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JRC TECHNICAL REPORT

D5.21 Report on Workshops

rev. 0

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NC2I-R

Combination of CP & CSA

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D5.21 Report on Workshops

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Summary

This deliverable summarizes the presentations given at the Workshop organized by the NC2I-R project consortium in cooperation with the SNETP/NC2I Task Force. The workshop was part of the SNETP "Nuclear Days" event which was held on 17-19 March 2015 in Brussels.

The "Nuclear Days" event gathered approx. 180 participants from which around 25 attended the NC2I Workshop. Other events included the SNETP General Assembly and Governing Board, the NUGENIA General Assembly and conferences and the ESNII conferences.

Approval

Rev.	Date	First author	SP leader	Project Coordinator
0	16 June 2015	M. Fütterer (JRC) 16/06/2015	C. Auriault (LGI) 16/06/2015	T. Jackowski (NCBJ)

Distribution list

Name	Organisation	Comments
P. Manolatos	EC DG RTD	
All beneficiaries	NC2I-R	Through internet workspace

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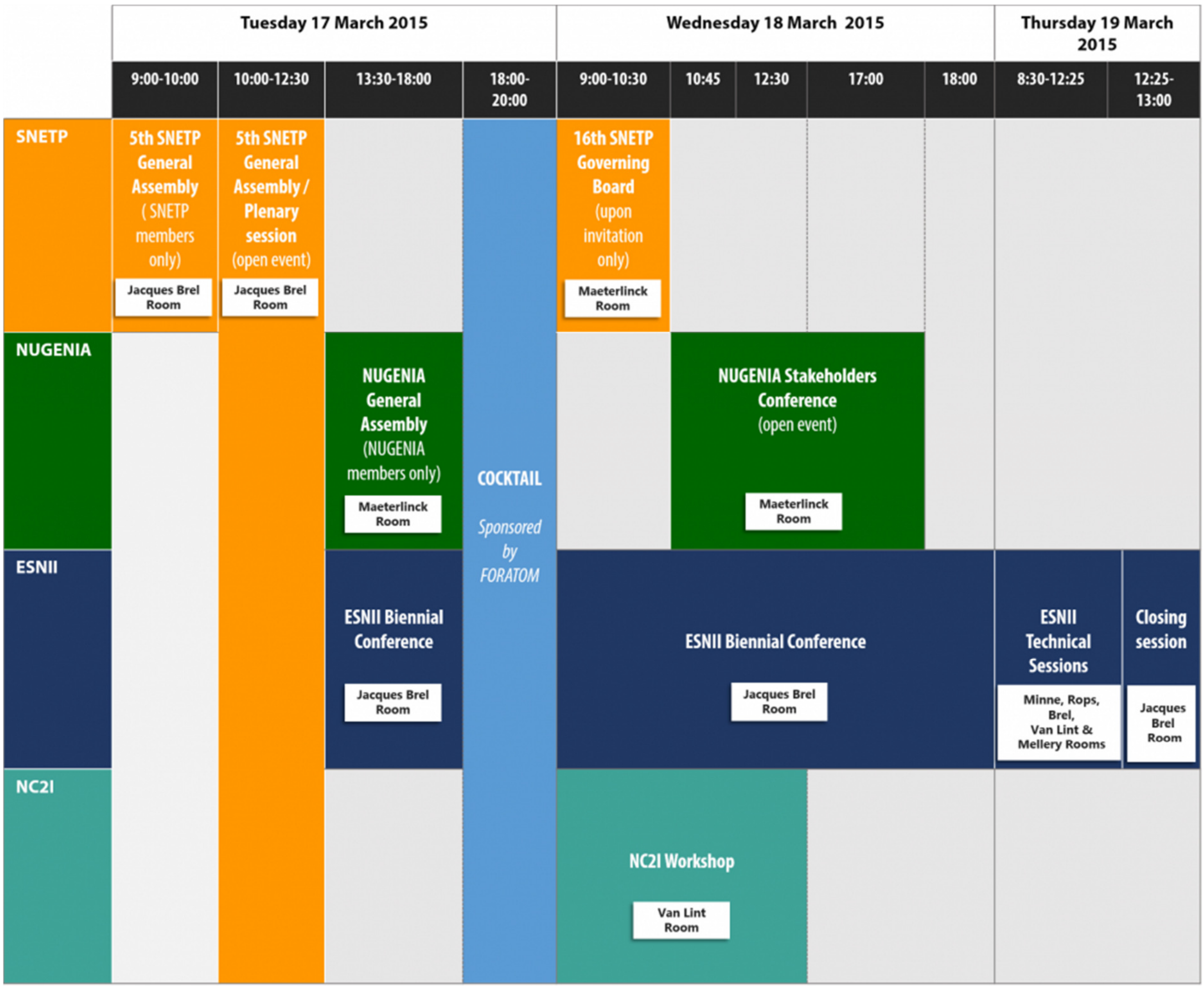
1 Feedback from NC2I Workshop

The SNETP Nuclear Days took place in Brussels 44 Center, Passage 44, B-1000 Brussels, Belgium on 17-19 March 2015. The agenda is given below.

The event was attended by 180 registered participants for all events together, including the

- SNETP General Assembly and Governing Board
- NUGENIA General Assembly and conferences
- ESNII conferences
- NC2I Workshop

The NC2I workshop itself was attended by 25 persons, several of them strategists from internationally operating companies and organizations.



2 Agenda

The program of this workshop was structured in the following three sessions:

Technology

1. Nuclear cogeneration: concept and technology status, D. Hittner
2. Recent developments: main achievements of the FP7 ARCHER project, S. Knol
3. Nuclear cogeneration: advantages of the HTR safety concept, O. Baudrand
4. Supporting R&D infrastructures: highlight on synergies with the SUSEN programme

Energy System, Market & Economics

1. Nuclear cogeneration as a potential game-changer to support the Juncker Agenda, M. Fütterer
2. Market opportunities, possible business models and system integration, R. Stahl, C. Auriault
3. Economics of nuclear cogeneration: an EU/US comparison, P.M. Plet

Way forward

1. The European Nuclear Cogeneration Industrial Initiative: progress status, way forward, K. Rozycki
2. The GEMINI transatlantic partnership: views from the US side, M. Haynes

Nuclear Cogeneration Industrial Initiative Workshop
Brussels, 18 March 2015

NC2I
Nuclear Cogeneration Industrial Initiative

NC2I Workshop

An event during the European Nuclear GEN II, III, IV DAYS

Brussels 44 Center
Passage 44, 1000 Brussels
Draft programme
18 March 2015

09:00-12:30	
09:00	Opening: NC2I in the context of SNETP and the SET-Plan *Kajetan Różycki, NCBJ, Poland – Chairman of the NC2I Task Force*
Session 1: Technology	
09:10	1.1 Nuclear cogeneration: concept and technology status *Dominique Hittner, Areva, France*
09:30	1.2 Recent developments: main achievements of the FP7 ARCHER project *Steven Knol, NRG, The Netherlands – ARCHER Coordinator*
09:50	1.3 Nuclear cogeneration : advantages of the HTR safety concept *Olivier Baudrand, IRSN, France*
10:10	1.4 Supporting R&D infrastructures: highlight on synergies with the SUSEN programme *Jana Kalivodova, CV Rez, Czech Republic*
Session 2: Energy System, Market & Economics	
10:30	2.1 Nuclear cogeneration as a potential game-changer to support the Juncker Agenda: re-industrialization, energy security, jobs, climate change mitigation *Michael Fütterer, JRC*
10:50	2.2 Market opportunities, possible business models and system integration *Riitta Stahl, Fortum, Finland and Camille Auriault, LGI Consulting, France*
11:10	2.3 Economics of nuclear cogeneration: an EU/US comparison *Pierre-Marie Plet, E.ON, Germany, and Riitta Stahl, Fortum, Finland*
Session 3: Way Forward	
11:30	3.1 The European Nuclear Cogeneration Industrial Initiative: progress status, way forward *Kajetan Różycki, NCBJ, Poland – Chairman of NC2I Task Force and Coordinator of the NC2I-R Project*
12:00	3.2 The GEMINI transatlantic partnership: views from the US side *Mark Haynes, NGNP Alliance, US (via conference call)*
Closing Session	

12:10	Q&A
12:20	Closing *Tomasz Jackowski, NCBJ*
12:30 Adjourn	

3 Short Summary of Presentations

3.1 The European Nuclear Cogeneration Industrial Initiative: An Introduction (K. Rozycki, NCBJ)

In his introductory talk, K. Rozycki presented NC2I as a pillar of SNETP and outlined the opportunities and challenges on the way to demonstration and market deployment of nuclear cogeneration in Europe.

3.2 Nuclear Cogeneration: Concept and Technology Status (D. Hittner, AREVA)

D. Hittner described the rationale and concept of nuclear cogeneration using HTR technology. He explained details of the current technology status and required future work before demonstration and market deployment can be achieved.

3.3 Recent Developments: Main Achievements of the FP7 ARCHER Project (S. Knol, NRG)

S. Knol presented an overview on the recently completed FP7 ARCHER project. ARCHER is the most recent HTR technology project co-financed by the European Commission. Some unique results from the 5 technical Work Packages were highlighted.

3.4 Nuclear Cogeneration: Advantages of the HTR Safety Concept (O. Baudrand, IRSN)

O. Baudrand's presentation focused on the advantageous safety features of HTR technology, on feedback from existing installations and on licensing requirements. His conclusions confirmed that HTR technology is safe and robust and thus well suited for use in industrial applications.

3.5 Supporting R&D infrastructures: Highlight on Synergies with the SUSEN Programme (Martin Ruščák, CV Řež)

M. Ruščák presented how the experimental infrastructures and test facilities built as part of the SUSEN project in the Czech Republic can support the technology development toward demonstration of HTR-based nuclear cogeneration.

3.6 Nuclear Cogeneration as a Potential Game-Changer to support the Juncker Agenda (M. Fütterer, JRC)

M. Fütterer provided the latest news on the development of the European energy policy and how nuclear cogeneration can contribute its share to meet the objectives of the Energy Union. He also spoke about the diverging positions on nuclear power across EU Member States and the expected benefits from nuclear cogeneration.

3.7 Market Opportunities, Possible Business Models and System Integration (R. Ståhl, Fortum, C. Auriault, LGI)

R. Ståhl and C. Auriault qualitatively analyzed the process heat market in industry and discussed various proven business and ownership models in the nuclear and chemical industry with a particular emphasis on risk reductions.

3.8 Economics of Nuclear Cogeneration: a EU/US Comparison (P.M. Plet, E.ON)

P. M. Plet explained a method to evaluate the economic performance of a nuclear cogeneration plant and presented a sensitivity analysis of two case studies from the EU and the US on the dominating parameters which influence the economics of nuclear cogeneration.

3.9 The European Nuclear Cogeneration Industrial Initiative: Progress Status, Way Forward (K. Rozycki, NCBJ)

K. Rozycki's talk summarized the status of NC2I as an SNETP task force and shortly presented the status of the active project NC2I-R. He also presented the international involvement of NC2I and progress made internationally in China, the USA, Japan, Korea and Indonesia.

3.10 The GEMINI Transatlantic Partnership: Views from the US Side (M. Haynes, NIA)

During the workshop, M. Haynes from the NGNP Industry Alliance in the US intervened by telephone and provided an oral update on the activities in the US and the collaboration with NC2I in the form of the GEMINI Initiative signed in June 2014.

Because no slides were presented at the NC2I workshop, the status of GEMINI is provided here in the form of a conference presentation co-authored by NC2I and NIA and given at the ICAPP 2015 conference in early May 2015.

4 Annex

169 pages

NC2I
Nuclear Cogeneration Industrial Initiative

The European Nuclear Cogeneration Industrial Initiative:
an introduction

Kajetan Różycki
NCBJ, Poland
Chairman of NC2I Task Force,
18 March 2015, Brussels

www.nc2i.eu

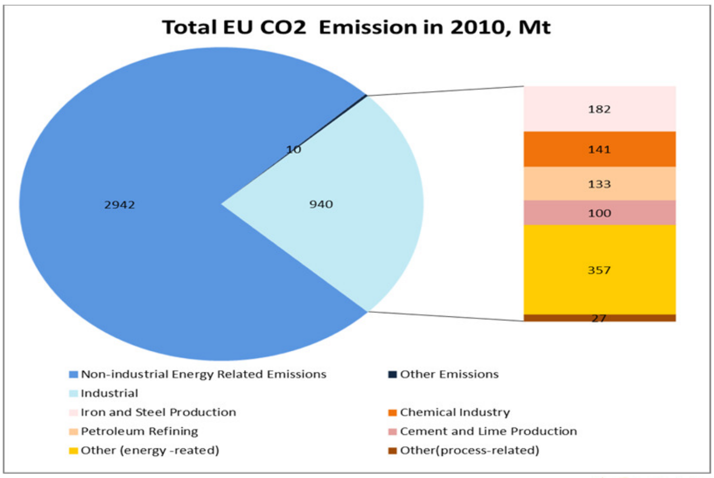
NC2I is one of SNETP's strategic technological pillars, mandated to coordinate the demonstration of high temperature nuclear cogeneration.

SNETP Sustainable Nuclear Energy Technology Platform
www.snetp.eu

1

How to address industry's emissions?

NC2I
Nuclear Cogeneration Industrial Initiative



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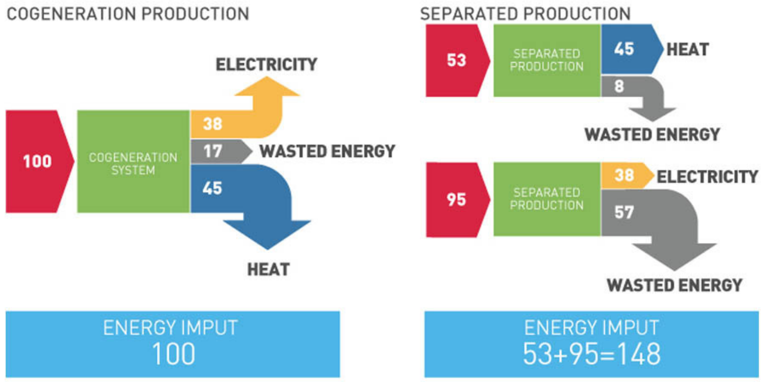
An answer: Cogeneration



Source: http://www.gruppoab.it/en/guida_alla_cogenerazione/cogenerazione.asp

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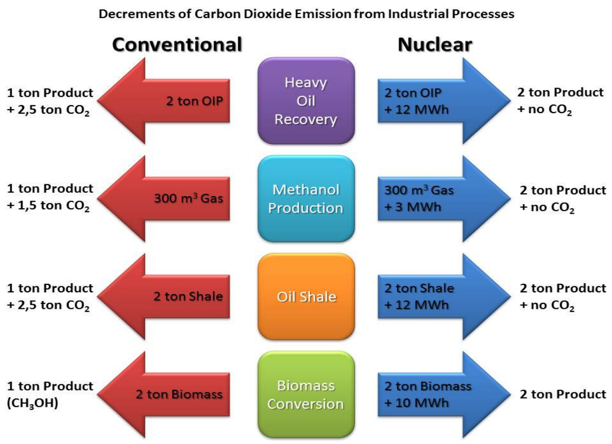
www.snetp.eu

www.nc2i.eu

Example benefits from Cogeneration



NC2I is one of SNETP's strategic technological pillars, mandated to coordinate the demonstration of high temperature nuclear cogeneration.

www.snetp.eu

www.nc2i.eu

Challenges we may address this way:

NC2I Nuclear Cogeneration Industrial Initiative

- Emissions
- Carbon Leakage
- Energy Security
- Unemployment (due to industry moving out)

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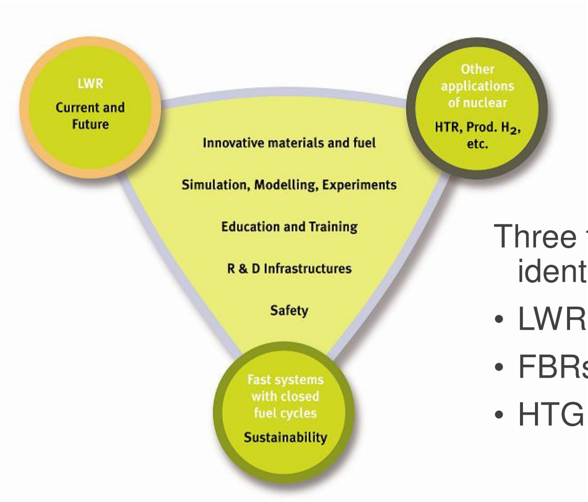
SNETP Sustainable Nuclear Energy Technology Platform www.snetp.eu

Context within SNETP

NC2I Nuclear Cogeneration Industrial Initiative



Three technologies identified:

- LWRs
- FBRs
- HTGRs

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SNETP Sustainable Nuclear Energy Technology Platform www.snetp.eu

NC2I
Nuclear Cogeneration Industrial Initiative

www.nc2i.eu

Thank you for your attention.

Any questions?

NC2I is one of SNETP's strategic technological pillars, mandated to coordinate the demonstration of high temperature nuclear cogeneration.

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Sustainable Nuclear Energy Technology Platform
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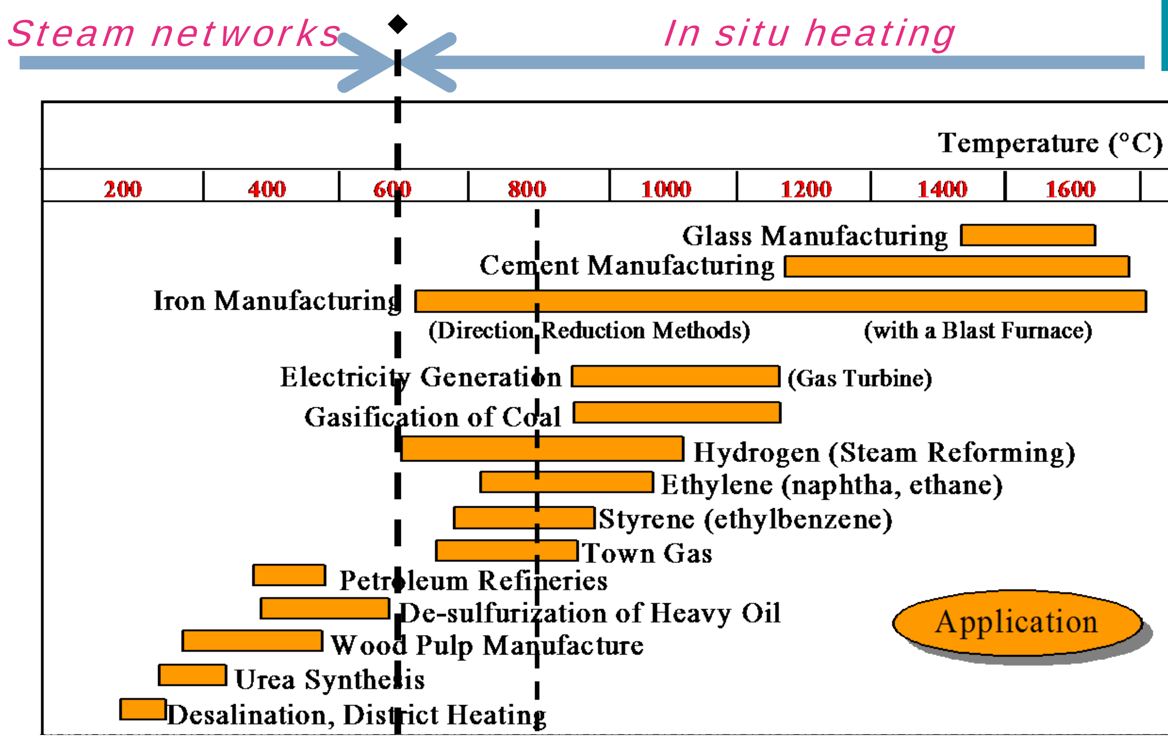
Concept and technology status of HTR for industrial nuclear cogeneration

D. Hittner
AREVA NP

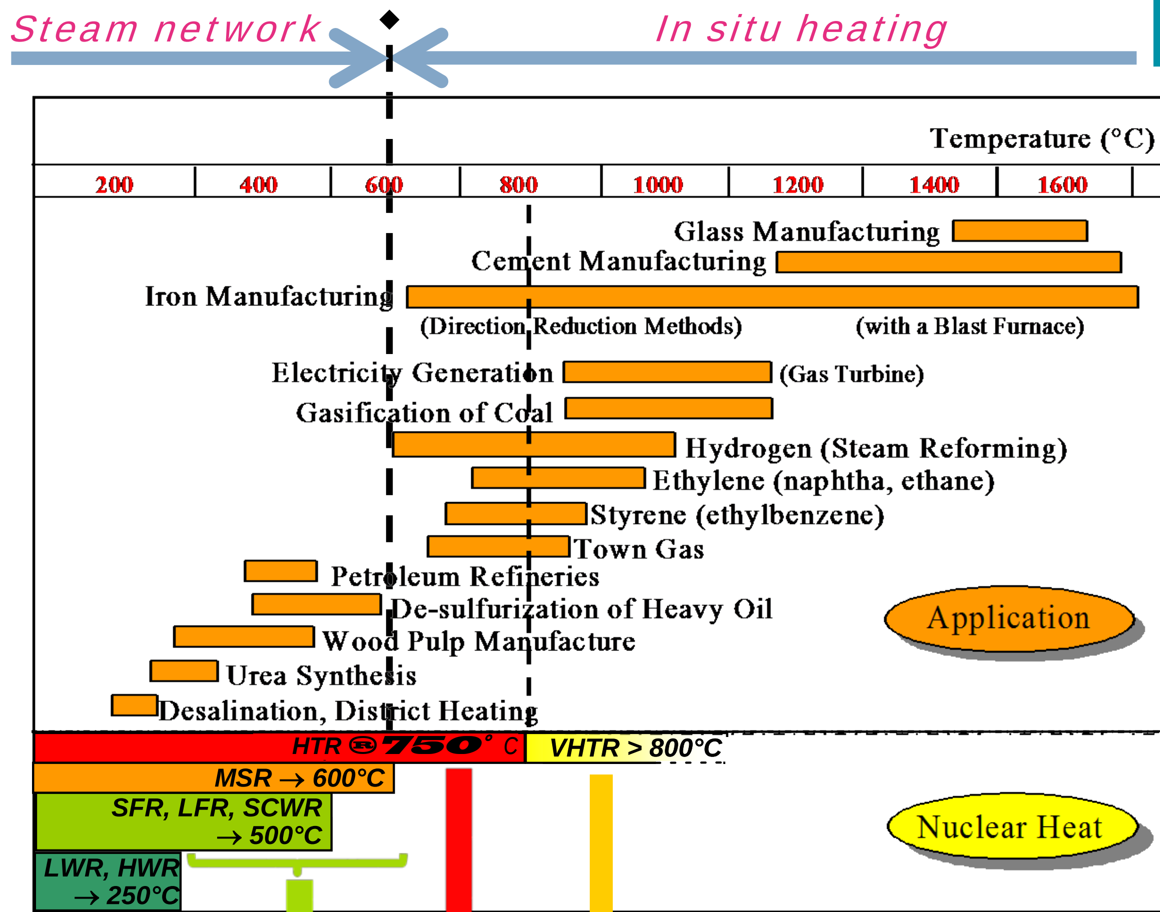
NC2I Workshop, Brussels, 18/03/2015

AREVA

Process heat needs from industry



Process heat needs from industry



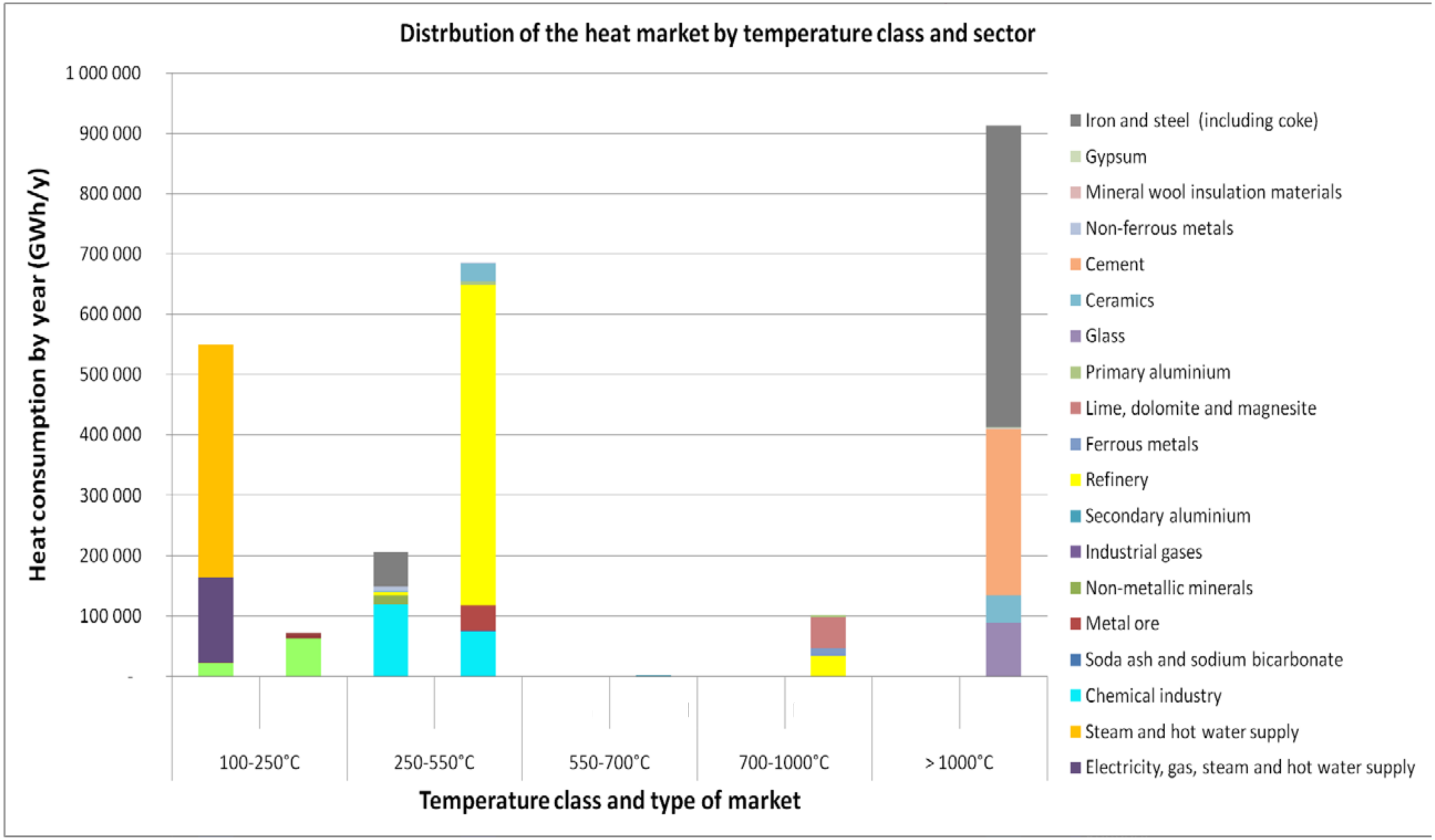
Ready to be used (already industrial experience) but limited scope

Still to be developed
Materials and fuel are challenging
Industrial ~ 2050

Still to be developed
Industrial ~ 2050
Competitiveness?

