SNETP
Sustainable Nuclear Energy Technology Platform

NC2I
Nuclear Cogeneration Industrial Initiative

NC2I VISION PAPER

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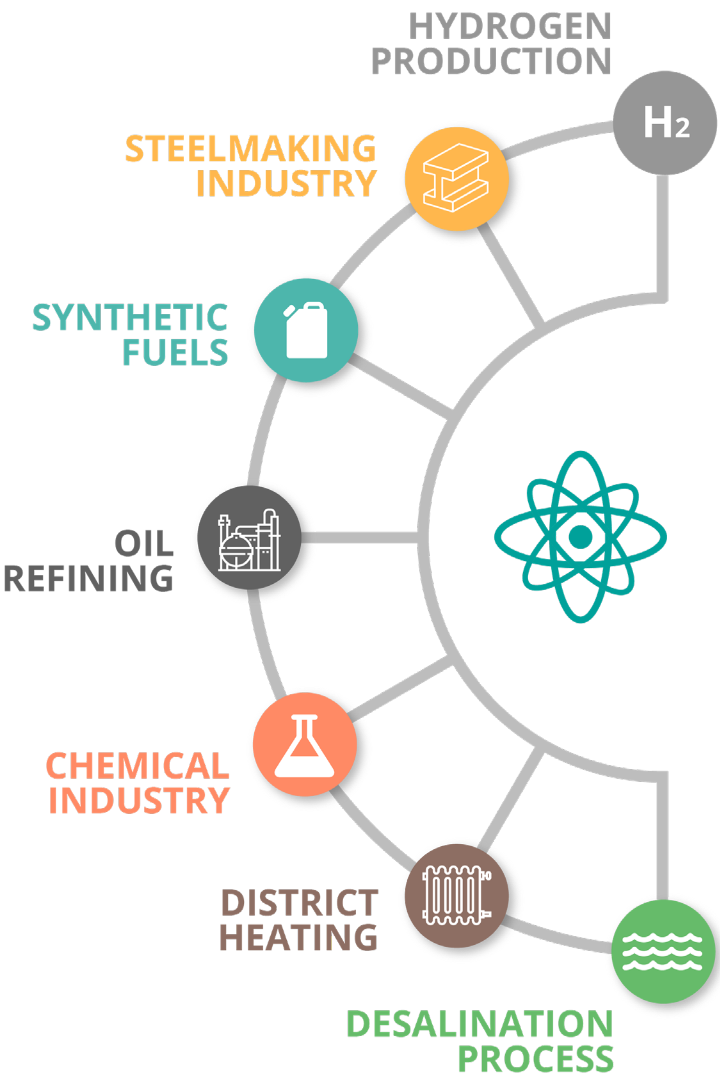

www.nc2i.eu

This document has been prepared by the NC2I Task Force established within the Sustainable Nuclear Energy Technology Platform.

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Foreword

It is well-known that the prosperity of societies is strongly correlated with their energy use. Nowadays energy is essential for effective food production, access to water, lighting, heating and cooling, industry, transport, communication and entertainment. Access to energy is becoming a basic human right.

Among the different sources of energy, nuclear is one of the most efficient. Indeed, less than half a gram of Uranium-235 is required to supply energy for an average house over one year, and nuclear produces nearly 1/3 of the electricity in Europe today. Nuclear technology, however, has not yet said its final word. If we compare the evolution of combustion from a fireplace to supercritical boilers, I would place Generation I and II nuclear reactors at the level of a tiled stove. There is a need and there is room for many improvements and innovations. In order to explore these paths, major European nuclear stakeholders set up the Sustainable Nuclear Energy Technology Platform (SNETP).

When we're talking about energy we usually mean electricity, but we should bear in mind that over twice more energy is used for heating and cooling. A paradox lies in the fact that due to physics, producing electricity through combustion or nuclear reactions demands to produce even more heat, and in most cases we treat it as troublesome waste. However, through cogeneration we can turn this waste into a valuable resource.

