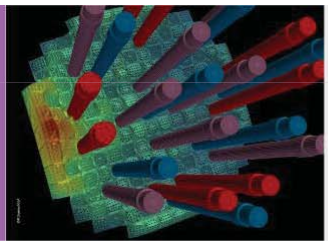
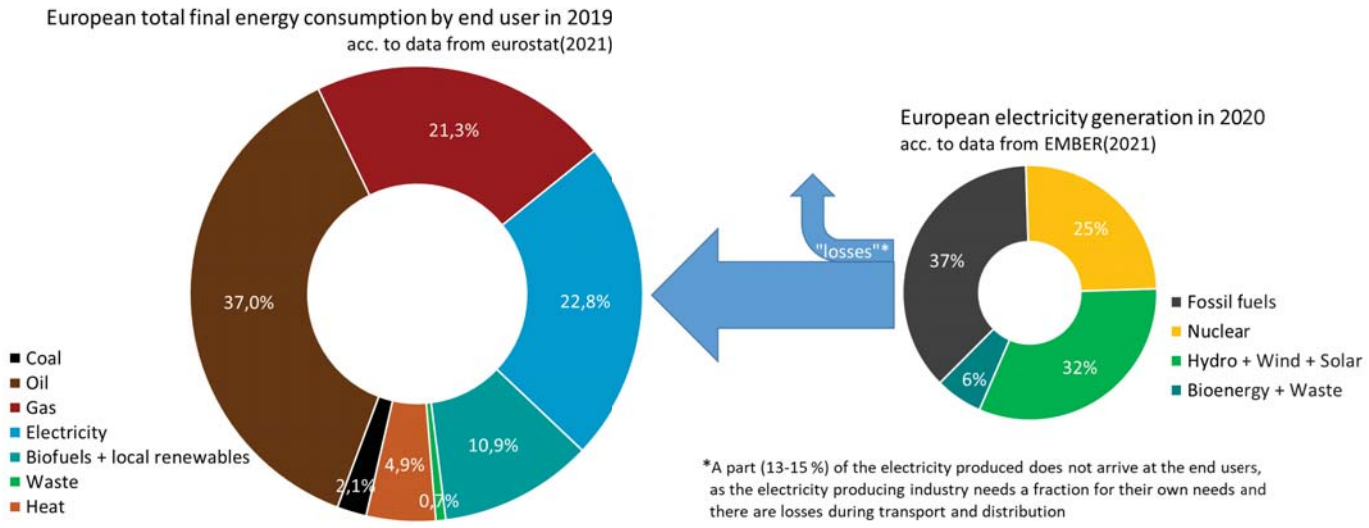


Nuclear Cogeneration with High Temperature Reactors

Józef Sobolewski
National Centre for Nuclear Research (Poland)

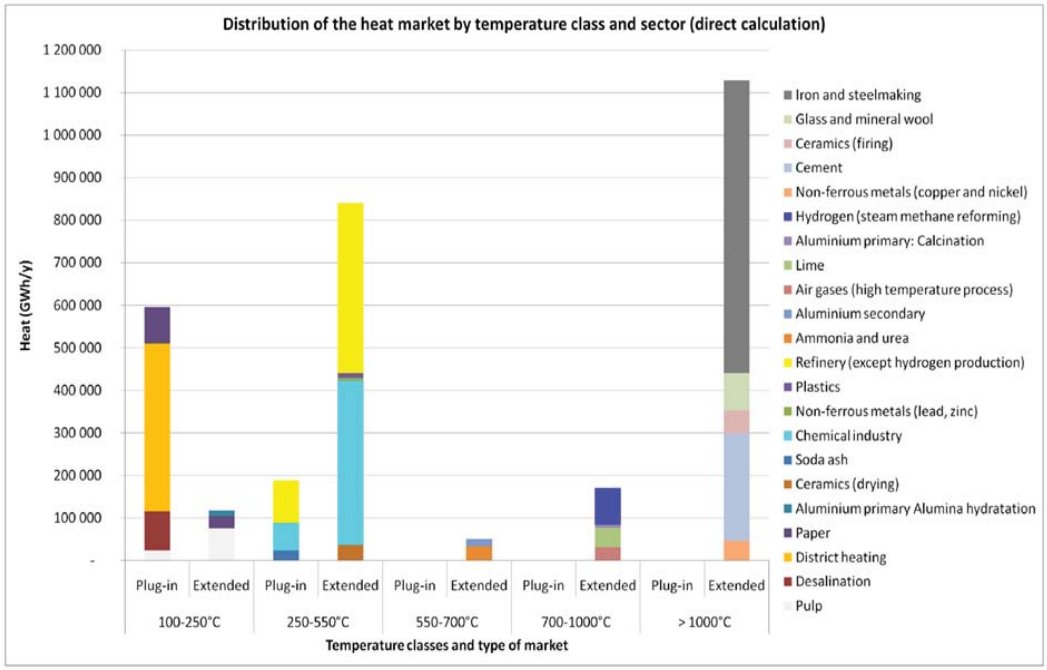
SNETP Sustainable Nuclear Energy Technology Platform
NC2I Nuclear Cogeneration Industrial Initiative
NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

