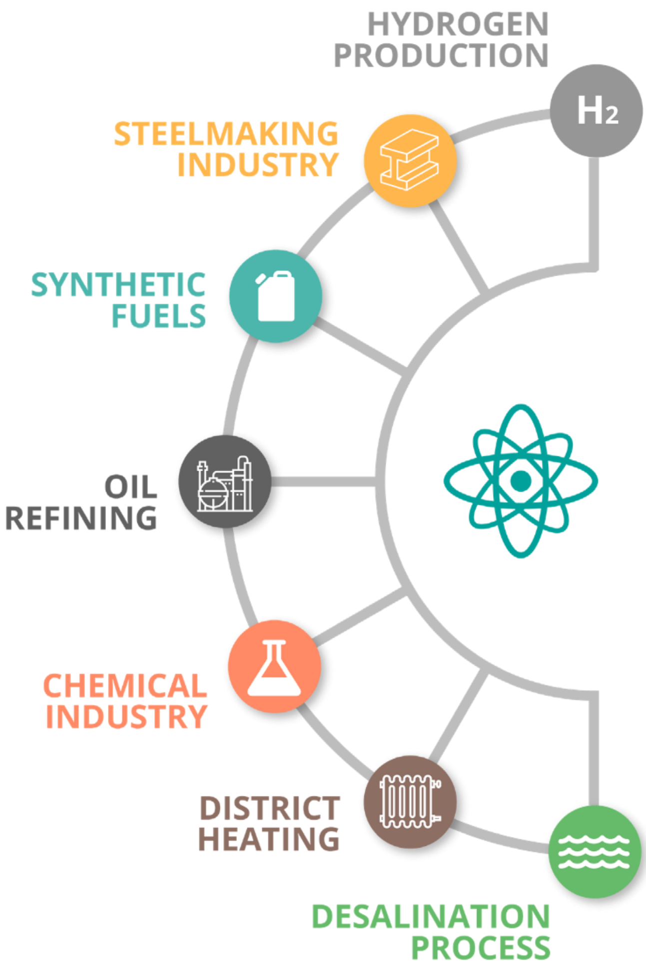
SNETP Sustainable Nuclear Energy Technology Platform

NC2I Nuclear Cogeneration Industrial Initiative

NC2I Roadmap

October 2020



NC2I aims to make
a significant contribution to Europe
by providing clean and competitive
energy beyond electricity
by facilitating the deployment
of nuclear cogeneration plants.

This document has been prepared by the
Nuclear Cogeneration Industrial Initiative
established within the
Sustainable Nuclear Energy Technology Platform

Main contributors
Dominique Hittner
Jozef Sobolewski
Michael Fütterer
Gilles Quénéhervé

October 2020

A Roadmap for the Deployment of Industrial Nuclear Cogeneration in Europe

The Green Deal objectives cannot be reached without curbing industrial greenhouse gas emissions

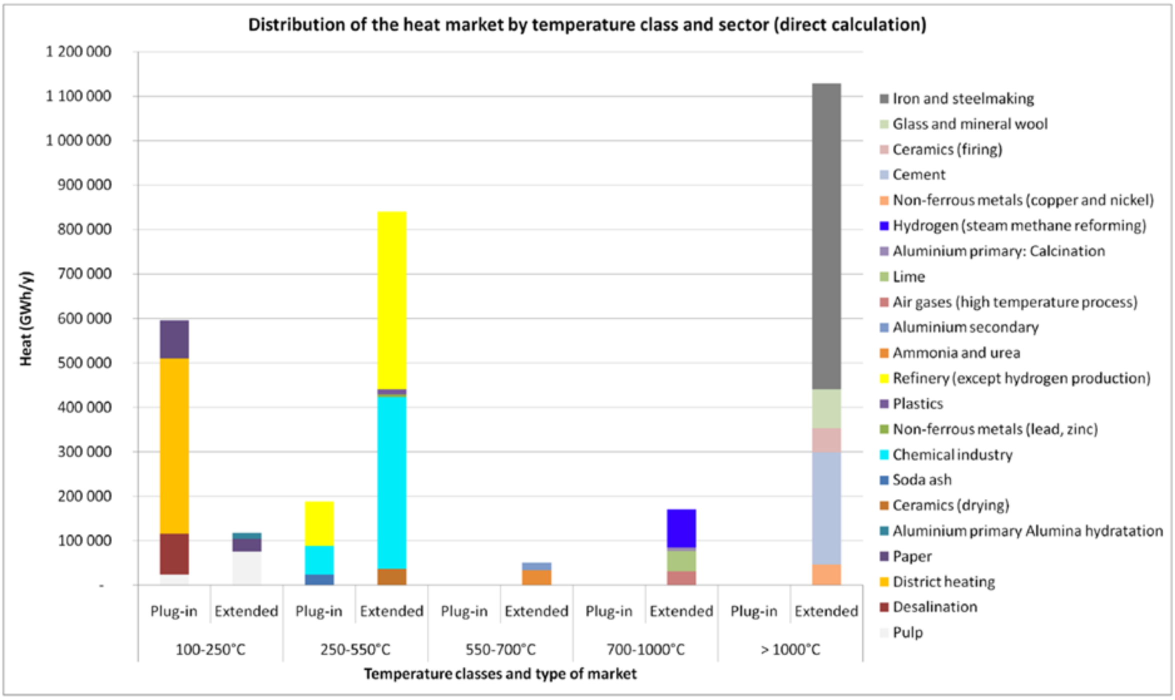
Electricity generation is responsible for about ¼ of greenhouse gas emissions related to global human activities today. Industry on the one hand, transport on the other, each represent emissions of the same order of magnitude [1] with industrial processes being almost entirely dependent on fossil fuel combustion. For reaching the Green Deal objective of carbon neutrality in Europe by 2050, it is therefore essential to focus the effort of decarbonization not on electricity alone, but in addition to address the energy needs and emissions of industry.