Mature technology
Large scope
Industrial demonstration required
First deployment possible within 10 years

Process heat market per temperature range



The modular HTR concept

- **High temperature > 600° C**
  - **Need of**
    - Refractory materials
    - Chemically inert coolant
    - Robust fuel for high temperature operation

⇒ **Moderator: graphite**

Coolant: helium

⇒ ***Additional favourable safety features***

- ***Huge thermal inertia***
- ***Strongly negative temperature coef.***
- ***No void effect***

TRISO particle fuel

- **The modular concept**

Intrinsic passive safety
Core melting excluded
No exclusion zone required

The industrial concept for process heat applications : nuclear cogeneration

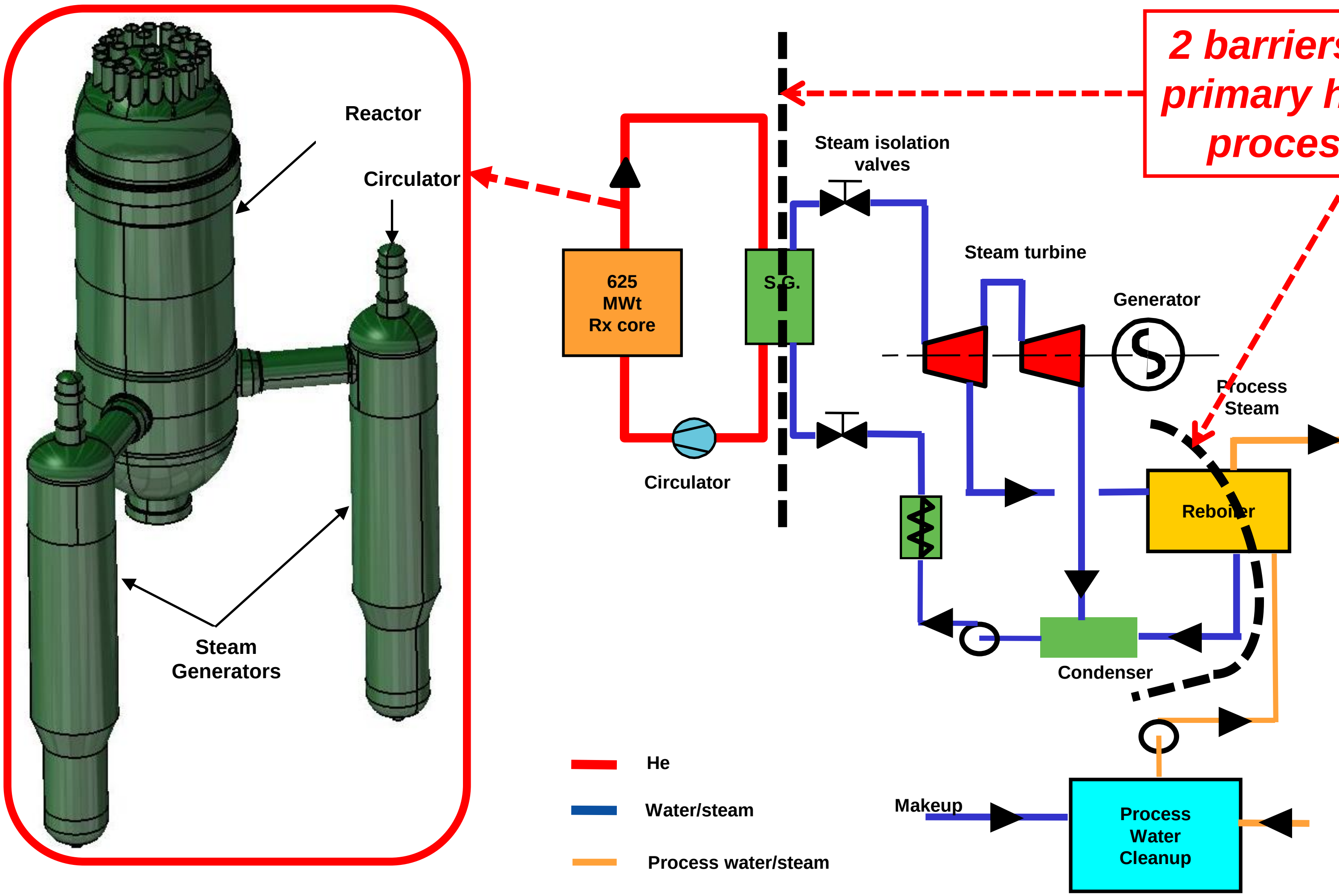
- **Main constraints for nuclear energy**
  - **The power of nuclear reactors cannot vary very quickly**
  - **To be competitive, nuclear industry needs standardized designs built in series**
- **Requirements of industrial energy users**
  - **Process heat / steam needs vary from one site to the other**
  - **Some processes may induce fast heat / steam load transients**

  + **Most of the industrial sites need both process heat / steam and electricity**

⇒ **The solution for supplying process heat / steam with a nuclear reactor is cogeneration, with a possibility of variable share between electricity and heat / steam supply**

+ **Using as much as possible existing technology for first application ASAP**
  - **Reactor temperature < 750° C to be able to use existing industrial materials**
  - **Use of steam generator(s) to transfer heat from the primary circuit to heat and power applications**

The HTR cogeneration concept



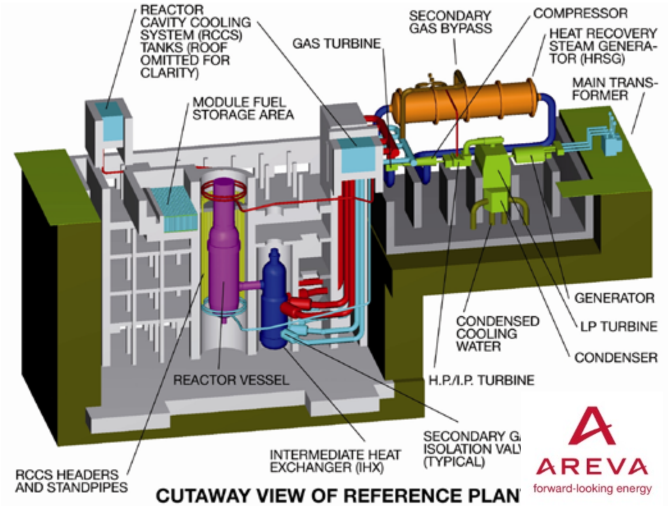
HTR technology maturity: the worldwide experience

- First developments of HTRs in the 1950's
- The two major innovations
  - TRISO coated particles in the early 1960s', improved in the following decades
  - The modular concept developed in the 1980s' in Germany and in the US
- Several high temperature test reactors & industrial prototypes built ➡
- High temperature opened a large scope of process heat applications: the coupling of reactors with industrial processes has been explored in Germany since the 1970s' (PNP project) ➡
- Recent international industrial prototype designs
  - USA: the NGNP project launched by DOE in the 2000s' initially for H_2 production at ~ 1000° C, then oriented towards lower temperature process heat applications
    - Important achievements in technology (fuel and materials for high temperature)
    - Limited design work
  - South Africa: PBMR project designed an industrial prototype; stopped in 2009
  - China: HTR-PM

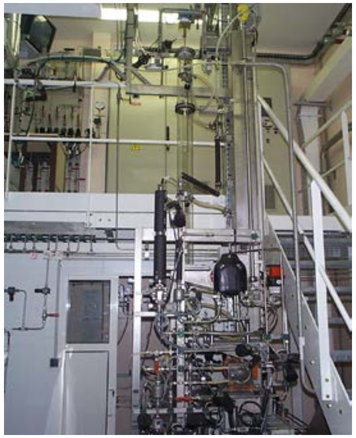
HTR technology maturity: the European experience

- **The legacy of the German HTR development mostly recovered through FP4 to FP7 projects**
- **AREVA developed the conceptual design of a combined cycle cogeneration HTR (ANTARES programme)**
- **Several European organizations have been involved in international design projects (PBMR, NGNP, HTR-PM)**
- **Mastering of key HTR technologies from FP 5 to 7 (RAPHAEL, ARCHER, etc)**
  - **Recovery of the main achievements of the German programme**
  - **Selection and qualification of materials for high temperature (graphite, vessel steel, Ni base alloys…)**
  - **Manufacturing of fuel**
  - **Development of a European safety approach for modular reactors**
  - **Development and performance assessment of a key component : the plate IHX**

Recent achievements in Europe



ANTARES



UO_2 kernel fabrication

UO_2 kernel coating

(CEA Cadarache)

Manufacturing of compacts (CERCA / AREVA)

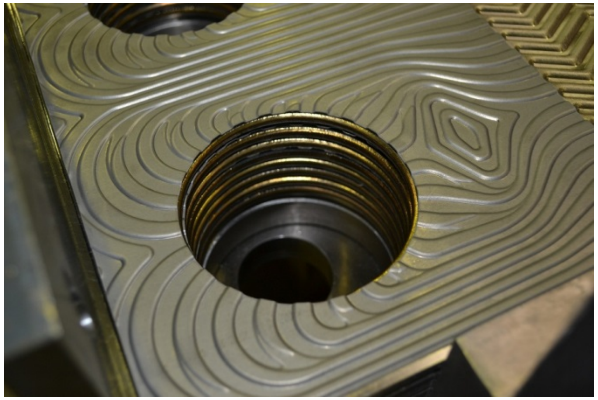


Plate IHX mock-up, manufactured by ALFA-LAVAL and tested in the ARCHER project

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Main assets of HTRs for application to industrial cogeneration

- **High temperature**
  - **With present technology**
    - Reactor operating temp. < 750° C
    - Applications with steam heat carrier < 550° C
  - **In the longer term reactor operating temp. > 800° C**
    - Depending on the availability of advanced materials and fuel
- **Modular concept**
  - ⇒ **Medium size depending on reactor technology**
    - Block type core (600 MWth
    - Pebble bed core (300 MWth

⇒ **Fits with the energy needs of industrial processes**

- ⇒ **Intrinsic passive safety**

⇒ **Risk of core melt excluded**
No need of exclusion zone

⇒ **Siting on existing industrial platforms acceptable**

- **Cogeneration**

⇒ **Flexibility required for industrial application**

- **Mature technology**

⇒ **Beginning of deployment possible ~ 10 years**

⇒ **Complies with European objectives of CO_2 emission decrease**

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What is still needed for deployment of cogeneration HTRs?

- **Demonstration of industrial operation of HTR cogeneration**

For that purpose the technology for designing a HTR is mainly available, but we still need:

1. **A viable funding scheme**
   - **Public support for the first phase of the project (design and licensing)**
     - Bridge the gap for too long term ROI for private investors
     - De-risk the demonstration project (mainly licensing risk)
   - **A convincing business model to attract investors for the construction phase**
2. **A partnership between the suppliers of the nuclear cogeneration plant, the future operators and the industrial energy end-users**
   - **In particular a long term commitment of end-users to buy the steam / electricity produced by the HTR**

What is still needed for deployment of cogeneration HTRs?

- **Demonstration of industrial operation of HTR cogeneration**

For that purpose the technology for designing a HTR is mainly available, but we still need:

3. **An optimized design (competitive, complying with the operators' and end-users' requirements, reliable, easily maintainable, etc.)**
4. **A robust and convincing safety demonstration**
   - **The basis of the modular concept: to be able to rely on physical properties of the reactor, as a substitute for redundant engineered safety systems to demonstrate the safety of the nuclear system**
   - **The possibility to take into account the outstanding robustness of TRISO fuel as 1st safety barrier and possibility to benefit from it to relax the requirements on the 3rd safety barrier (containment)**
   - **The behavior of graphite internals in accident conditions**

AREVA

What is still needed for deployment of cogeneration HTRs?

- **Demonstration of industrial operation of HTR cogeneration**

For that purpose the technology for designing a HTR is mainly available, but we still need:

5. **An industrial infrastructure for manufacturing**
   - **Components: no major technical challenge for manufacturing HTR components, but**
     - Difficulty to find manufacturers for prototype components without commitments for a series
     - Very few possible suppliers for the heaviest components $\Rightarrow$ large procurement delays
   - **Fuel**
     - No HTR fuel industrial manufacturing capability in Europe. Taking into account the large delays needed for qualifying the industrial fuel, a non-European HTR fuel supply should be considered for the demonstration (e.g. US supply)
6. **An available test facility infrastructure for qualification of components**
   - **In particular large scale helium loops**

Conclusion

- **High Temperature Gas Cooled Reactors can contribute in time to the European objectives of CO_2 emission reduction, if available secondary steam cycle technology is selected, at least in a first phase.**

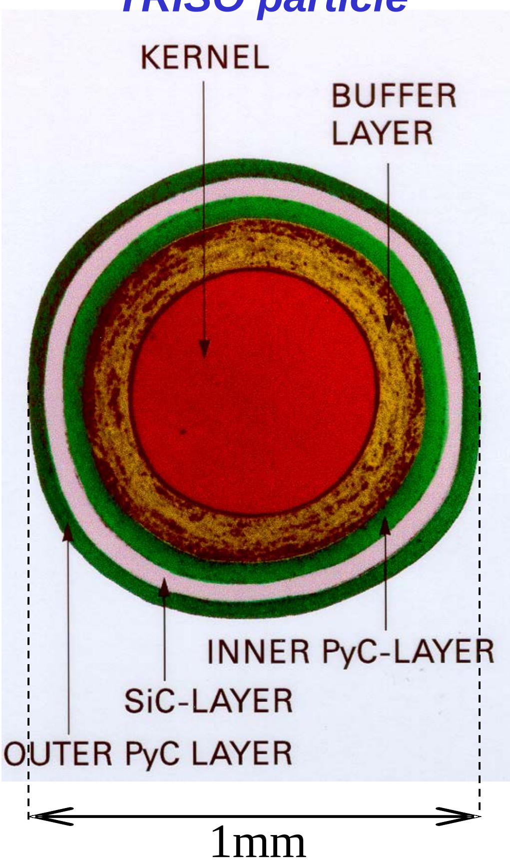
- **This is a mature technology, of which Europe got a significant experience.**

- **What is needed for initiating the industrial deployment of nuclear cogeneration is an industrial scale demonstration of operation of a cogeneration HTR.**

- **The key factors of success of such a demonstration are**
  - **To get a sound funding scheme, with an essential role of public support, at least in the design and licensing phase of the project,**
  - **To develop the industrial and test facility basis required for manufacturing and qualifying components, including possible international partnerships (e.g. for fuel)**

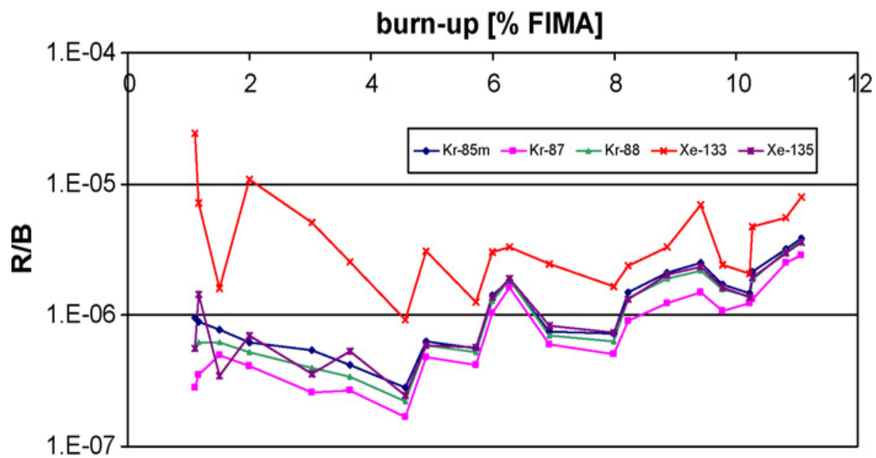
The TRISO fuel

TRISO particle



- **No significant fission product release from TRISO particles**
  - **In normal operation**

HFR-EU1bis:
- **11% FIMA,**
- **1250° C in pebble centre**



  - **In accident condition, up to at least 1600° C**

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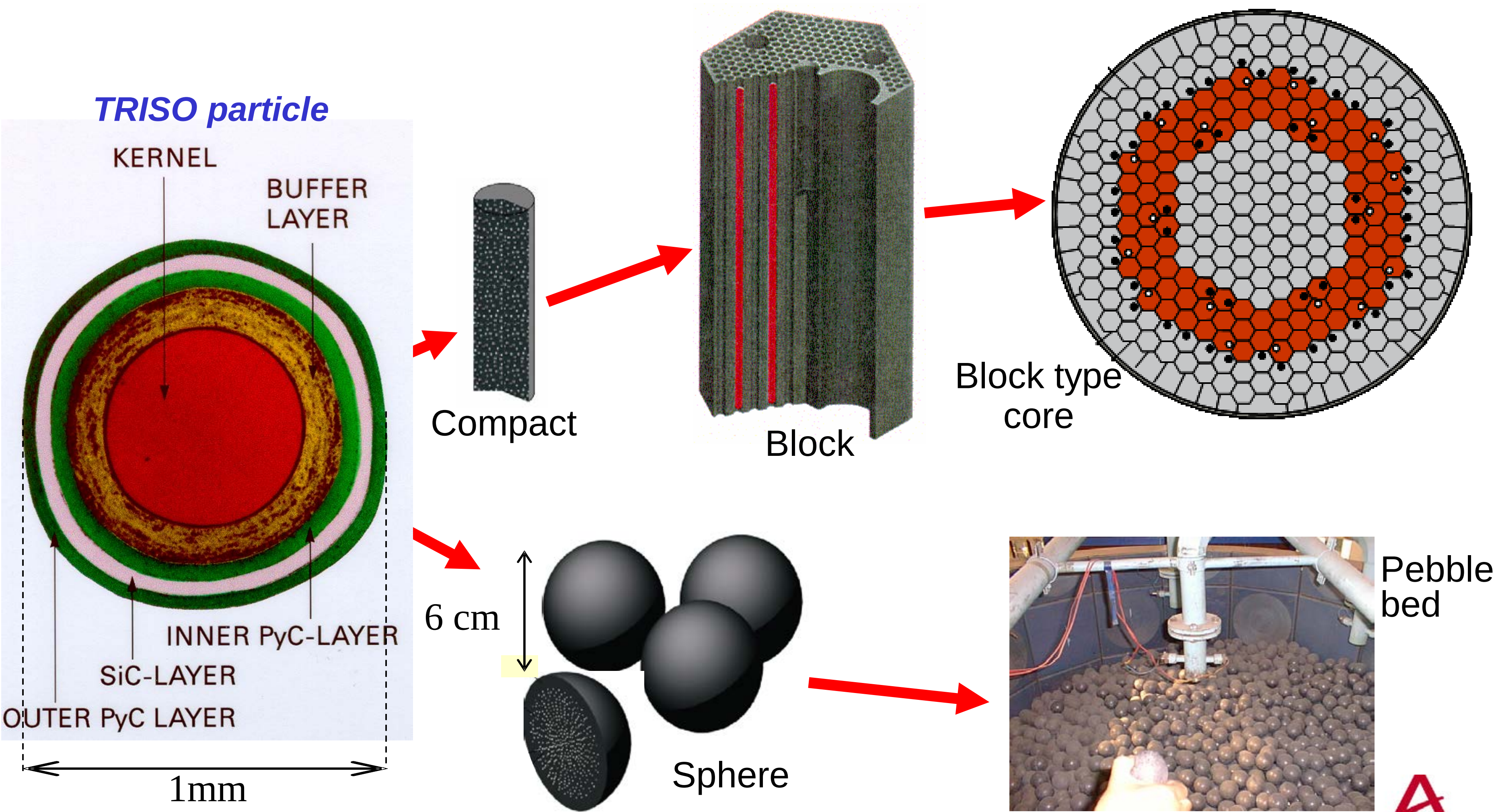
The TRISO fuel



The HTR modular concept

- In a HTR, when the temperature increases, the fission stops. Nevertheless the decay heat is still to be released.

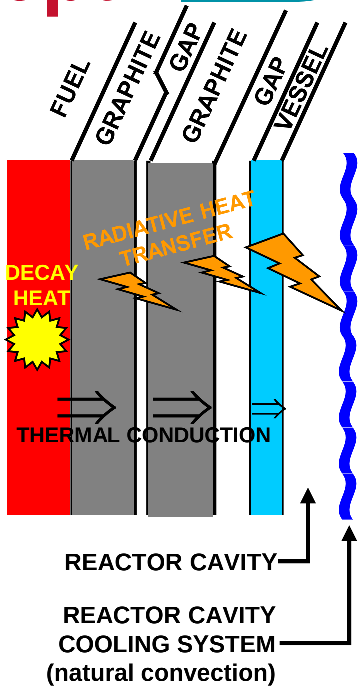
- If the decay heat is not too high, a balance between
  - The generation of decay heat
  - The release of heat by conduction and radiative heat transfer

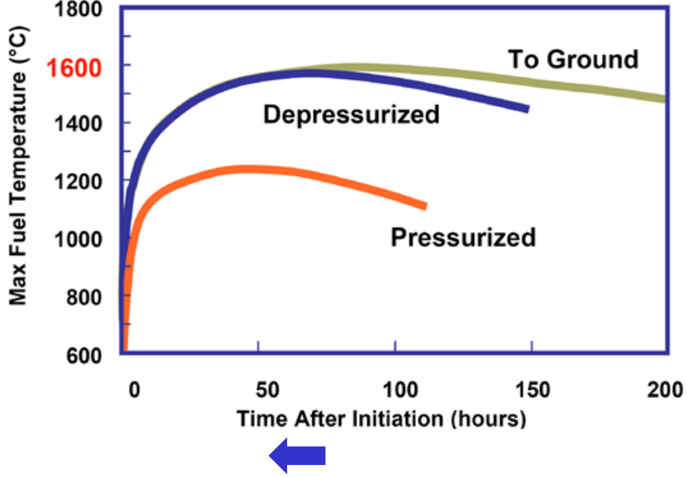
  can be reached below a temperature at which the integrity of particles would be jeopardized (> 1600° C), with consequently significant radioactive releases.

- Depending on the reactor design, the limit of power is between 300 and 600 MWth

⇒ No need of engineered safety system with high reliability and high redundancy for extracting decay heat, based on simple physics
  - ⇒ Simplification in the safety design
  - ⇒ Investment savings

- Modular HTRs are based on this simplified safety design. All present projects use this concept.

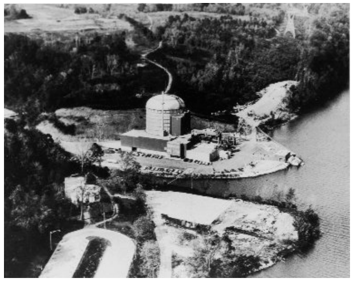




The HTRs built and operated in the world

Test reactors


DRAGON, U.K. (20 MW, operated 1963-76)


Peach Bottom, US (200 MWth, operated 1967-74)


AVR, Germany (15 MWe, operated 1967-88)


HTR-10, China(10 MWth, operated since 2000)


HTTR, Japan (30MWth, operated since 1998)

Industrial prototypes


Fort Saint-Vrain, US (300 MWe, operated 1976-89)

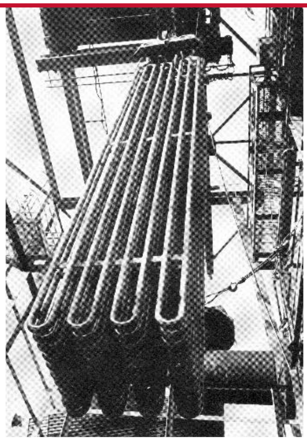

THTR, Germany (300 MWe, operated 1986-89)


HTR-PM, China (2 x 106 MWe)

The experience of nuclear process heat applications

- Several industrial experiences at relatively low temperature
- The German demonstration programme for HTR process heat applications at high temperature (PNP)

Coal to Liquid with nuclear simulated steam generation



Conversion of coal into liquid transport fuel with nuclear heat source demonstrated at the level of industrial pilot plant

- Lab scale testing, 1973-1980 with 5.0 kg/h
- Semi-technical scale testing, 1976-1984 with 0.5 t/h
- Gasification at 750-850° C and 2-4 MPa
- Total coal gasified: 2413 t
- Operation time of ~26,600 h with ~13,600h under gasification conditions

10 MW steam CH_4 reformer mock-up for nuclear application

AREVA

The ARCHER Project

NC2I Workshop, 18 March, Brussels

archer
Advanced Reactor
for Cogeneration of
Heat & Electricity-R&D

Steven Knol
Michael Futterer, JRC-IET
Ferry Roelofs, NRG
Norbert Kohtz, TÜV Rheinland
Mathias Laurie, JRC-ITU
Derek Buckthorpe, AMEC & Manchester University
Walter Scheuermann, Stuttgart University-IKE
Patricia Ho-Hune, LGI

European framework HTR programs

2000 Restore European HTR knowledge base

2005 Expand knowledge base by strategic HTR R&D

2010 Connect to end users

2011 R&D in support to demonstration

2013 Support to the emergence of a possible European Research Initiative on co-generation

Programs HTR-L, -M, -P, …

RAPHAEL

europairs
End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

Archer
Advanced Reactor for Cogeneration of Heat & Electricity-R&D

NC2I-R

ARCHER builds on the HTR technology basis established in previous European programs

The ARCHER project

ARCHER started in 2011 and had a duration of four years

The project ensures the HTR technological knowledge base in Europe is maintained and expanded

ARCHER directs the existing knowledge base towards a demonstrator project via:

- **Link to end users/coupling**
- **Licensing & Safety**
- **Fuel performance and licensing**
- **Graphite & steels to be adopted**
- **Steam generator & heat exchanger**
- **Dissemination of HTR knowledge and experience to a new generation**
- **International contact (GIF) and (public) communication**

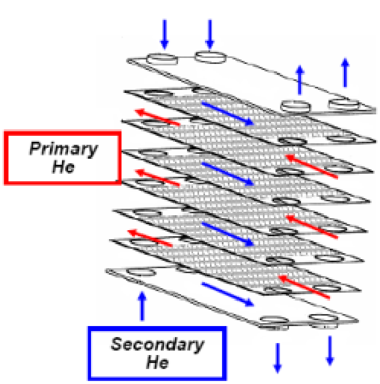
Status

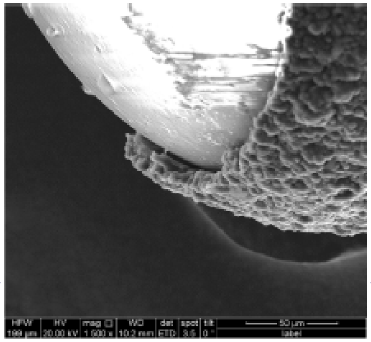
The program ended in January 2015, all deliverables are expected to be finalized and submitted. Many results are presented at HTR2014.

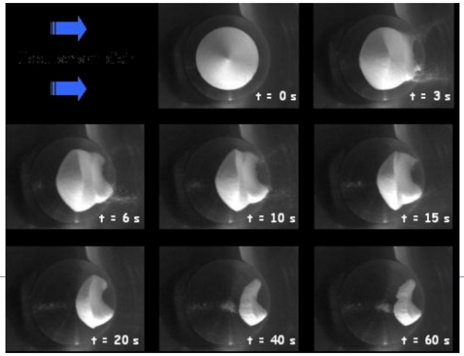
Next to the 33 European consortium partners, several international collaborations have been established with INL (United States) and the Kurchatov Institute (Russian federation). NWU (South Africa) became a consortium partner

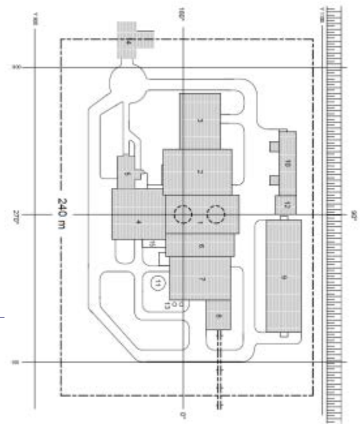
Mid-term review by the European Commission was positive, no scope adjustments were recommended

Currently, the last technical and financial reporting is being finalized









ARCHER Lay-out

Sub-Project 0: Coordination

- **SP Leader: Ir. Steven Knol, NRG, The Netherlands**

Sub-Project 1: System Integration

- **SP Leader: Ir. Ferry Roelofs, NRG, The Netherlands**

Sub-Project 2: Safety Aspects

- **SP Leader: Dipl.-Ing. Norbert Kohtz, TÜV Rheinland, Germany**

Sub-Project 3: Fuel & Fuel Cycle

- **SP Leader: Dr Mathias Laurie, JRC-ITU, Germany**

Sub-Project 4: Materials & Components

- **SP Leader: Mr Derek Buckthorpe, AMEC & Manchester University, UK**

Sub-Project 5: Knowledge Management

- **SP Leader: Dr Walter Scheuermann, Stuttgart University-IKE, Germany**

ARCHER Project Management Office

- **PMO: Patricia Ho-Hune, LGI, France**

Work Package highlights

SP1: System Integration

WP1.1: Coupled System Specification

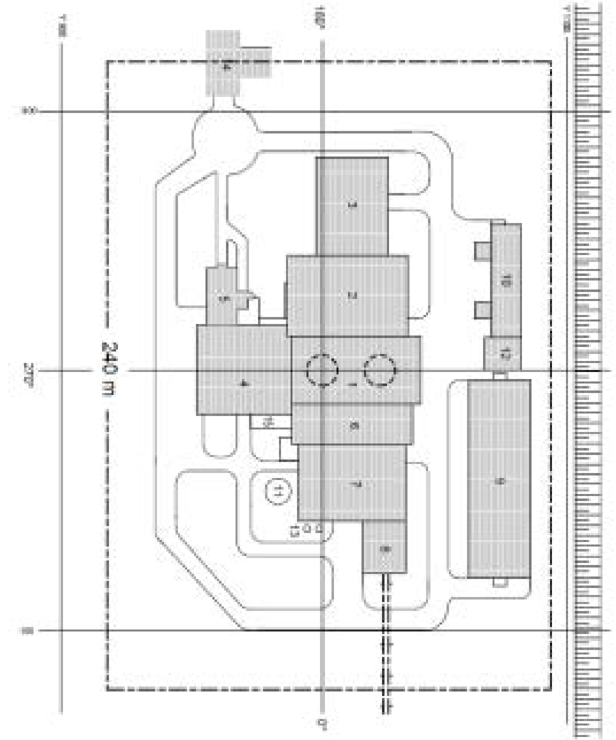
- European oil refining and petrochemical plant
- South African coal-to-liquid process

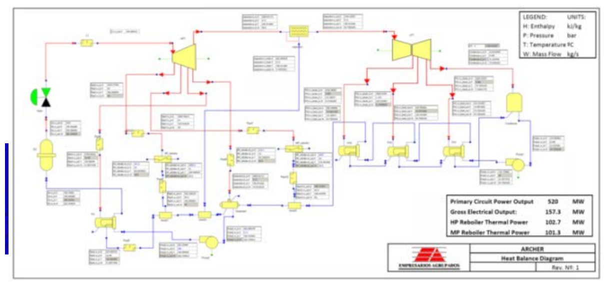
WP1.2: Technology GAP and SWOT analysis

- Technology GAP study the European system
- SWOT analysis South African system

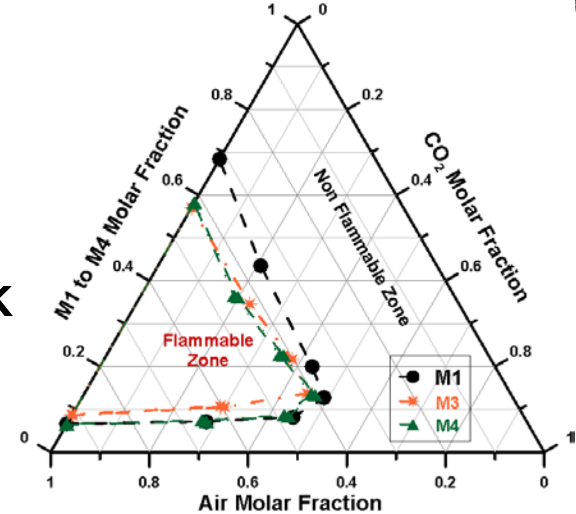
WP1.3: Primary System Code Integration

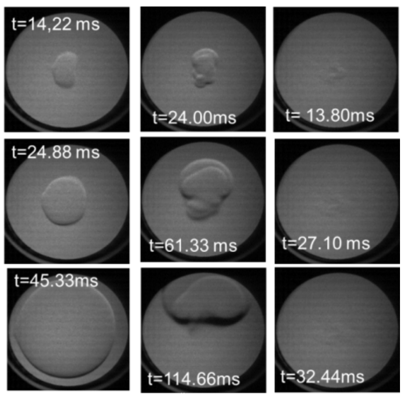
- A computer code inventory is established of computer codes being used, for which the requirements for integration, developments and qualification are assessed





SP2: Safety Aspects





WP2.1: Air Ingress

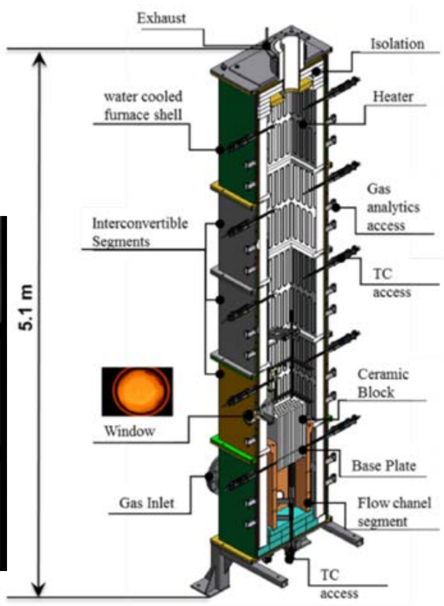
- **Experimental results of the NACOK facility are acquired and assessed**

WP2.2: Water Ingress

- **Flammability studies**

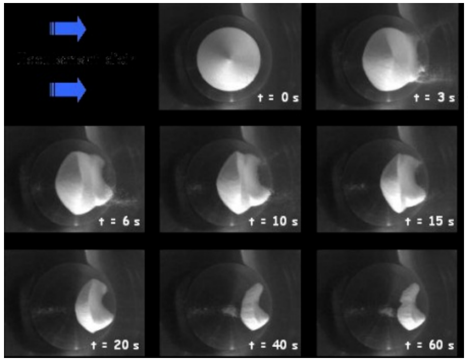
WP2.3: Source Term Analysis Chain

- **Focus on dust mobilization, and tritium permeation**

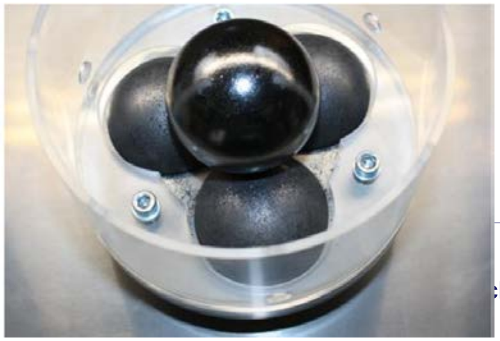


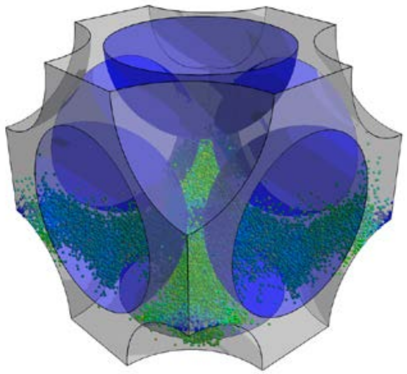
WP2.4: Thermal Safety Issues

- **Hotspot analysis, porosity in pebble beds**



WP2.5: Integrity Concept of the Helium Pressure Boundary





SP3: Fuel & Fuel Cycle

WP3.1 Fuel Basic Properties

- **Mechanical properties of PYCASSO particles**
- **Ag and I behaviour**
- **Pressurized Coated Particles (CPSTRESS)**

