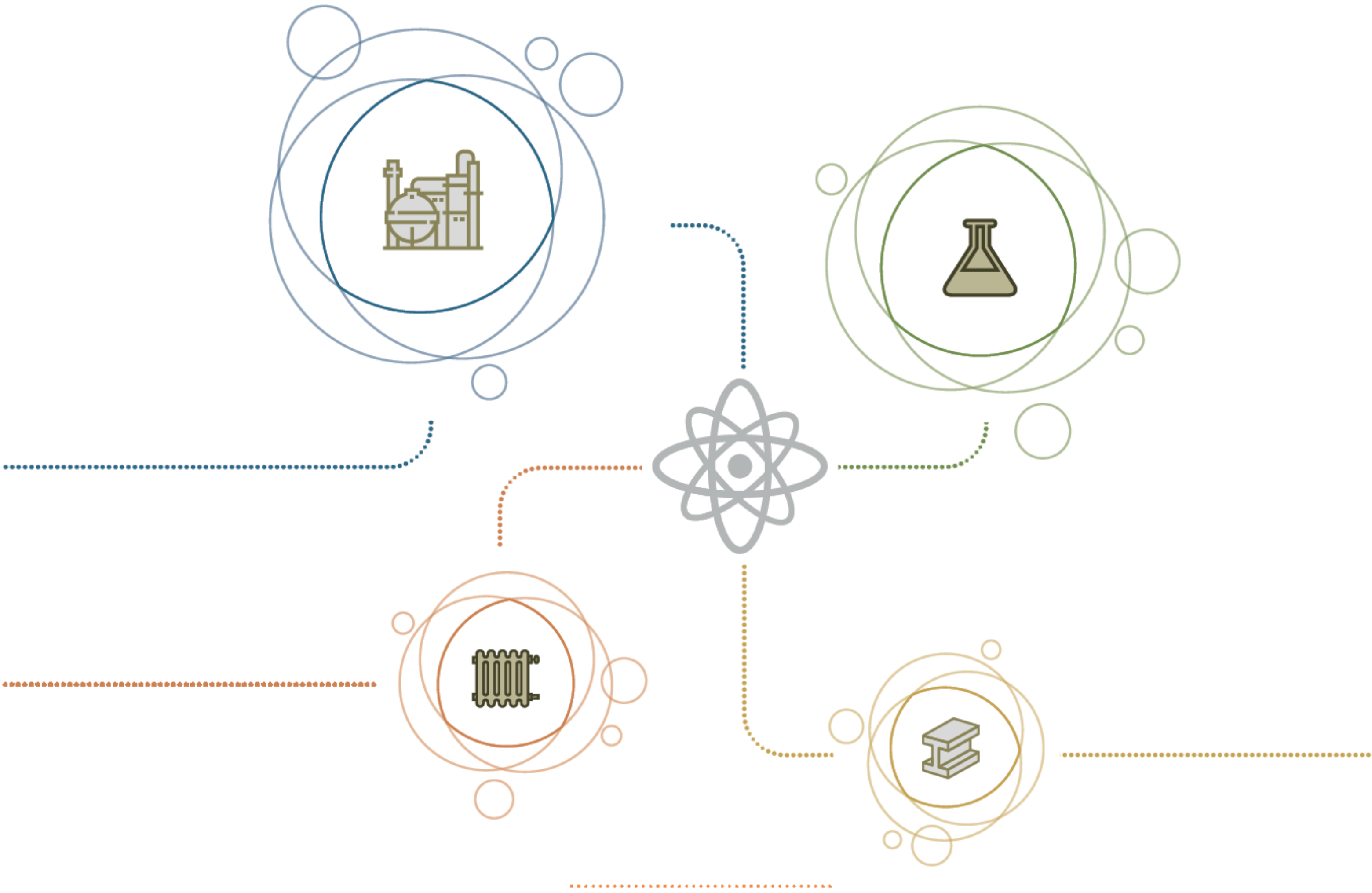
MINISTRY OF ENERGY

Possibilities for deployment of high-temperature nuclear reactors in Poland



Report of the Committee for Analysis and Preparation of Conditions for Deployment of High-Temperature Nuclear Reactors

The Committee for Analysis and Preparation of Conditions for Deployment of High-Temperature Nuclear Reactors (the HTR Committee, for short) was appointed by the Minister of Energy on July 13, 2016. During several months the HTR Committee collected and analyzed data on the demand of energy in form of heat with a temperature above 250°C and investigated a possibility to meet these energy needs with HTR[1] reactors.