Nuclear heat, a unique solution for curbing industrial greenhouse gas emissions

Industry is a large emitter of CO_2 owing to the needs of energy-intensive high temperature processes and through the significant emissions from some processes. While decarbonisation of electricity generation is progressing, today, almost unnoticed by the public, practically all process heat, is produced by fossil fuels. A new low-carbon process heat source must be available continuously, in large amounts and at a competitive price. Stability of electricity generation is already a serious issue with increasing fractions of variable renewables, but for process heat production, only nuclear energy can meet these requirements. Nuclear process heat supply is a simple, fast and efficient use of nuclear energy in industry. There is no other CO_2-lean energy source, which can provide the required amounts of energy. In addition, CO_2 emissions of the processes themselves could be drastically reduced by the large-scale use of hydrogen. Salient examples are the substitution of coke for iron ore reduction in steel making or the use of nuclear hydrogen for ammonia production instead of hydrogen produced by steam methane reforming of natural gas. Several high-temperature processes for hydrogen production are under development internationally. If the heat is supplied by nuclear reactors, these processes are extremely CO_2-lean and would even enable decarbonisation of aviation and maritime transport which are difficult to electrify. Hydrogen or hydrogen derivatives could be used for these purposes.

As shown in Figure 1 [2], there are very few industrial applications requiring temperatures that can be provided by present industrial water-cooled reactors (≤ 250˚C). In this temperature range, district heating is the main application – whereas most industrial process heat applications, as well as CO_2-free hydrogen production, require higher temperatures. About half of the current heat market is in the range of 250-550˚C, while the other half is above 1000˚C.

Several Gen IV systems (SFR, LFR, MSR, SCWR, VHTR) can be considered for reaching the range 250-550˚C or possibly more for some of them in the longer term. Taking into consideration the different Technology Readiness Levels and economic viability of these reactor technologies, NC2I and independent analyses (e.g. [7]) consider only the first step of VHTR technology, HTGR (High Temperature Gas cooled Reactor) as a realistic candidate for obtaining the required impact by the 2050s as stipulated by the Green Deal. Longer-term evolutions towards higher temperature applications (>950˚C) can follow at a later stage with the VHTR.



"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

Figure 1: Distribution of the European heat market by temperature class and sector [2]

A deployment target for nuclear process heat to contribute to the Green Deal

Presently, Poland is intending the development of HTGR in view of substituting coal and imported natural gas for providing process heat to its chemical and petrochemical industries [3]. Thirteen industrial sites were identified with a combined heat demand of 6.4 GWth. At the same time, the European process heat market attainable by existing nuclear technologies (< 550˚C) can be estimated in Figure 1 to be 87 GWth [2]. In the following it is assumed that in the EU, a quarter of this demand (22 GWth) can be covered by nuclear process heat by 2050. This seems plausible because it would be a market share comparable to the nuclear part in electricity generation. Depending on the type of applications, this could avoid between 40 and 70 Mt of CO_2 emissions per year and save enormous amounts of natural gas imports.

