High Temperature Reactors: the nuclear cogeneration alternative for fossil fuel energy in industry
– European situation and perspective -

Werner von Lensa (HTR-TN)

S. de Groot (NRG), M.A. Fütterer (JRC-IE), A.I. van Heek (NRG), D. Hittner (Areva NP Inc.)

ICCFG conference Dresden
The European High Temperature Reactor Technology Network, HTR-TN

- **21 partners** from 11 EU countries
  - 5 nuclear engineering companies
  - 2 large utilities
  - 1 worldwide graphite manufacturing leader,
  - 8 research centres,
  - 3 universities

- **Created in 2000** for supporting industrial development of HTR

- **Roadmap for HTR deployment**

- 12 projects (~ 45 M€) in **FP5-6 & 7**, including the 19 M€ RAPHAEL
  + Participation in several non-EURATOM projects ($H_2$, materials)

- **Stabilize European HTR know-how**

- **International engagement**

---

AMEC
Ansaldo Nucleare
Areva NP
Areva NC
Belgonucléaire
Commissariat à l’Energie Atomique (CEA)
Delft University of Technology (TU Delft)
Electricité de France (EdF)
Empresarios Agrupados
Forschungszentrum Jülich (FZJ)
GrafTech
Joint Research Centre of the E.C. (JRC)
NEXIA Solutions
Nuclear Research & consultancy Group (NRG)
Nuclear Research Institute – Rêz (NRI)
Paul Scherrer Institut (PSI)
Suez-Tractebel
Universität Stuttgart
University of Applied Sciences Zittau/Görlitz
VTT Technical Research Centre of Finland
Nuclear Power Markets

- Electricity only 16%
- Nuclear only for electricity
- Heat Market & Transport dominating
- Penetration of nuclear into two directions
- Combined Heat & Power (CHP) saves resources & CO₂ emissions
- Nuclear Process Heat (NPH) not really taken into account
- NPH/CHP: innovation in the energy sector !!!

Forms of energy utilisation

- Oil 43%
- Gas 16%
- Electricity 16%
- Coal 7%
- Combustible renewables 14%
- Other renewables 4%

Heat Market

Nuclear Energy today
Energy Flows in the Global Electricity System

Use of Wasted Energy Is a Huge Opportunity !!!

Cogeneration of Heat & Power (CHP)

Fuel Utilisation in CHP Plants

Fuel Utilization

- Waste Heat
- Useful Heat
- Power

Optimum Point

Example:
- Live Steam Temperature: 530 °C
- Product Heat Temperature: 100 °C

Power only
Combined Heat and Power (CHP)
Heat only

Heat Production % of Plant Capacity

0 100
High Temperatures = High Efficiency

<table>
<thead>
<tr>
<th>Water / Steam Cycle – focused on Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>subcritical</td>
</tr>
<tr>
<td>simple</td>
</tr>
</tbody>
</table>

Supercritical Steam:
>217.5 bar; >374.2°C

Thermal Efficiency of the Water/Steam Cycle [%]

LWR THTR GT-MHR HTR + USC

350 bar / 700 °C / 720 °C
300 bar / 600 °C /620 °C
The High Temperature Reactor

- Helium cooled nuclear reactor
- Ceramic core: inherent safety features
- High temperature heat allows for:
  - High efficiency electricity generation
  - High quality heat supply to industrial processes
Europe has the largest HTR experience in the world

- Europe built HTR up to the industrial prototype scale

  - DRAGON (U.K.)
    1963 - 76
  - AVR (FRG)
    1967 - 1988
  - THTR (FRG)
    1986 - 1989
  - HTR-Modul
    Market ready

- Europe developed the technology of components for industrial process heat applications

  - 10 MW mock-up of a He-He heat exchanger
  - 10 MW steam CH₄ reformer mock-up for nuclear application
European HTR knowledge base re-established, maintained and expanded

- HTR-TN initiative in European Framework Programs:
  - FP5: HTR-N, HTR-L, etc. programs
  - FP6 RAPHAEL program, [www.raphael-project.org](http://www.raphael-project.org)
  - FP7: EUROPAIRS program, [www.europairs.eu](http://www.europairs.eu)
  - FP7: ARCHER proposal (recently submitted)