Applying cogeneration to nuclear energy may significantly change the European landscape and economy. No more ashes, no more combustion dust, no more poisons like SO_2, NOx or mercury in the air, but rather clean and affordable energy to heat our houses and kindle our industry. These are the goals of the Nuclear Cogeneration Industrial Initiative – one of the three pillars of SNETP.

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.

NC2I Mission

The Nuclear Cogeneration Industrial Initiative (www.nc2i.eu) was established as one of the three pillars of the Sustainable Nuclear Energy Technology Platform (SNETP - www.snetp.eu). In line with the objectives and timing foreseen by the Strategic Energy Technology Plan (SET-Plan) issued by the European Commission, NC2I proposes an effective nuclear technology for reaching the SET-Plan targets. Its mission stems from the energy needs assessment of the European economy and focuses on realising a significant **contribution to clean and competitive energy beyond electricity by facilitating the deployment of nuclear cogeneration plants.**

1. Need for cleaner and competitive heat

Nuclear power is a reliable technology for electricity production without harmful emissions. Today's industrial nuclear power plants produce 26% of all electricity [1] and 52% of energy from non-combustible sources in Europe. However, electricity represents only 24% of the European energy consumption, while heating and cooling for residential and industrial uses account for 50%. Almost 100% of derived heat is obtained from combustion and only 0.2% from nuclear reactors. This implies that an effective European energy strategy has to address this sector with high priority although it is merely invisible to the general public. The expected political and socio-economic benefit is very significant.

2. Low temperature cogeneration

In addition to electricity generation, heat from present industrial nuclear reactors is already being used up to 240°C in several European countries and worldwide, e.g. for district heating, seawater desalination or various needs of process heat in the paper and pulp industry. As confirmed by related studies (NC2I-R project [2], IAEA [3]), the significant existing experience in nuclear cogeneration of heat and power has shown that nuclear energy can substitute fossil fired cogeneration without drawback in terms of compatibility with end-user needs, performance, reliability and safety, and even with advantages in terms of economic aspects such as competitive cost and price stability, reduction of emissions, and customer satisfaction.

1 - All data for energy 2015 EC28 : http://ec.europa.eu/eurostat and http://heatroad-map.eu/

2 - C. Auriault, O. Baudrand, M.A. Fütterer, Experience Feedback from Nuclear Cogeneration, 2015 International Congress on Advances in Nuclear Power Plants, ICAPP'15, Nice, France, 3-6 May 2015.

3 - Advanced Applications of Water Cooled Nuclear Power Plants - IAEA-TECDOC-1584 (July 2007)

4 - A. Bredimas, "Market study on energy usage in European heat intensive industries", EUROPAIRS project, FP7, Deliverable 131, 27/05/2011

5 - A. Bredimas, "Results of a European industrial heat market analysis as a pre-requisite to evaluating the HTR market in Europe and elsewhere", Nuclear Engineering and Design, Vol. 271, p. 41-45 (May 2014)

6 - Advances in Nuclear Power Process Heat Applications – IAEA-TECDOC-1682 (May 2012).

3. High temperature industrial heat

About 95% of the process heat market in most industrialised countries is characterised by high energy intensity and high temperature (see figure below, from data of Ref. [4]). This, coupled with strong dominance of fossil fuels in heat production, results in high emissions, not only of CO_2, but also of fine dust, heavy metals, NOx, SO_3 and others. As a consequence, many issues concerning public health, environment, energy security, geopolitics, socio-economics etc. are at stake. As long as no commercially viable alternative exists, fossil fuels remain the sole option for the many high temperature processes that power our industry.

In Europe, about 50% of the process heat market is found in the temperature range up to 550°C (today mainly in the chemical industry, in the future possibly in steelmaking, hydrogen production, etc.) [4], [5]. Therefore, to advance broader applications of nuclear cogeneration in the industrial processes that require heat supply at high temperature, international technology developments are focusing on nuclear reactor types designed to deliver this high temperature heat.

