Non-Electric Applications of Nuclear Heat (NEANH) Task Force

Virtual Workshop and Information Exchange on Development of Cogeneration Applications of Gen IV Nuclear Technologies

SUMMARY REPORT

July 12-13, 2022

July 12, 15:00 - 17:00 CEST

July 13, 14:00 - 17:00 CEST

Background

NEANH Task Force Background

The Generation IV International Forum (GIF) is a co-operative international endeavour set up to carry out the research and development (R&D) needed to establish the feasibility and performance of the next generation (Gen-IV) nuclear energy systems.

Beginning in November 2020, GIF facilitated an open exchange of expert views on the position of Gen-IV systems regarding applications of nuclear fission-generated heat beyond the electric grid. These activities suggested a path forward for GIF to leverage work being conducted internationally and identify the benefits that Gen-IV reactor systems could bring to the non-electric energy sector in the context of future energy markets. At the 51st GIF Policy Group (PG) meeting held on 20-21 May 2021, the GIF Policy Group members decided to establish a new integrated Task Force (TF) on Non-Electric applications of Nuclear Heat (NEANH TF), which was officially launched in October 2021 for a period of 24 months.

Workshop purpose and expected outputs

A virtual workshop was held in July 2022 to align members of the NEANH TF at the same level of technical knowledge regarding novel deployment opportunities for advanced nuclear systems. This “internal” discussion among the nuclear technology community helped the NEANH TF prepare for engagement of end-users at the in-person workshop in October 2022, held in the same spirit as the GIF Industry Forum.

The workshop served as the basis for a high-level summary report on work that has been conducted by the participating GIF signatories on non-electric applications of nuclear energy, and areas of interest as the work moves forward.

Furthermore, analysis tools (with summary of capabilities), key results, and relevant reports will be captured within a database developed and maintained by the GIF Technical Secretariat on behalf of the NEANH members.

Workshop program and participation

The workshop was held over two days, Tuesday July 12th and Wednesday July 13th between 15:00 – 17:00 and 14:00 – 17:00 CEST, respectively.

This workshop provided an opportunity for 18 speakers to discuss and present their work on non-electrical applications of nuclear heat through 14 dedicated sessions and two moderated panel discussions. The presentations were provided by 7 different national laboratories from three different continents, 3 international organisations, and one private potential end-user company. The workshop program is provided in Annex 1 of this summary report.

A maximum of 50 and 49 participants attended day 1 and day 2 of the workshop, respectively. A detailed list of participants is provided in Annex 2 of this summary report.

Workshop Introduction and Context

There is a strong motivation for expanding the role of nuclear technologies beyond electricity generation to include direct use of heat and provision of energy to off-grid applications, as well as the production of hydrogen for use both as an energy carrier and as feedstock to displace fossil hydrocarbons.

Currently, in most signatory countries, electricity demand is met by individual generators that provide electricity to the grid, which is managed separately by independent grid operators. Notably, this separation between generation and transport/distribution of electricity was introduced in several countries during market liberalization efforts in the 1980s to allow for competition in order to grant attractive prices for consumers. In contrast, thermal energy demand by industrial stakeholders is typically met by individual thermal plants.

Electricity generation accounts for roughly a quarter of final energy use while heat and transportation accounts for the majority of energy consumption.

The challenge to replace fossil fuels is already immense and is expected to be further increased by growing energy demand and stringent environmental goals.

Historically, nuclear energy has been used as a baseload electricity source with high capacity factors. However, as the share of variable renewables increases in the power mixes of many countries, so does the need for flexibility. This raises new questions for nuclear energy and how to utilize it more efficiently, particularly alongside other sources such as variables renewables, hydropower, and in combination with non-electric applications and energy storage technologies.

Other key questions include:

- What is the ideal mix for Nuclear-Integrated Energy Systems within various markets based on criteria such as cost, environmental impact or security of supply?
- What are the driving factors (economic and other) that nuclear technologies can leverage through integrated energy systems (IES) production coupling?
- What are the optimal coupling strategies between IES technologies and advanced nuclear plants?

There is consensus among the nuclear energy community that now is the right time to move forward towards demonstration and deployment of nuclear-powered cogeneration pilot plants to demonstrate their technical and economic potential.

What are the opportunities?

In recent years many countries have increased their decarbonisation ambitions. A largely shared aim is to reach net-zero by mid-century. In this context, there is growing attention to cost: How much will economy-wide decarbonisation cost? What are some near term opportunities to achieve success?