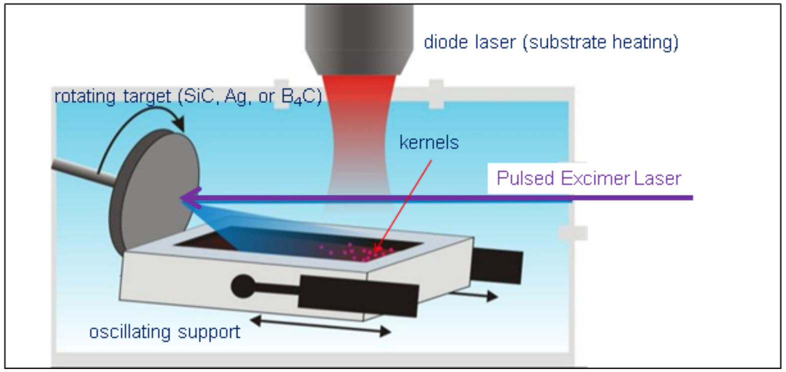
WP3.2. Integral Fuel Element Irradiation Performance and Safety Testing

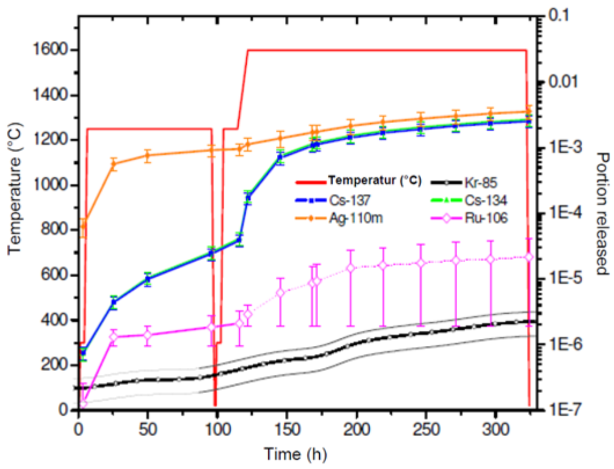
- **KUFA tests on irradiated fuel pebbles**

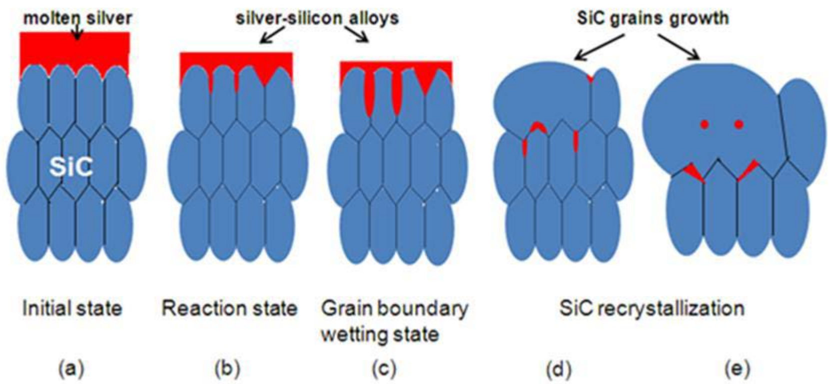
WP3.3 HTR Fuel Back end

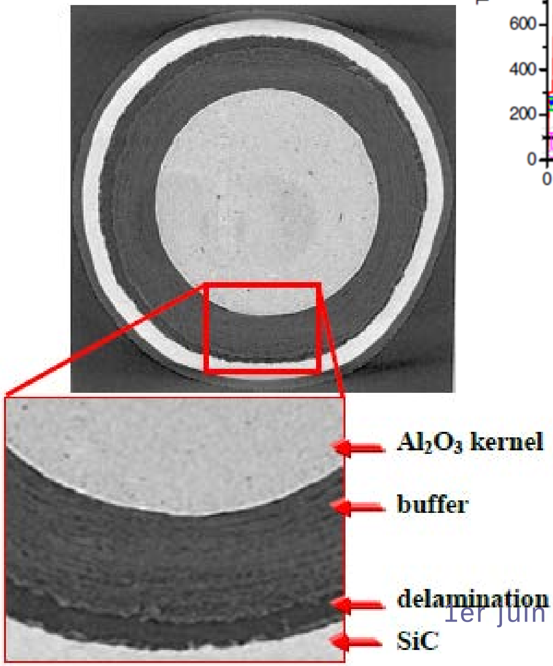
- **Studies to investigate behaviour under storage conditions**

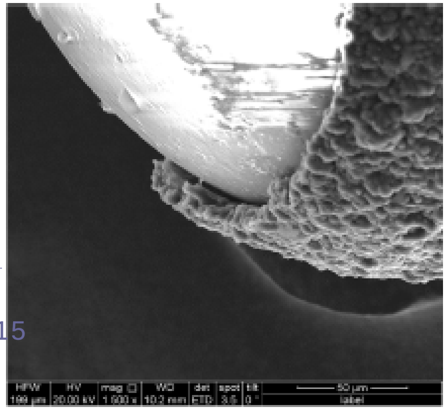
Fabrication of B4C coated particles by PLD



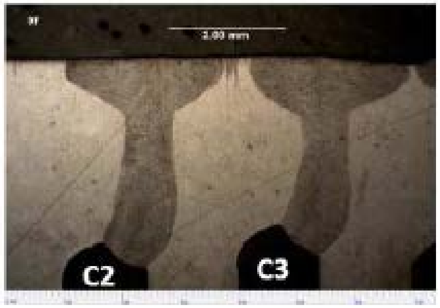








SP4: Materials & Components



WP4.1: Graphite

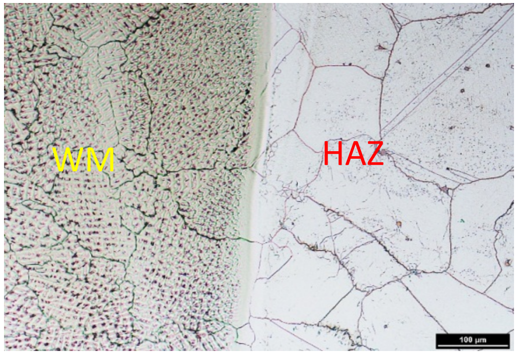
- **Continuation of the INNOGRAPH irradiation experiments**

WP4.2: High Temperature Alloys and Instrumentation

- **in-pile and out-of-pile tests to investigate materials used in Steam Generator, IHX and other components**

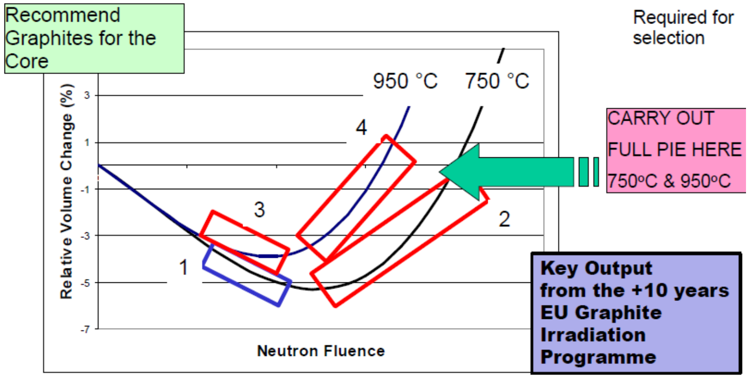
WP4.3: Intermediate Heat Exchanger

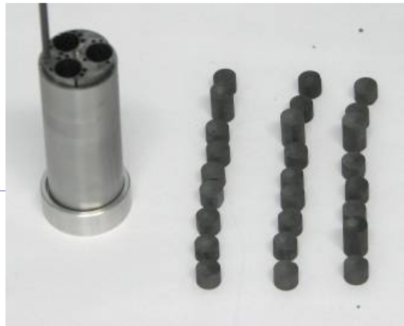
- **Fabrication, characterization and testing of IHX**



WP4.4: Heat Transport Circuit

- **Study on operational transients**

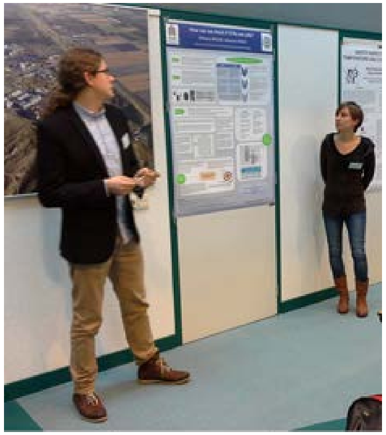




SP5: Knowledge Management: Dissemination and Communication, Education and Training

Dissamination & Communication

- 2 EUROCOURSE schools organized
- 4 Newsletters issued
- Exchange Platform set up for students



The winning poster

- HTR-textbook "*Concept s of self-acting decay heat removal in modular High Temperature Reactors*", written bij Prof. Kugeler, edited by N. Haneklaus
- TV Documentary

ARCHER – Final stages

End of the project is nearby. The technical program ended the 31st of January 2015, 110 deliverables are finalized and submitted, the final 4 are in the validation process.

A large amount of work is already completed and contributed to the knowledge base extensions in, and outside of Europe. During HTR2014, many results have been shared in 16 presentations spread over all topics.

Although ARCHER has ended, the HTR research in Europe continues with NC2I. The Deliverables from ARCHER are made available to the NC2I-Task Force for future use.

Lessons learned

Strong combination of technical and modeling work benefits both, by producing additional data from experiments, and better understanding by the modelling work

34 partners are challenging to manage, but definitely feasible

International collaboration important, but sometimes difficult to synchronize

There is a solid technical base in Europe for HTR technical knowledge, but demonstrator project could bring more focus and targeted research

Acknowledgment

Many thanks to all people involved, especially the Subprojectleaders of Archer, and the HTR-TN representatives. The work was made possible by the European Commission under the grant agreement no: 269892.

Thank you for your attention!

NC2I-R
Nuclear Cogeneration Industrial Initiative Research and Development Coordination

Nuclear cogeneration: advantages of the HTR safety concept

O. Baudrand – IRSN

olivier.baudrand@irsn.fr

Content

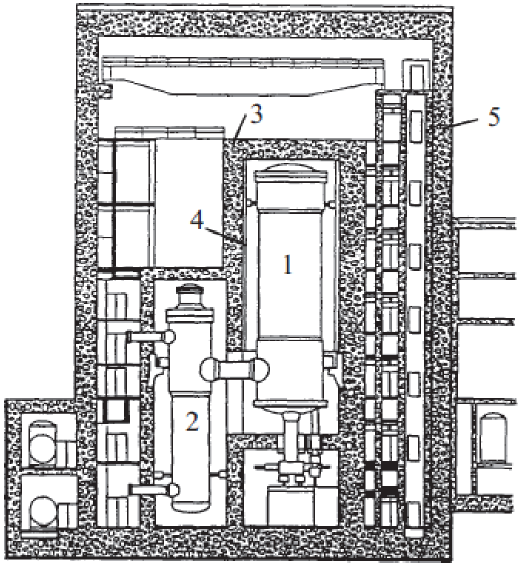
- Safety studies in the NC2I-R FP7 project
- Lessons from feedback
- Foreseen layouts
- Recall of « generic » licensing steps
- Elements for licensing application
- Specific safety requirements
- Advantages of HTR safety concept for cogeneration
- Pending options
- Outline

Safety studies in the NC2I-R FP7 project

- Main questions:
  - ❑ Are there specific licensing risks associated with nuclear cogeneration?
  - ❑ How to cope with?
- Main goals of safety studies in NC2I-R
  - ❑ Analyse the feedback on nuclear cogeneration
  - ❑ List the specific issues associated with cogen. and propose a set of safety requirements adapted to cogeneration
  - ❑ Identify the potential impact on licensing procedure (or construction authorization)
  - ❑ Make the synthesis of R&D items to support safety demonstration

Lessons from feedback

- Nuclear plants in operation
  - ❑ Mainly PWRs
  - ❑ Heat production
  - ❑ Heat production has low impact on the nuclear plant operation
  - ❑ Primary circuit is separated from the heat grid by two « barriers » at least (steam generators, heat exchangers)
  - ❑ <u>No specific safety case in the Safety Report</u>

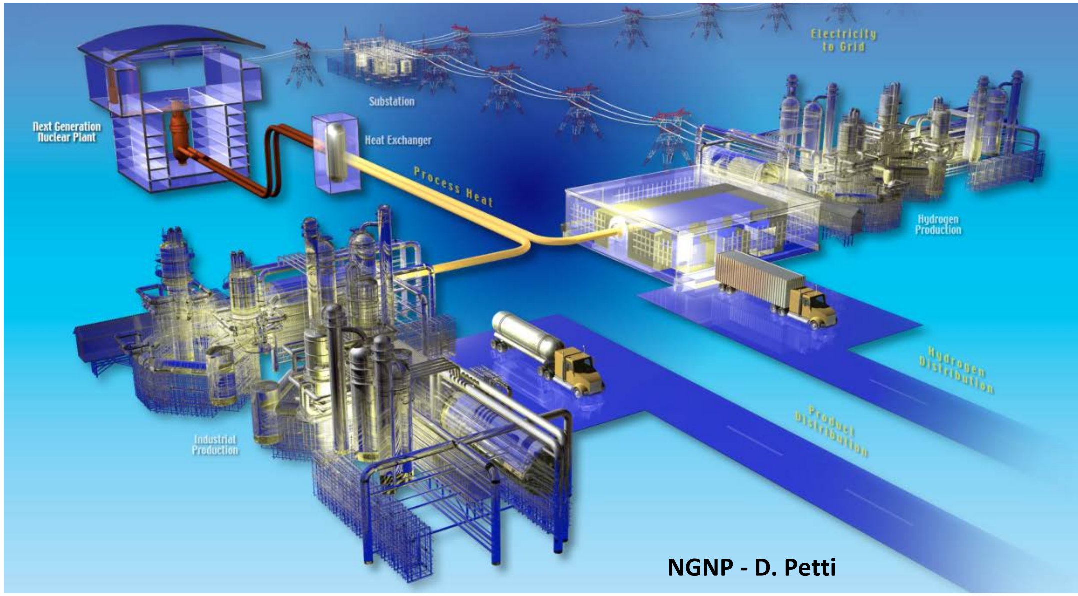


HTR Module elevation (SIEMENS)

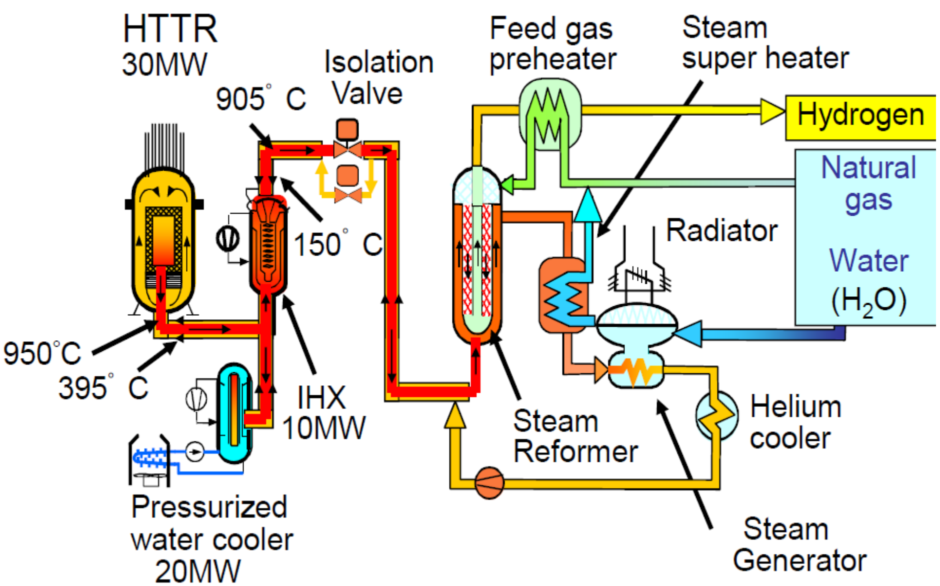
- Past projects with HTRs
  - ❑ Specific risks identified for process heat => R&D programs on hydrogen production process – analysis of chemical risks, explosion risks
  - ❑ Process steam: studies on tritium permeation

Foreseen layouts

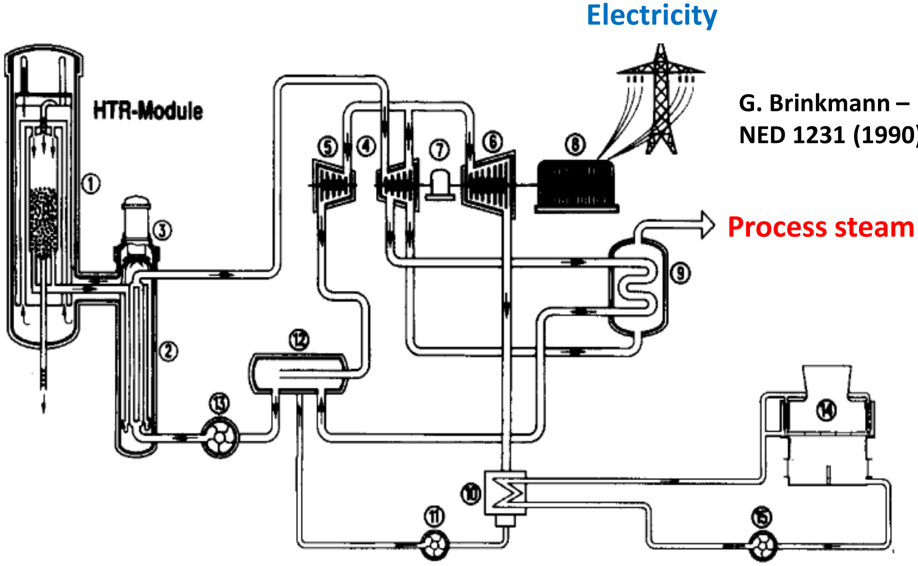
- ➢ Multipurpose installation : heat (steam, hot water) & electricity for an urban and industrial zone
- ➢ Heat (process steam) & electricity production for an industrial cluster



NGNP - D. Petti



Steam reforming – K. Verfondern
ICTP-IAEA school Trieste 2011



G. Brinkmann – NED 1231 (1990)

Recall of « generic » licensing steps

1) Presentation of the safety objectives and safety options
   - ❑ Discussions with Safety Authorities / Commissions of experts
   - ❑ First review by TSO

Integration in site industrial make-up

Validation
Safety approach
Feasibility

2) Public inquiry: Environmental impact study + Risk analysis (extract from Preliminary Safety Report)
   - ❑ Review by local Authorities / security authorities
   - ❑ Review by independent associations, etc.

Interface with industrial risks

Legal aspects
Public acceptance
Site validation

3) Construction and operation license: Safety Report + Emergency Planning
   - ❑ Safety analysis of the SR, EP report
   - ❑ Feedback of commissioning tests

Specific safety studies

Interface with industry EPs

Safety demonstration
Security

Cogen.

Elements for licensing application

- Application for licensing/construction authorization => based on risk analysis
- Some items of the RA relevant for cogeneration:
  - ❑ Demonstration of sufficient separation between the radioactive materials in the NPP and the fluid delivered to the customer (whether industrial or domestic)
  - ❑ Analysis of the external hazards potentially induced by the processes and specific equipment in the vicinity (explosive materials in processes, turbines, conventional boilers used as back-up facilities, etc.)
  - ❑ Analysis of the risks induced by the nuclear plant (radioactive or chemical release, missiles from turbines, explosions)
  - ❑ Potential for domino effects (multiple installations => accident worsening)

Non specific

Specific safety requirements

- Elimination of the risk of noticeable contamination of the delivered fluid (water, steam or helium) / guarantee of an efficient monitoring of the fluid quality
- Limitation of exclusion zone and low population zone => ex.: no protection measures needed for the industry operators in the vicinity of the plant (= if needed, operators of industrial sites could continue to monitor processes in case of accident on the NPP)
- No significant impact of heat demand variation on the core and reactor structures loading
- No significant increase of the contribution of external hazards in the global risk when cogeneration is taken into account (i.e. risk due to the proximity of industrial facilities low in relative)

Advantages of HTR safety concept for cogeneration

- Low risk of contamination of the delivered fluid:
  - ❑ Low contamination of primary helium (=> continuous purification)
  - ❑ primary pressure < secondary pressure
- Low sensitivity to helium cooling transients
  - ❑ High neutronic stability of the core
  - ❑ High thermal inertia of the graphite vs core power
  - ❑ Helium cooling limits the severity thermal shocks
- Easy load following (modularity)
- Structural robustness of the design
  - ❑ Mechanical stability of the core structure
  - ❑ Residual heat removal by conduction in core => tolerance to deformation of cooling channels
- Ultimate cold source diversification = air and water
  - ❑ Protection against water contamination by industrial processes
  - ❑ Protection against external fire hazards

Pending options

- Mastering of tritium permeation to secondary circuit => technical solutions to be validated

Note : objective is that tritium concentration in process steam remains lower than an "approval free" limit.

- Definition of an envelope safety case involving radioactive releases (ex.: depressurisation accident)
  - ❑ Not cogen. Specific
  - ❑ Depends on confinement strategy and design

Outline

- HTR safety concept is robust against external hazards
- HTR Technical features should allow for flexible operation
- HTR has a potential for very low radioactive releases in case of accident (exclusion zone close to the plant) – no interference with safety distance (against external hazards)
- Current licensing procedures are convenient for nuclear cogeneration with HTR provided some adaptations:
  - ❑ consistency of nuclear and conventional emergency planning
  - ❑ Regulatory basis for assessment of delivered fluid safety

Research centre Řež

SUSTAINABLE ENERGY (SUSEN)

Martin Ruščák

Centrum výzkumu Řež s.r.o.
Research Centre Rez

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INVESTICE DO VAŠÍ BUDOUCNOSTI

2007–13
OP Výzkum a vývoj pro inovace

Presentation Content

- Research centre Rez
- SUSEN project
  - Technical infrastructure
  - Budget
  - Time schedule
  - Research programmes
    - Technological Experimental Circuits
    - Structural and System Diagnostics
    - Nuclear Fuel Cycle
    - Material Research

Research Centre Řež

- R&D organization in power generation industry / nuclear technologies
- Member of the UJV Group
- 300 employees

Company activities in brief

Project SUSEN

- **SUSEN = SUStainable Energy project**
  - **to create a large infrastructure for sustainable R&D activities**
  - R&D support of safe operation of current NPPs of GenII and GenIII and of preparation NPPs of GenIV and fusion reactors
- **Approved in December 2011 by the European Commission and The Czech Ministry of Education, Youth and Sports (MSMT)**
  - Financing up to December 2015
  - Responsibilities to EC and MSMT up to 2020
- **Subsidy beneficiary – Centrum výzkumu Řež**
  - Partner – University of West Bohemia in Plzen
  - Maximum subsidy amount: 2.451 billion CZK (~95 millions EUR)

Project SUSEN

Objectives of project:
Construction of a research infrastructure focused to energy research with emphasis on nuclear technologies

SUBSIDY BENEFICIARY**:**
Centrum výzkumu Řež s.r.o.
(Research Centre Rez)
A member of the NRI Group
PARTNER:
West Bohemia University
MAXIMUM SUBSIDY AMOUNT:
CZK 2.451 milliard

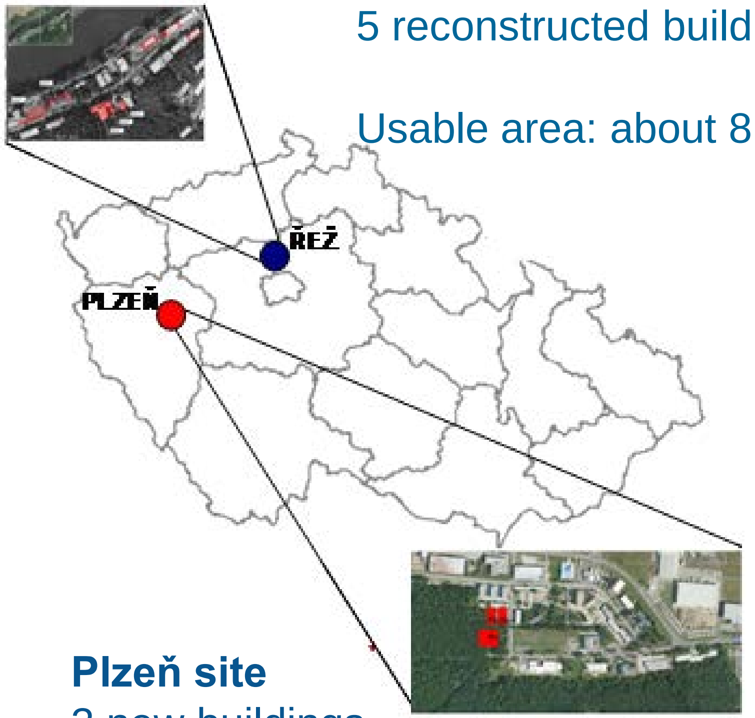
01/2012:
Start of project

12/2013 -12/2020:
R&D outputs and proving sustainability

12/2015:
End of construction

Rez site
1 new buildings,
5 reconstructed buildings,

Usable area: about 8,450 m^2



Plzeň site
3 new buildings
Usable area: about 3,860 m^2

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Project objectives:

- **21 particular research outputs and**
- **52 research outcomes**
- **…to be achieved within the period 2013 to 2020**

- **To achieve these objectives, it is necessary to extend the infrastructure of Research Centre Rez:**
  - Build new diagnostic centre and reconstruct or extend 5 buildings in Rez – all buildings but one are completed
  - Build new experimental hall and rent two more buildings in Plzen - completed
  - Procure necessary experimental equipment and instruments – in progress

Project SUSEN

Technological Experimental Circuits

TEC

Structural and System Diagnostics

SSD

Project SUSEN

Nuclear Fuel Cycle

NFC

Material Research

MAT

Project SUSEN

Technological Experimental Circuits

Gen IV

SCWR Loop for Fuel Qualifiacation Tests

Ultracritical Water Loop

S-ALLEGRO Helium Loop

HTHL Loop

SCO2 Loop

Fusion

High Heat Flux Test Facility for ITER Programme

Neutron Generators

TBM Platform

Hydrogen Technologies

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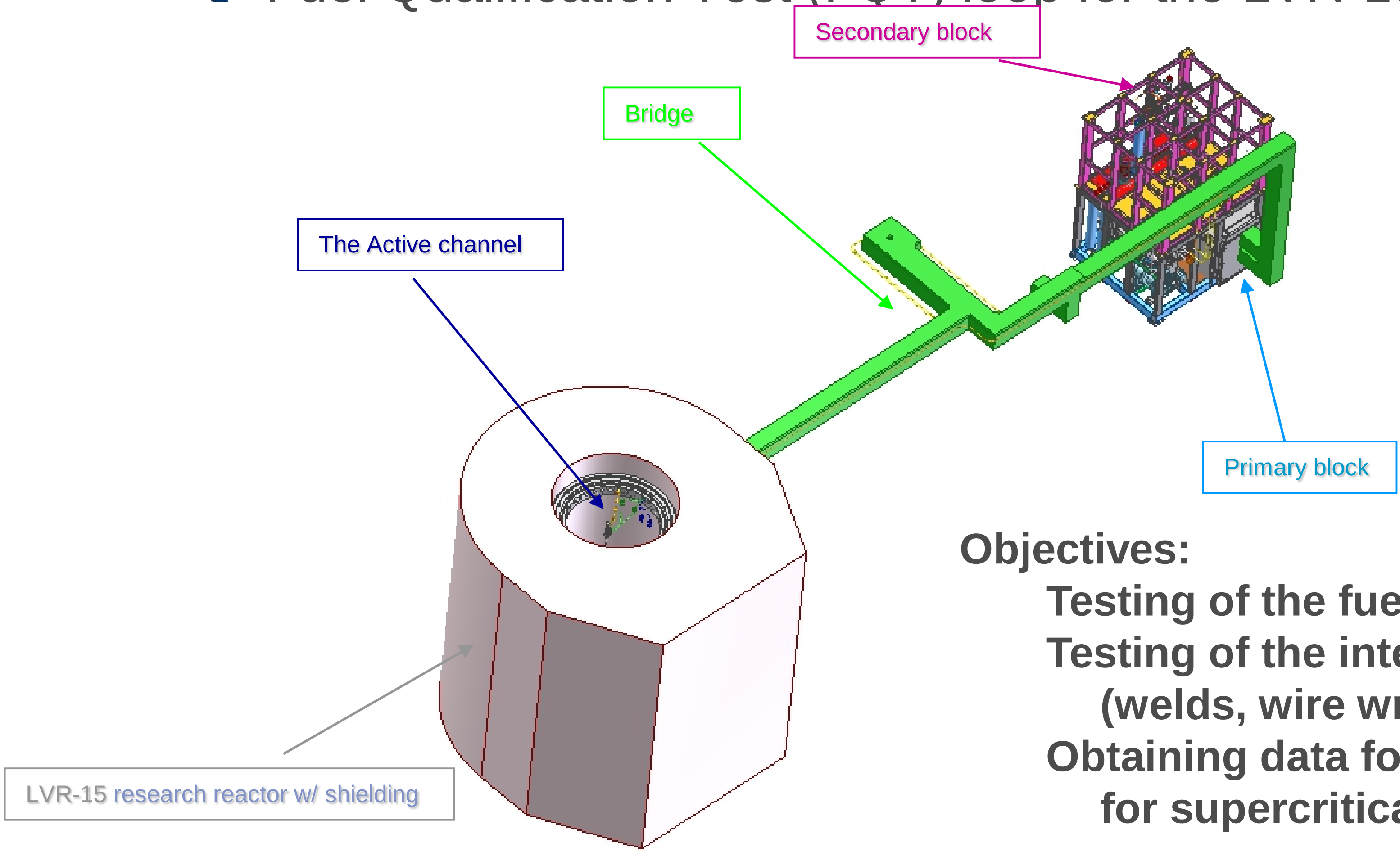
FQT SCWR Loop

- **Main facility / laboratories:**
  - Fuel Qualification Test (FQT) loop for the LVR-15 research reactor



Objectives:

Testing of the fuel cladding in pile;

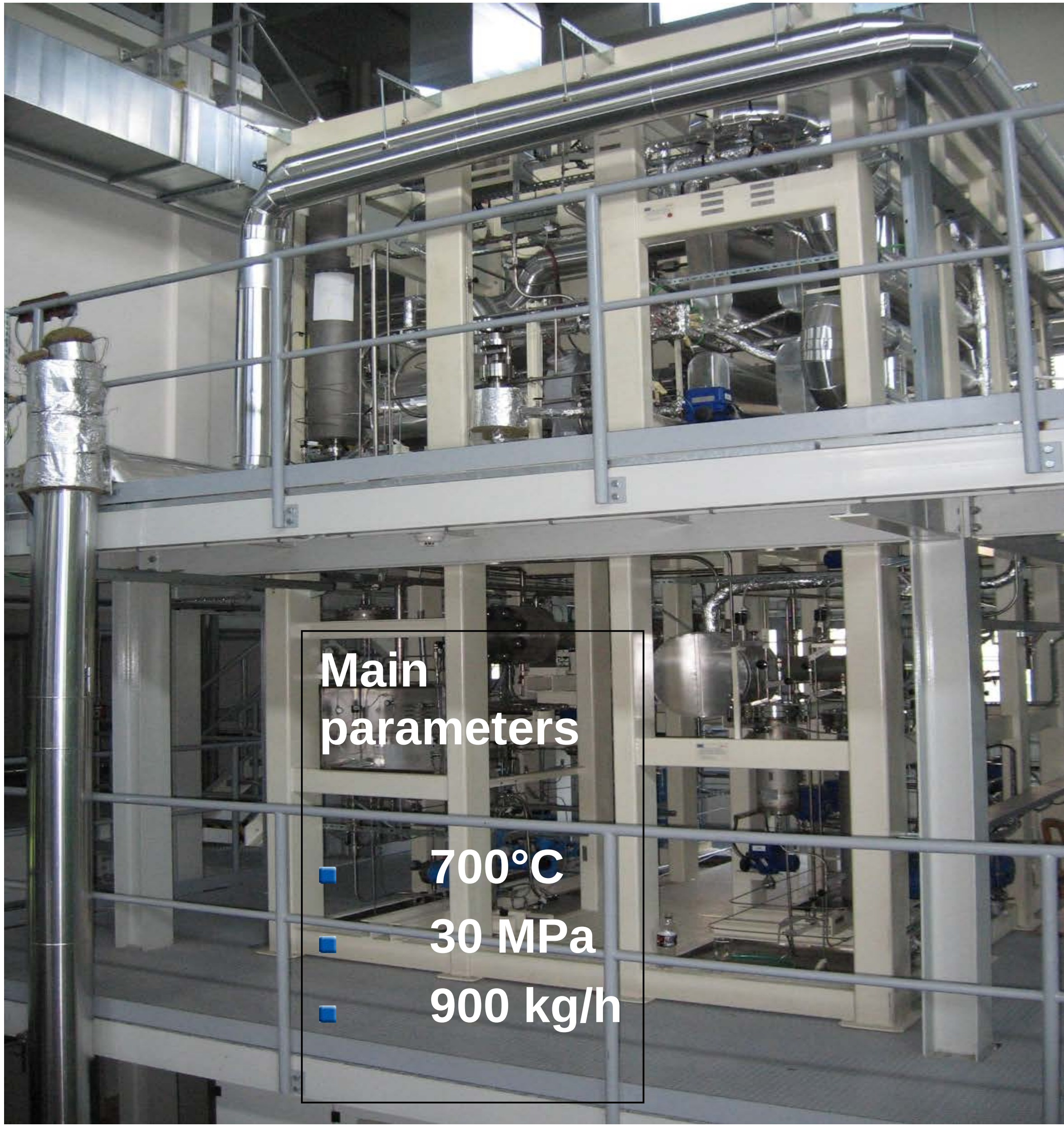
Testing of the integrity of the assembly (welds, wire wraps, etc.);

Obtaining data for heat transfer predictions for supercritical water conditions.

