FISA 2019
9th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
4-7 June 2019
Pitesti, Romania

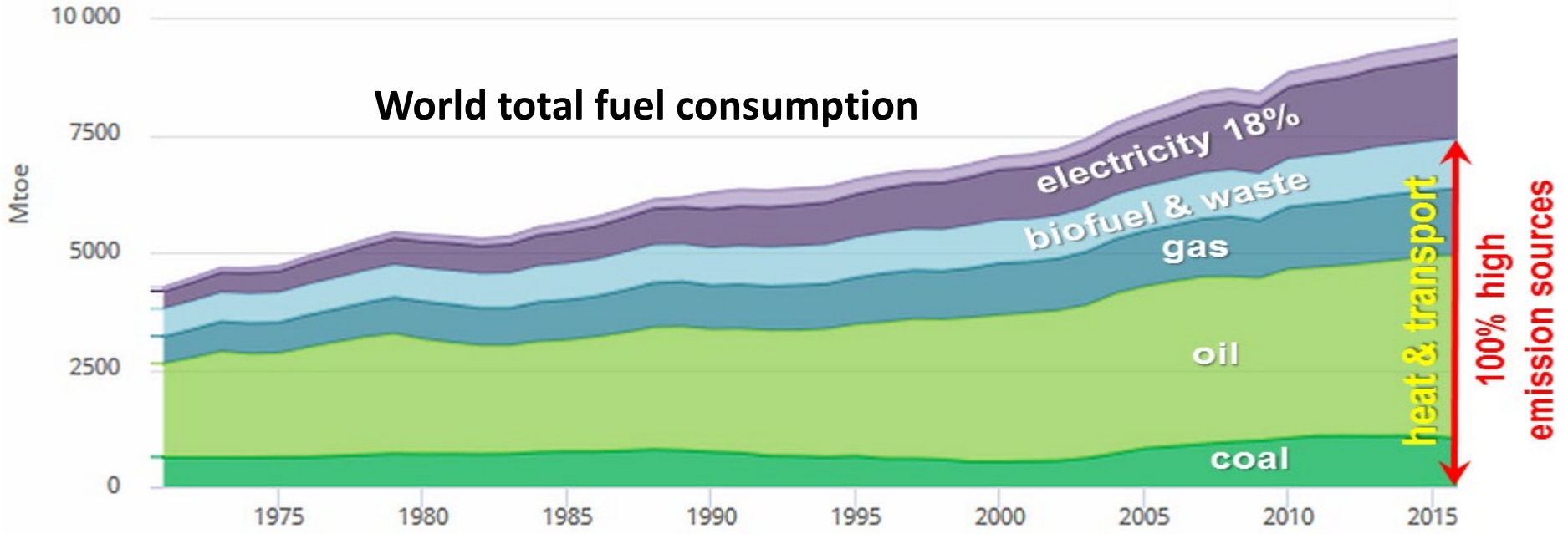
Nuclear Cogeneration with High Temperature Reactors

NC2I-R and GEMINI+ projects

www.nc2i.eu www.gemini-initiative.com

Grzegorz Wrochna
National Centre for Nuclear Research, Poland

Clean energy challenge - beyond electricity



- **Reducing to zero emission from electricity production would solve only 1/6 of the problem**
- **Industry needs high temperature heat (>500°C)**
- **Synthetic H-rich fuels for electric cars with fuel cells is the future of transport (>700°C heat needed to produce them)**

