EU market for process heat applications

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Workshop on "Technical and Economic Assessment of Non-Electric Applications of Nuclear Energy"

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This presentation is based on findings of the market study carried out by LGI in the frame of the EUROPAIRS project (2009-2011)

This project was supported by the Euratom 7th Framework Programme

www.europairs.eu
What is the “heat market”?
What is the “heat market”?
What is the “heat market”? 

Combined heat and power plant

Fuel

(CO2)

Electricity

Steam

(Industrial facility)

Fuel

Fuel

CO2

(CO2)
What is the “heat market”?

Combined heat and power plant

(\text{CO}_2)

Electricity

Steam

Fuel

\text{CO}_2

Industrial facility

Plug-in

Extended
What is the “heat market”? 

Plug-in  

Extended
What is the “heat market”? 

Combined heat and power plant 

Electrical grid 

Base raw materials e.g. H₂, N₂, O₂ 

Industrial facility 

Plug-in 

Extended 

Fuel 

CO₂ 

Steam 

Electricity
What is the “heat market”? 

**Polygeneration**

**Plug-in**  
**Extended**
What is the “heat market”?

Polygeneration

Plug-in

Extended
What is the “heat market”? 

Polygeneration

- Combined heat and power plant
- Electrical grid
- CO₂
- Fuel

Pre-heating

- Electricity
- Steam

Plug-in

Extended

Industrial facility

LGi CONSULTING

PROJECT MANAGEMENT + INNOVATION + ORGANISATION + INFORMATION TECHNOLOGY
Status of cogeneration today

- Cogeneration is a mature technology
- Gas is the reference technology
- Max process temperature ~ 550°C

- Nuclear cogen was proven for low temperatures (< 200°C)
- Europe has a leading experience
  - district heating (Eastern Europe, Russia)
  - paper (Switzerland), salt refinery (Germany)
  - desalination (Japan and Kazakhstan)
  - large scale industrial park (Canada)
Results: size of markets

Polygeneration

Pre-heating

Plug-in

Extended heat market

Market of conventional cogeneration today

Potential short-term market for nuclear cogeneration

Market difficult to supply in the short and medium term

784 TWh/y

117 TWh/y

361 TWh/y

1 830 TWh/y
Results: distribution by temperature/sector

Distribution of the heat market by temperature class and sector

- Heat consumption by year (GWh/y)
- Temperature class and type of market

- Iron and steel (including coke)
- Gypsum
- Mineral wool insulation materials
- Non-ferrous metals
- Cement
- Ceramics
- Glass
- Primary aluminium
- Lime, dolomite and magnesite
- Ferrous metals
- Refinery
- Secondary aluminium
- Industrial gases
- Non-metallic minerals
- Metal ore
- Soda ash and sodium bicarbonate
- Chemical industry
- Steam and hot water supply
- Electricity, gas, steam and hot water supply
Results: distribution by temperature/sector
“Plug-in” market

- Mostly replacing existing cogeneration plants based on fossil fuels

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Infrastructures available</td>
<td>- Flexibility</td>
</tr>
<tr>
<td>- Operational compatibility of industrial parks</td>
<td>- Average installed thermal capacity per site</td>
</tr>
<tr>
<td>- Climate policies and concerns on energy supply and costs</td>
<td>- Availability and back-up capacities</td>
</tr>
<tr>
<td>- Several regions with significant industrial densities</td>
<td>- Sector specific issues</td>
</tr>
<tr>
<td>- Sector specific opportunities</td>
<td>- Nuclear acceptability, contamination, safety</td>
</tr>
<tr>
<td></td>
<td>- Industrial uncertainty</td>
</tr>
</tbody>
</table>
Polygeneration of hydrogen and oxygen

- **Production technologies still to be demonstrated**

- **Several advantages**
  - On-site direct added value
  - Economies of scale
  - Energy storage
  - New markets accessible
    - H2 for e.g. fuel cells, ammonia synthesis and iron reduction, O2 for existing and new markets (e.g. glass, steel, clean coal techs, H2)
  - Distant supply of final consumers via industrial gas pipelines
    - *Europe has the largest pipeline network in the world*
Nuclear pre-heating

• Applicable in any “heating neutral” sector
• Significant reengineering may be required
  - Need for detailed analysis by sector

• Examples
  - Glass: contribution to raw materials melting via a combination of nuclear pre-heating, fuel combustion (also oxy-fuel) and electrical boost
  - Iron and steel: air (or pure O2) pre-heating or steel scraps pre-heating
  - Aluminium: hydration of alumina (using steam) and contribution to alumina calcination (≈ drying process)
  - Ceramics: drying of shaped materials (moisture removal)
  - Lime, cement: raw material pre-heating
## Extrapolation to the world