Various reactor concepts can be considered e.g. the well-known Generation IV International Forum concepts, including modular High Temperature Reactors (HTR) and their long-term evolution towards very high temperatures (VHTR), Super-Critical Water Reactors (SCWR), Molten Salt Reactors (MSR) and different Fast neutron Reactor concepts cooled by either Sodium (SFR), Lead (LFR) or Gas (GFR).

However, for near-term solutions delivering process steam up to 550°C, the HTR is currently the only option [6] and the one that covers the largest range of temperature. Moreover, modular HTR designs feature unique simplicity owing to their intrinsic passive safety concept which makes expensive redundant and active engineered safety systems superfluous. This is a clear advantage for siting in proximity to industrial end users and for competitiveness, which are prerequisites for any industrial deployment.

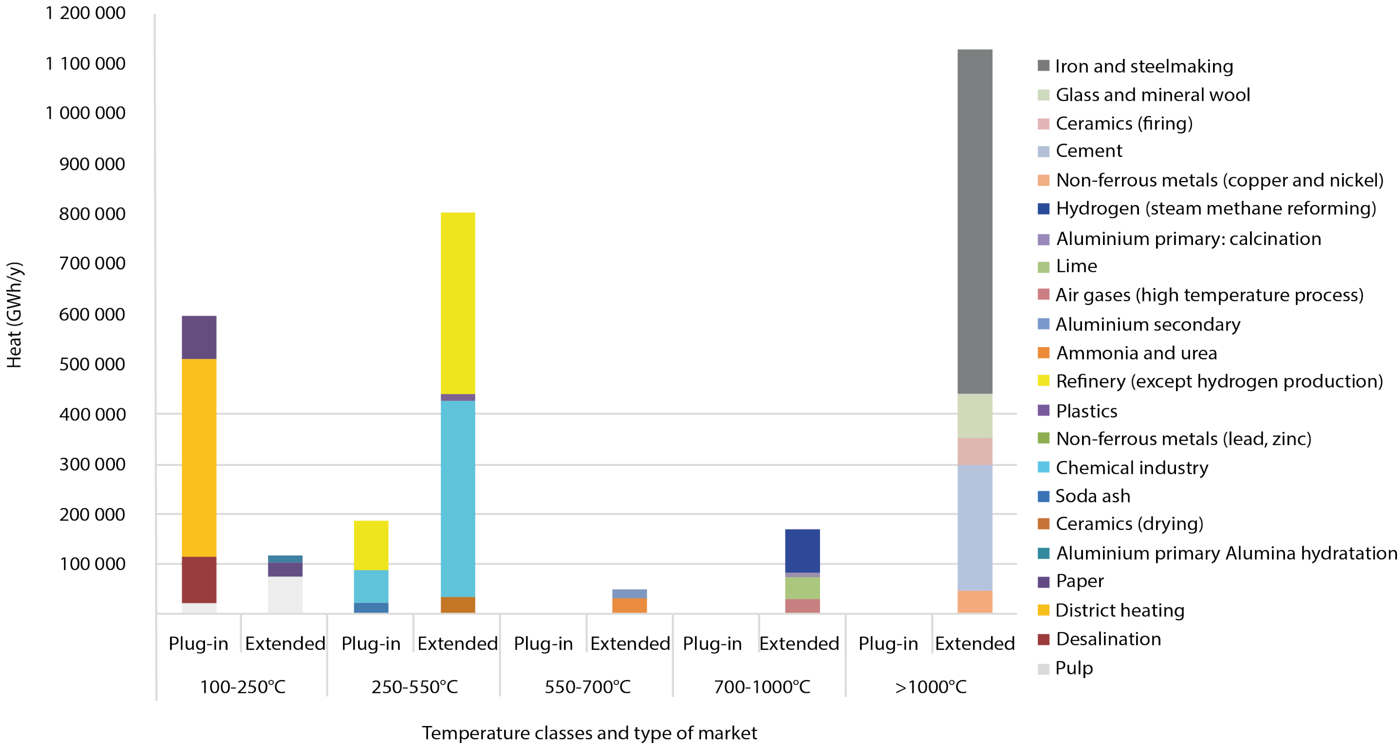

Figure: Distribution of the European heat market by temperature class and sector [4]