A first step of this programme is to demonstrate its feasibility at the level of a test reactor, the European High Temperature Experimental Reactor (EUHTER) [4]. This is a credible opportunity to start a development programme in the EU for delivering nuclear process heat to industry in the short term. Beyond this first step and assuming a steady pace of development, it can indeed lead, as shown below, to achieving the proposed target of 22 GWth of industrial process heat capacity by 2050.

The scenario presented here assumes that the commercial model to be designed and built for industrial applications is based on the design options developed in the Horizon 2020 Euratom funded GEMINI+ project for a nuclear boiler of 180 MWth (Figure 2 [5]). It also assumes that EUHTER will use the same design and technology options with the objective to create a precursor experience for design, licensing, procurement, construction and operation of a commercial reactor.

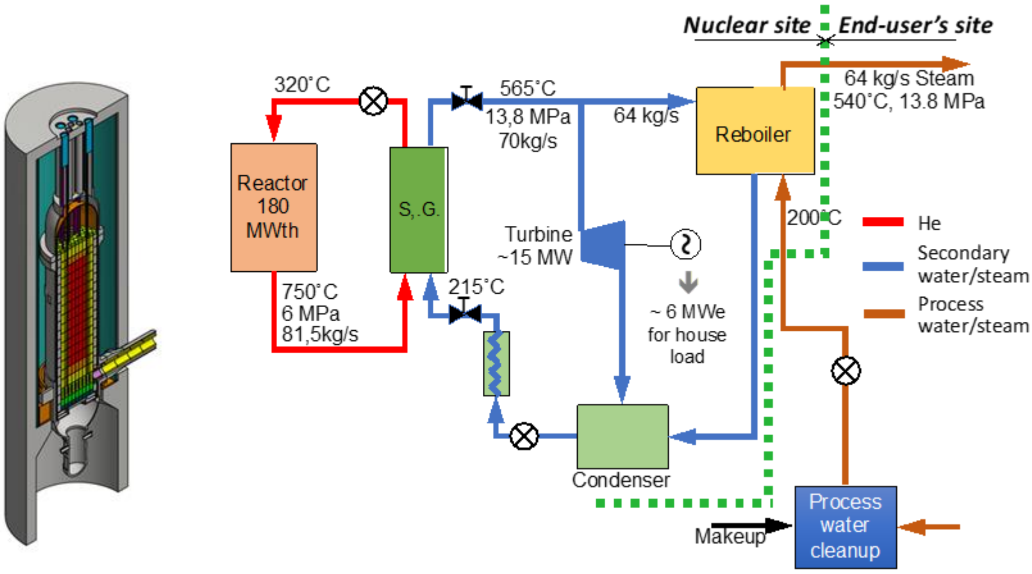


Figure 2: The GEMINI+ HTGR boiler

Initiation phase

After 2 years of design (conceptual and basic design), a decision for the detailed design and construction of EUHTER must be taken and the reactor will start operation by the end of the 2020s. Construction of EUHTER is planned to receive support from the Polish government. Possible EU and international participation are yet to be discussed. EUHTER is meant to de-risk and facilitate later deployment in industry, which should be financed by private investments. Immediately after the design of the experimental reactor, the international design team will start working on the industrial reactor prototype. At the end of the FOAK design, process heat user industry will have available all necessary elements (a design with a cost, the licensing feasibility already acquired with EUHTER) for purchasing the first commercial reactor, which can then be built and start supplying steam to an industrial site in the first half of the 2030s.

Ramp-up phase

The following ramp-up is expected to allow

- bringing into operation up to 10 reactors per year, by gradually increasing construction capacity;
- reducing the duration of individual reactor projects (site-specific design, procurement, construction, commissioning) from initially 8 to 5 years.

Such an acceleration of production capacity is certainly realistic: in the 1980s in France, it was possible to bring for several consecutive years 4 to 8 reactors per year of 2800 MWth (900 MWe) each into production [6]; it seems thus possible to deploy at least 10 considerably simpler and smaller reactors of 180 MWth per year. In addition, while the duration of 8 years for each design and construction project corresponds indeed to the industrial experience of Le Creusot forges and site construction of big LWR reactors by EdF, it does not seem unreasonable to shorten this period to 5 years for a much smaller and simpler reactor, owing to the use of modular methods of manufacturing and construction fully applicable for a reactor of the size of GEMINI+ boiler.