European total final energy consumption by end user



Eurostat energy statistics 2019 (May 2021): Energy statistics - an overview - Statistics Explained (europa.eu)
EMBER EU Power Sector in 2020: EU Power Sector 2020 - Ember (ember-climate.org) or Agora Energiewende and Ember (2021): "The European Power Sector in 2020: Up-to-Date Analysis on the Electricity Transition", C. Redl, F. Hein, M. Buck, P. Graichen and D. Jones, Jan 2021, 202/02-A-2021/EN

Distribution of the European heat market by temperature class and sector



Plug-in market: heat is supplied via steam networks in the range 100-550˚C.
The range 250-550˚C represents approx. 87 GWth in Europe alone.
Extended market: remaining heat market

A. Bredimas: Market study on energy usage in European heat intensive industries, FP7 Euratom project EUROPAIRS, D131, Rev. 2, 05/2011.

15th Strategic Energy Technology Plan (SET Plan) conference

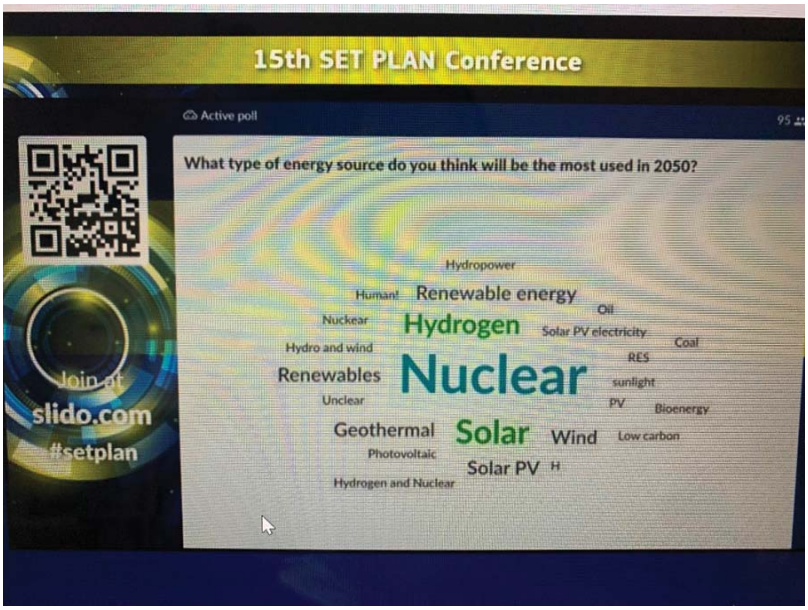
Bled (Slovenia) on the 25th and 26th of November 2021.

“Research and Innovation to deliver a just and sustainable energy transition”.

- This event attracted over 500 participants (2/3 online and 1/3 on-site), which made it a major international research and innovation event beyond the EU alone. Among the participants, over 300 represented companies.
- This interactive event allowed polling attendees about their opinion. The most common answers were visualized in the form of a word cloud with the most quoted energy source represented by the largest letters in the centre.

For participants the most used source of Energy in 2050 will be

NUCLEAR



https://snetp.eu/2021/12/20/nc2i-chair-attended-the-15th-set-plan-conference/

HTGR, a promising technology to contribute to Green Deal objectives

HTGR (High Temperature Gas-cooled Reactor) technology is mature and available for early implementation.