R&D program for (Very) High Temperature reactor systems

Coordinated action in which nuclear and non-nuclear industry assess the feasibility and boundary conditions of connecting a HTR to conventional industrial processes

European framework proposal with generic HTR R&D, focused on demonstration
Present HTR/VHTR projects in the world

- Japan: HTTR, experimental reactor, 30MWth, in operation since 1998
- South Korea: NHDD
- China: HTR-10, experimental reactor, 10MWth, in operation since 2000
- China: HTR-PM, industrial prototype, 2x250 MWth, start of operation 2013
- USA: NGNP, industrial prototype for CHP and Hydrogen Production, start of operation 2021
- France: programme ANTARES for CHP 600 MWth
- Russia: project GT-MHR
- Kazakhstan
- South Africa: industrial demonstrator, for Process Heat & Cogeneration
- Japan: HTTR, experimental reactor, 30MWth, in operation since 1998
- Japan: GTHTR 300, 600 MWth
- EU ?
- COLLABORATION POTENTIAL ???
End-User Requirements for Industrial Process Heat Applications with Innovative Nuclear Reactors for Sustainable Energy Supply

EUROPAIRS: a new FP7 project started 1 September 2009

Potential end-user industries and nuclear cogeneration experts identify the viability conditions of a nuclear heat source (HTR focus) connected to industrial processes

Technical, economic, licensing and resource efficiency aspects are assessed
- 23 organisations
- The consortium is continuously expanding, also via end-user contacts
Industry requirements

In case the fossil energy used is replaced by nuclear

- Saving on carbonaceous feedstock consumption
- Reduction of CO₂ emission
‘Current end user requirements can be met with modest gas temperatures (750°C–800°C) to supply electricity, steam and heat’

HTR well suited!
Potential Number of HTGRs in US

- Petrochemical (150)
- Fertilizers/Ammonia (100+)
- Sasol Secunda Plant
- Coal-to-Liquids (100s)
- Petroleum Refining (50-100)
- Oil Sands/Shale (200+)

1 Million Metric Tons CO2/year avoided for every HTGR (500 MWth) used in lieu of Natural Gas
The SET-plan

- The European Strategic Energy Technology plan (SET-plan) target: “to deliver sustainable, secure and competitive energy”

- By 2020:
  - 20% reduction in greenhouse gas emissions compared to 1990 levels (30% if global agreement)
  - 20% reduction in global primary energy use (through energy efficiency)
  - 20% of renewable energy in the EU’s overall mix (minimum target for biofuels of 10% of vehicle fuel)

- By 2050: indicative 60 to 80% reduction in GHG

- To be achieved by technology development:
  - Wind
  - (Concentrated) Solar
  - Smart Grid
  - Bio-energy
  - Fuel cells and hydrogen
  - Carbon Storage and Sequestration
  - Nuclear power

- For each of these technology fields, ‘technology platforms’ have been established
Overview (Europe viewpoint)

Strategic Energy Technology - plan

Wind
Solar
Smart Grid
Hydrogen
CCS
Bio-energy

SNE-TP

GenII/III Reactors
Fast Neutron Reactors
Heat & Cogeneration Applications

ESNII
ESNII Task force

NC2I
Nuclear Cogen working group

Industrial participation: Europairs
EU R&D Collaboration & Framework
International R&D collaboration
International demonstration collaboration
The SET-plan

- **Industrial participation** is required for eligibility for funding
- ‘**Industrial initiatives**’ are defined for each SET-plan technology platforms
- These initiatives define **required R&D, implementation strategy**, expected contribution to meeting SET targets, planning, finances, etc.
- The SET-plan, and the platforms are highly ambitious. Recently the European Commission has provided **cost reservation** required for meeting the targets to the Parliament:

NucNet News No. 70: EC Adopts **EUR 50 Billion** Plan For New Energy Investment

7 Oct (NucNet): The European Commission (EC) has adopted proposals calling for the public and private sectors to help invest an additional 50 billion euro (EUR) (73 billion US dollars) in low carbon technologies including nuclear in order to address climate change, secure European energy supply, and secure the competitiveness of EU economies.
‘Nuclear’ in the SET-plan

- For now one nuclear industrial initiative is communicated from SNE-TP: the **Sustainable Nuclear energy Industrial Initiative (ESNII)**. Concept paper describing the initiative has been submitted.