Available reactor technologies were reviewed recognizing High Temperature Gas-cooled Reactors (HTGR) as the best option. The advantage of this technology over others results from the unique features of **inherent safety** that prevent core melting as well as technological maturity and technical parameters optimal to the needs of the industry. An estimation of the construction costs of this type of reactor was carried out and the profitability of the investment was preliminarily analyzed in comparison with conventional technologies. It has been shown that while providing reasonably low cost crediting of investment, the price of steam from HTGR may be comparable to the price of steam from gas boilers. Today, gas is burdened with a high risk of lack of availability and price increase as well as uncertainty of CO_2 emission costs.

HTGR TECHNOLOGY IS AN ALTERNATIVE, WHICH CAN ENSURE:
Poland becoming gradually less dependent on gas imports from one supplier due to reduction of its needs to the level covered by own extraction, Nordic gas pipeline and gas terminal.
Reduction of CO_2 emissions, which increases the pool available for coal-based energy.
Providing domestic industry with the heat sources of a predictable costs, resistant to changes in fuel prices and independent from the price of CO_2 emission allowances.
Launch of production of HTGR reactors with high export potential.

In conclusion, the HTR Committee recommends to begin preparation of HTGR deployment.

A business model proposed in the report envisages establishing a special purpose company, own mainly by industrial heat users. The first task of the company (provisionally called HTR-EPC) would be to develop a preconception study upgrading the analysis carried out by the HTR Committee and to conduct negotiations with potential foreign partners. Successful conclusion of these steps would give a green light to start designing the reactor. Positive opinion of nuclear regulator should clear the path towards investment decisions and reactor constructions in chosen locations. The first HTGR's are supposed to be commissioned around 2031. Simultaneously - in fact, right at the start - the HTR-EPC would begin the preparation and construction of a low-power HGTR experimental reactor, needed to accelerate design work and licensing of commercial reactors.

THE HEAT DEMAND

The heat demand in Europe is spread at a level of 600-900 GWh / year in temperature ranges below 250°C, 250-550°C and above 1000°C with relatively low demand between 550°C and 1000°C. The lowest range needs can be met by light-water reactors (LWR). However, industrial installations using such temperatures are generally small and scattered, which makes nuclear reactors difficult to use. The district heating sector

[1] For the purpose of this report, HTR stands for reactors providing temperature above 250°C in general, while HTGR refers specifically to High Temperature Gas-cooled Reactor technology.

has significant potential, today however, it uses waste heat from large energy reactors in few countries only. The source of urban heat could be an SMR reactor of a PWR type, being developed in several countries around the world. However, HTGR reactors have the advantage of possibly being located close to the human settlements thanks to their inherent security features described below.

The steam of T≈500°C is a standard heat carrier in many large industrial plants, especially chemical ones. There, HTGR deployment could be made easier by exchanging outdated gas of coal boilers, without changes in existing installations, that include electricity producing turbines for the needs of the plant. The demand of Polish industry for steam with such parameters is about 6,500 MW in several locations. In practice, the demand for HTGR reactors up to 2050 could be roughly estimated to be 10-20 units in Poland, 100-200 units in the EU and 1000-2000 units in the world.

The highest range, above 1000°C has a bright future due to the production of hydrogen and hydrogen-based fuels. The HTR Committee recommends to begin preliminary research on selected reactor technologies (such as VHTR or Dual Fluid Reactor - DFR) because, as of today, there is no proven nuclear technology in this area.