<table>
<thead>
<tr>
<th>Region</th>
<th>Plug-in market</th>
<th>Total market</th>
<th>GDP 2011 (approx.)</th>
</tr>
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<tbody>
<tr>
<td>Europe</td>
<td>~ 800 TWh/y (EUROPAIRS)</td>
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<td>~ 3,600 TWh/y (MPR Associates)</td>
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<td>China</td>
<td>1,200 – 1,700 TWh/y (est.)</td>
<td></td>
<td>7,000 bn€ / 10% of world</td>
</tr>
<tr>
<td>India</td>
<td>300 – 500 TWh/y (est.)</td>
<td></td>
<td>2,000 bn€ / 3% of world</td>
</tr>
<tr>
<td>Russia</td>
<td>300 – 500 TWh/y</td>
<td></td>
<td>2,000 bn€ / 3% of world</td>
</tr>
<tr>
<td>Brazil</td>
<td>400 – 500 TWh/y</td>
<td></td>
<td>2,500 bn€ / 4% of world</td>
</tr>
<tr>
<td>World total</td>
<td>3,000 – 5,000 TWh/y ~ 370 – 630 GW</td>
<td>11,000 – 16,000 TWh/y</td>
<td>69,000 bn€</td>
</tr>
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*HTR will only address a part of this market!!!*
Conclusions (1/2)

• **Europe is an attractive heat market**
  - Large heat consumption, good share already supplied by cogeneration
  - Strong industrial infrastructures

• **Nuclear reactors could supply a good share of the market**
  - Plug-in market with flexible steam and electricity production
  - Polygeneration of H2 and O2 distantly
  - Pre-heating
  - Vision of industrial ecosystems around a nuclear plant
Conclusions (2/2)

- The world may represent a very large heat market for HTR
  
  - Very high potential for BRICS countries and other emerging economies, and potential market growth

  - A global (cooperation to) study of the world’s industrial heat market would help assess in a second step the potential market of HTR in the world and make its business case robust

  - The EU and US studies can be a good basis
Thank you for your attention
Questions?
Backup slides
Methodology

• Dual approach:
  – **Direct**: Detailed analysis by industrial sector
  – **Indirect**: Based on CO2 emissions declared in EU ETS

• Market survey (April - September 2010)
  Responding organisations:

<table>
<thead>
<tr>
<th>European associations</th>
<th>Individual companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>COGEN Europe</td>
<td>Leading oil company</td>
</tr>
<tr>
<td>European Aluminium Association</td>
<td>Leading pulp and paper company</td>
</tr>
<tr>
<td>European Industrial Gas Association</td>
<td>Leading soda ash producer</td>
</tr>
<tr>
<td>European Steel Technology Platform</td>
<td>Leading steelmaking company</td>
</tr>
<tr>
<td>European Lime Association</td>
<td>Leading lime company</td>
</tr>
<tr>
<td>Confederation of European Paper Industry</td>
<td>Utility of a medium-scale chemical cluster</td>
</tr>
<tr>
<td></td>
<td>Fertiliser company</td>
</tr>
<tr>
<td></td>
<td>Two industrial gases companies</td>
</tr>
</tbody>
</table>
Results: process temperatures

- Iron and steelmaking
- Glass and mineral wool
- Ceramics (firing)
- Cement
- Non-ferrous metals (copper and nickel)
- Hydrogen (steam methane reforming)
- Aluminium primary: Calcination
- Lime
- Air gases (high temperature process)
- Aluminium secondary
- Ammonia and urea
- Non-ferrous metals (lead, zinc)
- Refinery (except hydrogen production)
- Plastics
- Chemical industry
- Soda ash
- Ceramics (drying)
- Aluminium primary Alumina hydration
- Paper
- District heating
- Desalination
- Fulp

Temperature (°C)
Bibliography

• Lack of information on heat consumption in Europe

• Statistical reporting via a common Eurostat-IEA questionnaire to Member States

• Results are
  – Unreliable: diverging estimations for the same information
  – Incomplete: only heat sold to market is considered
  – Imprecise: distribution by sector is too rough and mostly unattributed

<table>
<thead>
<tr>
<th></th>
<th>IEA</th>
<th>EUROSTAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat production</td>
<td>766 741</td>
<td>1 619 086</td>
</tr>
<tr>
<td>Heat consumption</td>
<td>677 259</td>
<td>1 206 939</td>
</tr>
</tbody>
</table>
Precisions on EU ETS

- EU Emissions Trading Scheme directive dated from 1996 and amended several times

- Good fraction of the total energy market, especially the one most impacted by climate policies

- Statistical uncertainty regarding the reporting sector, in particular in sector “combustion of fuels” (total thermal input > 20MWth): Ecofys study
Precisions on EU ETS

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Network of industrial gases pipelines in Europe
Network of industrial gases pipelines in Europe

