HTGR for heat market
Plans in Poland

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Chairman of European consortium

GEMINI+ NC²¹
Nuclear Cogeneration Industrial Initiative
• Reducing to zero emission from electricity production would solve only 1/6 of the problem
• Industry needs high temperature heat (>500°C)
• Synthetic H-rich fuels for electric cars with fuel cells is the future of transport (>700°C heat needed to produce them)
Heat demand for different temperatures

European industrial heat demand

<table>
<thead>
<tr>
<th>Temperature Range</th>
<th>Heat Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 250°C</td>
<td>LWR</td>
</tr>
<tr>
<td>250-550°C</td>
<td>HTGR</td>
</tr>
<tr>
<td>550-700°C</td>
<td></td>
</tr>
<tr>
<td>700-1000°C</td>
<td>VHTR, ...</td>
</tr>
<tr>
<td>&gt; 1000°C</td>
<td></td>
</tr>
</tbody>
</table>

Source: EUROPAIRS study on the European industrial heat market

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HTGR in Poland
HTGR for Poland

- 13 largest chemical plants have installed today 6500MW of heat at T=400-550°C
- They use 200 TJ / year, equivalent to burning of >5 mln t of natural gas or oil
- 165 MW<sub>th</sub> reactor size fits all the needs
- Estimated market by 2050 PL: 10-20, EU:100-200, world:1000-2000
- Possible replacement of 200 MW<sub>e</sub> cogeneration units in future
- Increasing interest in T=500-1000°C for H<sub>2</sub> production

### Table: HTGR plants in Poland

<table>
<thead>
<tr>
<th>Plant</th>
<th>boilers</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZE PKN Orlen S.A. Płock</td>
<td>8</td>
<td>2140</td>
</tr>
<tr>
<td>Arcelor Mittal Poland S.A.</td>
<td>8</td>
<td>1273</td>
</tr>
<tr>
<td>Zakłady Azotowe &quot;Puławy&quot; S.A.</td>
<td>5</td>
<td>850</td>
</tr>
<tr>
<td>Zakłady Azotowe ANWIL SA</td>
<td>3</td>
<td>580</td>
</tr>
<tr>
<td>Zakłady Chemiczne &quot;Police&quot; S.A.</td>
<td>8</td>
<td>566</td>
</tr>
<tr>
<td>Energetyka Dwory</td>
<td>5</td>
<td>538</td>
</tr>
<tr>
<td>International Paper - Kwidzyn</td>
<td>5</td>
<td>538</td>
</tr>
<tr>
<td>Grupa LOTOS S.A. Gdańsk</td>
<td>4</td>
<td>518</td>
</tr>
<tr>
<td>ZAK S.A. Kędzierzyn</td>
<td>6</td>
<td>474</td>
</tr>
<tr>
<td>Zakl. Azotowe w Tarnowie Moscicach S.A.</td>
<td>4</td>
<td>430</td>
</tr>
<tr>
<td>MICHELIN POLSKA S.A.</td>
<td>9</td>
<td>384</td>
</tr>
<tr>
<td>PCC Rokita SA</td>
<td>7</td>
<td>368</td>
</tr>
<tr>
<td>MONDI ŚWIECIE S.A.</td>
<td>3</td>
<td>313</td>
</tr>
</tbody>
</table>

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Minister of Energy in July 2016 appointed „Committee for deployment of high temperature reactors”.

Chairman: G. Wrochna

Members from:

- Nuclear R&D: NCBJ
- Engineering: Energoprojekt, Prochem
- End-users: Azoty, Orlen, Enea, Tauron, KGHM

Associates: PAA (regulator), NCBR (R&D funding agency), PKO BP (bank)

Report published January 2018: tiny.cc/htr-pl

Minister of Energy has given a green light to proceede with implementation of the conclusions.
Conclusions of the HTR Committee

In agreement with other international studies:


Feedback from industry

- Several sites use ~500°C steam networks
- Need to exchange old boilers with HTGR
- Electric island already there
- HTGR parameters matching standard boilers: 540°C, 13.4 MPa, 165 MW*th, 230 t/h
* +10% for internal use
Coal, gas & HTGR economy

Coal & gas boilers compared to HTGR 165 MW<sub>th</sub>, 230 t/h of steam 540°C, 13.8 MPa.
Current fuel prices. 30/60 years boiler/HTGR lifetime.
For HTGR: 15 idle days/year, 80% of power used.
Design cost covered by the first 10 HTGR’s.