In addition to energy markets, the decarbonisation challenge for the feedstock market must not be overlooked. For example, a supply of low-carbon intensity hydrogen feedstock could enable considerable emission reductions for processes such as steel production and ammonia production. In this context, the vast demand for low-carbon electricity, heat, or commodities implies an opportunity for nuclear energy.

The energy transition has entered into a new sustainability paradigm that goes beyond emissions reductions, and includes issues related to energy sovereignty, energy security, technology leadership, economic growth, and equitable development.

Renewables alone are not sufficient in most countries to meet the expected demand for low carbon energy, and nuclear energy is a leading option to support renewables, especially in regions with high energy demand per unit area.

We have to learn to manage “VUCA” energy systems, i.e., energy systems that are characterized by their volatility, uncertainty, complexity and ambiguity (in particular due to political decisions that change priorities while long-term planning would be required) if we are to be successful in achieving our decarbonization ambitions.

Transporting heat and hydrogen over long distances comes with penalties in efficiency. Therefore, collocation of generation and consumption should be considered early in the design of future systems and infrastructures. Regulatory gaps related to the separation between nuclear and conventional installations as elements of integrated energy systems need additional exploration.

Pathways to decarbonisation

Nuclear energy can contribute in at least four ways to the decarbonisation of our economies: through long-term operations (LTO), new builds of conventional large scale reactors, small modular reactors (SMR), and non-electric applications.

Overall, around 90 Gt of CO2 could be avoided between 2020 and 2050 if nuclear energy is deployed following an ambitious goal of 1100 GWe installed globally by mid-century. This goal is aligned with the average nuclear deployment across all 90 pathways considered by the Intergovernmental Panel on Climate Change (IPCC) compatible with the objective to limit global warming to 1.5 °C.

Emerging markets

Private industry has recently expressed interest in exploring nuclear energy to meet their energy needs, providing an opportunity for the nuclear industry to engage other industries to enable collaboration in systems analysis and further development of IES.

Private stakeholder timelines generally are not aligned with recent development timelines for large scale nuclear energy. The anticipated faster deployment of SMRs would create an opportunity for greater private sector engagement in non-electric applications.

The production of certain chemicals, such as synthetic hydrocarbons and ammonia, represents a large and growing market opportunity for nuclear cogeneration.

The cost of natural gas is now several times higher than one year ago, which is expected to impact the cost of conventionally produced hydrogen and the competitiveness of hydrogen produced by electrolysis (which could be driven by fission-generated heat and electricity).

Energy sovereignty and security of supply are key to the decision of many nation states and the private sector on whether to develop and deploy nuclear energy systems.

Past experience in GIF signatory countries in nuclear cogeneration presented at the workshop

Several short presentations delivered at the workshop provided examples of previous and existing experience in GIF signatory countries regarding the use of nuclear cogeneration, including:

- UK Calder Hall Magnox (fuel plant, shut down in 2003)
- Norway Halden BWR (steam for the Saugbrugs paper factory, shut down in 2018)
- Switzerland Gösgen PWR (transport of steam over 2 km to a cardboard factory).
- Switzerland Beznau (district heating)
- Various Eastern European countries (district heating)
- Japan (seawater desalination)
- Canada Bruce A CANDU (district and industrial heating, cogeneration stopped in 1997)
- Germany Stade PWR (salt refinery, nuclear plant shut down in 2003)

Reflections and lessons learned from these applications include:

- It is important to consider heat applications at the design phase of nuclear systems. Retrofitting a system originally designed for electricity exclusively could be expensive.
- There is precedent to operate these cogeneration systems reliably and without safety issues.

- Nuclear standards and regulations have evolved since the previous successful demonstrations were operating and must be reviewed as a part of current efforts.

The Next Generation Nuclear Plant (NGNP) initiative (U.S. Department of Energy) has developed technical and economic analyses of processes that could use nuclear heat from High Temperature Gas cooled Reactors.