TOMORROW?
Europe: Air Liquide’s industrial gas pipelines operated in Northern Europe
Hydrogen markets

<table>
<thead>
<tr>
<th>Product</th>
<th>Consumption [bn m³]</th>
<th>Growth rate [%/year]</th>
<th>Share of total [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2003</td>
<td>2008 extrapolation</td>
<td>2003</td>
</tr>
<tr>
<td>Refining</td>
<td>30.56</td>
<td>44.74</td>
<td>49.7</td>
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<tr>
<td>Ammonia</td>
<td>19.44</td>
<td>19.50</td>
<td>31.6</td>
</tr>
<tr>
<td>Methanol</td>
<td>3.36</td>
<td>3.10</td>
<td>5.5</td>
</tr>
<tr>
<td>Metals</td>
<td>2.67</td>
<td>3.25</td>
<td>4.3</td>
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<tr>
<td>Cyclohexane</td>
<td>1.01</td>
<td>1.11</td>
<td>1.6</td>
</tr>
<tr>
<td>Aniline</td>
<td>0.95</td>
<td>1.05</td>
<td>1.5</td>
</tr>
<tr>
<td>Caprolactam</td>
<td>0.71</td>
<td>0.75</td>
<td>1.2</td>
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<tr>
<td>H₂ Peroxide</td>
<td>0.70</td>
<td>0.75</td>
<td>1.1</td>
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<tr>
<td>Oxo Alcohols C8</td>
<td>0.34</td>
<td>0.35</td>
<td>0.6</td>
</tr>
<tr>
<td>Oxo Alcohols C4</td>
<td>0.26</td>
<td>0.27</td>
<td>0.4</td>
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<tr>
<td>Toluene Diisocyanate</td>
<td>0.38</td>
<td>0.35</td>
<td>0.6</td>
</tr>
<tr>
<td>Hexamethylenediamine</td>
<td>0.31</td>
<td>0.33</td>
<td>0.5</td>
</tr>
<tr>
<td>Adipic Acid</td>
<td>0.15</td>
<td>0.16</td>
<td>0.3</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>0.10</td>
<td>0.10</td>
<td>0.2</td>
</tr>
<tr>
<td>Tetrahydrofuran</td>
<td>0.21</td>
<td>0.22</td>
<td>0.3</td>
</tr>
<tr>
<td>Fats and oils</td>
<td>0.31</td>
<td>0.30</td>
<td>0.5</td>
</tr>
<tr>
<td>Float glass</td>
<td>0.04</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>Electronics</td>
<td>0.03</td>
<td>0.04</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>61.53</strong></td>
<td><strong>76.41</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Additional potential market for fuel cells: + 154 bn m³ (+200%)

67% produced on purpose

33% by-product
Ammonia

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>350-400°C</td>
<td>Heat</td>
</tr>
<tr>
<td>400-600°C</td>
<td>Heat</td>
</tr>
<tr>
<td>500-600°C</td>
<td>Heat</td>
</tr>
<tr>
<td>350-380°C</td>
<td>Exothermic</td>
</tr>
<tr>
<td>300°C</td>
<td>Exothermic</td>
</tr>
<tr>
<td>350-550°C</td>
<td>Power</td>
</tr>
<tr>
<td>350-550°C</td>
<td>Power</td>
</tr>
</tbody>
</table>
Chemical industry: location of clusters
Mega cluster Antwerp Rotterdam Rhine Ruhr
Cost structure in the chemical industry

Source: CEFIC
Crude oil

Separation

Upgrading

H2

Retreating

Production of primary petrochemicals

Further processing

Oil products
- Diesel, gasoline...

Basic molecules
- Benzene, ethylene...

Elaborated chem.
- PVC, PS, elastomers,
- Butenes, Nylon...

Chemistry

Plastics

...
District heating market share in Europe

District heating is most developed in Scandinavian and Eastern Europe

District heating typical consumptions:
600 – 1200 MWth large cities
10 – 50 MWth in smaller ones

Temperature range: 80-150°C
Max distances: 10-15 kms
Annual load factor: 50%

District heating significant market shares in European countries (Source: EHP 2010)
Cogeneration from 8 CANDU reactors and biomass
7 200 MWe nuclear
5 350 MWth steam

1680 kg/s MP steam
+ 315 kg/s back-up

Consumers:
heavy water production unit, plastic producer, a 30 000 m2 greenhouse, a 12 000 m3/y ethanol plant, a 200 000 t/y alfalfa plant, an apple juice concentration plant and an agricultural research facility.
Cost structure and energy mix in the pulp and paper industry

- Recovered Paper 5.1%
- Labour 12.9%
- Maintenance 9.3%
- Market Pulp 15.9%
- Electricity 9.7%
- Chemicals 17.6%
- Fuels 12.3%
- Wood 17.3%
- Other 0.5%