Tools to be used: SET-Plan, SNETP, NC2I

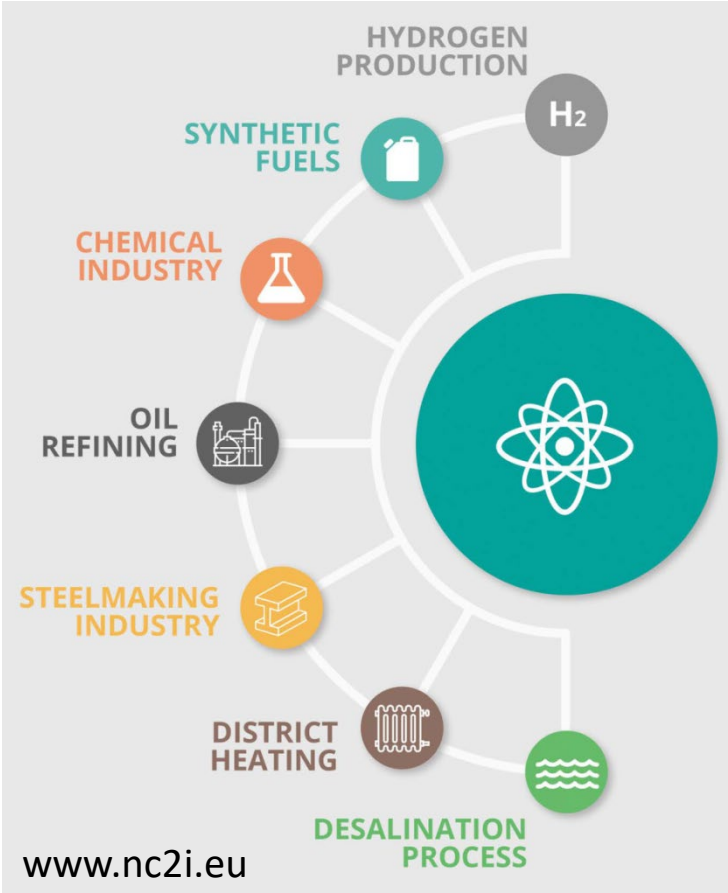
The European Strategic Energy Technology Plan (SET-Plan) includes several energy technologies.

Each one is covered by corresponding European Technology & Innovation Platform.

Nuclear Cogeneration Industrial Initiative (NC2I) is one of three pillars of Sustainable Nuclear Energy Technology Platform SNETP Sustainable Nuclear Energy Technology Platform

NC2I Nuclear Cogeneration Industrial Initiative mission:

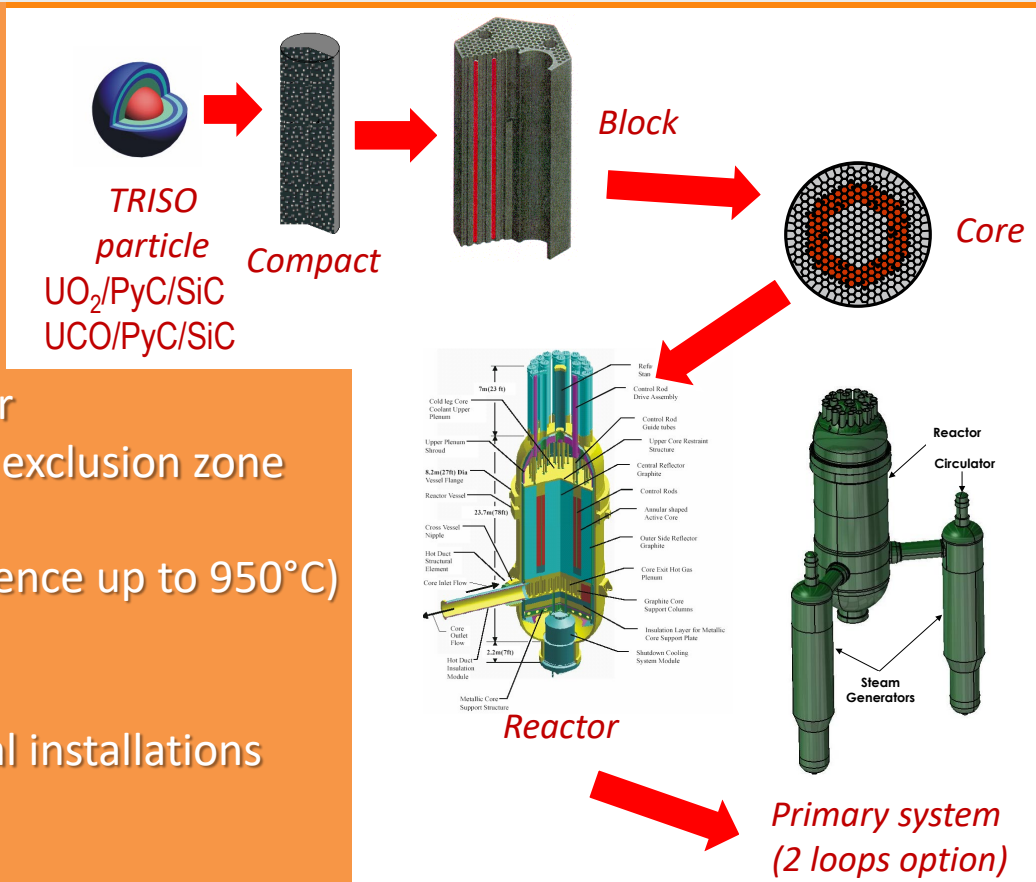
Contribute to clean & competitive energy beyond electricity by facilitating deployment of nuclear cogeneration plants



www.nc2i.eu

High Temperature Gas-cooled Reactor (HTGR)