Results

The anticipated deployment schedule of nuclear boilers is described in Figure 3. It includes the development required for Europe to become autonomous for fuel supply at the time of industrial deployment, while the fuel for the experimental reactor can still be procured on the international market (US, China or Japan). It also includes the required R&D necessary to bridge the few residual technology gaps identified during the GEMINI+ project [8]. The incremental growth of boiler capacity is plotted in Figure 4 showing that the assumed target of 22 GWth can be reached before 2050. In this manner nuclear process heat can bring a significant new contribution to the Green Deal, not to speak about other important benefits of nuclear cogeneration for Europe. These include improving energy security by reducing natural gas imports, contributing to keep European leadership in nuclear energy, keeping highly qualified jobs in the EU which are presently lost to countries with lower carbon constraints, and even supporting the return of energy-intensive industries to Europe so as to reduce security of supply vulnerabilities, which had become painfully apparent during the COVID-19 pandemic.

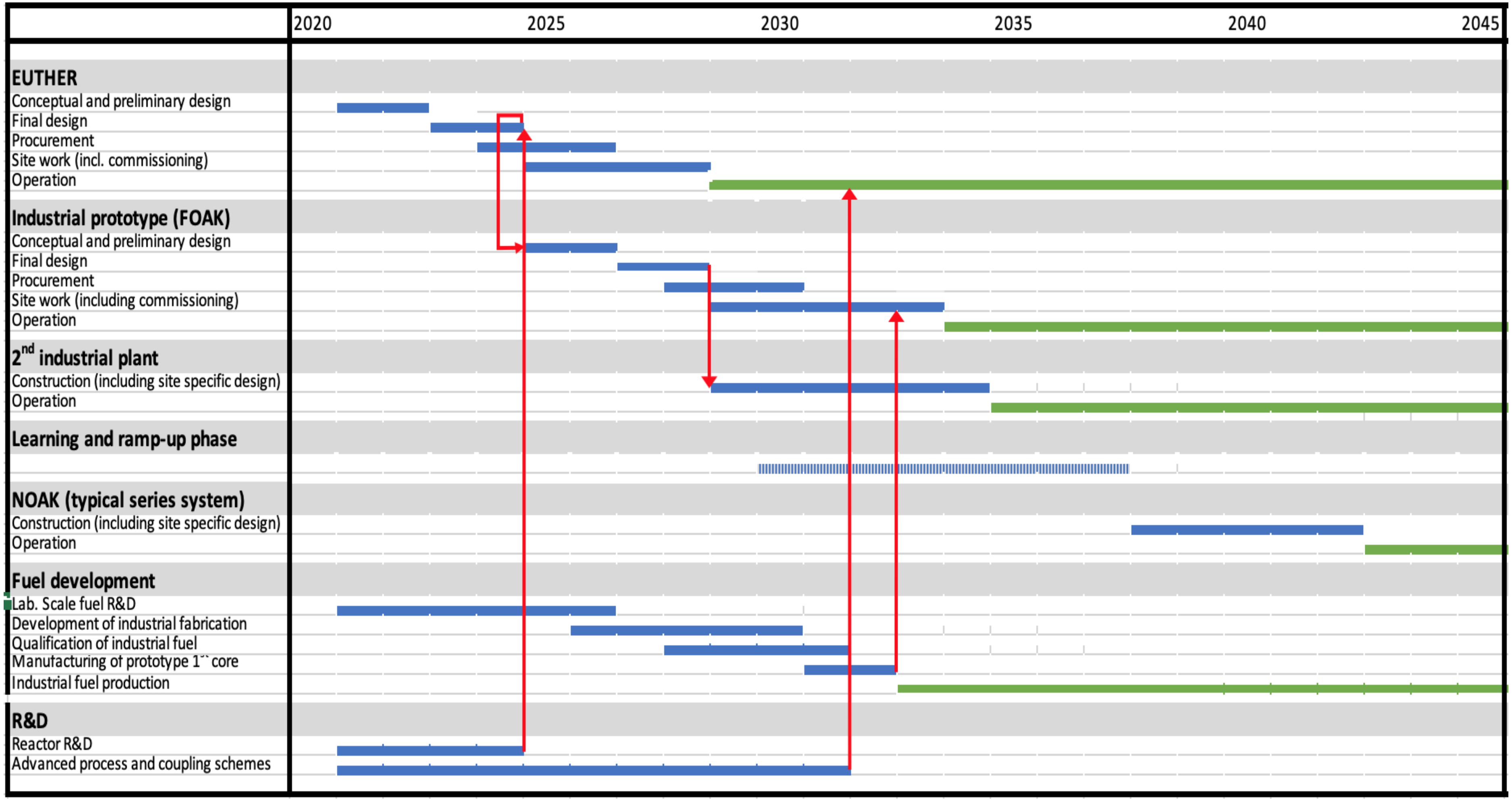