THE CHOICE OF TECHNOLOGY

According to the HTR Committee, HTGR reactors are the optimal technology for T≈500°C. The research programs run by SNETP, the OECD NEA and the British government lead to similar conclusion. Several research and industrial reactors have been built with the use of this technology (including 2 × 250 MW_{th} under construction in China), which confirms its maturity. Still, it is not commercially and commonly used and its implementation on an industrial scale (serial production of reactors) would be a global breakthrough in the energy industry.

A UNIQUE ADVANTAGE OF HTGR TECHNOLOGY IS ITS INHERENT SAFETY – NO RISK OF CORE MELTDOWN

The TRISO fuel, where the uranium dioxide is in the SiC coating, has been tested to ~1700°C. Even in case of failure of all safety systems and loss of coolant, the core cools down spontaneously thanks to radiation of heat and convection. This makes possible placing such a reactor in an immediate vicinity of industrial installations or even human settlements.

COSTS AND ECONOMIC ADVATAGES OF HTGR

The costs of the steam of 540°C and 13.8 MPa from various sources have been compared. Gas and coal fired boilers as well as 165 MW_{th} HTGR gas were assumed to produce 230 tons of steam per hour. The cost of designing and licensing of HTGR was estimated at PLN 500 million (~120 mln €), while the cost of building one HTGR was estimated at 2.0±0.6 billion PLN net (~480±140 mln €). The analysis was performed using different values of input parameters in order to take into account uncertainties related to the expected price of CO_2 emissions and interest rate. The analysis shows that with the discount rate of 4% and the price of CO_2 emissions 20-50 €/t, the estimated levelized cost (LCOE) of steam from HTGR, averaged over the plant lifetime, is 36 PLN/GJ (~7 €/GJ). It turned out to be comparable to the cost of steam from a gas boiler amounting 36-42 PLN/GJ (~7-10 €/GJ).

Investing PLN 500 million (~120 mln €) for the reactor project (after a positive result of the preconception study) in 2019-2023 would allow making decisions on investments in specific locations after 2023, when the economic conditions will be much better defined.

Making decisions on HTGR technology the following economic factors should be taken into account besides purely financial considerations:

- **reduction of dependency on gas import**
- **reduction CO_2 emissions**
- **predictability of operating costs**
- **export potential**

TECHNOLOGY AVAILABILITY

Despite the existence of several research and commercial HTGR reactors - there is no reactor design ready for multiplication on an industrial scale. Competences and experience are scattered throughout the word as a result of completion of individual projects. Existing knowledge is not protected by patents and many studies are in the public domain. A large part of the competencies scattered in the EU, USA, Japan and Korea were successfully collected in the Euratom Gemini + project coordinated by the NCBJ. The key element of HTGR technology is the safe TRISO fuel. There are several production lines in the world where tested fuel may be bought from. Such fuel may be used for the first reactors in Poland before building domestic fuel factory.

BUSINESS MODEL

Currently, none of the big companies designing nuclear reactors (except China) declares their readiness to undertake the implementation of the HTGR project alone. This creates the possibility of setting up a new company in Poland - mentioned above HTR-EPC - that would gather scattered competences and intellectual property. The HTR-EPC should have a majority share of Polish capital while foreign companies could participate as shareholders or subcontractors. The presence of Polish chemical and energy companies among the participants of the HTGR project would guarantee validity of the preconception study, and in the next stage, adaptation of the reactor design to the specific needs of the recipients.

RECOMMENDED SCHEDULE

- 2018: Agreement between the Ministry of Energy and Ministry of Science and Higher Education on the implementation of the HTGR program + a possible governmental program
- 2018: Establishment of HTR-EPC company + incorporation of foreign partners
- 10 MW_{th} experimental reactor:
  - 2018-20: design (PLN 150 million, ~36 mln €),
  - 2020-25: licensing and construction (PLN 600 million, ~143 mln €)
- 165 MW_{th} commercial reactor:
  - 2018: a preconception study (PLN 10 million, ~2.4 mln €)
  - 2019-23: designing (PLN 500 million, ~120 mln €)
  - 2023-26: preparation of the first HTGR construction (PLN 500 million, ~120 mln €)
  - 2026-31: construction of the first HTGR (PLN 1500 million, ~360 mln €)