10.49</td>
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<tr>
<td>Wind electrolysis</td>
<td>Wind</td>
<td>Water</td>
<td>504.8–499.6</td>
<td>5.89–6.03</td>
</tr>
<tr>
<td>Nuclear electrolysis</td>
<td>Nuclear</td>
<td>Water</td>
<td>–</td>
<td>4.15–7.00</td>
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<tr>
<td>Nuclear thermolysis</td>
<td>Nuclear</td>
<td>Water</td>
<td>39.6–2107.6</td>
<td>2.17–2.63</td>
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<tr>
<td>Solar thermolysis</td>
<td>Solar</td>
<td>Water</td>
<td>5.7–16</td>
<td>7.98–8.40</td>
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<tr>
<td>Photo-electrolysis</td>
<td>Solar</td>
<td>Water</td>
<td>–</td>
<td>10.36</td>
</tr>
</tbody>
</table>

Source: M. Kayfeci et al., Chap. 3 Hydrogen Production, in Solar Hydrogen Production, Academic Press, 2019
On Business Case Opportunities for Nuclear Production of Hydrogen (with existing reactor technologies)

Utilities:
- Arizona Public Service Company (Palo Verde NPP)
- Exelon
- EDF Energy
- Vattenfall
- Rosatom
- Foratom
- EPRI

Motivation:
- Diversify revenues (when electricity prices are too low)
- Contribute to clean energy objectives

System approach needed to assess costs and benefits

Concept of “Energy Hub” – EDF Energy in the UK
Integrated Energy Systems (Hybrid Energy Systems)

• How to design low carbon energy systems using all possible low carbon technologies:
  - Renewables
  - Nuclear
  - Fossil with CCS

• Coupling of the power sector with the non-power sector through 3 low carbon energy vectors:
  - Electricity
  - Heat
  - Hydrogen

- Economics of such systems requires sophisticated modelling approaches, able to inform on interactions between generation technologies, grid, energy storage and demand:
  - Optimize in terms of CO₂ emissions and overall costs
  - The value (economics) of a given technology depends on what is present in the system
Coupling via Electricity and Hydrogen (electrolysis)

NPPs: typically LWRs

POWER
- Atom
- Sun
- Wind
- Low C electricity

Direct use (electrification)

Electrolysis

H₂

Clean fuel

storage

INDUSTRY
BUILDING
TRANSPORT
- FCV
- EV
Coupling via Electricity, Heat and and Hydrogen

NPPs: typically LWRs + HTRs

3 low-carbon energy vectors: electricity, heat, hydrogen
Macro-economic impacts of nuclear programmes

- Energy transition: transformation of energy sectors:
  - Importance of energy policies, level-playing field, taxonomy, green deal, financing support, etc
  - Competition between technologies
  - Socio-economic impacts and accompanying measures (e.g. reconversion)
- Macro-economic impacts of nuclear programmes:
  - Job creation (direct, indirect)
  - Other effects (importance of long-term power supply at stable production costs) – e.g. PPAs with energy-intensive industries
- Post-covid recovery plans and energy transition
  - IEA Sustainable Recovery Report (2020): 4.5 jobs are created per $million invested in LTO projects, or twice more employment than onshore wind
  - For new nuclear, situation comparable to off-shore wind
Take-aways

• Challenge of decarbonizing the whole energy sector requires all low carbon technologies

• Nuclear: existing + advanced reactors (SMRs incl. HTRs)

• Economics of existing nuclear: “economy of scale” (+ cost reduction measures)

• Economics of SMRs: “economy of serial production”
  – Economics of HTRs: multiple revenue streams

• HTRs provide unique characteristics that should make this technology attractive from an economic point of view:
  – Ability to provide all 3 low carbon energy vectors, electricity, heat and hydrogen
  – Flexibility to switch / adapt to market conditions – will be an important advantage

• Besides technological costs specific to HTRs, the “value” to the system needs to be assessed using sophisticated modelling