Economics of nuclear cogeneration
EU/US comparison

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Outline

- Objectives of the economic assessment
- Economic analysis
- Evaluation for „real site“ scenarios
- Evaluation of CTL/GTL processes
- Conclusions
## Objectives

- Identify the main factors influencing economics of HTRs;
- Evaluate the profitability of nuclear cogeneration for different profile of end-users;
- Define some high level requirements for HTRs based on economic considerations.

## Boundary Conditions

- Operator vision with assumptions similar to current projects;
- NOAK HTR-MODULE 250, specifications provided by AREVA.
- Different scenarios based on real end-user needs or operating installations;
- Open-literature energy scenarios;

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**NC2I Economic assessment is driven by utilities’ considerations**
Key factors of success

HTR sustainability factors

Meeting the needs of the present without compromising the ability of future generations to meet their own needs.
Reference case

The investment cost assessment and economic analysis of an HTR-MODULE 250 has been made on the basis of the analyses of an HTR-MODULE 200 in the 1990ies.

The HTR-MODULE 250 is a two-modular plant for cogeneration of power and process steam for chemical complexes.

- Legal and economic conditions of Germany
- Plant is integrated in the site of the chemical complex
- Due to the special requirements the plant is equipped with two diverse process steam lines in parallel and two turbine sets (in case of a shutdown of one module always 50% of the steam is ensured)
- On-site manufacturing of the large components (pressure vessels) is required
- 500MWth (2x250) or 210 MWe
- Process steam:
  - 19 bar, 250°C, 42.9 kg/s
  - 3.5 bar, 139°C, 104.3 kg/s
### Overview of main parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>NC2I Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>2 x 250 MWth</td>
</tr>
<tr>
<td>Overnight costs</td>
<td>1862 €/kWt</td>
</tr>
<tr>
<td>O&amp;M costs</td>
<td>6,23 €/MW.t</td>
</tr>
<tr>
<td>Lifetime</td>
<td>40 years</td>
</tr>
<tr>
<td>Reference gas price</td>
<td>35 €/MWh + 10 €/t CO₂</td>
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<tr>
<td>Design development costs</td>
<td>Excluded</td>
</tr>
<tr>
<td>Technical basis</td>
<td>Near-term applications (750°C outlet temperature, SG, plug-in market)</td>
</tr>
</tbody>
</table>
Evaluation of Nuclear Cogeneration

- Usual in nuclear projects:
  - High initial investment
  - Long payback time
  - High cost of delay (interests)
  - Uncertain future revenues

- Emerging trends:
  - Small is beautiful…
  - Secure/Increase revenues (or benefits)

- Pending or under discussion:
  - Who pays the first unit?
  - What if… accident?

\[
NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_T}{(1+r)^T}
\]

- \( C_0 \) = Initial Investment
- \( C \) = Cash Flow
- \( r \) = Discount Rate
- \( T \) = Time

NC2I
Nuclear Cogeneration Industrial Initiative
Economic Assessments within NC2I

- E.ON
- Nuclear Cogeneration
- Heat/steam for various end-user configurations
- CTL and GTL processes

Economics within NC2I
Economic Assessments: The model

Main Input Data
- Construction costs
- O&M costs
- Decommissioning costs
- Fuel costs
- Lifetime
- Electricity prices
- Heat prices
- HTR availability
- Construction time & delay
- Tax rate
- Interest rate

<table>
<thead>
<tr>
<th>Item</th>
<th>Variation min</th>
<th>Variation max</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTR construction costs in year 0</td>
<td>-30%</td>
<td>+30%</td>
</tr>
<tr>
<td>O&amp;M costs in year 0</td>
<td>0</td>
<td>+100%</td>
</tr>
<tr>
<td>Decommissioning costs in year 0</td>
<td>0</td>
<td>+200%</td>
</tr>
<tr>
<td>Fuel costs in year 0</td>
<td>-30%</td>
<td>+100%</td>
</tr>
<tr>
<td>Lifetime</td>
<td>-30%</td>
<td>+30%</td>
</tr>
<tr>
<td>Electricity price in year 0 (Electricity price increment)</td>
<td>0</td>
<td>+100%</td>
</tr>
<tr>
<td>Steam price (incl. CO2) in year 0 (Heat price increment)</td>
<td>-50%</td>
<td>+100%</td>
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<tr>
<td>HTR Availability</td>
<td>-20%</td>
<td>+10%</td>
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<tr>
<td>Construction time</td>
<td>0</td>
<td>+50%</td>
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<tr>
<td>Delay during commissioning</td>
<td>0</td>
<td>+2</td>
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<tr>
<td>Tax rate</td>
<td>-10%</td>
<td>+40%</td>
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<tr>
<td>Interest rate (Inflation rate) (Alternative cost of capital)</td>
<td>-30%</td>
<td>+50%</td>
</tr>
<tr>
<td>Design and licensing duration</td>
<td>0</td>
<td>+2</td>
</tr>
<tr>
<td>Design and licensing cost</td>
<td>0</td>
<td>+300</td>
</tr>
</tbody>
</table>