Ultracritical Water Loop (UCWL)

- Conception of UCWL is based on our experiences with supercritical water loop (SCWL).

- The parameters of UCWL of future conventional Rankine-Clausius cycles.



Experimental Complex HELCZA

Use

- High heat flux cyclic loading of various materials
- Extreme heat flux testing of various materials
- Testing of fusion first wall and divertor targets modules

Parameters

- Electron source power: 800 kW
- Accelerating voltage: 60 kV
- Rasterizing frequency: 20 kHz
- Heat flux density: 40 MW/m^2 (maximum 40 GW/m^2)
- Modules dimension: 2m x 1m or 1,5m x 1,5m
- Angle of incidence of beam: 90º

S-ALLEGRO - Helium Experimental Loop

Main goals:

- Verify the basic safety characteristics of helium cooled reactors
- Ensure data for TH codes validation
- Non-active functional tests, reliability tests, long-term component testing
- In model scale check these ALLEGRO characteristics
- Emergency heat removal system, decay heat removal system
- Transients
- Piping system
- Construction materials
- Manufacturing technology (welding)
- Purification system
- Component testing

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S-ALLEGRO - Helium Experimental Loop

- **The loop will be realized in two phases**

- **Phase I**
  - One main compressor
  - One main cooling loop
  - One DHR loop without compressor
- **Phase II**
  - Two main compressor
  - Two main cooling loop
  - Three DHR loops
  - N2 cooling
  - He vessel for LOCA

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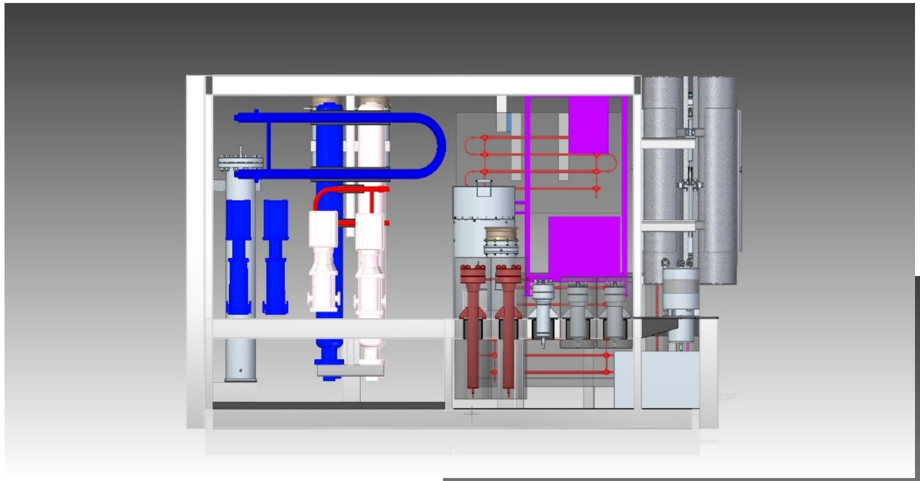
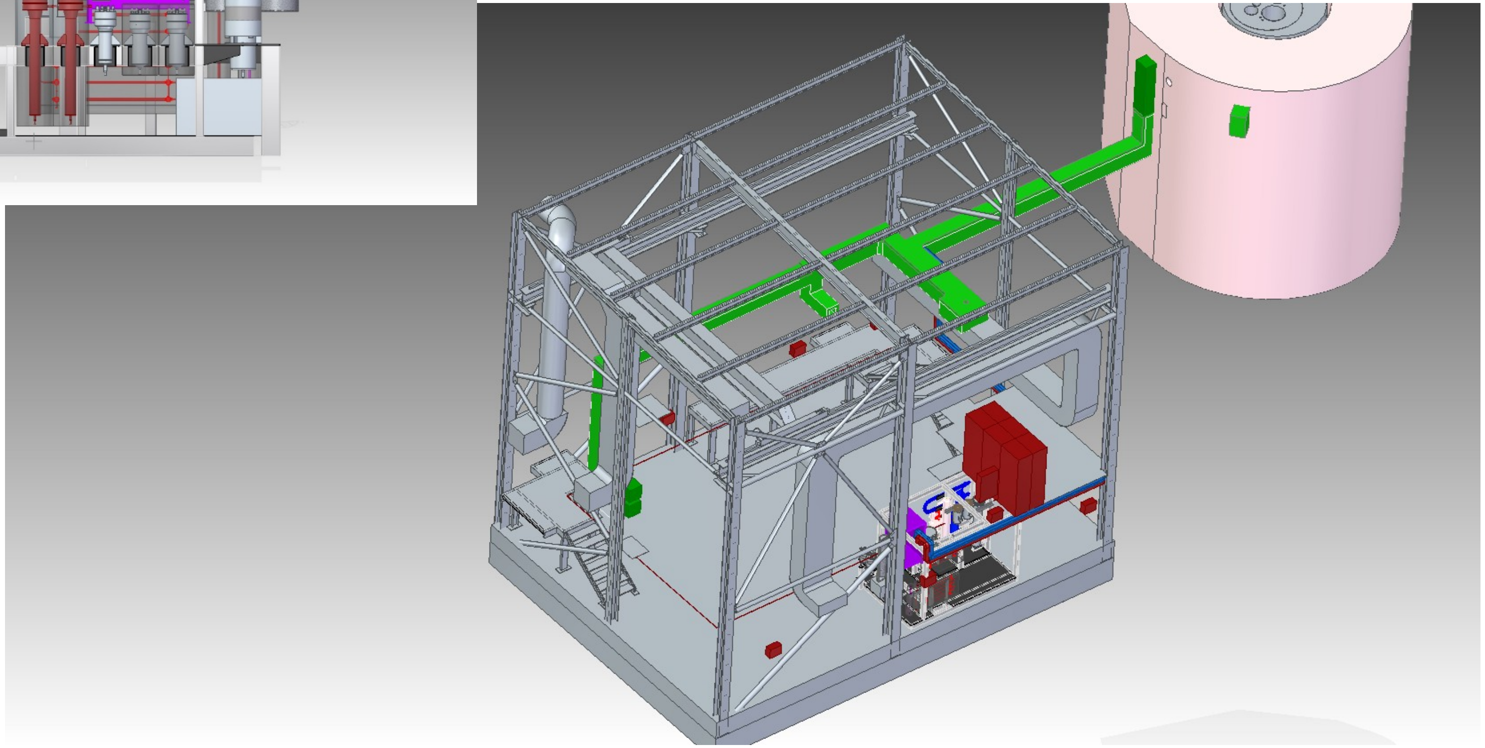
High Temperature Helium Loop

Operating parameters
Temperature: 900 °C
Pressure: 7 MPa
Flux rate: 38 kg He/h
In-pile operation



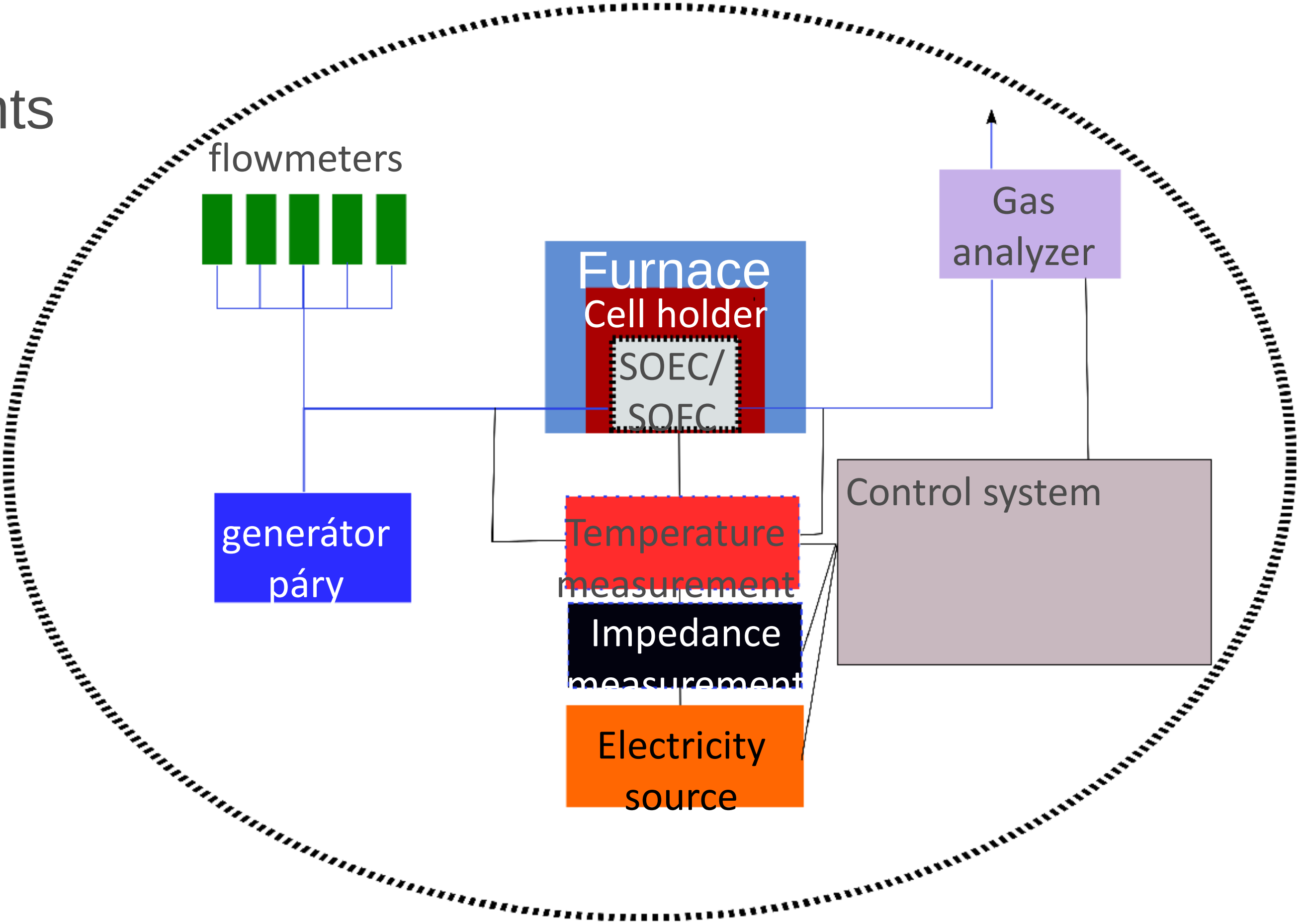


High Temperature Helium Loop

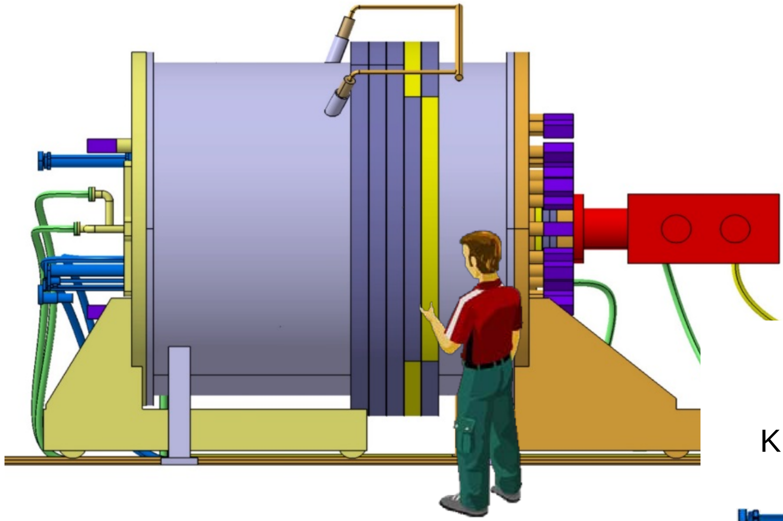
- **Testing (exposure) of VHTR and GFR structural materials in simulated helium coolant and irradiation in test reactor LVR-15**
- **Investigation of high temperature corrosion and changes of properties of tested materials**
- **Possible materials for testing:**
  - High temperature steels
  - High temperature alloys
  - Graphite
  - Ceramics (SiC, etc.)
- **Specimens will not be mechanic stressed during exposure. Mechanical tests are possible after exposure**

Facility for Testing of High Temperature Fuel Cells

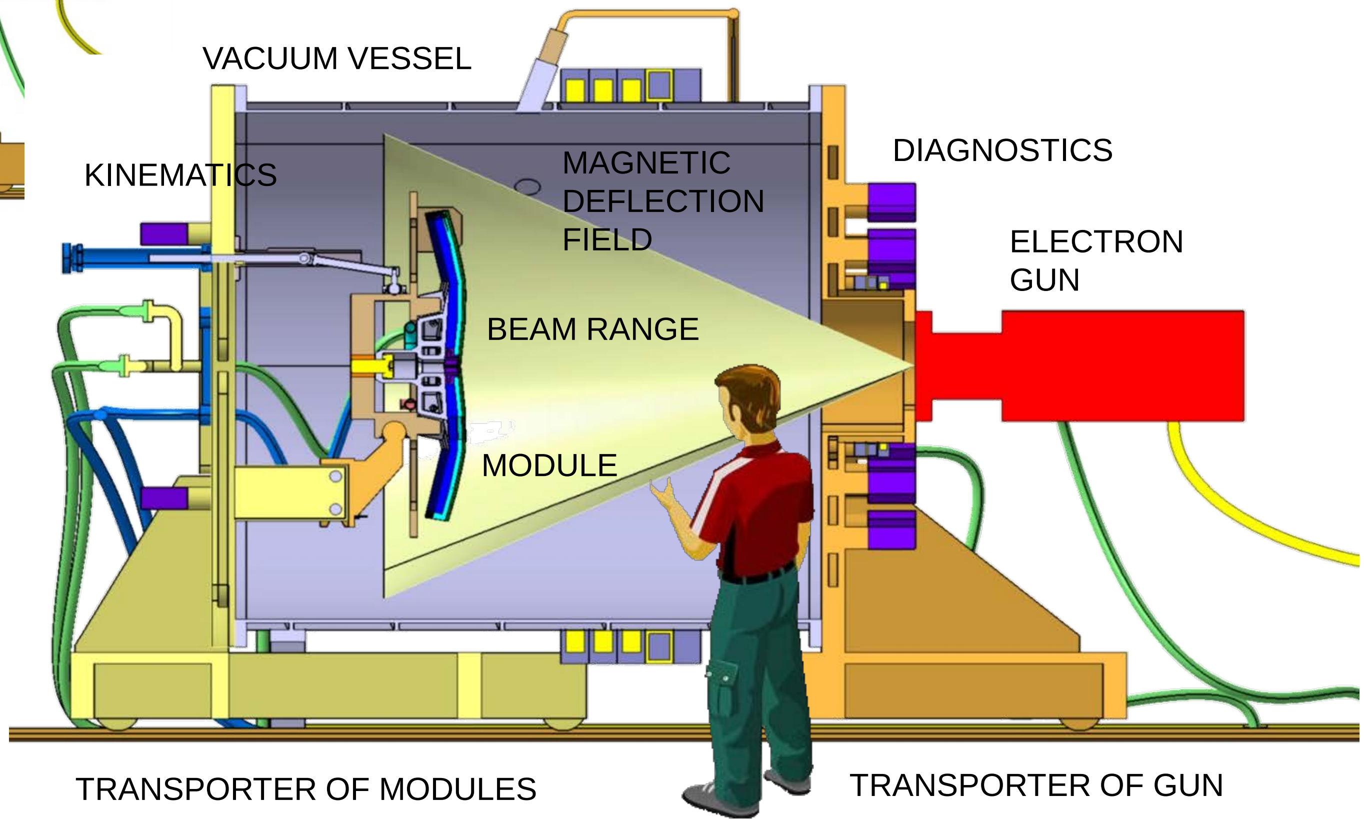
- **Tests:**
  - Power measurements
  - Polarization curves
  - Gas composition
  - Impedance
- **Long-term tests:**
  - SOEC/SOFC
  - Various flowrates, power, temperature



Experimental Complex HELCZA



Exposition distance	2 m
Vessel inner diameter	2.5 m
Vessel inner length	2.8 m
Vessel volume	11 m^3
Vessel weight	22 t



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Project SUSEN

Technological Experimental Circuits

TEC

Structural and System Diagnostics

SSD

Project SUSEN

Nuclear Fuel Cycle

NFC

Material Research

MAT

Structural and System Diagnostics

- **Main goals**
  - Lifetime prolonging of current generation of nuclear power plants, beyond 60 years
  - Supporting actions in development of materials and diagnostic systems for future operation of new generations reactors (Gen IV, Fusion)
- **Main aims**
  - Material studies of highly irradiated materials
  - R&D of diagnostic systems

Project SUSEN

Structural and System Diagnostic

SSD

Highly sensitive analytical instruments centre

NDE

laboratory

LOCA

laboratory

Hot cell laboratory

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Centre of Highly Sensitive Analytical Instruments

- **Main goal:**
  - To build the center for the studies of reactor structural and core materials used in designs of current nuclear power plants and of advanced materials for future nuclear reactors of Gen. IV and fusion reactors.
  - To equip the centre by state-of-the-art instruments allowing us to obtain complex and cutting-edge knowledge.

- **The main objective**
  - To gain new knowledge about the degradation mechanisms of microstructural and microchemical changes of materials exposed to reactor conditions including:

    - high neutron doses
    - high temperatures
    - mechanical stresses
    - corrosive environments

Centre of Highly Sensitive Analytical Instruments

- Main laboratories:
  - **Transmission Electron Microscopy** (HR-STEM) with atomic resolution and very low detection limits of chemical elements
  - **Scanning Electron Microscopy** with **Focused Ion Beam** (SEM-FIB) and analytical detectors **EDS, WDS a EBSD**
  - **Secondary Ion Mass Spectroscopy** (SIMS) for isotopic analysis
  - **Sample preparation lab** for advanced electron microscopy and SIMS
  - **Light Optical Microscopy** (LOM) with **microhardness attachment** (MHV) for fundamental microstructure analysis
  - **Nanoindentor** for micro-mechanical material properties analysis

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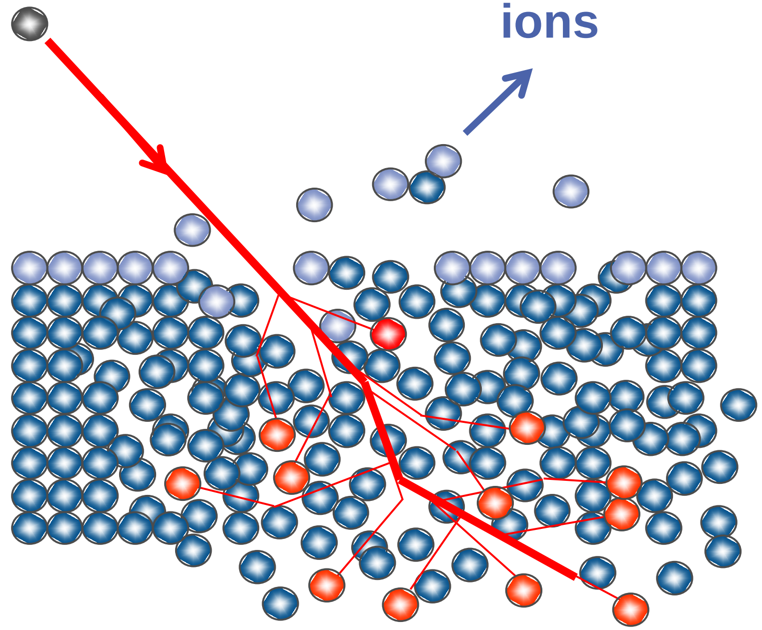
NDE Laboratory

- **Main objectives:**
  - Development of new methodologies for non-destructive evaluations of critical constructional parts of nuclear power plant
    - ferrite, austenitic and heterogeneous welded joints and components of complex configuration
    - concrete structure of nuclear reactor pressure vessel cavity
  - Developing a new universal HW and SW manipulator management system for testing welds of critical nodes of the primary and secondary NPP circuits

Secondary Ion Mass Spectrometry (SIMS)

Magnetic sector SIMS: CAMECA ims 7f

SIMS principle



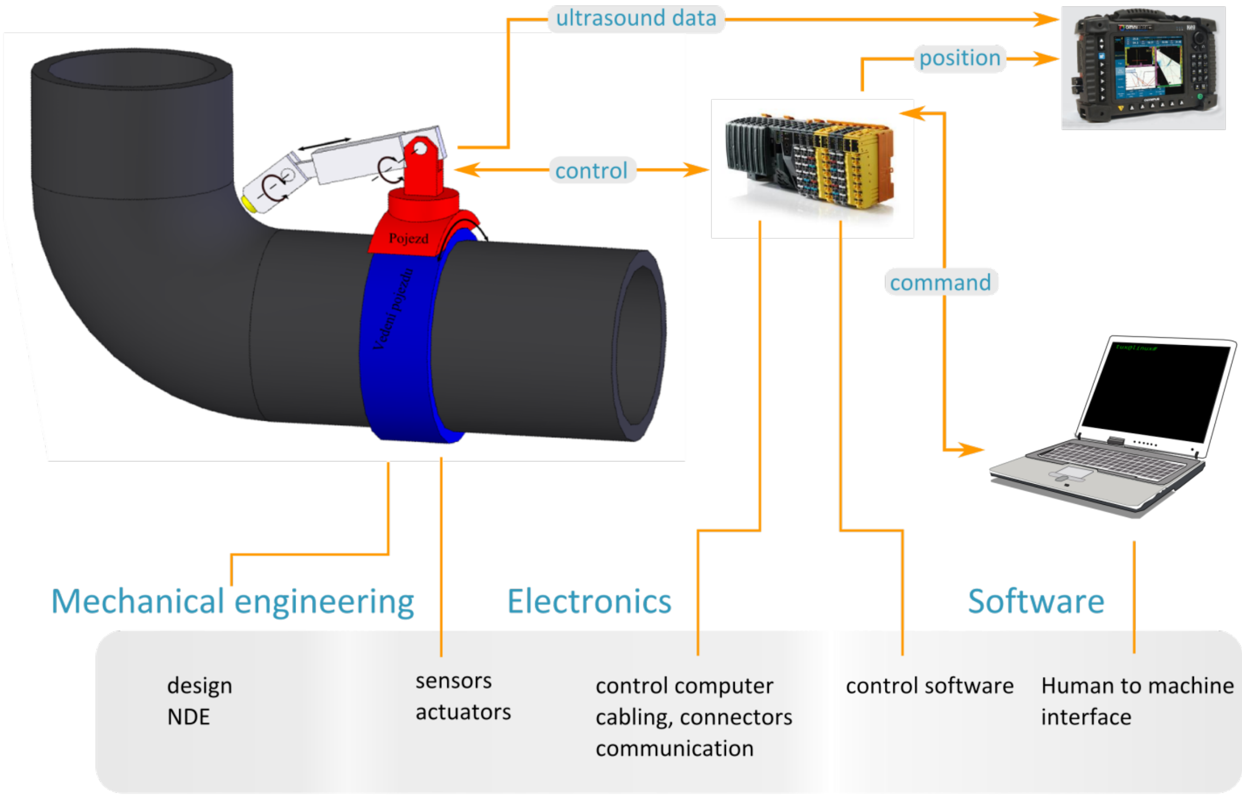
SIMS reveals elemental and isotopic surface composition

NDE Laboratory

SUSEN

Main laboratories

- Electro-mechanical laboratory of robotics
- Laboratory of non-destructive testing
- Laboratory of cracks and discontinuities studies
  - The laboratories cover whole automated NDE tool chain



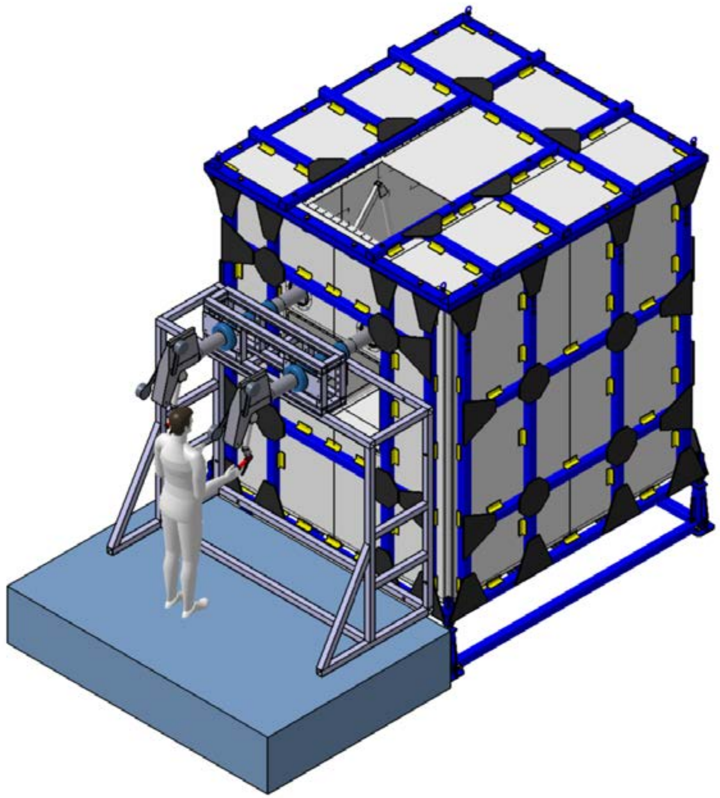
LOCA Laboratory

- **Main objective:**
  - Developing new procedures of thermal and radiation resistance verification and behaviour of structural materials and systems under the extreme conditions of severe accidents.
- **Main technologies:**
  - LOCA device
  - High voltage testing room
  - Gamma irradiation device

- **Main LOCA**
  - V = 1-10 m3
  - Tmax= 270-320 °C
  - pmax,(abs) = 20 - 112 bar
- **Vessel for simulation H2 explosion**
  - Tmax=320 – 550 °C
  - pmax,(abs) = 20 - 112 bar
- **Post-LOCA**
  - V = 1-10 m3
  - Tmax=150-250 °C
  - pmax,(abs) =10-20 bar

Hot Cell Laboratory

- **Main objectives:**
  - Study of the microstructure degradation and mechanical properties of nuclear reactor structural components materials after long operational exposure;
    - Very high temperature testing (up to 1200°C) of mechanical properties,
    - CGR at cyclic loading, a development and implementation of low-cycle fatigue testing with creep interaction (fatigue-creep), and creep testing
  - Development of new fuel cycle technologies for fluorite technology-based nuclear reactors of new generations



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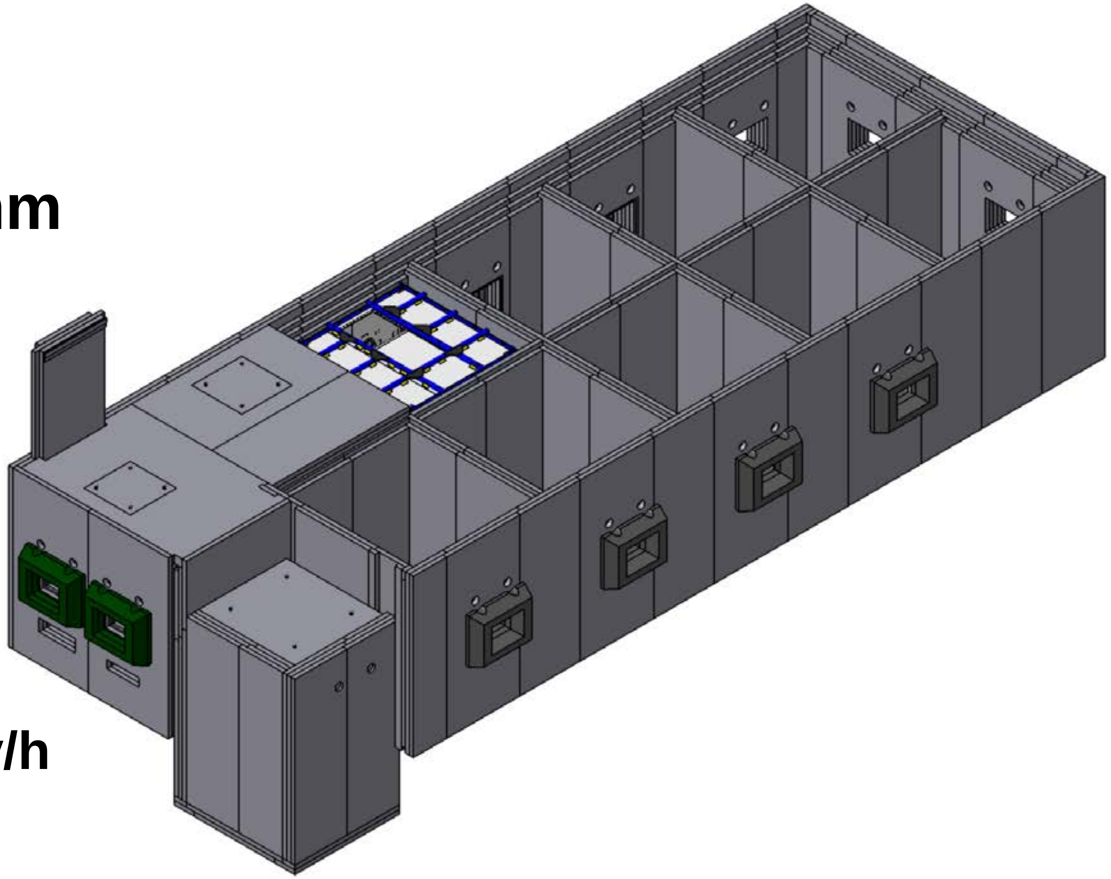
Layout of the Hot Cells

- **8 gamma hot cells, 2 alpha hot cells and 1 semi-hot cell** will be constructed.