- Several test reactors and industrial prototypes
- In the last 2 decades in Europe
  - Several design projects
  - Large progress in the technology
    - National R&D programmes
    - Euratom funded projects (17 projects)
    - International cooperation (Generation IV International Forum)
- An industrial prototype, HTR-PM, started operation in China last year.

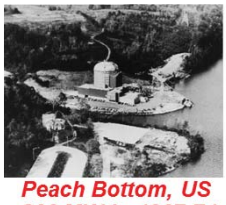
DRAGON, U.K. 20 MW, 1963-76

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

AVR, Germany 15 MWe, 1967-88

THTR, Germany 300 MWe,1986-89

HTR-10, China 10 MWth, since 2000



Peach Bottom, US 200 MWth, 1967-74

HTR-PM, China 2x250 MWth, since 2021

HTTR, Japan, 30 MWth, since 1998

Modular HTGR

GEMINI+

GEMINI+ selected for funding in the frame of the 2016 call of H2020

- 3.5 years project, 4 M€
- Started in September 2017, completed in February 2021
- Initiated by the (European) Nuclear Cogeneration Industrial Initiative (NC2I) for implementing its strategy meant

High Temperature Gas-cooled Reactor

- Modular design & construction
- Wide possible power range up to several hundred MWth
- Coolant – Helium
- Moderator – Graphite
- Fuel based on TRISO particles dispersed in a graphite matrix
- Outlet temperature up to 750˚C (qualified existing industrial materials), 900-1000˚C (with advanced materials).

Safety

- Very favourable safety features: high thermal inertia, refractory materials, leak tight fuel up to very high temperature
- Safety based on inherent physical properties of the reactor and purely passive behaviour (no need of action from personnel or from any powered automatic device).
- Temperature of the fuel kept without any action need below limits that would threaten its integrity. No physical possibility of core melting and of high radioactive release
- No exclusion zone around the nuclear plant: possibility to locate the nuclear plant close to the industrial site
- Elimination of many redundant active safety systems existing in present reactors: an asset for competitiveness

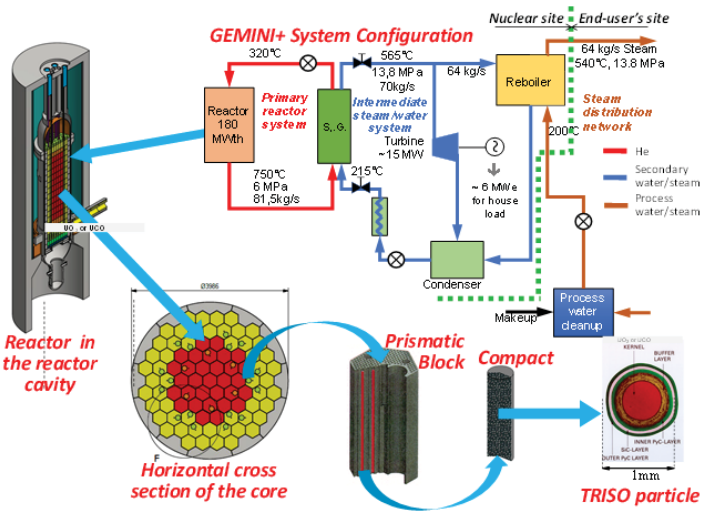
https://iopscience.iop.org/article/10.1088/1742-6596/2048/1/012043; https://iopscience.iop.org/article/10.1088/1742-6596/2048/1/012030; https://iopscience.iop.org/article/10.1088/1742-6596/2048/1/012004

Main achievements of GEMINI+

GEMINI+ was designed to support early demonstration of industrial nuclear cogeneration of electricity and steam in Poland using an inherently safe HTR.

Main results:

- Flexible standard design that can address needs for process steam in industry.
- Safety approach meeting present highest safety standards.
- Identification of residual technology gaps.
- Better understanding of industrial application needs: Importance of hydrogen for industrial applications.
- Proposals for integration of high temperature nuclear cogeneration systems in global or local energy systems.