<table>
<thead>
<tr>
<th></th>
<th>Steam cost LCOE M PLN /GJ</th>
<th>F-NPV M PLN</th>
<th>E-NPV M PLN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount rate</td>
<td>8%</td>
<td>4%</td>
<td>8%</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt; emission cost /t</td>
<td>20€  50€</td>
<td>20€  50€</td>
<td>50€</td>
</tr>
<tr>
<td>Coal boiler OP-230</td>
<td>27  37</td>
<td>25  35</td>
<td>158  619</td>
</tr>
<tr>
<td>Gas boiler OG-230</td>
<td>37  43</td>
<td>36  42</td>
<td>20  144</td>
</tr>
<tr>
<td>HTGR 165 MW</td>
<td>55  55</td>
<td>36  36</td>
<td>-268  538</td>
</tr>
</tbody>
</table>

Cost of steam from HTGR could be comparable to that from coal/gas

Largest uncertainties:
discount rate, CO<sub>2</sub> emission cost, coal & gas price & availability.
Why HTGR not used widely?

- **Traditional business model:**
  - Big contract between big Vendor and big Utility
  - Vendor could be sure to find a buyer sooner or later
  - Utility was not afraid to order a reactor similar to others already in use

- **Such approach for HTGR created „chicken and egg” dead loop**
  - No vendor can afford detailed design before having an order
  - No user (e.g. chemical company) will order a reactor not even designed
  - Too high level of risk on both sides (vendor and user) is the barrier

- **Solution: let’s users become the vendor**
  - reactor designed by SPV own by users
A user point of view

- Power and chemical companies use today coal- and gas-fires boilers to produce heat
  - In 2030-2050 most of them will need to be replaced

- Replaced with what? What will be less expensive and less risky?
  - Coal and gas
    - Large uncertainty on fuel price and cost of CO$_2$ emission (20-75€/t)
    - Risk of finishing domestic coal resources
    - Risk of gas supply from a single source
  - Nuclear HTGR
    - Technological risk – no design ready to buy
    - Uncertainty of „overnight” reactor cost (2,0±0,6 MPLN / 165 MW$_{th}$)
    - Strong dependence of profitability on cost of money (discount rate)
Changing the user’s point of view

- Division of the project into 2 phases (design + construction) delays the investment decision by 5 years
  - Uncertainty on fuel prices and CO₂ cost largely reduced
  - Design is known and construction cost much better predicted
- Designing controlled by the users ensures:
  - fulfilling the user requirements
  - trust of the users in the design
- Cofinancing by several users ensures:
  - cost sharing and possibility of using R&D funds
- Cofinancing by public money ensures:
  - reduction of the users expenses
  - decisive security for managers
HTGR programme

Designing Experimental HTGR
150 M PLN
50% from state?
~6 MPLN/year/partner

Construction of Experimental HTGR
600 M PLN
100% from EU?
(EU structural funds)

Designing Commercial HTGR
500 M PLN
50% from state?
~12 M PLN/year/partner

Construction of Commercial HTGR
2000 M PLN
100% end-user
(UE/PL support for long term loan)

OPEX (B+R)

CAPEX (investment)

2018 2020 2023 2025 2031

1$ ≈ 3.7 PLN
1€ ≈ 4.2 PLN

4 industrial partners assumed

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Additional challenges

- **Breaking economy of the scale**
  - **cogeneration** (~100% use of energy)
  - **large market** (PL: 10-20, EU: 100-200, world >1000)
  - **SMR: factory fabrication** (not construction at a site)

- **Universality**
  - **Same design for different applications**
    - steam for chemical factory
    - cogeneration: turbines + district heating
    - ???
  - **Separation from the user installations**
    - no influence of user installations on the reactor

These challenges are addressed by the Gemini+ project
Nuclear Cogeneration Industrial Initiative

- Part of Sustainable Nuclear Energy Technology Platform

www.nc2i.eu

Mission:
Contribute to clean & competitive energy beyond electricity by facilitating deployment of nuclear cogeneration plants

GEMINI - partnership of EU NC2I with US NGNP Industrial Alliance

Euratom project: 4 M€/3y
Winner of Euratom SMR competition
26 partners from EU, Japan, Korea & US