Thickness of steel shielding:

  - **perimeter shielding 500 mm**
  - **ceiling shielding 400 mm**
  - **floor shielding 300 mm**



- **Max. source activity up to 300 TBq ^{60}Co**

Dose Equivalent Rates γ = 1.38 µSv/h

In each hot cell will be hermetic, easily removable box from stainless steel

Equipment Inside the Hot Cells

- Manufacturing of the specimens (cutting, welding, drilling, machining) :
  - Electrical discharge machine (EDM)
  - CNC machining center
  - Electron beam welding machine (EBW)
- Meechanical / SCC testing:
  - Universal tensile test machine loading up to 250kN
  - Tensile test machine for combined axial-torsional
  - High frequency resonance pulsator up to 50kN
  - Electromechanical creep machine up to 50kN
  - Fatigue machine
  - Autoclave with water loop
- Microscopes (SEM, LOM), nanoindentation device.

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Technological Experimental Circuits

TEC

Structural and System Diagnostics

SSD

Project SUSEN

Nuclear Fuel Cycle

NFC

Material Research

MAT

Nuclear Fuel Cycle

- **Main goals**
  - To expand and construct a research infrastructure to support:
    - nuclear fuel cycle of GIV reactors,
    - radioactive waste management (RWM), including its final disposal,
    - severe accidents experimental studies,
    - non-spreading of nuclear weapons and the environmental impact,
    - SUSEN project analytically

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Nuclear Fuel Cycle NFC

Laboratory of Induction Heating

Laboratory of Geological Disposal

Laboratory of Radioactive Waste Management Technologies

Laboratory of Nuclear Fuel Reprocessing and Fluoride Chemistry

Analytical Laboratory

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Anaerobic Boxes

SUSEN - scientific-technology platform to support a deep geological repository development

Research of engineered barriers (IB):

- Canister material corrosion research under anaerobic conditions – VaV support of geological repository safety
- Analysis of corrosion products
- Microbiological corrosion research – EC project MIND

Research of an interaction between IB and the host rock:

- Resistance of potential canisters materials research under natural conditions
- Impact of corrosion product on bentonite behavior
- Research of IB degradation under anaerobic conditions

Research of an repository host rock, incl. natural analogues:

- Redox sensitive radionuclides migration studies
- Samples acquired under anaerobic conditions analysis

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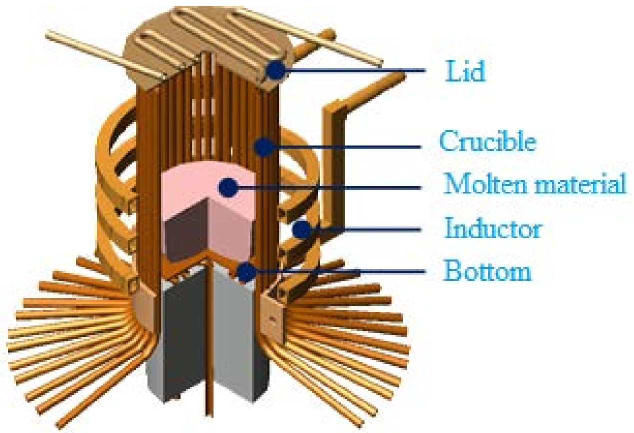
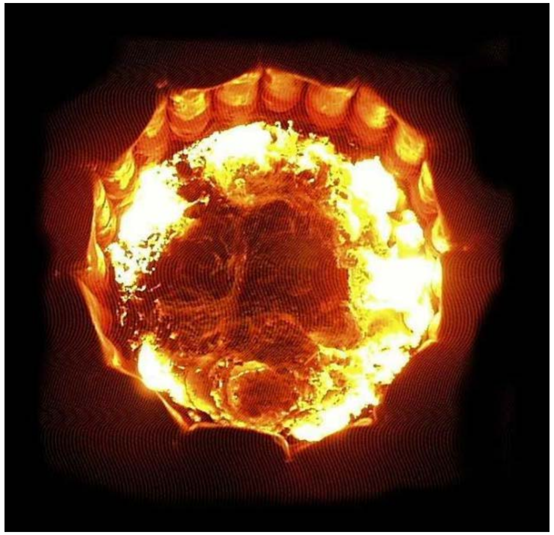
Laboratory of Induction Heating

- ## What is planned?
  - Induction heater with cold crucibles:
    - Generator A – 160 kW (1-2 MHz) – **also in ZCU**
    - Generator B – 300 kW (0,1 – 0,5 MHz)
  - Equipped with vacuum chamber
  - Located within a controlled area (Cat. 3 workplace with IRS) - **Rez**



- ## What can it do?
  - Heating up conductive/semiconductive and/or non-conductive materials up to 3000°C
  - Different conditions:
    - Gases
    - Radioactivity
    - Volumes of cold crucible (up to 50 kgs of material ~ 25 Ltrs



- ## For what research?
- Investigation of phase diagrams and melts properties
- Modeling and investigation of nonstandard situations at nuclear power reactors (in- and ex-vessel severe accidents)
- Vitrification of radioactive wastes
- Powder remelting to ingot
- High temperature synthesis of materials
- Crystal growth (mono-, multicrystals)
- Glass synthesis
- Production of fused refractors

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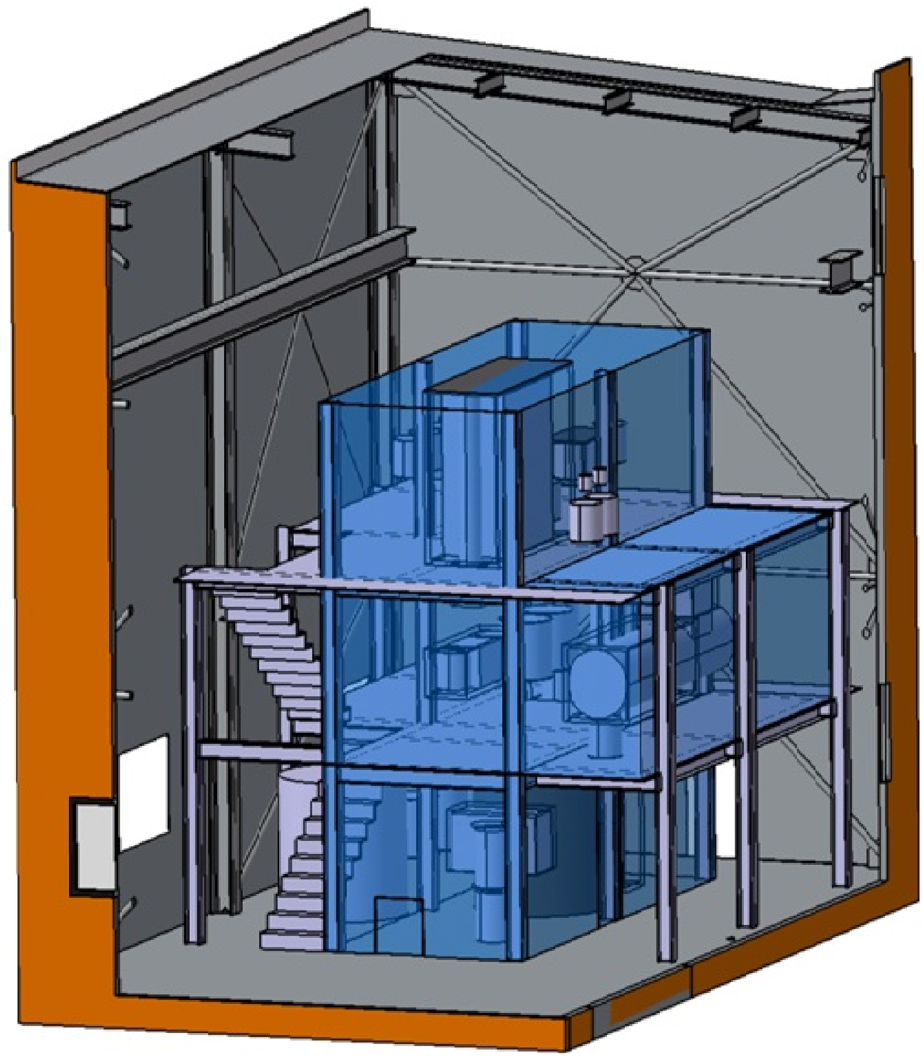
Laboratory of RAW management

high temperature technology for disposal of radioactive waste with at least twice the volume reduction factor compared to currently used procedures at the Czech nuclear power plants.

a combination of a prototype of high temperature technologies and a technological node of pretreatment of melting salt and ion resin and the final node of immobilization of waste salts.



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Material Research

Development of

- ferritic/martensitic steels for application in an environment with temperatures up to 650°C (steam turbines and supercritical fossil power plants and inactive circuits of Generation IV nuclear reactors),
- austenitic steels and high-level austenitic alloys for components stable in aggressive environments at high temperatures and pressures,
- new welding technologies for advanced materials

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Material Research

MAT

Mechanical Testing Laboratories

Laboratories of Analytical Chemistry and Electrochemistry

Laboratory of Metallography and Surface analysis

Laboratory of Fusion Welding

(partner UWB)

NC2I
Nuclear Cogeneration Industrial Initiative

Nuclear Cogeneration:

A potential game-changer to support the European Energy Union

Michael A. Fütterer (JRC)

www.SNETP.eu

Outline

- Juncker Priorities
- The Energy Union
- Who will benefit and how?
- What will change?
- Concrete benefits from Nuclear Cogeneration

Juncker Priorities

NC2I
Nuclear Cogeneration Industrial Initiative

1. A new boost for jobs, growth and investment
2. A connected digital single market
3. A resilient Energy Union with a forward-looking climate change policy
4. A deeper and fairer internal market with a strengthened industrial base
5. A deeper and fairer Economic and Monetary Union (EMU)
6. A reasonable and balanced free trade agreement with the United States
7. An area of Justice and Fundamental Rights based on mutual trust
8. Towards a new policy on migration
9. Europe as a stronger global actor
10. A Union of democratic change.

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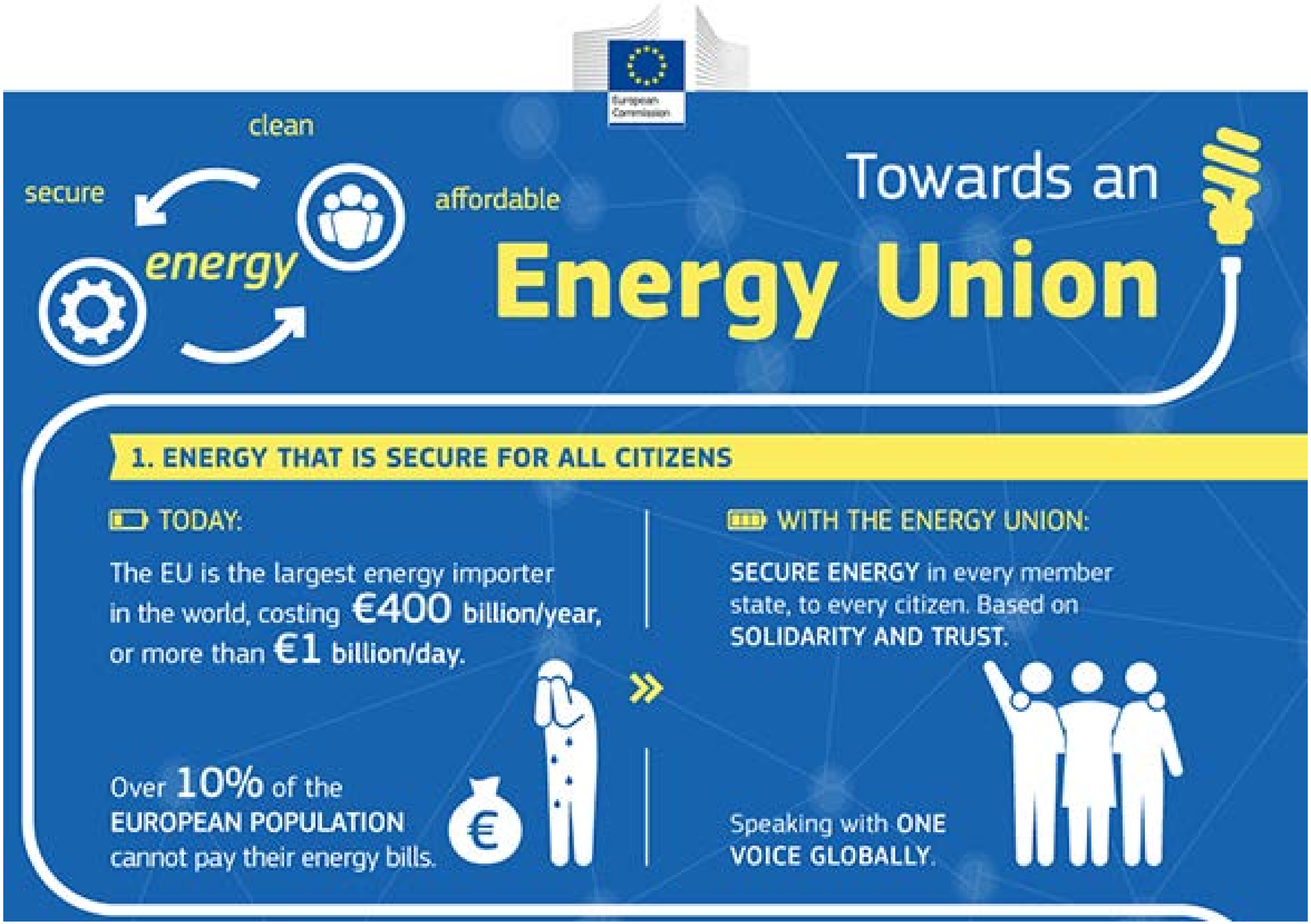

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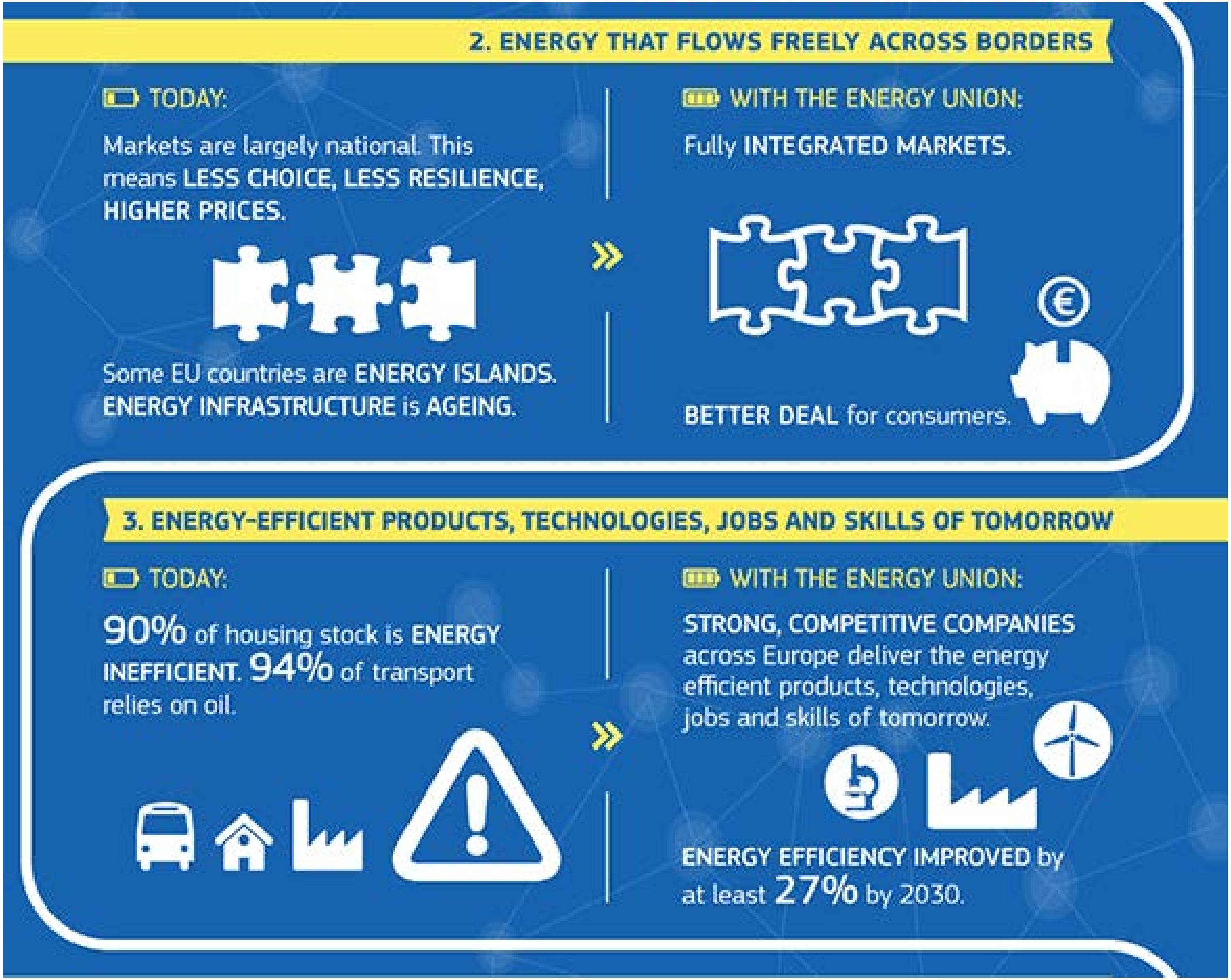

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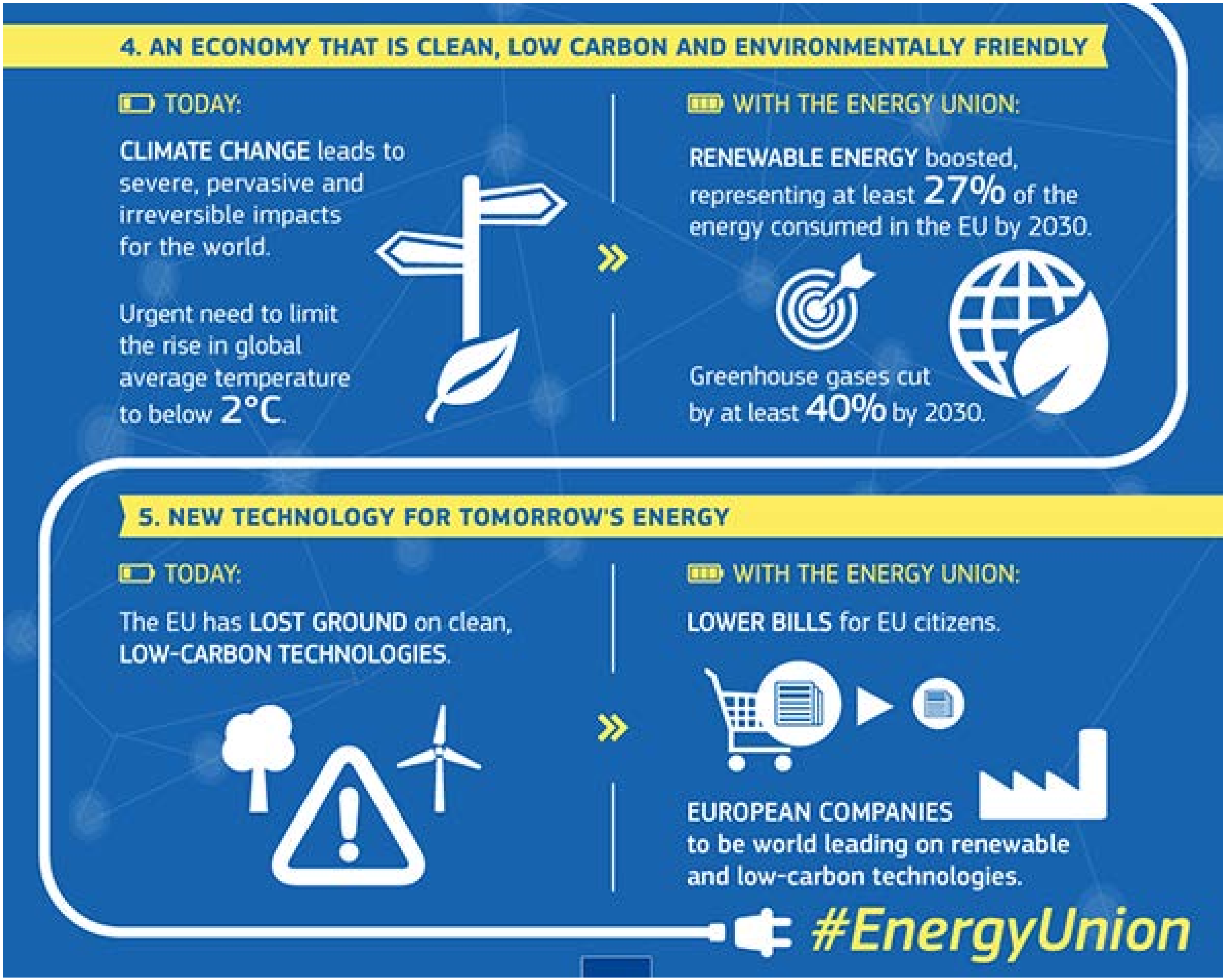

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Schedule

Nuclear Cogeneration Industrial Initiative

25 February 2015:
Commission issues Energy Union Strategy


EN

EN

Later in 2015:

- Communication on the EU position for the climate negotiations
- Communication on how to bring its electricity interconnection level to 10 % by 2020.

Other initiatives in **2015, 2016 and 2017**

March 2015: European Council meeting discussed strategy (Atomic Questions Working Group 11.3.2015)

Nuclear mentioned 6 times:

- The EU is highly dependent on the import of **nuclear** fuel and related services to Member States where **nuclear** energy is part of the energy mix. Diversification of supply is important to ensure security of supply. The Commission will update and enhance the requirements on the information to be provided, in accordance with Article 41 of the Euratom Treaty, on **nuclear** installation projects.
- Equally, putting the EU at the forefront of smart grid and smart home technology, clean transport, as well as clean fossil fuel and the world's safest **nuclear** generation, is central to the aim of turning the Energy Union into a motor for growth, jobs and competitiveness.
- **Nuclear** energy presently produces nearly 30% of the EU's electricity. The EU must ensure that Member States use the highest standards of safety, security, waste management and non-proliferation. The EU should also ensure that it maintains technological leadership in the **nuclear** domain, including through ITER, so as not to increase energy and technology dependence.

AQWG of 11.3.2015

DG ENER: overview of Energy Union communication

Euratom already covers most of the communication, in particular:

- Energy security, solidarity and trust (by the European supply agency, and the provisions of the communication on energy security strategy)
- Decarbonised economy
(nuclear electricity = 53% of EU low carbon electricity)
- Research, Innovation and Competitiveness
(EU should keep nuclear technology leadership)

- ❑ 9 Member States (UK, FR, HU, SK, CZ, LT, BG, RO and PL) would have appreciated if the communication had better recognized the key role of nuclear energy in energy security and decarbonisation.
- ❑ AT requested that the Energy Union should not be used to promote nuclear energy. FR strongly objected.
- ❑ SE will not support anything that could favor investments in nuclear technologies.

➔ No unanimity in sight with respect to current and future role of nuclear in the European energy landscape

Concrete Benefits from Nuclear Cogeneration

NC2I
Nuclear Cogeneration Industrial Initiative

For countries favorable to nuclear:

- **Safety:** HTR/HTGR can be built with extremely attractive safety features
- **Performance:** NC boosts efficiency
- **Timeliness:** Technologically easily accessible non-electric market 90 GWth (steam < 600°C)

Concrete Benefits from Nuclear Cogeneration

NC2I
Nuclear Cogeneration Industrial Initiative

- **Environment:**
  - CO_2 savings (and other GHG and pollutants):
    600 MWth saves:
    1 Mt/yr CO_2 if replacing natural gas
    1.8 Mt/yr CO_2 if replacing coal
  - Because the consumption is so high, any CO_2 curbing strategy can only be effective if addressing also industrial process heat.

- **Cost:** **x** €/t CO_2 saved; cost stability

- **Energy Security:**
  Gas is better used as feedstock;
  Diversification of energy supply

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Concrete Benefits from Nuclear Cogeneration

- **Interoperability:**
  - System Integration Options with variable renewables
  - Load following, energy storage, poly-generation
- **Re-industrialization:**
  - halt "carbon leakage"
  - maintain strategically important bulk industries in EU; increase industry part of GDP from 16% to 20% by 2020
  - keep European energy-intensive and nuclear industries competitive and at top notch level
- **Economy (based on current numbers):**
  - Jobs: approx. 1205 direct jobs/GWth
  - GDP: approx. 168 M€/yr/GWth

Conclusion

- Any effective CO_2 curbing strategy must address industrial process heat.
- Nuclear Cogeneration is a large, long-term, strategic infrastructure investment.
- It has large potential impact to make the Energy Union successful.

Back-ups

Nuclear Cogeneration Industrial Initiative

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Energy Union

Why must the EU act?

- **Biggest energy importer** in the world
  53% at around € 400 bn/year
- **Incomplete internal energy market**,
  some parts of the EU remain isolated **energy islands**.
- **Renewable energy not fully integrated into the electricity system**.

Objective:

- Significantly reduce Europe's reliance on fossil fuels…
- …by removing barriers to the flow of energy…
- …in a fully integrated EU-wide energy system

Who will benefit and how?

Nuclear Cogeneration Industrial Initiative

European citizens:

- **Limit energy bills** using smart technology
- **Generate own energy** from renewable sources and feed this into the electricity grid
- Better energy security will **reduce the risk of black-outs**.

Businesses:

- **New energy and climate technologies and services**
- **Green growth and jobs** in the EU and **export opportunities** abroad
- **More certainty** for investors, with price signals reflecting long-term needs and clear policy objectives.

Climate:

- An ambitious **reduction of at least 40 % in CO_2 emissions** by 2030
- **More renewable energy** in the EU's energy mix
- **Energy efficiency** will be **increased**, especially in the building and transport sectors.

What will change?

NC2I
Nuclear Cogeneration Industrial Initiative

The Commission proposes

- doing more to ensure that Member States **implement and enforce** existing legislation
- passing legislation to **increase gas and electricity supply security** and other measures to **reduce Europe's reliance on dominant suppliers**
- setting up an Energy Infrastructure Forum to **make sure major infrastructure projects** are **delivered** where and when needed
- passing legislation to **modernise the European energy market** and **reinforce the regulatory framework** at regional and European level
- passing legislation to ensure the **2030 climate and energy targets** are reached
- making **energy costs and prices more transparent**
- making **buildings more energy-efficient** and **decarbonising** the **transport** sector
- putting an initiative on global **energy and climate technology and innovation** leadership in place

Market opportunities, possible business models and system integration

C. Auriault (LGI Consulting), R. Stahl (FORTUM)

Nuclear days 2015, Brussels, 18th March

www.nc2i.eu

NC2I Nuclear Cogeneration Industrial Initiative

NC2I is one of SNETP's strategic technological pillars, mandated to coordinate the European nuclear cogeneration roadmap.

SNETP Sustainable Nuclear Energy Technology Platform

www.snetp.eu

Summary

1- Scope and objectives

2- Market opportunities

3- Current business models of a chemical park

4- Ownerships models of a NPP

5- Business model of a HTR for industrial applications

1-Scope & objectives

2- Market opportunities

3- BM chemical park

4- Ownership models NPP

5- BM coupled system

Scope

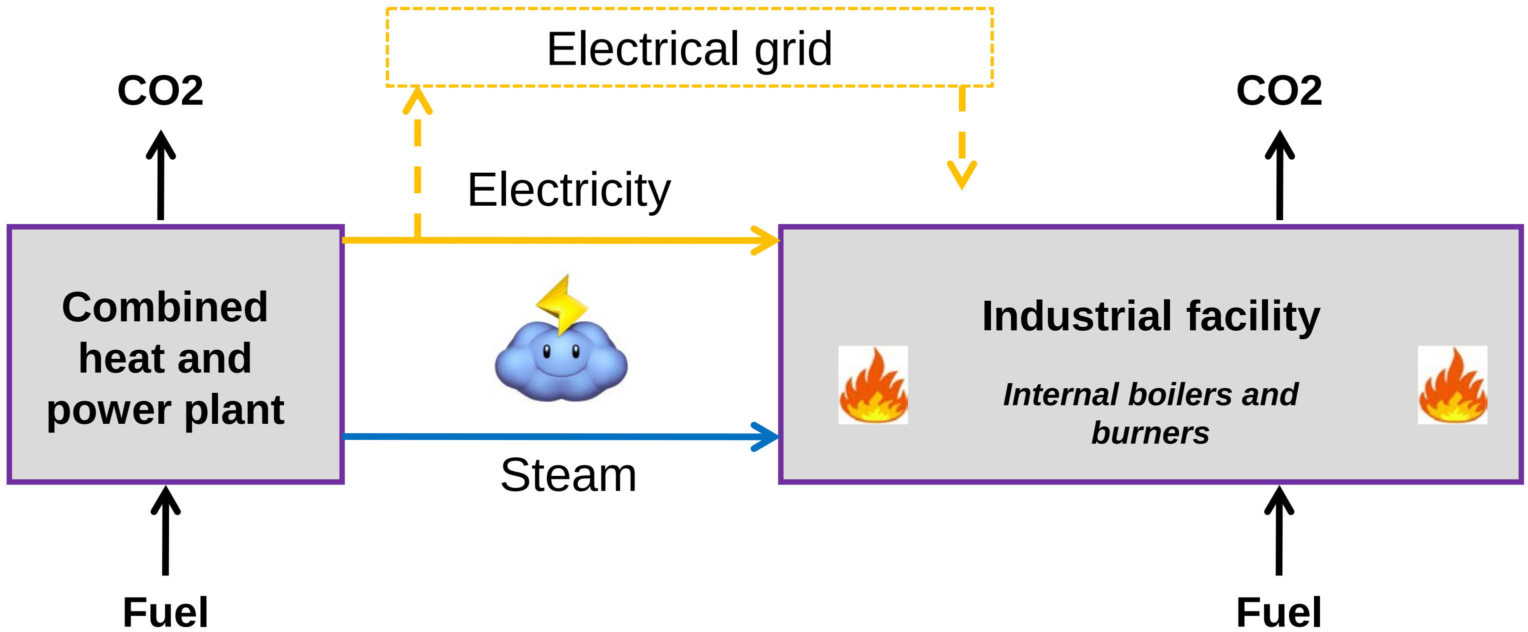
Qualitative analysis of the market and the opportunities

Quantitative economics analysis conducted in another presentation

Objectives

- Understand the industrial heat market
- Identify the possible applications for an HTR
- Have a clear representation of the current situation of chemical park’s business models and ownership solutions for an NPP
- Determine the opportunities resulting from the coupling of an HTR coupled with a chemical park

Segmentation of the industrial heat market



Plug-in

(784 TWh/y)

Extended

(1,830 TWh/y)

Source: LGI Consulting (EUROPAIRS, 2011)

1-Scope & objectives

2- Market opportunities

3- BM chemical park

4- Ownership models NPP

5- BM coupled system

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Nuclear Cogeneration Industrial Initiative

Opportunities in the heat market for nuclear cogeneration

Best opportunities in the current heat-intensive industries

- Chemical industry
- Oil refining sector
- Hydrogen production (Steam Methane Reforming)

Innovative technologies

- Hydrogen production (HT electrolysis, chemical cycles)
- Coal-To-Liquid

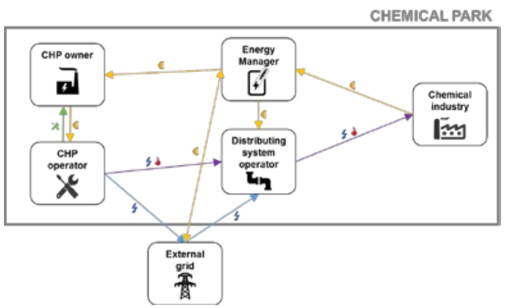
SNETP
Sustainable Nuclear Energy Technology Platform

Definition of a Business Model

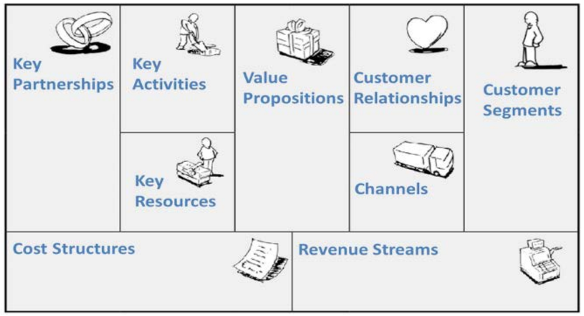
- **Osterwalder**[1] (2004) "So differently put the business model is an abstract representation of the business logic of a company. And under business logic I understand an abstract comprehension of the way a company makes money, in other words, what it offers, to whom it offers this and how it can accomplish this".