Bottom-up approach based on detailed inputs and focus on parameters sensibility
Sensitivity Analysis

Reference case:
- NPV: +233 M€
- IRR: 9.9%
- Positive NPV after 24 years

If electricity production:
- LCOE = 81.6 €/Mwe.h

External factors:
- High influence of heat price (with high impact of CO₂ prices)
- Moderate influence of electricity prices
- Moderate influence of lifetime

Availability, discount rate & heat price are the most influential parameters

Sensibility analysis shows robustness of the main parameters

NPV > 0 for reference case (!) BUT no design, licensing or FOAK costs
NC2I site mapping

Aim was to localize and characterize chemical and petrochemical sites within Europe which can be a potential market for deployment of HTR’s.

Focus on:
- refinery distillation steam;
- refinery distillation superheated steam;
- petrochemicals - reaction enthalpy;
- steam as utility for industrial complex;
- paper steam (drying).
Site Mapping Results

- 132 industrial sites investigated, data provided for 57 sites.

< 200 MWth: robust gas plant market,
> 300 MWth: market opportunities for HTR at chemical plants
Study for different sites

Different configurations tested, with a sensitivity analysis:
- Chemelot (220 MWth, 180 Mwe)
- Gdansk (246 MWth, 22 Mwe)
- Trzebinia (39 MWth, 4,4 Mwe)

⇒ “small” sites hardly competitive
Further investigations (Chemelot)

Evaluation of the ideal HTR size and the ratio between thermal and electrical production for Chemelot

The effect of HTR size on T/E Ratio

- In Case 1: $y = -0.1359x^2 + 1.5204x - 1.217$, $R^2 = 0.9737$
- In Case 2: $y = -0.1832x^2 + 1.7834x - 1.588$, $R^2 = 0.9912$
Energy storage scenario

- Evaluation of shifting the production between electricity and heat, depending on the electricity price
  - Impact on the NPV is quite marginal
  - Configuration potentially challenged by capital costs
CTL/GTL processes

Different scenarios:
- Reference scenario: Secunda West Plant as is
- Nuclear hydrogen in support of CTL
- Replace coal generated steam and electricity with the same from nuclear co-generation
- Replace Steam Methane Reforming (SMR) with Plasma Arc Reforming (PAR). Dry reform CH4
- Replace SMR with PAR; Wet reform CH4.

➔ Substitution of coal generated process steam and electricity offers the best opportunity for nuclear co-generation
➔ High capital cost and impact of CO2 prices challenge the profitability of the conventional CTL process
Conclusions and challenges

• An HTR design of 500 MWth, supplying a chemical complex could be economically viable; end-users >200 MWth is a priority

• Energy scenarios for gas & coal prices show an increase of heat price in Europe and hence good perspectives for HTR competitiveness from 2025 on;

• Design development (or adaptation) costs challenge the viability of a project. Standardization within Europe (especially for regulations and licensing) is an absolute priority.

• To maximize revenues for smaller chemical complex, a broader range of services (e.g. integrated energy supply: Heat and electricity, district heating, grid stabilization..) is to be investigated.

• A case with electricity-only production would hardly compete with current alternative electricity sources (Hydro, Coal, large nuclear).

• Specific applications (CTL/GTL) hardly viable under current market conditions.
Thank you for your attention
Basic representation of an HTR Market

HTR PLANT

Electricity (*)

Industry processes

Heat

Energy storage

H₂, chemicals

Transmission & Distribution
Retail services

Transmission & Distribution
Retail services

CUSTOMERS

Increasing competition of gas

Increasing competition of coal, renewables and other nuclear

* Water pumping possible