The plug-in market is the part of the market in which heat is supplied to industrial processes by steam distribution networks in the temperature range 100-550˚C. Today steam is produced by fossil fuel fired cogeneration plants or boilers, which can be substituted by nuclear plants delivering steam with the same characteristics, without any changes in the existing steam distribution infrastructure. The remaining heat market is the extended market. In the range 250-550˚C, the European heat market represents more than 100 GWth. This includes a large part of industrial applications requiring higher temperature steam than what Light Water Reactors could deliver.

NC2I Strategy

In line with the ambitious goals and the agenda of the Strategic Energy Technology Plan (SET-Plan) issued by the European Commission, NC2I endeavours to provide a timely nuclear contribution to the European heat needs.

NC2I aims at unlocking and using the potential of nuclear cogeneration to substitute at large scale fossil fuels in industrial and residential heat applications. Hence, it focuses on collecting and developing the know-how needed for industrial deployment of nuclear cogeneration and then on demonstrating the feasibility of this technology for supplying industrial process heat in an economically competitive way, as well as the feasibility of licensing a nuclear system based on this technology for collocation of a nuclear heat source with such applications.

1. Low temperature cogeneration

Although the experience of low temperature cogeneration with LWRs has been largely positive, up to now such installations remain rather rare and at the scale of a few tenths of MWth. Based on the analysis of the existing experience and of its so far limited market penetration, NC2I is supporting initiatives to facilitate further deployment of low temperature nuclear cogeneration.

In particular NC2I is following the present development of Integrated PWR Small Modular Reactors (SMR) that might offer new prospects for low temperature cogeneration: the power delivered by these systems often matches well with end-user needs in several EU countries. Their safety design, based on systematic use of passive systems might exclude massive radioactive releases in accidental conditions. Consequently, the construction of such reactors in close vicinity to agglomerations or industrial sites might be acceptable, thus avoiding high costs for long-distance heat transport and resulting heat losses. These SMRs could therefore substitute fossil-fired boilers or cogeneration plants to deliver hot water or steam to existing heat networks without requiring changes to these heat distribution infrastructures. However, these applications are limited to a relatively small market sector with applications up to approximately 250°C.

2. High temperature industrial heat

For the much larger market of industrial processes requiring steam up to 550°C, NC2I considers HTR technology to be the most appropriate in the short/medium term for the following reasons:

- **HTR technology has a much higher technology readiness level than other concepts:** in Europe, extensive technology developments have been performed, including projects of recent Euratom Framework Programmes. Two test reactors (DRAGON in the UK and AVR in Germany), as well as an industrial prototype (THTR in Germany), were built and operated. Beyond Europe, China is building an industrial prototype plant with 2 reactors of 250 MWth each to be commissioned in 2018. Several other countries and private companies are also running HTR development projects, e.g. in the US, Canada, Japan, Korea and elsewhere.

- **The modular HTR design is based on an intrinsically passive safety concept**, using TRISO fuel withstanding over 1600°C in accidental conditions. Combined with relatively low power output and low power density, it makes a core melt-down impossible which facilitates collocation with industrial sites.