Tools used

- Ecosystem map

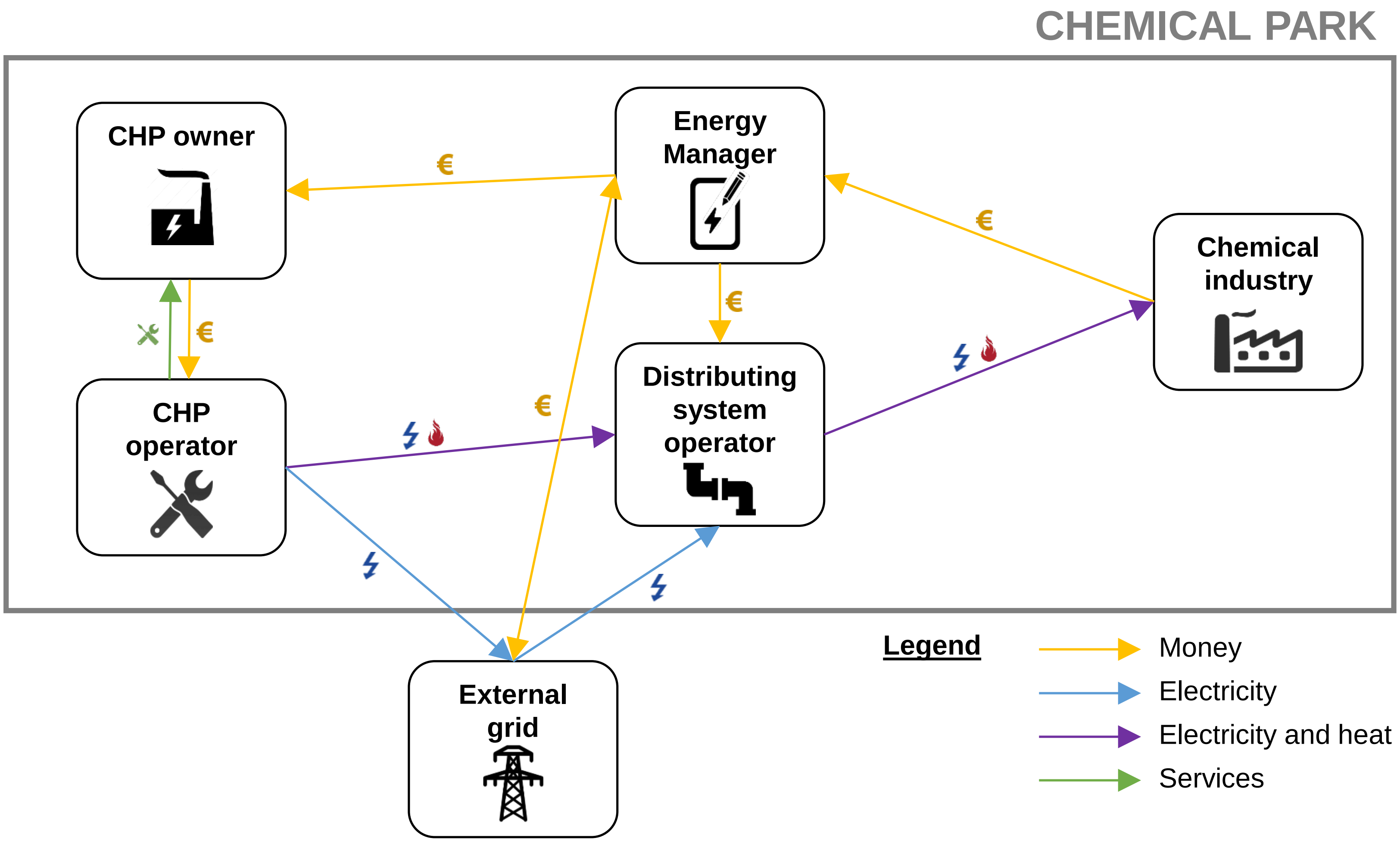


- Business Model canvas



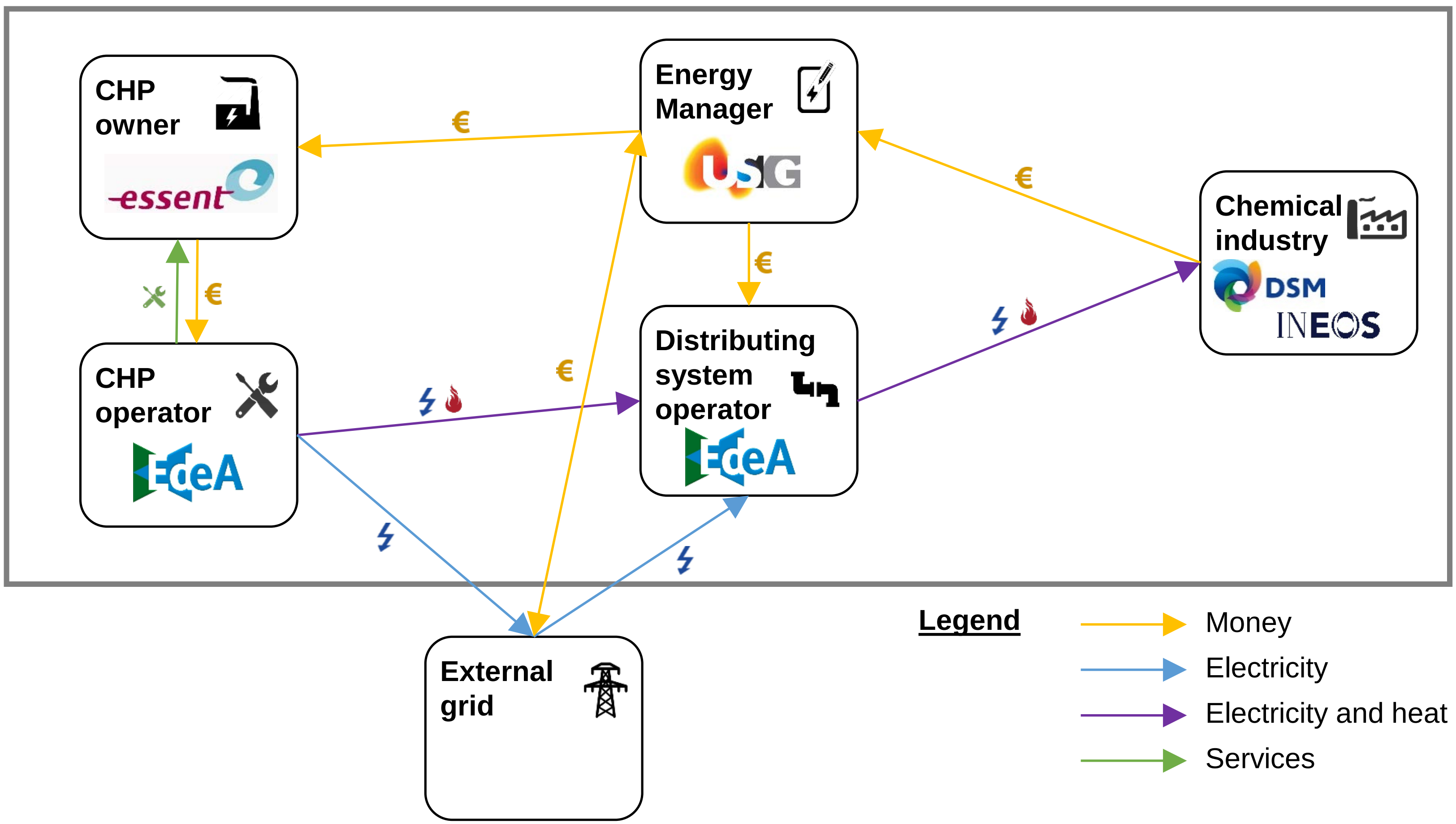
[1] Osterwalder, A., 2004. *"The Business Model Ontology L A Proposition in a Design Science Approach"*. PhD Thesis. Lausanne, Switzerland: Université De Lausanne.

- **Case n°1: No integration**

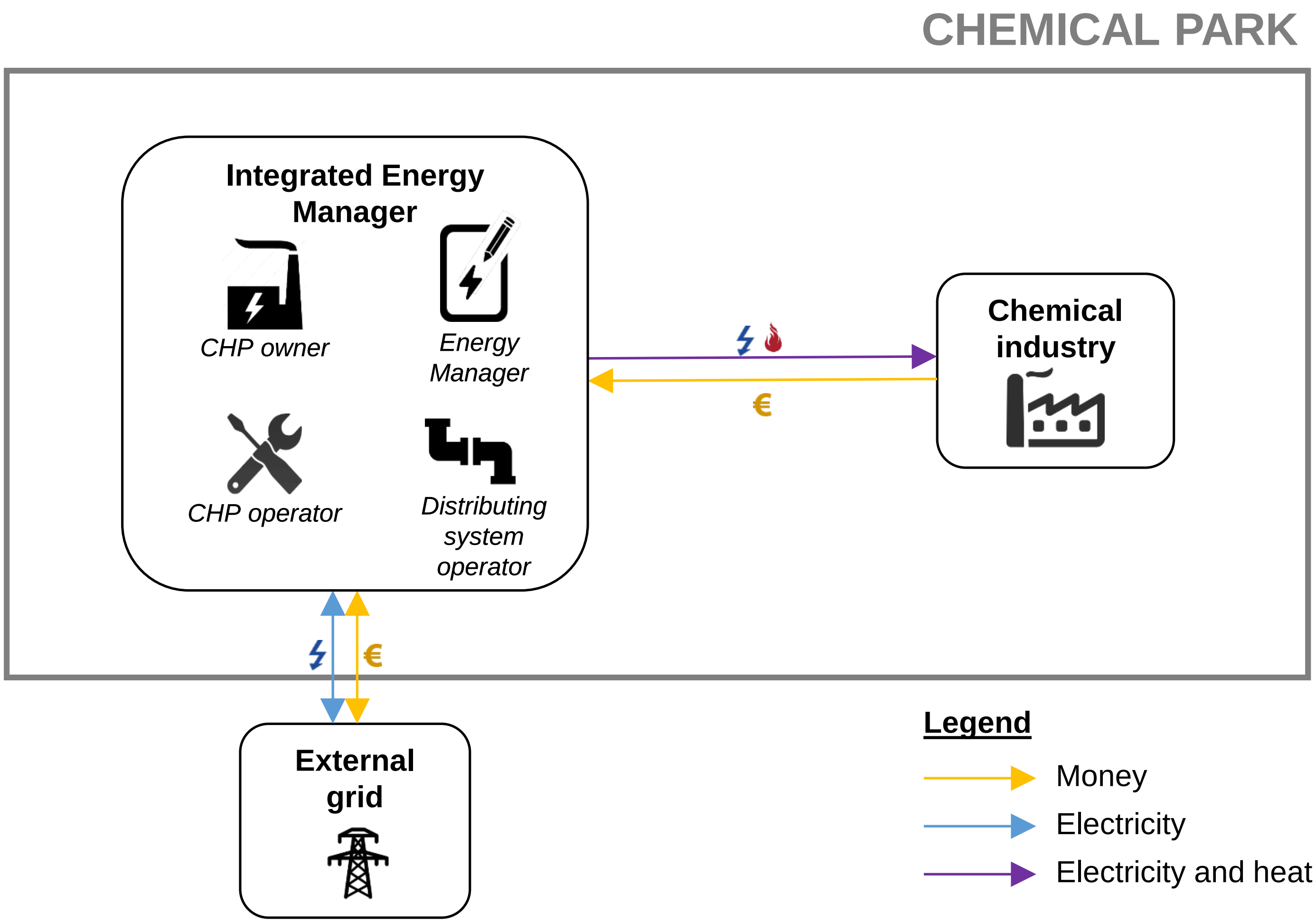


- **Case n°1: Example**

CHEMELOT PARK (The Netherlands)

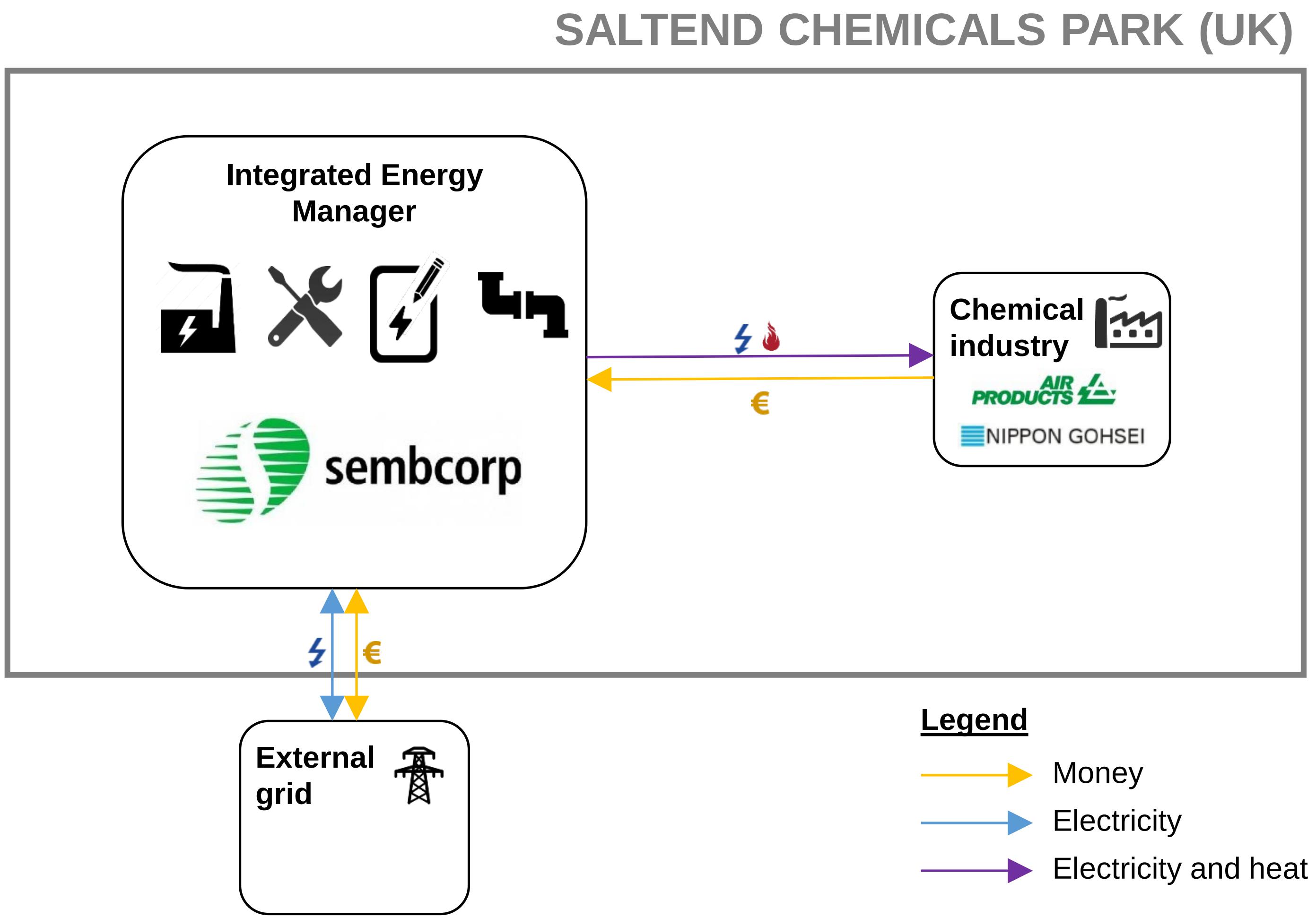


- **Case n°2: Energy Management integration**



NC2I Nuclear Cogeneration Industrial Initiative

- **Case n°2: Example**



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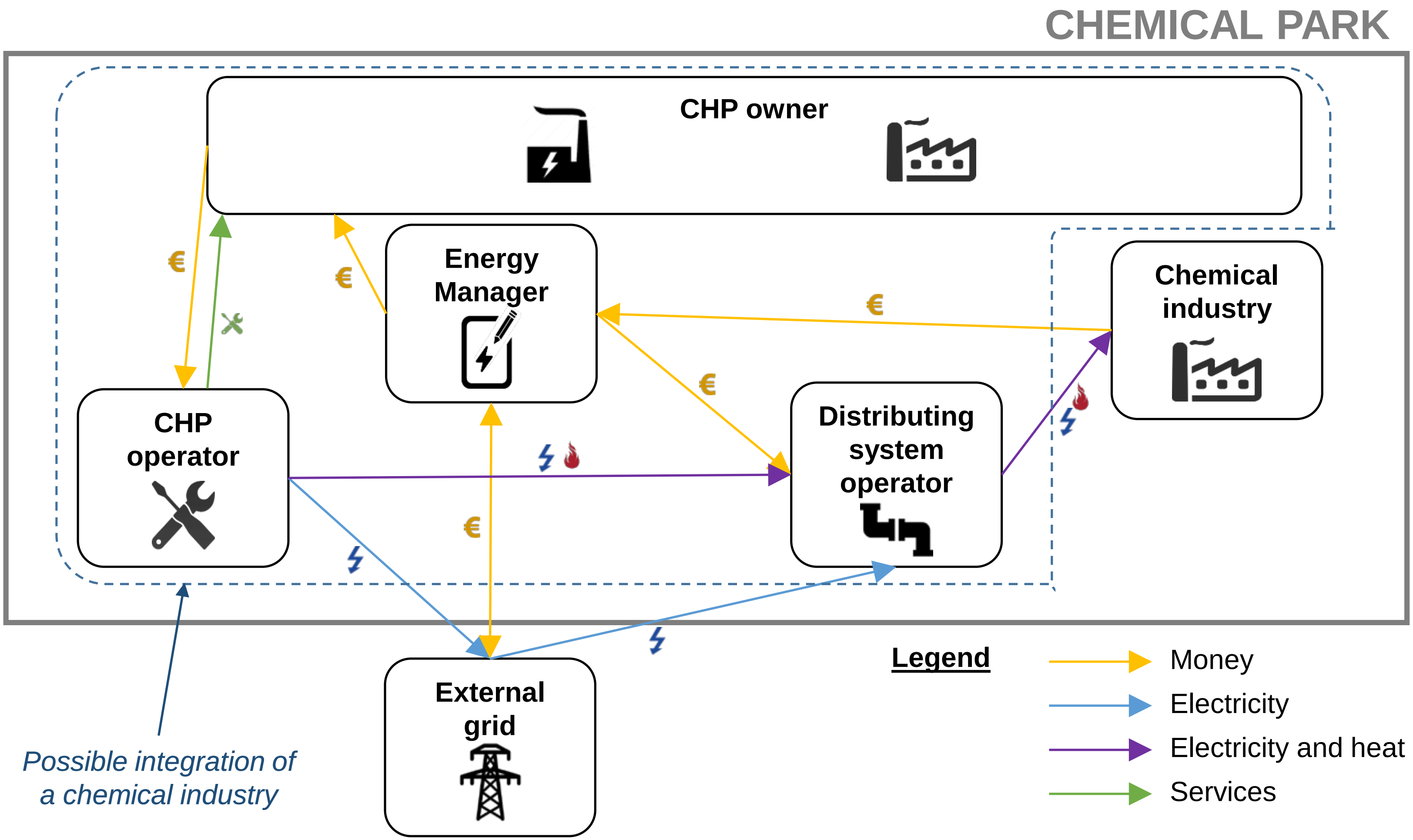
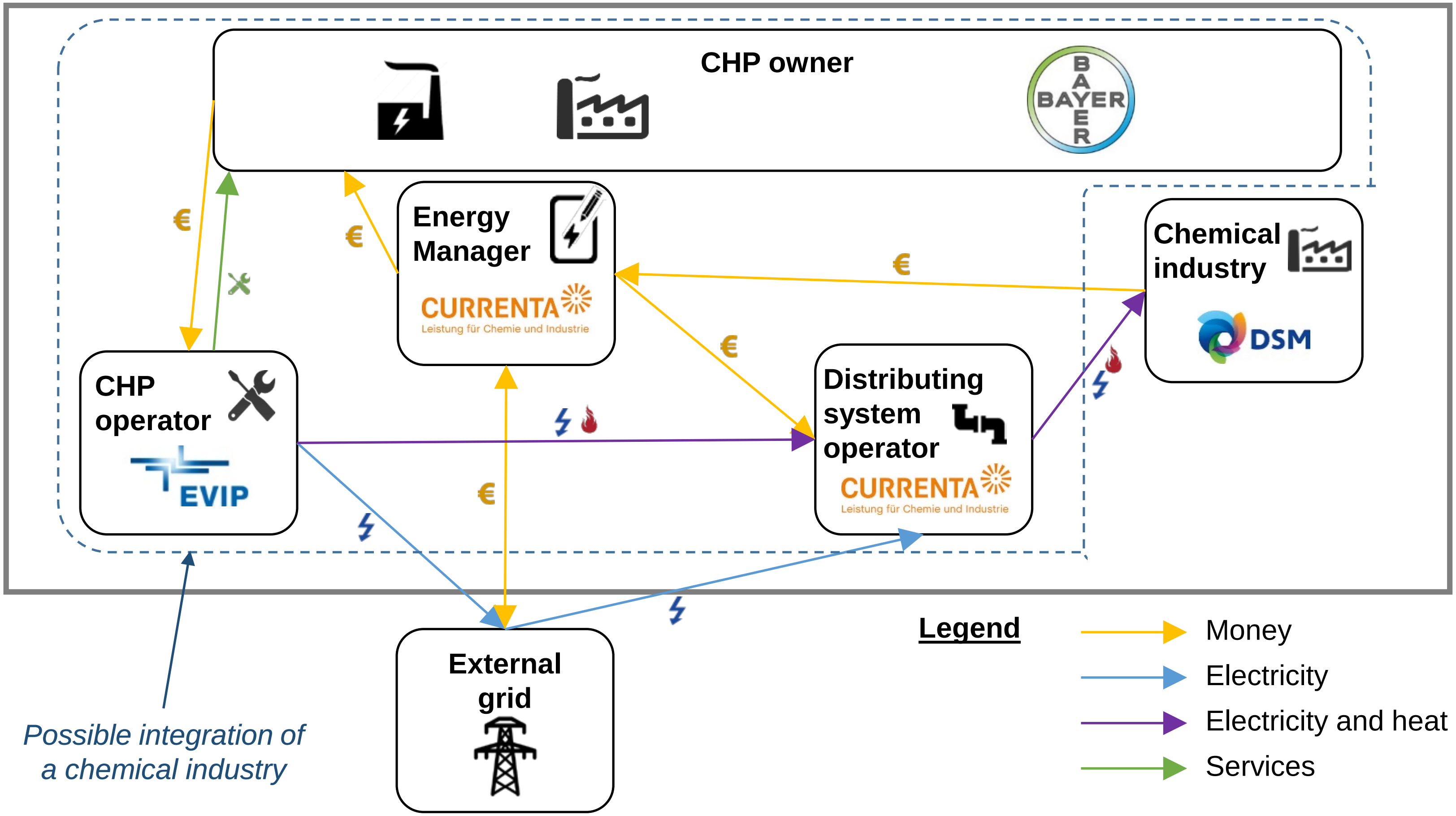
- **Case n°3: Integration with a chemical industry**



Case n°3: Integration with a chemical industry

BAYER BITTERFELD PARK (GERMANY)

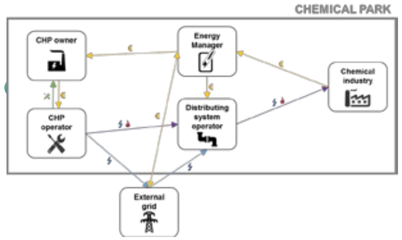


▪ End-user: chemical industry

END-USER: CHEMICAL INDUSTRY				
KEY PARTNERS	KEY ACTIVITIES	VALUE PROPOSITION	CUSTOMER RELATIONSHIPS	CUSTOMER SEGMENTS
	- Production of chemicals R&D - Waste management - Ensuring security - Transporting chemicals	- Sell chemical products - Reduce CO2 emissions - Develop Green chemistry		
	KEY RESOURCES		CHANNELS	
	- Energy (heat + electricity) - Raw materials - Processes and boilers			
COST STRUCTURE	- Energy costs (~50% of the production costs) - Raw materials - Investment for processes/land/boilers			REVENUE STREAMS

With an energy manager, chemical industries do not deal with energy issues and can **focus more on their core business.**

▪ Case n°1: non-integrated energy manager



CASE N°1: NON-INTEGRATED ENERGY MANAGER				
KEY PARTNERS	**KEY ACTIVITIES**	**VALUE PROPOSITION**	**CUSTOMER RELATIONSHIPS**	**CUSTOMER SEGMENTS**
- CHP owner - Distributing system operator - Utility (external grid)	- Negotiates contracts with industries - Buys electricity from the grid	- Ensures the supply of heat and electricity 24-7 with given characteristics (V, T°, P, etc.) - Supplies energy at best prices	- Enables the chemical industries to focus on their core business	- Industries located on the park
	KEY RESOURCES		**CHANNELS**	
	- Negotiation skills - Juridical workforce		- Direct relationships (onsite)	
COST STRUCTURE	- Energy bought from CHP operator	- Contracts from industries - Money from surplus electricity to the grid	**REVENUE STREAMS**	

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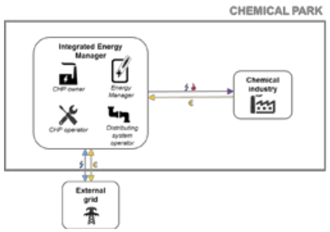
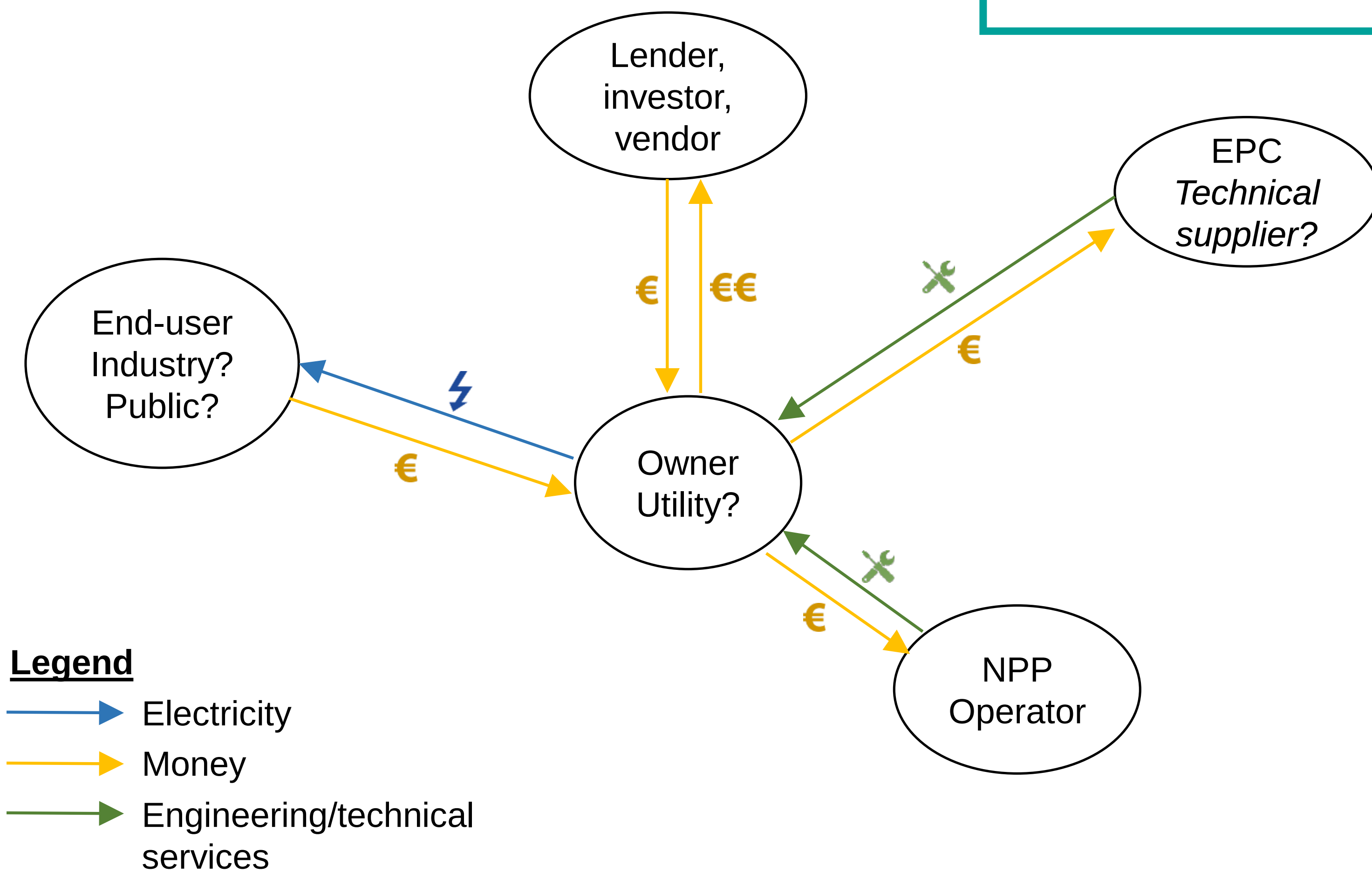
- **Case n°2: energy manager integration**



CASE N°2: ENERGY MANAGER INTEGRATION				
KEY PARTNERS	**KEY ACTIVITIES**	**VALUE PROPOSITION**	**CUSTOMER RELATIONSHIPS**	**CUSTOMER SEGMENTS**
- External grid	- Negotiates contracts with industries - Buys electricity from the grid - Operates CHP plant and distribution network	- Ensures the supply of heat and electricity 24-7 with given characteristics (V, T°, P, etc.) - Supplies energy at best prices	Enables the chemical industries to focus on their core business	Industries located on the park
	KEY RESOURCES		**CHANNELS**	
	- Negotiation skills - Juridical workforce - Distributing system - Technical workforce - CHP plant		Direct relationships (onsite)	
COST STRUCTURE	- Energy bought from CHP operator - Coupling system investment - CHP investment - O&M CHP costs		Contracts from industries Money from surplus electricity to the grid	**REVENUE STREAMS**