- **TRISO fuel:**
  - Leak tight to fission products <1600°C
  - Pebble-bed or prismatic core
- **Intrinsic safety:**
  - In case of accident, cools down by conduction & radiative heat transfer
  - No core damage possible, no need for exclusion zone
- **Coolant:** Helium ~750°C -850°C (experience up to 950°C)
- **Flexibility:** T°, power, heat/electricity adaptable for industry needs
- **Now:** steam 550°C for existing industrial installations and cogeneration plants
- **Future:** VHTR ~1000°C



Challenges: deployment, business model, licensing…

▶ Test reactors

DRAGON, U.K.
20 MW
1963-76

Peach Bottom, US
200 MWth
1967-74

AVR, Germany
15 MWe
1967-88

HTR-10, China
10 MWth
since 2000

HTTR, Japan
30 MWth
since 1998

▶ Industrial prototypes

Fort Saint-Vrain, US
300 MWe, 1976-89

THTR, Germany
300 MWe, 1986-89

HTGR technology well proven
by experimental and industrial reactors

- Why HTGR's are not widely used today?
- What are the barriers?
- Who are potential users?
- How big is the market?
- What business model should be used?
- How to license HTGR?
- What is the optimal deployment path?

NC2I organised two projects addressing those questions:

NC2I-R
Nuclear Cogeneration Industrial Initiative

2013-15, ~1.8 M€

GEMINI+

2017-20, ~4 M€

Nuclear Cogeneration Industrial Initiative – Research project

Partners from Europe + NWU, South Africa + FZJ, Germany

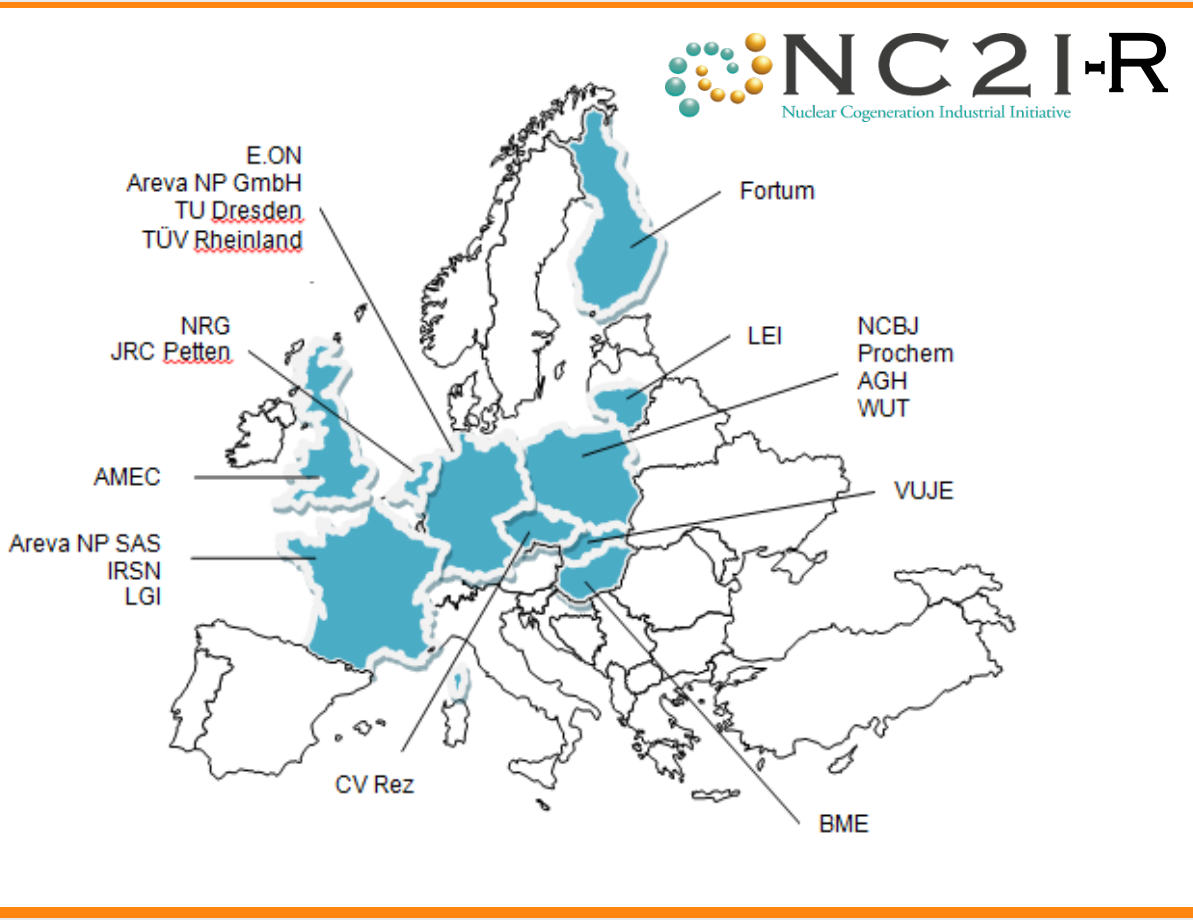
Coordinated by National Centre for Nuclear Research (NCBJ), Poland