GEMINI+

GEMINI For Zero Emission

Acronym: GEMINI 4.0

Topic: HORIZON-EURATOM-2021-NRT-01-05
Nuclear Research and Training, Safety of HTGRs

- Type of Action: EURATOM-RIA
- Duration: 36 months (2022 – 2025)
- No of partners: 22+, Lead – Framatome SAS
- Current status: Preparation of the Grant Agreement and Consortium Agreement
- Begin (KoM): June 2022
- Budget: 3.13 M€

Specifically

GEMINI 4.0 proposal received the SNETP label (Nr. 2021NC2I0006)

GEMINI 4.0 objectives

- Improvement of the design, by:
  - Resolving safety/licensing issues in Safety Options Report (SOR)
  - Core optimisation, Closing selected technology gaps
- Extension of applications: poly-generation, special focus on hydrogen plant,
  - Propose several comprehensive applications (coupling)
  - Provide technological schemes supported with techno-economic analyses
  - Safety and licensing of coupled systems
- Fuel for HTGRs in Europe
  - Plan for the development of European fuel cycle
  - Reference fuel, possible alternative fuels
- Licensing readiness
  - Assessment of the SOR by TSOs and regulators
  - Support potential candidate countries in the licensing of HTGR system
- Enhancing awareness of nuclear cogeneration
  - Develop and activate communication plans in different EU countries

GOSPOSTRATEG-HTR (GoHTR)

- GOSPOSTRATEG - strategic Polish program of scientific research and development (R&D) work "Social and economic development of Poland in the conditions of globalizing markets"
- Title: Preparation of legal, organizational and technical instruments for the HTR implementation (Gospostrateg1/385872/22/NCBR/2019)
- Finance: National Centre for Research and Development (approximately €4M)
- Duration: January 2019 – March 2022
- Consortium: Ministry for Climate and Environment, National Centre for Nuclear Research and Institute for Nuclear Chemistry and Technology.

Objectives

Preparation to the licensing process
- Pre-conceptual design
- Facility concept
- Analysis methodology

Material tests
- Implementation of testing procedures
- Identification materials for tests
- Irradiations in the MARIA reactor

Legal, social, economic and industrial aspects of the project
- Legal regulations for the HTR investments implementation
- Public and industrial communication

https://www.mdpi.com/1996-1073/15/6/2084

GOSPOSTRATEG-HTR programme

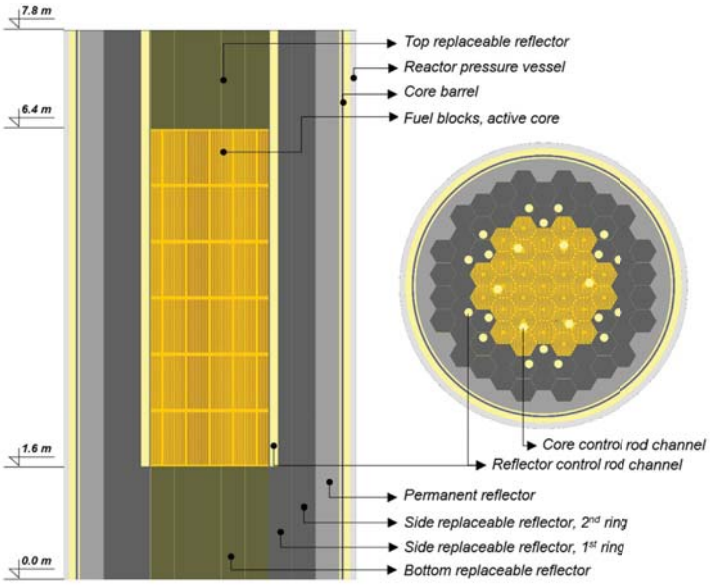
Phase A

- Development of methods for diagnostics of structural materials in the HTR construction;
- Development of methods for testing of structural materials in a nuclear reactor, and equipment for the execution of tests in the core;
- Research and analysis of selected chemical aspects of the production and use of TRISO fuel in the HTR nuclear reactor;
- Comprehensive analysis of the necessary changes to the legal environment and the potential benefits of social, economic and industrial units for the Polish economy.