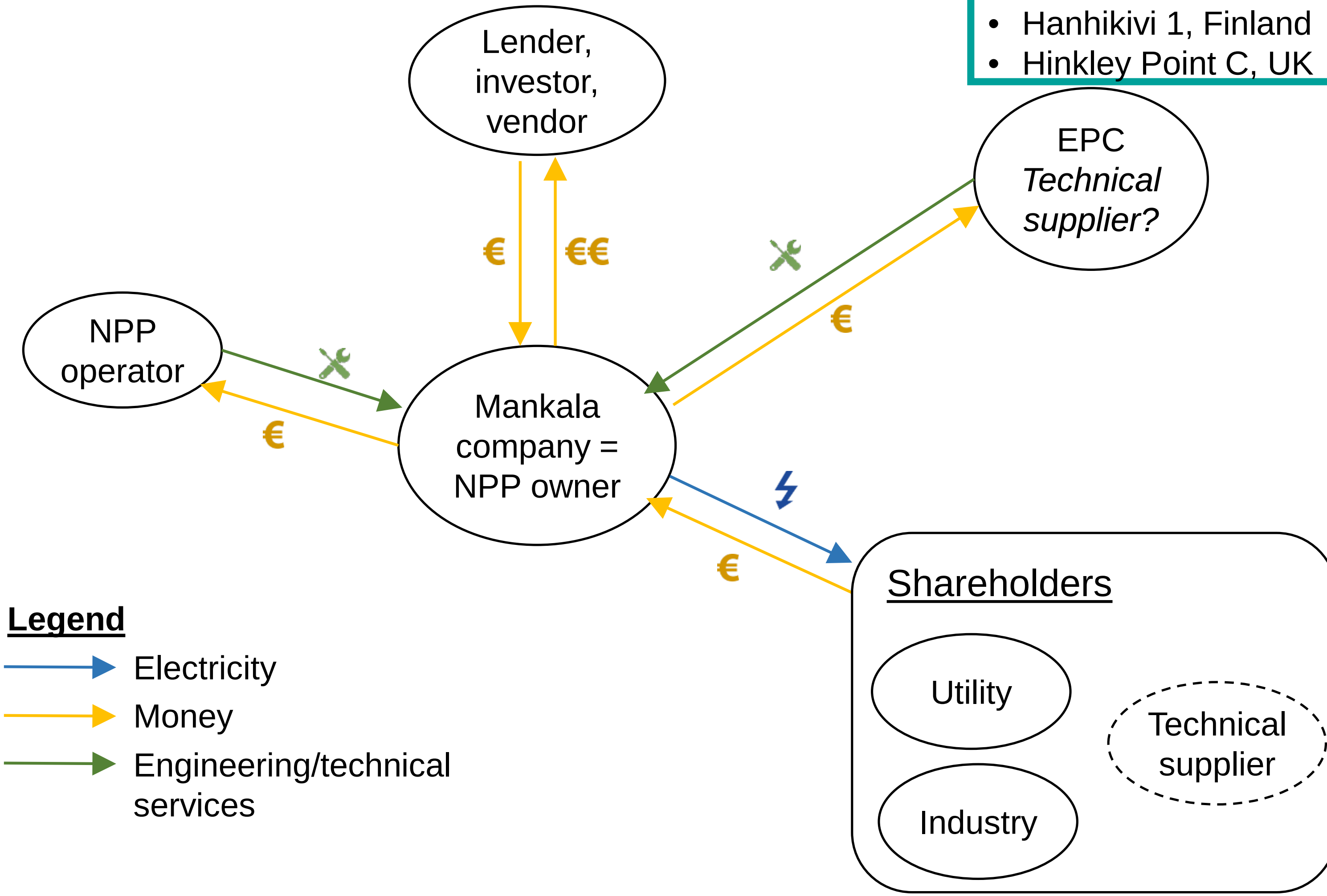
- **Case n°1: Standalone entity**

Example plants:
- Loviisa 1 & 2, Finland



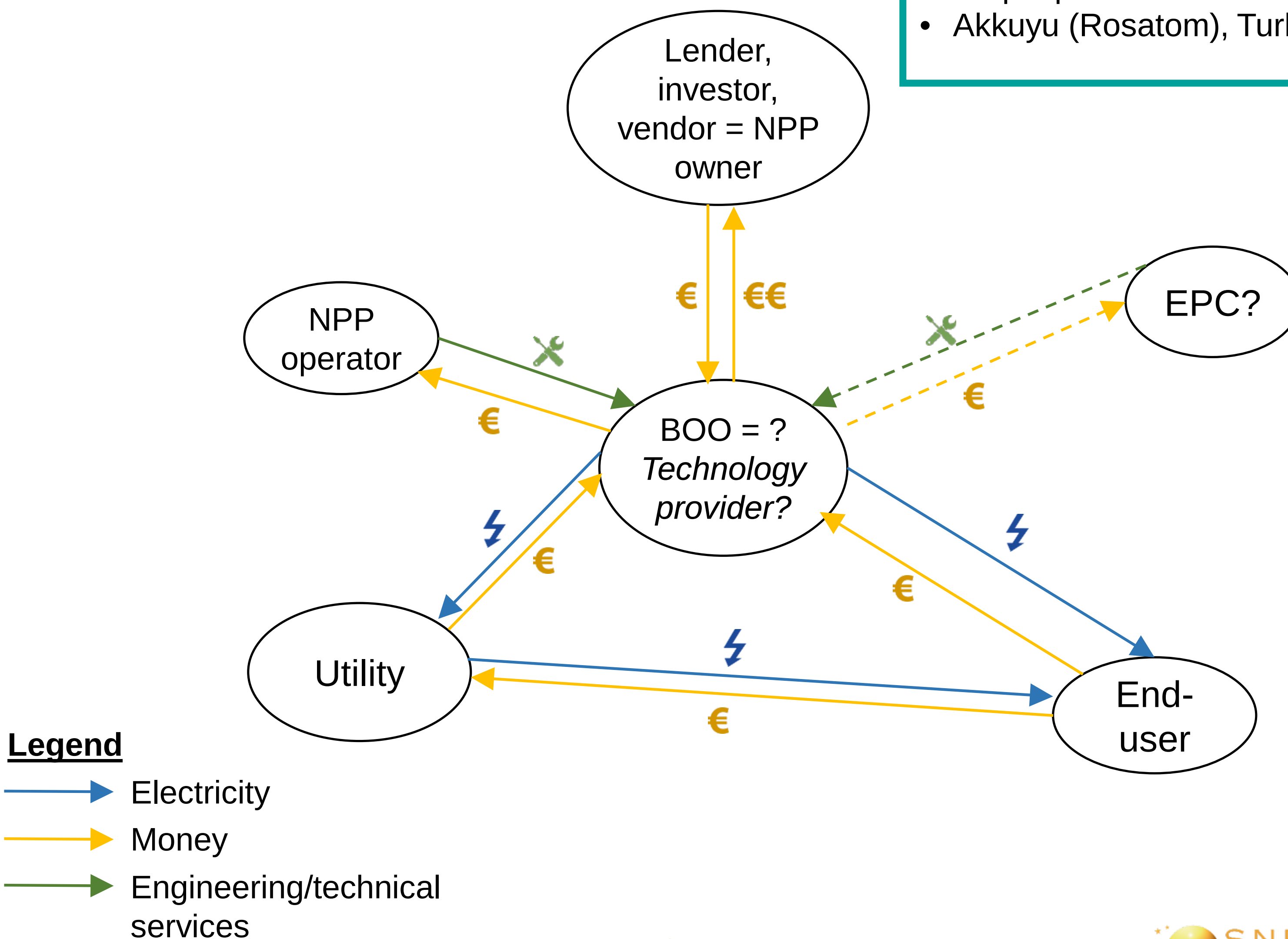
- **Case n°2: Co-owned generation plant**

Example plants:
- Olkiluoto 3, Finland
- Hanhikivi 1, Finland
- Hinkley Point C, UK



- **Case n°3: Build-Own-Operate**

Example plants:
- Akkuyu (Rosatom), Turkey



1-Scope & objectives

2- Market opportunities

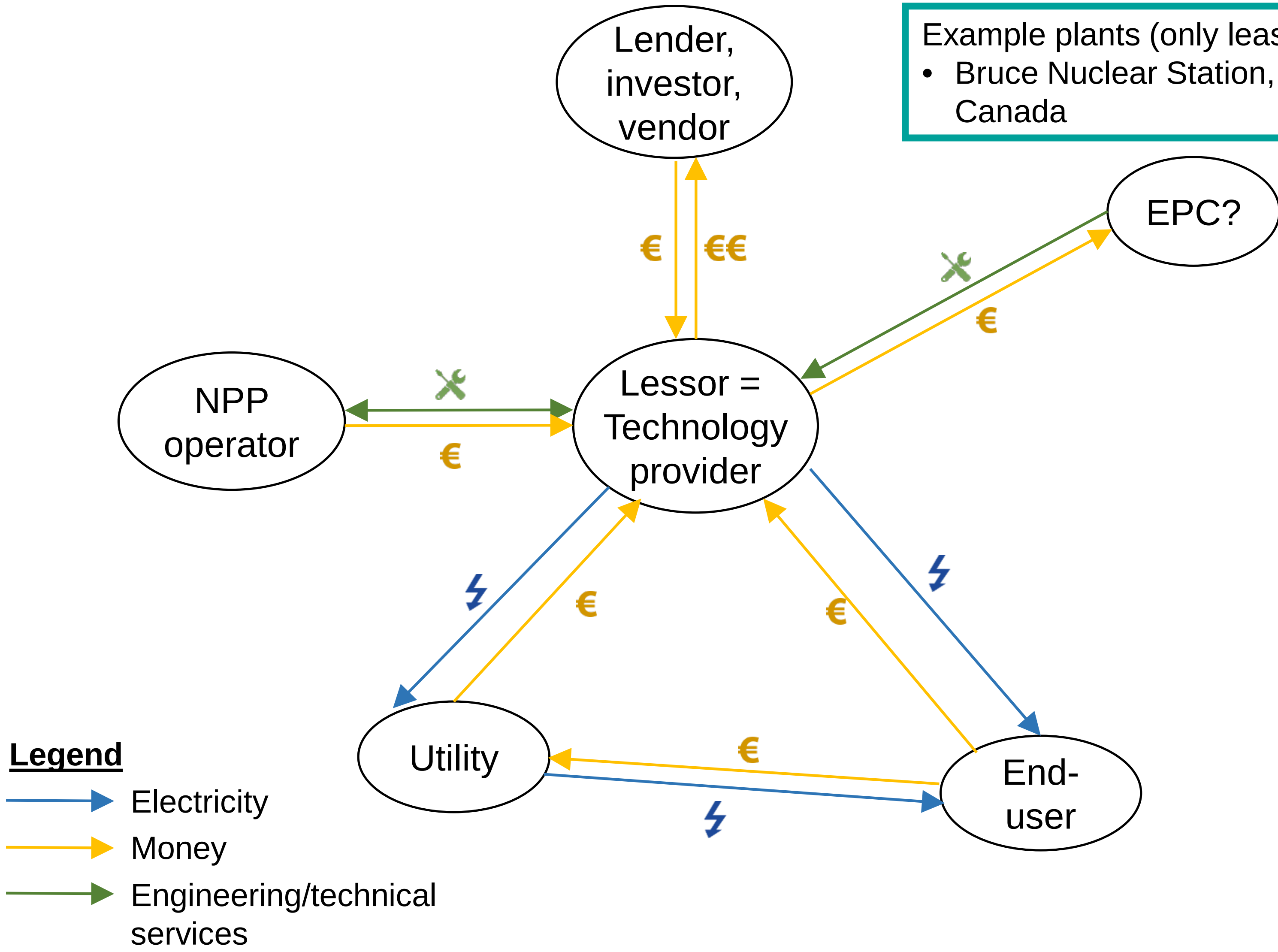
3- BM chemical park

4- Ownership models NPP

5- BM coupled system

- **Case n°4: Lease-to-own**

Example plants (only lease):
- Bruce Nuclear Station, Canada



- **Roles and risks in the ownerships models**

Roles	**Standalone entity**	**Co-owned generation plant**	**Build-Own-Operate**	**Lease-to-Own**
Utility	Full ownership	Partial ownership	Purchasing energy	Purchasing energy
Industry	Purchasing energy	Purchasing energy / Partial ownership	Purchasing energy	Purchasing energy
Vendor	Sell equipment and services	Sell equipment and services / Partial ownership	Full ownership	Fixed-term ownership

Risks	**Standalone entity**	**Co-owned generation plant**	**Build-Own-Operate**	**Lease-to-Own**
Utility	Depends on a market, may be high	Moderate	Low	Low
Industry	Low	Moderate	Low	Low
Vendor	May be high (turnkey delivery)	May be high (turnkey delivery) / Moderate (ownership)	Depends on a market, may be high	Depends on a market, may be high

NC2I Nuclear Cogeneration Industrial Initiative

Business models of a chemical park

Ownerships models for a NPP

- Several possibilities of business models
- New actors: EPC, lenders
- Only possible involving of a chemical industry through a Mankala company (co-owned generation plant)
- Energy Manager: decision-making actor, must include him in the Business Group

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Opportunities resulting from HTR powering a chemical park

- **Integration of nuclear actors** downstream in the value chain as Energy Manager
- **Energy storage**: store extra energy under another form through innovative technologies: production of hydrogen, coal-to-liquid, etc.
- Supplying **district heating** to a town located close to the chemical park
- Development of **new industrial parks**

Conclusion

- HTR can serve process industry with continuous heat and electricity delivery to its processes.
- The chemical industry presents the best opportunities for the implementation of high temperature nuclear cogeneration in a short-term view.
- Several business models exist depending on the integration of the different stakeholders and the ownership models of the NPP.
- Risks of a new technology such as HTR and markets can be shared through long-term contracts or by sharing the ownership with relevant parties

Thank you for your attention!

Contacts:

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riitta.stahl@fortum.com

CASE N°2: ENERGY MANAGER INTEGRATION

KEY PARTNERS	KEY ACTIVITIES	VALUE PROPOSITION	CUSTOMER RELATIONSHIPS	CUSTOMER SEGMENTS
Distribution system operator Utility (external grid) Heat & electricity consumers	Heat and electricity production Heat delivery to nearby industrial sites	The supply of heat and electricity 24-7 with given characteristics (V, T°, P, etc.) Long-term delivery of energy at nearly stable price CO_2 free energy	Long-term contracts Enables the chemical industries to focus on their core business	Industrial heat and electricity customers on the park Electricity markets/Electricity consumers (District heating customers)
	KEY RESOURCES		**CHANNELS**	
	HTR plant Negotiation skills Juridical workforce Distribution system Technical workforce		Direct relationships (onsite) Heat delivery system Electricity grid	

COST STRUCTURE	HTR investment O&M costs Personnel costs Fuel costs	Long-term contracts Electricity sales to the market Electricity/heat sales to end-consumers	**REVENUE STREAMS**

Conclusion

- HTR can serve process industry with continuous heat and electricity delivery to its processes
  - The chemical industry presents the best opportunities for the implementation of high temperature nuclear cogeneration
    - *The sector uses cogeneration*
    - *The required temperatures correspond to the output of an HTR*
    - *The power capacity of several parks is large enough to be compatible with the size of an HTR*
    - *Strong willingness to decrease the CO_2 emissions*
  - In the steel industry many processes require high temperature steam (above 700°C)
  - The hydrogen production mainly uses the SMR process, which is a possible application for HT nuclear cogeneration
  - The CTL (Coal To Liquid) and the CCS (Carbon Capture and Storage) technologies are also potential applications for HT nuclear cogeneration
    - *CTL requires temperatures between 450°C and 800°C which are compatible with HTR's output temperature*
    - *The CCS technologies could be applied to highly-emissive industries such as the chemical, steel, cement and refining industries*
- Risks of new technology and markets can be shared through long-term contracts or by sharing the ownership with relevant parties
  - Utility needs the electricity to be delivered to its customers
  - Utility may need district heat to its customers
  - Industry needs CO_2 free electricity and heat to its process with competitive price level
  - Vendor needs a demonstrator for its technology

Economics of nuclear cogeneration: an EU/US comparison

Workshop NC2I - Brussels
Pierre-Marie PLET
March 18. 2015

Contents

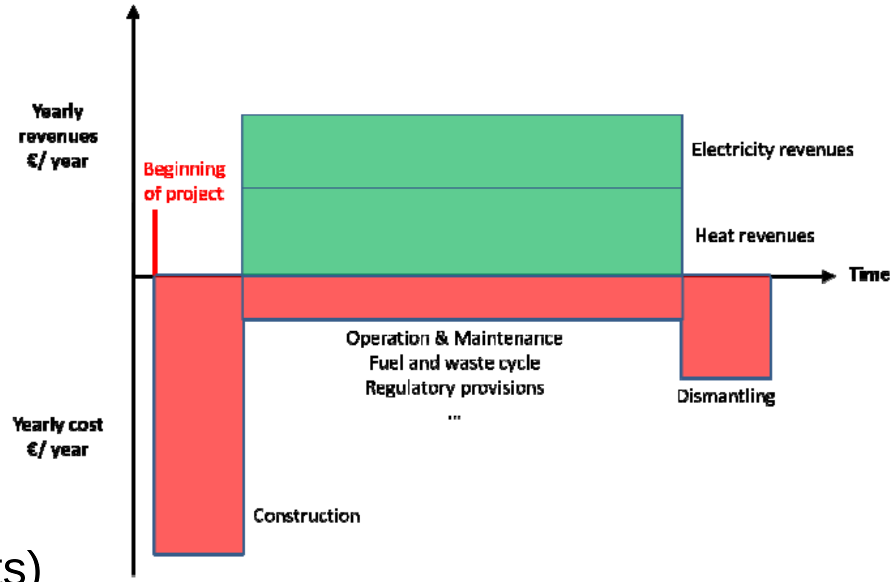
- Plant financial evaluation
- Reference case
- Comparison US/EU for main parameters
- Calculation results and sensitivity analysis
- Energy needs identified in the site mapping
- Preliminary conclusions

Evaluating a nuclear cogeneration project

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

- Emerging trends:
  - Small is beautiful…
  - Ensure/increase revenues (or benefits)
    - Feed-in tariffs (e.g. UK)
    - Cogeneration
    - (energy storage ?)

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



$$NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + ... + \frac{C_T}{(1+r)^T}$$

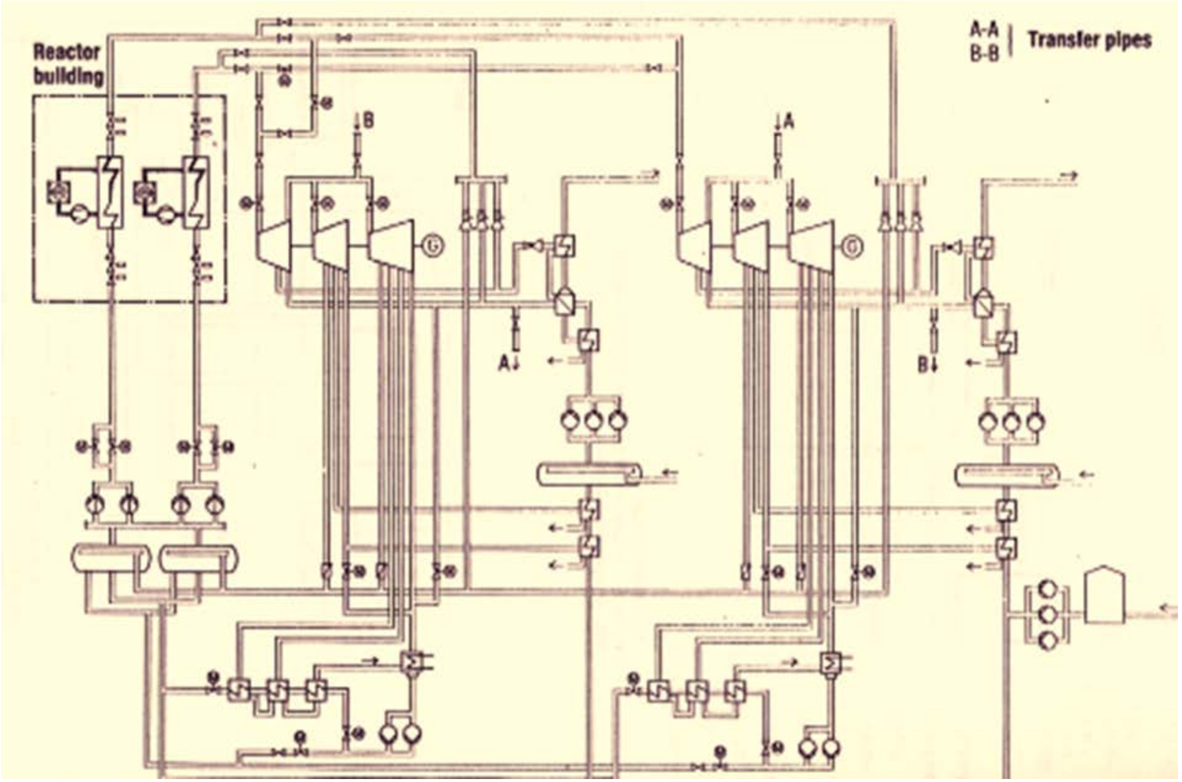
$-C_0 = Initial\ Investment$
$C = Cash\ Flow$
$r = Discount\ Rate$
$T = Time$

Case study based: Chemical plant in Germany

Data AREVA (provided in the frame of the NC2I project). 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.

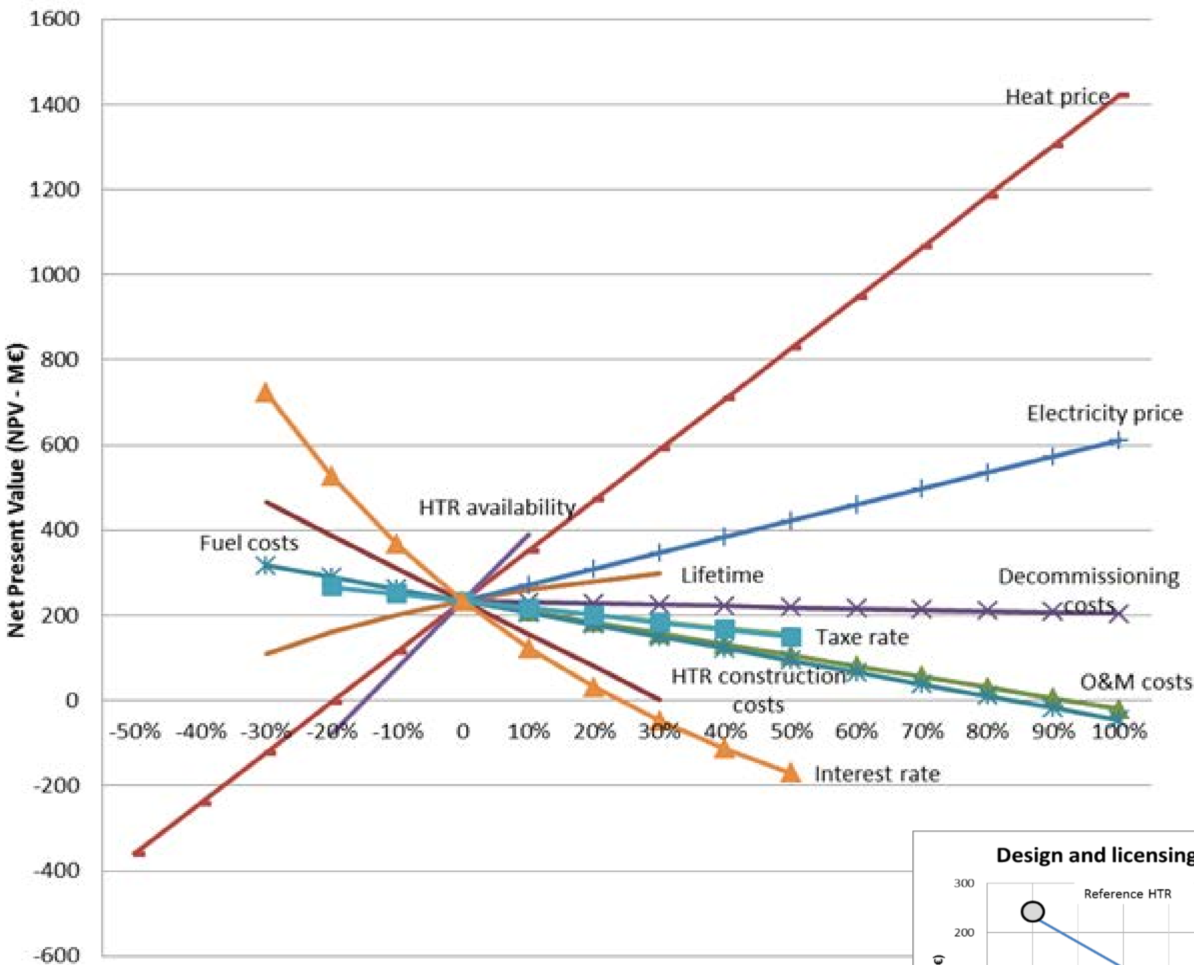
- Legal and economic conditions of Germany
- Plant is integrated in the site of the chemical complex
- due to the special requirements the plant is equipped with two diverse process steam lines in parallel and two turbine sets (in case of a shutdown of one module always 50% of the steam is ensured)
- On-site manufacturing of the large components (pressure vessels) is required
- Data : 500MWth (2x250)
  - 387.63 MWth(net) steam
  - 98.25MWel(net)
- Process steam :
  - 19 bar, 250°C, 42.9 kg/s
  - 3.5 bar, 139°C,104.3 kg/s



US / EU comparison – Main inputs for the model

	EU	US
Configuration	2 x 250 MWth	4 x 625 MWth
Overnight costs (rate:1,07 $/€ !)	1862 €/kWt	2200 $/kWt
O&M costs	6,23 €/MW.t	4,9 $/MWt.h
Lifetime	40 years	60 years
Reference gas price	35 €/MWh + 10 €/t CO_2	6-8 $/MMBtu (20-27 $/MWh)
Design development costs	Excluded	4 scenarios
Technical basis	Near-term applications (750°C outlet temperature, SG, plug-in market)	

Sensitivity analysis for most influent parameters



Reference case:

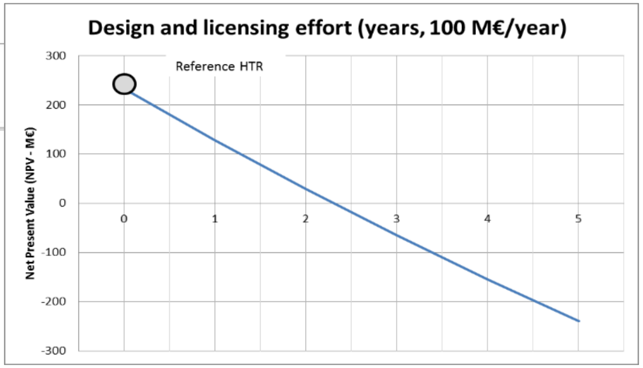
- NPV: + 233 M€
- IRR: 9,9 %
- Positive NPV after 24 years

If electricity production:

- LCOE = 81,6 €/Mwe.h

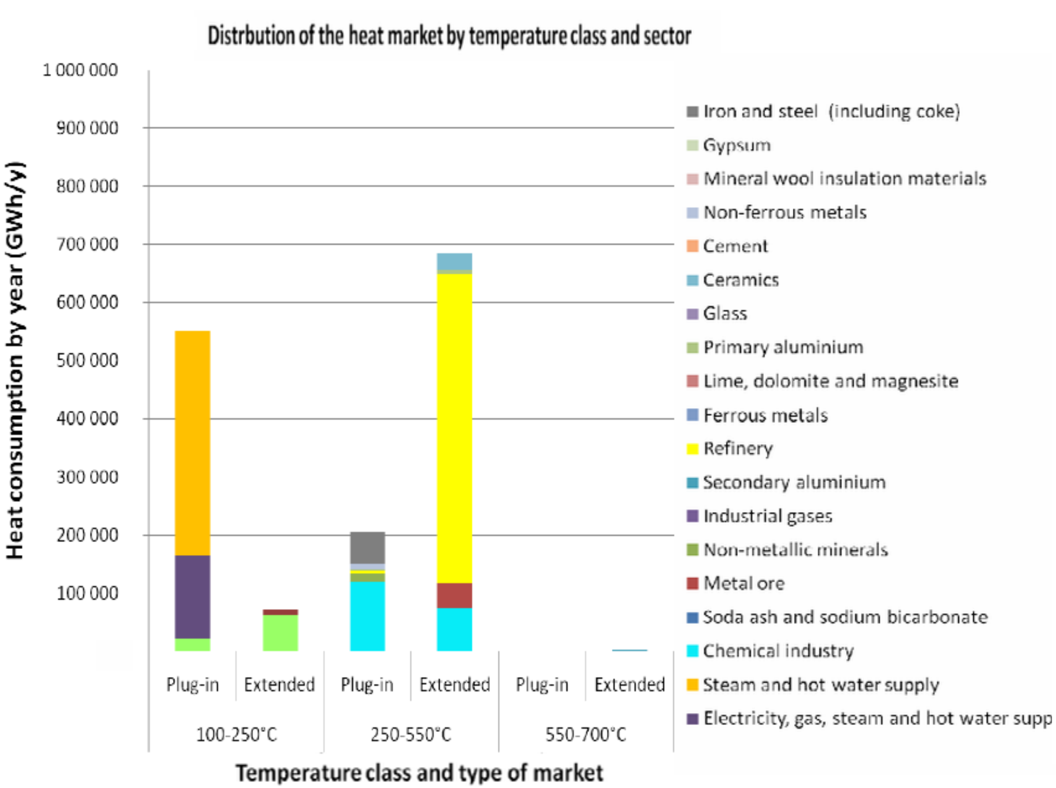
External factors:

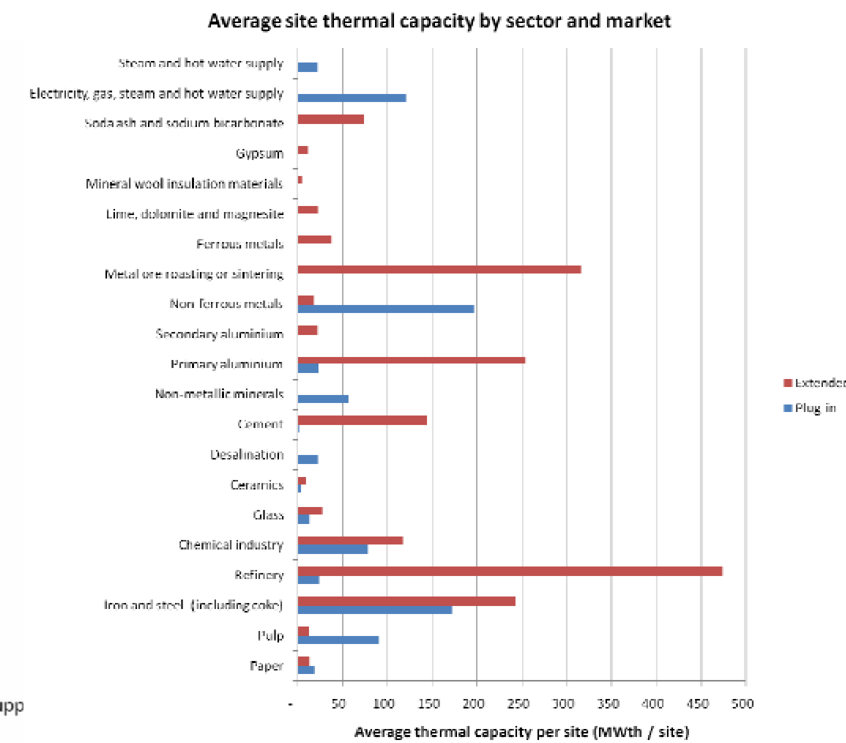
- High influence of heat price (with high impact of CO_2 prices)
- Influence of electricity prices
- Moderate influence of lifetime



Heat market overview

- Minimize design and project risks (at least for the 1st project(s))
  - Limitation of “technology gaps” : Outlet Temp. 750°C (Steam 550°C)
  - Limitation of customer‘s risks: Plug-in market targeted



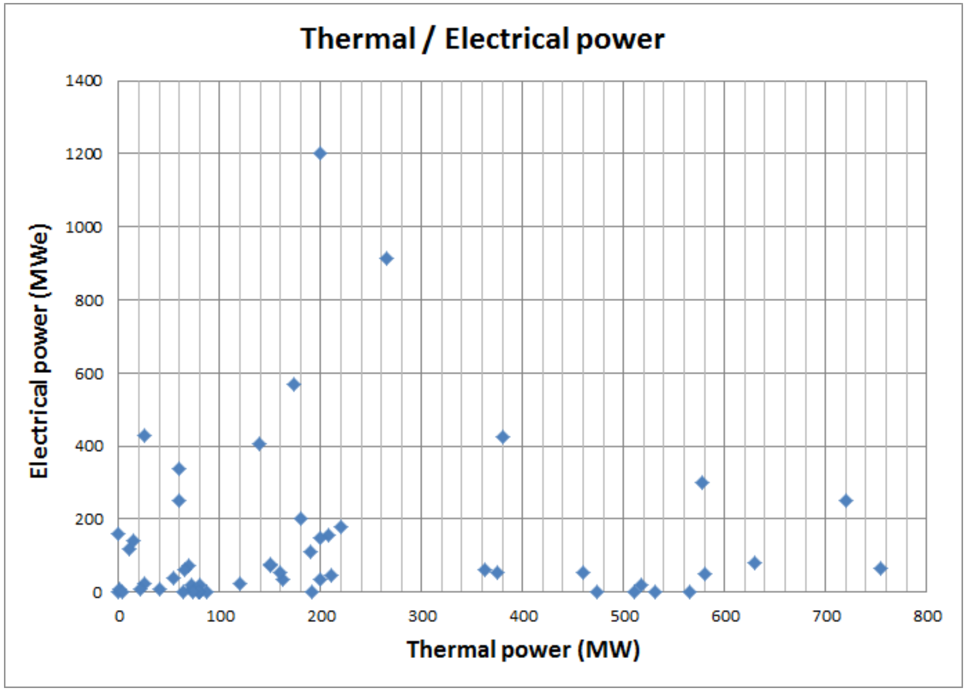


* Reminder: 2x250 MW = 4000 GWh/y

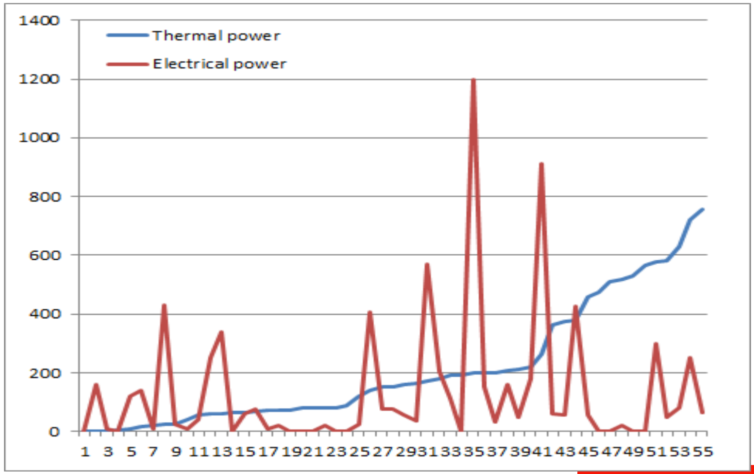
Results of the site mapping (NC2I - Task 4.2)

- Minimize design and project risks (at least for the demonstrator)
  - Limitation of “technology gaps” : Outlet Temp. 750°C (Steam 550°C)
  - Limitation of customer‘s risks: Plug-in market targeted

- 132 chemical complex investigated, data provided for 57 sites.