Figure 3: Proposed deployment schedule of nuclear process heat in Europe

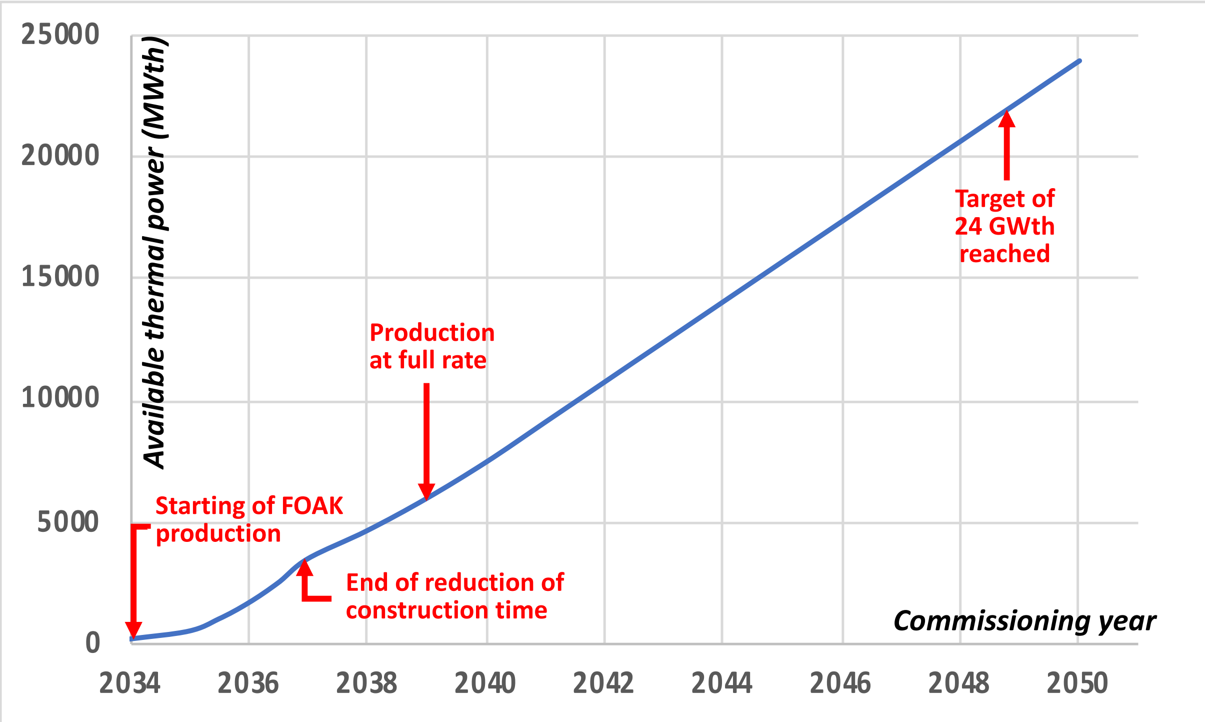


Figure 4: Anticipated growth of thermal boiler capacity

References

[1] https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

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

[3] https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/poland.aspx

[4] https://www.ncbj.gov.pl/en/aktualnosci/100-our-projects-made-it-map

[5] D. Hittner, G. Wrochna, Ch. Pohl, J. Lillington, M. Fütterer, W. Brudek, C. Chavardes, The GEMINI+ Project: Paving the Way for early Demonstration and Deployment of Industrial Nuclear Cogeneration, Proc. ICAPP 2019, Juan-les-Pins, France, May 2019.

[6] https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx

[7] UK Department of Energy and Climate Change, SMR Techno-Economic Assessment - Project 1 – SMRs: Comprehensive Analysis and Assessment SMR TEA Report: Volume 1 (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/665197/TEA_Project_1_Vol_1_-_Comprehensive_Analysis_and_Assessment_SMRs.pdf), 21 July 2016.

[8] Identification of residual technology gaps and qualification needs and plans for bridging these gaps, Deliverable 4.6 of the H2020 GEMINI+ Project, to be issued.