Phase B

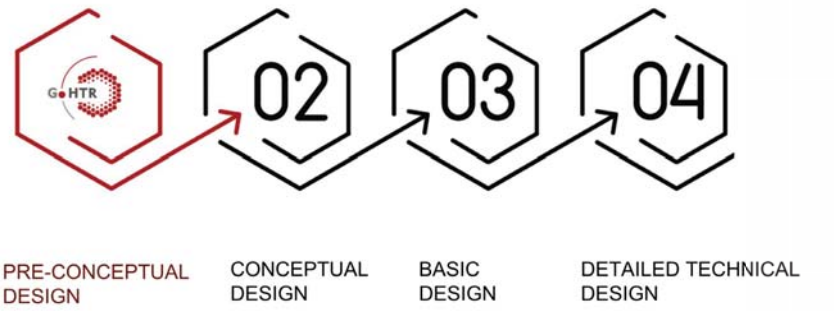
- Preparation licensing process (certification) of HTGR reactors on the example of a research reactor;
- Preparation draft of legal regulations for the HTR investments implementation; developing a strategy in the social, economic and industrial aspects of the project;
- Piloting of test procedures for the use of construction materials for the HTR reactor design, including tests in the Maria reactor core;
- Preparation of technical and economic assumptions for the construction of a fuel production unit for high-temperature reactors.

Pre-conceptual core design



NCBJ-MEiN Programme – HTGR Basic Design

- Contract No 1/HTGR/2021/14 between the National Centre for Nuclear Research and the Ministry of Education and Science entitled “Technical description of the HTGR gas-cooled high-temperature research nuclear reactor” signed on May 12, 2021 in Świerk. It is intended for the implementation of another batch of design works for the experimental HTGR, being also the technology demonstrator.
- The contract determines that the conditions for the construction of a high-temperature research reactor in Poland will be created within three years and that the conceptual design and further most of the basic design of such a device will be prepared. The reactor will be a prismatic type HTGR using TRISO fuel producing approximately 30-40 MWth at an outlet temperature of 750 ^{o}C.
- Time: 1.06.2021 – 1.06.2024.
- Value: approximately €14M



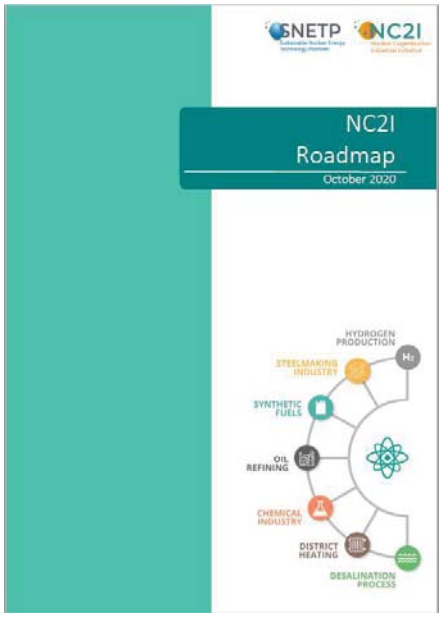
NCBJ-MEiN Programme – HTGR Basic Design

Scope of the project:

- Preparation of laboratory facilities with the necessary accreditations and a quality management system necessary to perform research in view of licensing materials for HTGR technology.
- Performing tests of materials that can be used for the construction of HTGR, in terms of compliance with the requirements of HTGR technology.
- Development of the basic design of the HTGR reactor (basic / preliminary design according to IAEA-TECDOC-881).
- Performing verification simulations for the project and preliminary HTGR safety report in accordance with the requirements of the Regulation of the Council of Ministers from 2012.
- Preparation of selected elements of the preliminary safety report (CSR) for HTGR in accordance with the Regulation of the Council of Ministers (as above).

A Roadmap for the Deployment of Industrial Nuclear Cogeneration in Europe

- NC2I aims to make a significant contribution to European priorities by providing clean and competitive energy beyond electricity by facilitating the deployment of nuclear cogeneration plants.
- HTGR is mature enough to be deployed by the end of this decade for process heat supply
- If the deployment is performed in a steady, but realistically feasible way, nuclear can bring a significant contribution to curb industry emissions by 2050.



https://snetp.eu/wp-content/uploads/2020/10/NC2I-roadmap-October.pdf

Thank You