Budget: 1 835 000 €

Coordination and support activities only

Duration: 24 months

Launched: October 2013



NC2I-R Work Packages

WP1 (NCBJ)

Analysis of perspectives of NC2I, including convertion to a legal entity.

Finding an optimum cooperation form for the 1st HTGR design & construction

WP2 (JRC)

A « map»of European institutions having experience and facilities useful for practical implementation of nuclear industrial cogeneration

WP3 (IRSN)

Safety and licensing issues, including: mapping the experience gained so far, suggesting licnesing procedures for nuclear cogeneration units.

WP4 (E.ON)

A roadmap for a demonstrator (including data from other WPs).

Study of various industrial scenarios and business models.

NC2I-R results

- Sample of >130 sites in Europe
- Mostly chemical industries

Case for Poland

- **13 largest chemical plants** have installed today 6500MW of heat at T°= 400-550°C
- They use **200 TJ / year,** equivalent to burning of >5 mln t of natural gas or oil
- **165 MW_{th} reactor output fits all the needs**
- Estimated market by 2050 PL: 10-20, EU:100-200, world: 1000-2000
- Possible replacement of 200 MW_e cogeneration units in future
- Increasing interest in T=500-1000°C for H_2 production

NC2I-R results taken by Poland

Minister of Energy in July 2016 appointed

„Committee for deployment of high temperature reactors”.

Chairman: G.Wrochna

Members from:

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

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

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

Minister of Energy has given a green light
to implement the conclusions.

18 MPLN (~4M€) for GOSPOSTRTEG project
to prepare legal, licensing & TSO framework

HTGR deployment plan in Poland

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

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

1$ ≈ 3.8 PLN
1€ ≈ 4.3 PLN

2019 2021 2024 2026 2032

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

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

OPEX (B+R)

CAPEX (investment)

4 industrial partners assumed

Investment decisions

Support for GEMINI initiative

Partnership of EU NC2I & US NGNP Industrial Aliance + JAEA Japan + KAERI Korea

Coordinated by National Centre for Nuclear Research (NCBJ), Poland

Budget: ~4 000 000 €

Duration: 36 months

Launched: Sept. 2017

www.gemini-initiative.com

GEMINI+ strategic objectives

A nuclear solution to address Europe's energy objectives (SET-Plan):
clean energy for Europe, safe and efficient use of nuclear energy,
secure Europe's energy supply, industrial jobs in Europe

WP1 – safety

A licensing framework for the development of a new nuclear cogeneration modular HTGR, addressing recent safety requirements (EU nuclear safety directives etc.)

WP2- conceptual design

A reference HTGR configuration acceptable for licensing both in Europe and in the USA, with a future objective to develop this technology in other countries.

WP3 – innovations

A safe nuclear HTGR system
compliant with the highest safety standards, able to provide energy to citizens and industry at a competitive cost.

WP4 – deployment

A plan for an industrial demonstration:
acceptable site,
appropriate funding and business schemes,
industrial and technological readiness,
ensuring supply chain for components,
spent fuel management…

Challenges addressed by the Gemini+ project

Innovative safety approach:

- Explore unique HTGR safety features to reduce the cost
- Address the safety of the coupling reactor / industrial processes

Breaking economy of the scale:

- Cogeneration (~80% use of energy)
- Large market (PL: 10-20, EU: 100-200, world >1000)
- SMR: factory fabrication of sub-systems with fast assembling on site

Universality:

Same design for different applications

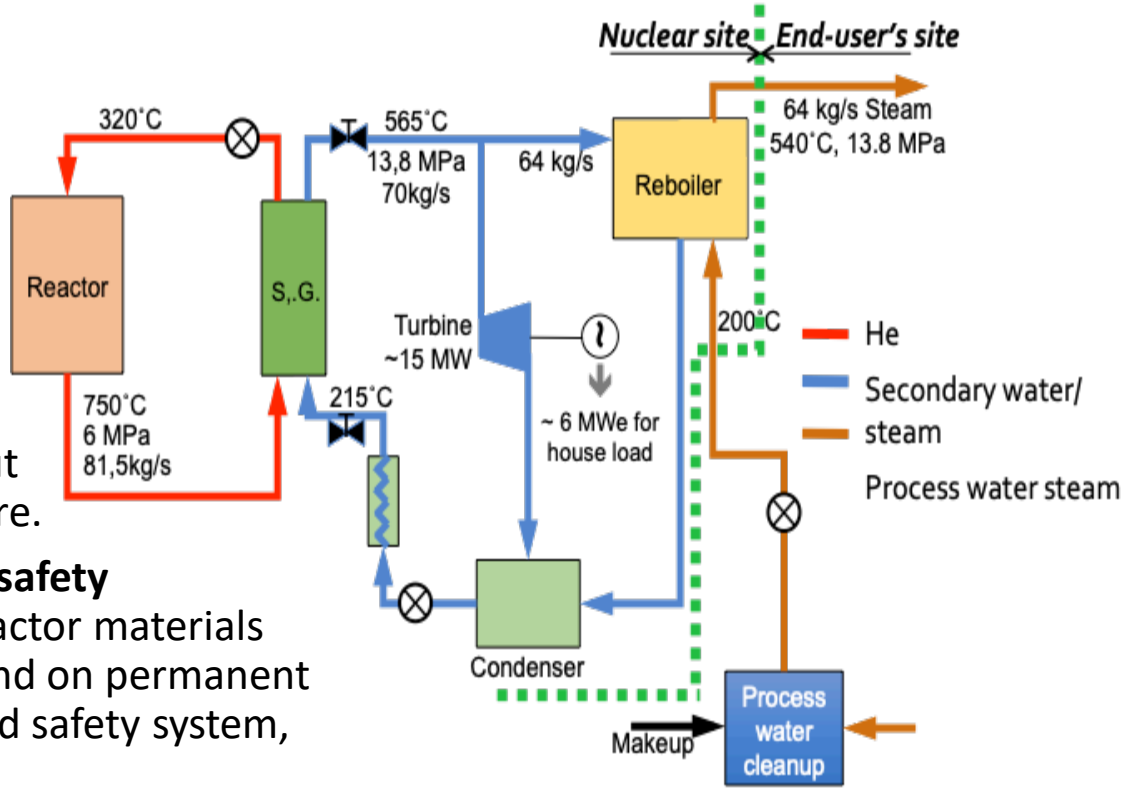
- Steam for chemical factory
- Cogeneration: turbines + various heat applications (district heating, industry)
- Potential for CO2 free hydrogen production

Separation from the user installations:

- No influence of user installations on the reactor

Design basis of GEMINI+ system: a flexible nuclear boiler

- **Delivering only steam**: the uses of steam (in industrial processes and/or in electricity generation) are outside of the nuclear system.
- **Can be plugged into** an existing industrial steam distribution network, substituting a fossil-fired boiler without any change in the existing infrastructure.
- With simple, robust and **fully passive safety** based on intrinsic properties of the reactor materials (conduction, radiative heat transfer) and on permanent natural circulation in the sole dedicated safety system, the Reactor Cavity Cooling System.



- All sub-systems (including the vessel) sufficiently compact to be **transportable by road**.

GEMINI+ follow-up

NC2I / Gemini+ consortium is preparing a proposal for the new Euratom call with the objective of facilitating the deployment of the nuclear industrial cogeneration system developed in GEMINI+ by

- **strengthening its licensing acceptability**
  by addressing a few issues (identified in GEMINI+)
  that need further R&D work + to comfort its safety demonstration;
- **enhancing its attractiveness for industry**
  by making the service it can offer more global,
  complementing steam supply by safe, CO_2 free, **hydrogen supply**;
- **supporting its political and societal acceptability**
  by strengthening its proliferation-resistant features,
  developing cores allowing to destroy plutonium and minor actinides
  or improving the long-term sustainability of nuclear energy (thorium cycle).

More info on NC2I-R & GEMINI+: **www.nc2i.eu** **www.gemini-initiative.com**