- **ESNII** focuses on the development and deployment of **fast neutron reactors**, with sodium cooled reactors as the main focus, and gas-cooled and lead cooled reactors as second options (closed U-Pu fuel cycle)

- The second, the **Nuclear Cogeneration Industrial Initiative** is under preparation. A draft **NC2I** concept paper available, for review by end-users, from Europairs

- **Nuclear fission** has to move towards **long-term sustainability** with a new generation of reactor types (Generation-IV): **maximise inherent safety**, **increase efficiency**, produce **less radioactive waste** and **minimise proliferation risks**. The bulk of the programme up to 2020 will be the design and construction of prototypes and demonstrators, fuel fabrication workshops and experimental facilities and a research programme to develop new materials and components to improve the industrial and economic viability

**2020 SET-Plan objectives:**

- The total public and private investment needed in Europe over the next 10 years is estimated as **€7 bn**. By 2020, the first Generation-IV prototypes should be in operation. The **first cogeneration reactors could also appear within the next decade** as demonstration projects to test the technology for **coupling with industrial processes**.
The **Sustainable Nuclear Energy Technology Platform (SNE-TP)** is a European forum gathering stakeholders sharing the same vision: from nuclear industry, research centres, technical support/safety organisations, universities, etc.

The overall goal is to support technological development for enhancing **nuclear fission in a sustainable energy mix**

- Low greenhouse gases emissions,
- Security of supply and
- Stable electricity prices
The major part of the nuclear community in Europe is represented in SNE-TP.
1 Maintain safety and competitiveness of today’s technologies

2 Enlarge the nuclear fission portfolio beyond electricity production (H₂, synthetic fuels, petrochemical/steelmaking/paper/cement industries, seawater desalination, etc.)

3 Develop Gen IV Fast Reactors with closed cycle to enhance sustainability (U-Pu fuel cycle)
Nuclear Cogeneration Potential in Europe

- Nuclear is the largest (GHG-free) electricity supplier in EU (31%)
- Electricity is only 20% of the EU energy market

➔ **Nuclear Cogeneration:**

= *Electricity* + *Process Heat from nuclear energy*

- enhances efficiency, saves prime fossil fuel, cuts emissions, if (waste) heat is used
- unlocks a huge new market and GHG reduction opportunity
The ‘other applications of nuclear energy’ pillar, has been strengthened by the **Nuclear Cogeneration Working Group**.

The Nuclear Cogeneration Working Group will:

- **Liaise with (international) activities**, networks and communities
- **Explore cogeneration options** (including FR and LWR cogeneration application)
- **Set up an R&D program** focussed on generic cogeneration issues: for example via the next European Framework call (issue expected in November)
- **Set up an industrial initiative**: the **Nuclear Cogeneration Industrial Initiative: NC2I**, based on the strategic alliance forged in the Europairs project, between nuclear community and potential non-nuclear industrial end-users: HTR focus
High Temperature Reactor (HTR) systems can provide safe, reliable and stable priced high temperature heat and electricity to industry on the short to medium term: nuclear cogeneration.

The European Strategic Energy Technology plan (SET-plan) targeting towards demonstration of nuclear cogeneration.

Nuclear Cogeneration Working Group of SNETP established to form an industrial initiative (NC2I: Nuclear Cogeneration Industrial Initiative).

Large market potential already existing. Even larger if transport fuel production is included.

These opportunities have a strong foundation:

- Europe has the largest HTR knowledge and experience base (although others are catching up rapidly)
- This basis has been re-established and has been expanded in recent and ongoing FP5, FP6, and FP7 programs

End users invited to participate in Europairs & NC2I
NC2I
Nuclear Cogeneration Industrial Initiative

Establishing a responsible fossil fuel alternative for European industry

Thank you for your attention

s.degroot@nrg.eu, +31 224 56 4338