- **The intrinsic safety concept of modular HTR enables drastic simplifications of the design.** There is no need for redundant and expensive active engineered safety systems as in other types of reactors. Thanks to that, **economic competitiveness** with fossil fuel firing can be reached at a relatively small power rating of this type of reactor, which is adapted to the needs of many European industrial sites. Therefore, the breakeven with the main competitor of nuclear energy, natural gas, the price of which is currently around $7US/MBtu, is attainable with HTR technology, not to speak about the impact of a possible increase in carbon tax and about gas prices in many Asian countries, sometimes 2 to 3 times higher than in Europe.

Additional advantages make HTR technology a good choice for higher temperatures and other applications:

- HTR technology can cover the largest temperature range: with proven materials, it can operate without risk for industrial application up to at least 750˚C reactor outlet temperature, while other concepts (except for the MSR) are limited to about 500˚C.

- HTR technology has high potential for further improvements: with the use of advanced materials and with innovative components, Very High Temperature Reactors (VHTR) could, in the longer term, supply heat to industrial applications beyond 900˚C, thus enabling large-scale bulk hydrogen production via thermochemical cycles or high temperature steam electrolysis. Even without the establishment of a «hydrogen economy», the European and global market of hydrogen is large and rapidly growing.

- HTR is suitable for various power conversion cycles: steam cycles are currently widely used for conventional cogeneration plants. Using HTR for steam cycle power conversion has been already tested. Alternative power conversion systems (e.g. direct Brayton cycles or indirect supercritical CO_2 cycles) could also be used in the longer-term and are under consideration for further enhanced efficiency.

As HTR technology is mature, the short-term objective is not to wait for further development, but to demonstrate its ability to be deployed for industrial cogeneration.

NC2I considers that an industrial demonstration project of high temperature nuclear cogeneration with a full-scale prototype of a future commercial system can be launched right now. Such a demonstration is the key for market breakthrough and it is achievable in Europe within approximately a decade.

For other types of systems mentioned above, industrial deployment is not expected before the middle of this century. Therefore, demonstration with HTR will also pave the way for longer-term cogeneration applications with other types of advanced nuclear systems.

Industrial cogeneration is widely used at many industrial sites all over Europe for production of steam at a maximum temperature of 550˚C. This steam is distributed to industrial applications by large steam distribution networks. At higher temperature, the heat required by applications is currently produced in situ by combustion of fossil fuel and no technology for heat transport is available, except for a few applications using molten salts up to 650˚C. The main objective of NC2I is to demonstrate high temperature nuclear cogeneration as soon as possible, which is a major innovation comprising certain risks (licensing, competitiveness). Therefore, in order to minimise additional technical, financial and schedule risks, NC2I proposes to focus this demonstration by substituting a HTR system to a conventional cogeneration plant for steam supply to an existing steam distribution network ("plug-in" application).

NC2I Actions

In order to achieve the demonstration of nuclear cogeneration at industrial scale as soon as possible, NC2I partners, in cooperation with authorities in target countries, are working to facilitate:

- the development of international cooperation around the project, so as to let it benefit from activities of international organisations, such as OECD/NEA, IAEA, and GIF, as well as other industrial and research capacities.
- the preparation of an updated licensing framework for a modular cogeneration plant including the highest recent safety requirements, in particular taking into account the feedback from the Fukushima accident and the European Nuclear Safety Directive.
- the definition of the most appropriate technical options of a commercial reactor design addressing the needs of specific end-users, competitiveness and updated safety requirements, at the same time minimising project risks.
- the selection of a construction site (appropriate physical and industrial conditions, involvement of local industry, support from politics and favourable public opinion).
- the development of a robust business model for the demonstration project, ensuring the most appropriate financing options and commitment of investing actors (national, European, private, possibly non-European) for the whole project duration.
- the building of an operational project team gathering available expertise and experience, while at the same time training a young generation of nuclear engineers, introducing them to the most modern technologies and tools.

NC2I will disseminate to all political and economic stakeholders information about the progress of the programme for demonstration of high temperature cogeneration, in order to contribute both to low temperature nuclear cogeneration and heat production by advanced reactor systems, in synergy with other SNETP pillars.

NOTES

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