- Biomass 52.5%
- Gas 38.0%
- Coal 3.8%
- Fuel Oil 4.6%
- Other Fossil Fuels 1.1%

Total Fuels Consumption: 1,226,810 TJ
Glass: regenerative melter

Principle of glassmaking:
• **melt** various chemicals (silica oxides mainly)
• **cool quickly** to keep their non-crystalline structure from liquid phase

Melting = 75% of energy

Final temperature:
1300°C - 1500°C

Numerous techniques including combined fuel and electric heating

Nuclear cogeneration potential:
• pre-heating up to 550°C
• heating with (oxy) fossil fuels
• electric boost
Steel: blast furnace

CO+H2

Hot O2 or air pre-heating
Steel: Electric arc furnace

- Electricity
- Pre-heating + O2

Diagram labels:
- Power cables
- Electrodes
- Hatch for iron ore, lime, and other material
- Oxygen inlet
- Tapping spout for molten iron
- Iron ore
- Door for removing slag
Steel: new concepts

- Carbon
  - Coke
  - Coal
  - Redsmelt
  - Smelting Reduction from coal
  - Smelting Reduction from NG
  - H₂ prereduction
  - Blast Furnace
  - H₂ by electrolysis of H₂O
  - Electrolysis
  - EAF

- Hydrogen
- Electrons

- Offgas
- CCS
- Iron ore
- Oxygen
- Coal
- Oxygen
- Process gas
- Hot metal and slag
- Electrolysis
- LGi Consulting
Lime: production concept

CaCO₃ -> CaO + CO₂ (1 d, >835°C)
CaO + CO₂ -> CaCO₃ (3 w., < 835°C)
Cement: rotary kiln gas-solid heat propagation
Vision of an industrial ecosystem
Which thermal power?

MW

Design duty

Peak load

Heat consumption

Base load

time
Which thermal power?

Nuclear cogeneration?
## Results

<table>
<thead>
<tr>
<th>(GWh/y)</th>
<th>Plug-in</th>
<th>Poly-generation</th>
<th>Pre-heating</th>
<th>Extended market</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect calculation</td>
<td>755 730</td>
<td></td>
<td></td>
<td>1 771 021</td>
<td>2 526 751</td>
</tr>
<tr>
<td>Direct calculation</td>
<td>783 989</td>
<td>116 636</td>
<td>361 113</td>
<td>1 829 715</td>
<td>3 091 432</td>
</tr>
</tbody>
</table>

- **The European heat market is large**
  - 289 to 353 GWth equivalent to 577 to 706 reactors of 500 MWth

- **30% of the existing heat market is externalised ("plug-in")**
  - 87 to 89 GWth equivalent to 173 to 179 reactors of 500 MWth

- **Polygeneration and pre-heating are hypothetical additional heat markets which may become significant**
  - Around 54 GWth equivalent to 108 reactors of 500 MWth
Strategies for entering the heat market

Number of potential consumers by sector

Engineering effort to adapt

Size of the market

Segment

Precautionary

Aggressive

A

B

C

D

E

F
Recommendations

- Liaise with organisations having an operational experience in nuclear cogeneration (in Europe, Canada, Russia, Japan, Kazakhstan) and with the International Atomic Energy Agency in order to benefit from their experience feedback.
- Focus in the short term on the market below 550°C, where the “plug-in” market concentrates.
- Limit the reactor thermal capacity (to around 100 MWth) to increase the number of potential customers.
- Identify prominent personalities in heat end-users susceptible to adopt nuclear cogeneration and determine a structured market approach (precautionary, segment, aggressive).
- Launch a detailed analysis for each priority segment in order to identify the most relevant sites (size compatibility, flat consumption, long-term industrial visibility, balance of calorific off-gases or by-products, cogeneration plant to be replaced, nuclear acceptance, water availability...).
- Investigate with the main technology providers in each industrial sector the potential of coupling a nuclear reactor with their processes and possibly launch common R&D projects.
Recommendations

• Partner with industrial gases producers and research organisations to develop hydrogen and air gases production technologies and the coupling with a nuclear reactor, as polygeneration may offer many advantages in terms of siting, acceptance, coupling, economics, and large-scale heat consumption.

• Analyse the regulatory, economic and fiscal contexts for cogeneration and nuclear energy in each Member State in order to identify the most relevant countries for nuclear cogeneration.

• Develop the business case of nuclear cogeneration in order to prove the competitiveness of the technology in each priority market segment (against the reference technology).

• Identify early potential adopters, specialised engineering companies and consultancies in each sector and collaborate to develop technically and economically the coupling concepts; relevant professional associations, European Technology Platforms and European R&D projects should also be approached.

• Investigate the potential of nuclear pre-heating with a detailed sector analysis, in particular for glassmaking, iron and steel, and lime.