- 20 chemical sites > 150 MW (PlugIn)
- 1 site > 2000 MW.th
- 1 site > 2000 MWe



Preliminary conclusions and challenges

- An HTR design, supplying energy to a chemical complex is profitable in the reference case calculated with penalising assumptions (especially for CO2 prices and Electricity prices).
- A case with electricity-only production would hardly compete with current alternative electricity sources (Hydro, Coal, large nuclear).
- 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.

Thank you for your attention…

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Nuclear Cogeneration Industrial Initiative

The European Nuclear Cogeneration Industrial Initiative: ***progress status, way forward***

Kajetan Różycki

NCBJ, Poland

Chairman of NC2I Task Force,

18 March 2015, Brussels

www.nc2i.eu

NC2I is one of SNETP's strategic technological pillars, mandated to coordinate the demonstration of high temperature nuclear cogeneration.

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Members of the NC2I:

NC2I is one of SNETP's strategic technological pillars, mandated to coordinate the demonstration of high temperature nuclear cogeneration.

Supporting projects:

European projects:

NC2I-R
Nuclear Cogeneration Industrial Initiative

europairs
End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

Archer
Advanced Reactor for Cogeneration of Heat & Electricity-R&D

National projects:

SYNKOPE

STAUB II

HTRPL

NETP's strategic technological pillars, mandated to coordinate the demonstration of high temperature nuclear cogeneration.

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POLAND: HTGRs for process heat („HTR*PL*”)

- Budget: $2m
- Goals:
  - Basic research on HTGRs
  - HTGR applications in various operating regimes (coal gasification, methane reforming)
  - Market review.

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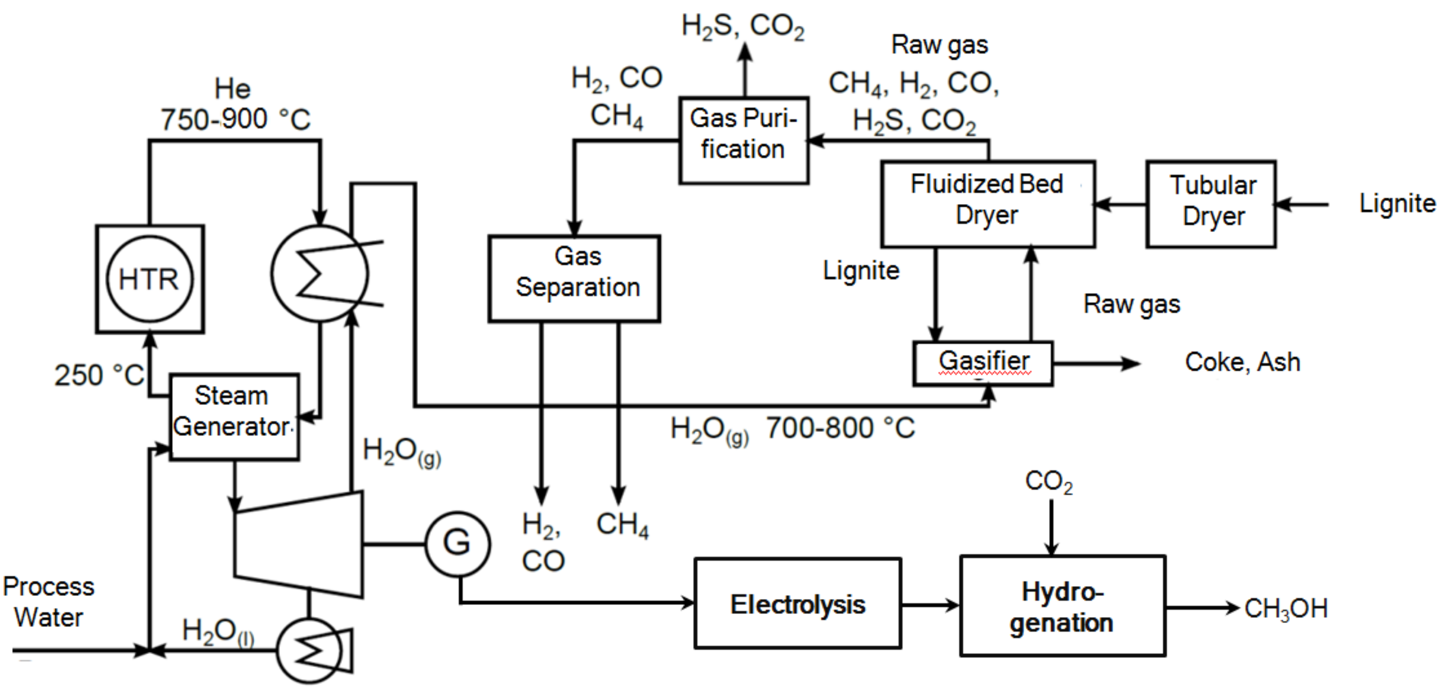
GERMANY: Synkope

- Work on gasification of lignite, using HTGR



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GERMANY: Staub-II

- Research on dust behaviour in high temperatures

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EU FP7: ARCHER project

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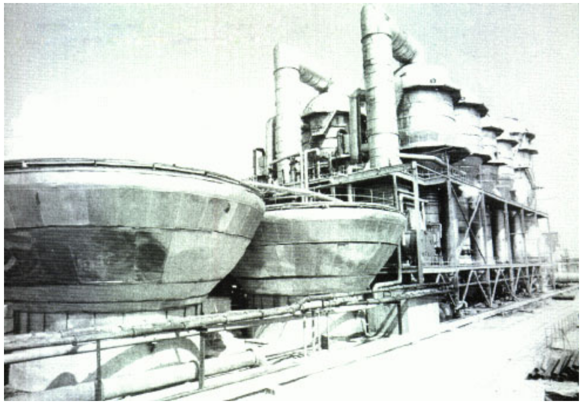
archer
Advanced Reactor
for Cogeneration of
Heat & Electricity-R&D

EU FP7: NC2I-R project:

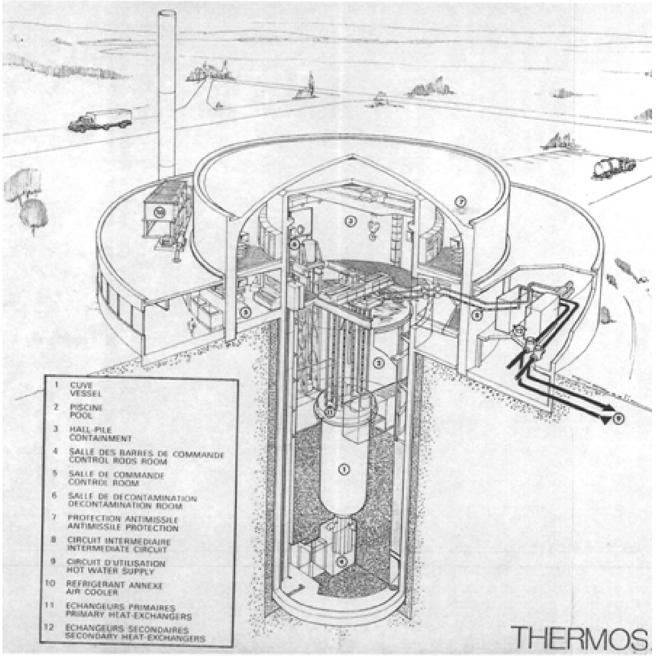
NC2I
Nuclear Cogeneration Industrial Initiative

- WP1: Structuration of NC2I
- WP2: Mapping of Infrastructures and competences
- WP3: Safety
- WP4: End-users
- WP5: Communication & Intl. Interactions.
- WP6: Management

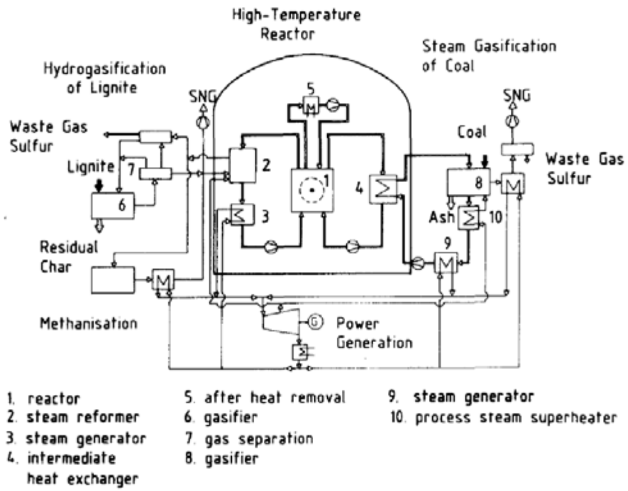
NC2I example activity: Mapping of past & present cogeneration projects



BN-350



Thermos



PNP-500

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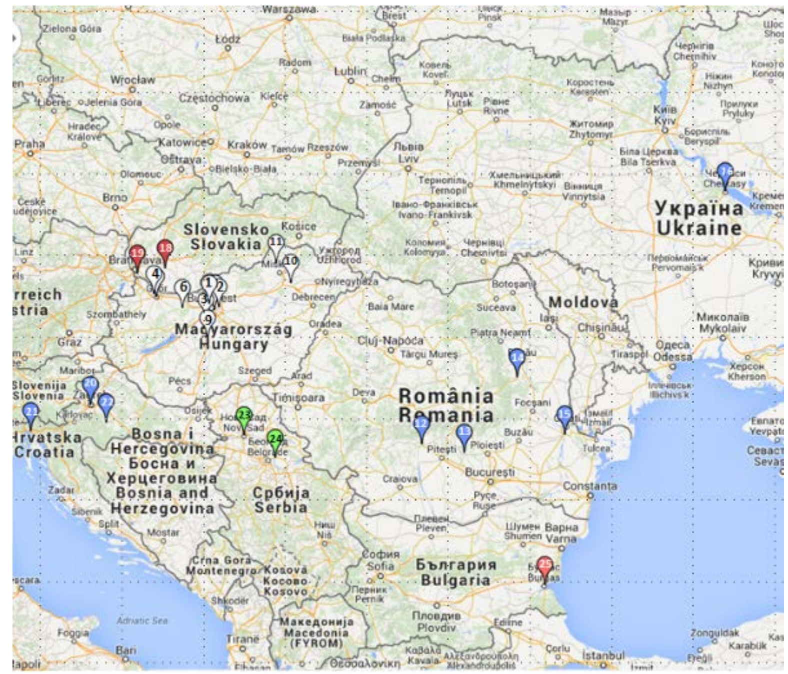
NC2I example activity: Mapping of Industrial Sites

Poland:

South-Eastern Europe:



Various data, including power and temperature requirements, for each site are available in D421 of NC2I-R (coordinated by PROCHEM)

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NC2I example activity: Mapping of Industrial Sites

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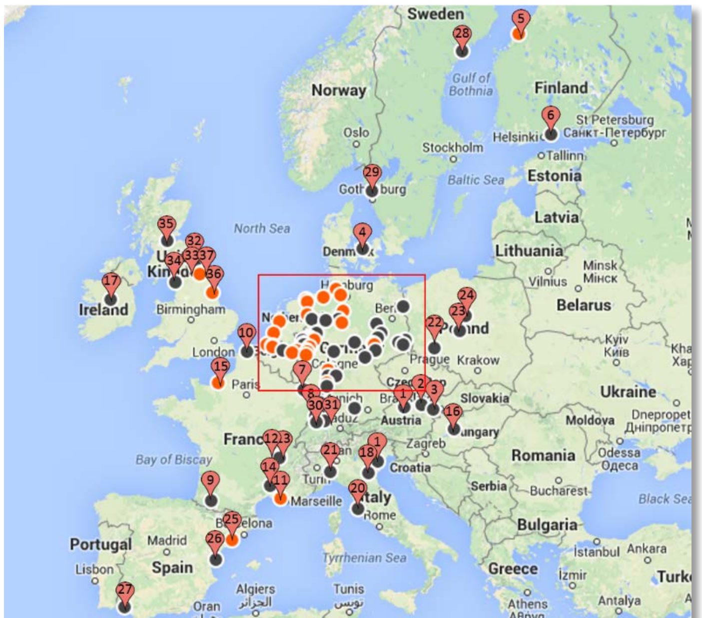
Western Europe:



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TWINS – our recent H2020 proposal

- Submitted to Euratom call in sept. 2014
- Budget: approx €4m
- Goal: joint EU-US design work on prototype plant

UNFORTUNATELY NOT SUCCESSFUL

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Worldwide progress:
Progress in China

- **HTR-PM plant** – under development (2×250 MWth, 210 MWe).
- **HTR-10** – operational (small prototype reactor at Beijing University).
- Construction progress shown at the HTR2014 conference in China

Photo: M. Fuetterer, JRC

Worldwide progress:
Progress in USA

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Piketon, Ohio (a.k.a. Portsmouth Gaseous Diffusion Plant)

•The NGNP entered discussion with managers of the site, as a potential **location** for the demo plant.

•Joint meeting (EU-US) scheduled in mid-April in Piketon

Worldwide progress:
Others:

- Japan (+ Indonesia)
- Korea
- US: X-Energy

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Thank you for your attention.

Any questions?

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GEMINI

A Trans-Atlantic Partnership to Accelerate the Development of Improved, Intrinsically Safe and Versatile Nuclear Energy Technology

The GEMINI Initiative

Presented by

Michael Fütterer (JRC-IET, NC2I) & Chris Hamilton (USNC, NGNP Industry Alliance)

Co-authors

From the NGNP Industry Alliance: D.J. Halter, M. Haynes, L. Sandell, F. Shahrokhi, C. Hamilton
From NC2I: C. Auriault, A. Bredimas, G. Brinkmann, M. Fütterer, D. Hittner, T. Jackowski, B. Wiechers, A. Racek, K. Rozycki, R. Schmitt, H. Tuomisto

On the basis of a common vision of the specific potential of HTGR for industrial deployment,

The NGNP Industry Alliance, based in the US

The Nuclear Cogeneration Industrial Initiative, based in Europe

decided to launch jointly the ***GEMINI Initiative****.*

What is the NGNP Industry Alliance?

www.ngnpalliance.org

- Formed in response to the U.S. Energy Policy Act of 2005
- Promotes the development and commercialization of modern HTGR technology ➔ recent milestones:
  - HTGR application studies of Waterford Louisiana site and of Canadian Oil Sands
  - HTGR assisted coal-to-liquids studies in 2 top U.S. coal states (Wyoming, Kentucky)
  - Worked with U.S. Congress and Administration to maintain strong funding for HTGR development work: approx. $600M since 2006
  - Close coordination with the Idaho National Laboratory
  - Completion of Business Plan in collaboration with U.S. Department of Energy
  - Selected for $3.2M Study of RCCS with Air Ingress by USDOE

Advanced Research Center

Manufacturing Excellence Consulting, Inc.

www.gemini-initiative.com 3

What is the Nuclear Cogeneration Industrial Initiative?

www.nc2i.eu

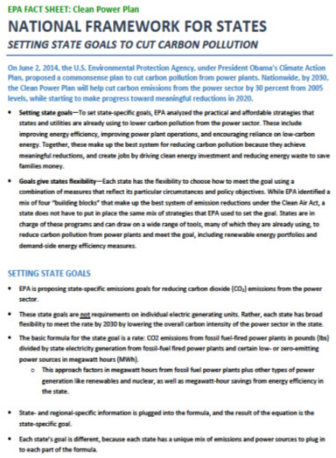
- NC2I was set up in 2011 as Europe's initiative for **nuclear cogeneration,** under the Sustainable Nuclear Energy Technology Platform (SNETP)
- HTGR was selected as the reference technology in order to reach **higher temperatures** for industrial applications
- NC2I builds on French &German legacy of 15 years of EU R&D programmes
- A **task force** gathers the nuclear developers, and a **business group** is currently being set up to structure a dialogue with end-users and investors

www.gemini-initiative.com 4

The global energy context: Worldwide concern for climate change

- In Europe, the SET-Plan fixed ambitious targets for reducing CO_2 emissions
  - - 40% by 2030

- In US, Clean Power Plan – EPA emission goals, June 2014
  - -30% by 2030



EPA FACT SHEET: Clean Power Plan

NATIONAL FRAMEWORK FOR STATES

SETTING STATE GOALS TO CUT CARBON POLLUTION

On June 2, 2014, the U.S. Environmental Protection Agency, under President Obama's Climate Action Plan, proposed a commonsense plan to cut carbon pollution from power plants. Nationwide, by 2030, the Clean Power Plan will help cut carbon emissions from the power sector by 30 percent from 2005 levels, while starting to make progress toward meaningful reductions in 2020.

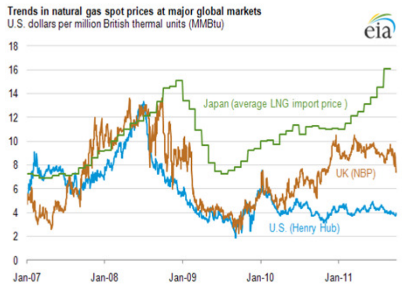
- **Setting state goals**—To set state-specific goals, EPA analyzed the practical and affordable strategies that states and utilities are already using to lower carbon pollution from the power sector. These include improving energy efficiency, improving power plant operations, and encouraging reliance on low-carbon energy. Together, these make up the best system for reducing carbon pollution because they achieve meaningful reductions, and create jobs by driving clean energy investment and reducing energy waste to save families money.
- **Goals give states flexibility**—Each state has the flexibility to choose how to meet the goal using a combination of measures that reflect its particular circumstances and policy objectives. While EPA identified a mix of four "building blocks" that make up the best system of emission reductions under the Clean Air Act, a state does not have to put in place the same mix of strategies that EPA used to set the goal. States are in charge of these programs and can draw on a wide range of tools, many of which they are already using, to reduce carbon pollution from power plants and meet the goal, including renewable energy portfolios and demand-side energy efficiency measures.

SETTING STATE GOALS

- EPA is proposing state-specific emissions goals for reducing carbon dioxide (CO_2) emissions from the power sector.
- These state goals are not requirements on individual electric generating units. Rather, each state has broad flexibility to meet the rate by 2030 by lowering the overall carbon intensity of the power sector in the state.
- The basic formula for the state goal is a rate: CO2 emissions from fossil fuel-fired power plants in pounds (lbs) divided by state electricity generation from fossil-fuel fired power plants and certain low- or zero-emitting power sources in megawatt hours (MWh).
  - This approach factors in megawatt hours from fossil fuel power plants plus other types of power generation like renewables and nuclear, as well as megawatt-hour savings from energy efficiency in the state.
- State- and regional-specific information is plugged into the formula, and the result of the equation is the state-specific goal.
- Each state's goal is different, because each state has a unique mix of emissions and power sources to plug in to each part of the formula.

The global energy context: Concern for security of energy supply

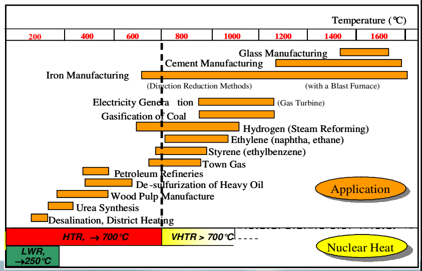
- The EU economy is significantly dependent on imported fossil fuel
  - High and volatile energy costs
  - Insecurity of supply due to international conflicts
  - ⇒ Concern about de-industrialization of Europe: unfavorable energy conditions contribute to relocation of industrial activities from Europe to other regions ("carbon leakage")



- US is currently flushed with cheap natural gas from fracking operation, however
  - Environmental concerns are brewing
  - Export to higher priced markets is expected to normalize worldwide price of natural gas

A shared vision of the assets and challenges for HTGR industrial deployment (1)

- Higher temperature than other present nuclear systems
  - ⇒ Possibility to operate in **cogeneration** mode with high **flexibility** for adjusting between electricity generation and process heat supply
  - ➢ A large market of industrial process heat supply identified in US and EU
  - ➢ New market for nuclear, not in competition with Gen III deployment
  - ➢ Very significant potential to contribute to
    - **Limitation of CO_2 emissions**
      - Industry responsible for 25% of European CO_2 emissions
      - Each 100 MWth of process heat supplied by HTGR would save yearly 140 000 t of CO_2 emissions if replacing natural gas and almost double if replacing coal
    - **Security of energy supply**



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A shared vision of the assets and challenges for HTGR industrial deployment (2)

- Unique intrinsic safety features
  - ➢ Even in worst case scenario, no significant core degradation and/or radioactive releases outside the reactor in accident condition
    - ⇒ Possible **co-location** with process-heat end-user industries
  - ➢ Simplification of the safety design
    - ⇒ Asset for **competitiveness**
- The most mature Generation IV technology
    - ⇒ Possibility of **early industrial deployment** with mostly proven technologies

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A shared vision of the assets and challenges for HTGR industrial deployment (3)

- Limited industrial experience with nuclear cogeneration until now, limited to lower temperatures
  - ⇒ Need for **industrial demonstration** of cogeneration with HTGR **as soon as possible** before large scale industrial deployment
- 3 phases for the demonstration program, with different leading actors and different level of financial (not primarily technical) risks

Design and licensing	Leader: designer	Significant risks
Construction Operation	Leaders: operator/end-user	Medium to low risks

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A shared vision of the assets and challenges for HTGR industrial deployment (4)

- Despite low technical risk, there are high risks in the first phase of the development of a new nuclear system
  - Large up-front costs (~ 1.5 G$ for completing design and licensing of prototype cogeneration HTGR) and long duration (about 7 years)
  - Timeframe for meeting regulatory requirements long and uncertain
  - Return on investment in 15 to 20 years

⇒Need to alleviate demonstration risks and make construction projects attractive for investors

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A shared vision of the assets and challenges for HTGR industrial deployment (5)

- Government funding would be needed to de-risk the project and would be in line with the government role:
  - Increased safety
  - Reduction of CO_2 footprint in industry
  - Increased job opportunities
  - Industrial energy supply security and diversity

Brussels, 24 June 2014
Signature of the MOU between NC2I and NGNP IA: the founding of GEMINI

⇒The NGNP Industry Alliance and NC2I decided to launch <u>the GEMINI Initiative</u> for facilitating this challenging phase by sharing the development efforts and the risks between US and Europe.

The GEMINI Initiative (1)

- The approach
  - Convergence of designs between Europe and the US
    - If possible same design
    - At least maximum convergence between both designs (e.g. most components identical, same fuel)
    - ⇒To reduce each partner's cost by sharing tasks
    - ⇒To combine the best engineering and research talents and means as well as the industrial capabilities both from the US and EU, including past experience and ongoing activities
  - Some residual differences may persist in order to address different market needs or regulatory requirements on both sides.
  - Industry and research organizations in the US and in Europe need to work under a strong international agreement to carry out the design and regulatory tasks, as well as the residual R&D and qualification.

The GEMINI Initiative (2)

- Main actors
  - ➢ Nuclear vendors
  - ➢ Research Centers
  - ➢ Governments
  - ➢ Investors
- Main outputs
  - ➢ Certified design
  - ➢ Identified supply chain
  - ➢ Qualified components
  - ➢ Sites for demonstration in the US and in Europe
  - ➢ Operator / end-users partnership for construction and operation

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A first action of the GEMINI Initiative: the TWINS proposal

- In September 2014, NC2I and NGNP Industry Alliance members have proposed a project in the **Euratom** call for proposal:

TWINS *[Transatlantic Working partnership for Intrinsic Nuclear Safety] scored very well but still awaiting funding*

- Key objectives
  - ➢ To select the main design options of the HTGR cogeneration system with the aims of
    - Maximum competitiveness
    - Enhanced safety
    - Maximum convergence between NC2I and Alliance designs
  - ➢ To define a safety approach for licensing and have it reviewed by TSOs
  - ➢ To elaborate a roadmap for the GEMINI Initiative, sharing its development program between US and EU partners
- Targeted outcome (2017): the technical and funding basis for starting the design and licensing of the prototype plant jointly in the US and in Europe

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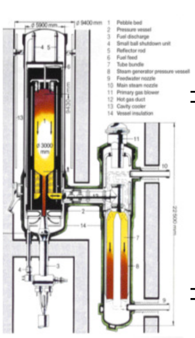
Basis for the HTGR cogeneration system design (1)

- To use the HTGR modular concept
  - For enhanced safety, economic competitiveness and adaptation to end-users needs
- To benefit from steam networks already in operation on large industrial sites:
  At least for the first applications, the coupling between the nuclear heat source and the process heat applications will be a **standardized "plug-in" coupling**, with the HTGR system substituting a conventional cogeneration plant

Basis for the HTGR cogeneration system design (2)

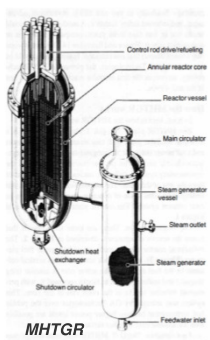


HTR-Modul

⇒No need for HTGR outlet temperature to exceed 700-750°C and process steam to exceed 550-600°C

⇒Possibility to rely on mature designs with steam generators and secondary steam cycle (HTR-Modul, MHTGR, etc.), adapting them to present regulatory frameworks

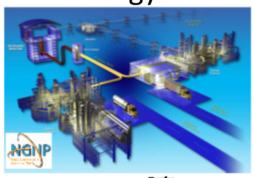
⇒Use of existing nuclear industry-proven materials for main components – Helium Pressure Boundary and Steam Generator

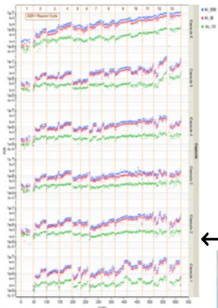


MHTGR

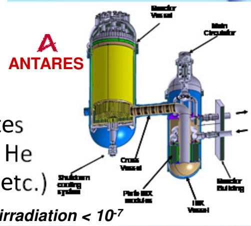
Basis for the HTGR cogeneration system design (3)

- Nevertheless, as long as no additional risks and delays are induced, to assess the benefit from progress of technology and **innovations** drawn from the most recent design experiences in Europe and in the US (ANTARES, NGNP…) or emerging from the GEMINI Initiative:





- Recent graphite grades selected by the European and US R&D
- The fuel developed in the US and being presently qualified in the AGR program
- Use of advanced technologies (composites for control rod cladding, membranes for He purification, advanced instrumentation, etc.)



← *Fraction of produced fission products released in the AGR 1 irradiation < 10^{-7}*

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Second Action of GEMINI: Piketon Ohio Site In the U.S.

- April 2015: NIA partners with the Southern Ohio Diversification Initiative (SODI) to develop HTGR-based Integrated Energy System at the Department of Energy's Piketon Site
- Piketon site is one of two large U.S. government-owned uranium enrichment sites. Currently in cleanup status: 3700 acres (1500 hectares)
- SODI is the officially recognized entity that will own the land as clean up is completed
- Strong local support for repurposing the site for nuclear power and integrated energy

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Second Action of GEMINI: Piketon Ohio Site in The U.S.

(continued)

- NC2I visit to Piketon in April, 2015. Attendance from U.S. DOE, NIA, SODI, U.S. Congress representatives Idaho National Laboratory and local governments
- NIA / SODI partnership moving forward on multiple fronts including project scoping, economic studies, approaching industrial partners and investors, and broadening base of political support
- Strong SODI support for partnership with EU and the identification of a partner site in Europe

Moving forward

- Currently the construction of HTR-PM is a major step for modern HTGR technology, paving the way to industrial deployment of modular HTGR
- The GEMINI Initiative focuses on the design and certifications required for bringing HTGR technology to the US and European industrial process heat market
- With the TWINS proposal, GEMINI is making a first step to move forward
- GEMINI partners welcome international support to their initiative