Analysis and optimization approaches

- Idaho National Laboratory (INL) has developed a suite of tools, comprising the Framework for Optimization of ResourCes and Economics (FORCE), for IES modelling analysis which includes modelling of multiple physical processes, process integration, safety analysis, optimization of capacity and dispatch and techno-economic analysis in the context of specific deployment regions and energy markets.
- The INL FORCE tools for IES analysis are available in the public domain and training modules for the tools are also available online at https://ies.inl.gov/SitePages/FORCE_2022.aspx.
- IAEA's FRAmework for the Modelling of Energy Systems (FRAMES) tool calculates the optimal dispatch of existing operating units subject to various constraints (e.g., CO2 emissions). This tool predicts that nuclear energy plays a major role in low carbon hydrogen in the absence of carbon capture and sequestration (CCS).
- IAEA is conducting a survey of nuclear utilities planning to produce hydrogen using energy from existing nuclear plants. Three U.S. utilities are currently planning small-scale demonstrations of on-site hydrogen production at operating PWRs.
- IAEA's Model for Energy Supply System Alternatives and their General Environmental impacts (MESSAGE) tool evaluates alternative energy strategies subject to constraints on new investments, fuel availability, emissions, etc.
- Canadian Nuclear Laboratories (CNL) has developed the Hybrid Energy System Optimization (HESO) model for techno-economic optimization of integrated energy systems and used it for case studies of different types of integrated systems (including renewables, SMRs, diesel generators, energy storage, and hydrogen production) for remote communities. The tool is not available publicly.
- The GIF Economic Modelling Working Group is updating its cost estimating guidelines and the economic assessment tool G4ECONS, which will include non-electric applications.

Takeaway Messages

- The nuclear community, including GIF, is ready to propose new and flexible energy solutions to end-users that would meet new economic, environmental, and political requirements. These sytems will be proposed at the October NEANH workshop in Toronto with industrial end users, policy makers and possibly investors.
- There is a good opportunity to expand the role of nuclear technologies beyond electricity generation to also include delivery of thermal energy and production of industrial feedstocks (e.g., hydrogen), especially in the context of international decarbonisation ambitions.
- There is an interest from private industry to explore nuclear energy, and an opportunity for the nuclear industry to engage other industries to enable full collaboration.
- There is a need to explore and communicate realistic timelines and costs for nuclear energy projects to enable private sector engagement in non-electric applications.
- There are historic examples of using nuclear energy for non-electric applications.
- Multiple analysis and optimization tools already exist and can be leveraged to inform the opportunity for NEANH.

Annex 1: Workshop Agenda

Day 1 – 12th July (Tuesday)	
15:00	**Introduction: Motivations for NEANH** (Shannon Bragg-Sitton, INL)
15:10	**WHAT ARE THE OPPORTUNITIES AT HAND?** *Moderated discussion opened to participants and supported by a panel* **Moderator:** ● Shannon Bragg-Sitton, INL **Panel:** ● Aiden Peakman, NIRO ● Michael Fütterer, EC JRC ● Gilles Rodriguez, CEA
15:40	**PATHWAYS TO DECARBONISATION** *Opening statements and then discussion moderated by Shannon Bragg-Sitton.* • Meeting Climate Change Targets: *The Role of Nuclear Energy* (Lucas Mir, OECD NEA)
16:00	**EMERGING MARKETS** *Opening statements (40 minutes) and panel discussion moderated by Aiden Peakman.* ● Feasibility Study of Nuclear Desalination using SMART Reactor (Han Ok Kang, KAERI) ● Hydrogen Markets: Growing Demand for Clean Hydrogen? (Paul Lucchese, IEA TCP) ● District Heating Opportunities, the case of Finland (Olli Soppela, VTT) ● Industrial Heat Demand in the Canadian Oil Sands (Bronwyn Hyland, Suncor)
17:00	**END OF DAY 1**

Day 2 – 13th July (Wednesday)	
14:00	**Introduction** (Shannon Bragg-Sitton, INL)
14:10	**PAST EXPERIENCE IN NUCLEAR ENERGY FOR COGENERATION** *Opening statements (30 minutes) and panel discussion moderated by Michael Fuetterer.* ● Past experience in cogeneration: the case of Canada (Ramesh Sadhankar, NRCan) ● Integration of HTGRs into Industrial Process Applications (Lee Nelson, INL) ● Past experience in nuclear process heat applications (Karl Verfondern, FZJ)
14:50	**DEMONSTRATION AND DEPLOYMENT STATUS** *Opening statements (30 minutes) and panel discussion moderated by Gilles Rodriguez.* ● Nuclear-hydrogen demonstration programs, the case of the United States (Richard Boardman, INL) ● Nuclear desalination and the challenge of thermal coupling (Alina Constantin, IAEA)

	• Hydrogen production using nuclear High Temperature Reactor (Taiju Shibata, JAEA)
15:30	**ANALYSIS AND OPTIMIZATION APPROACHES** *Opening statements (30 minutes) and panel discussion moderated by Ramesh Sadhankar.* • Analysis and Optimization Approaches: Presentation from the Idaho National Laboratory (Aaron Epiney, INL) • IAEA activities on the role of H2 in the Energy Transitions (Henri Paillere, IAEA) • Overview of optimization modelling and EMWG work on economic modelling (Megan Moore, CNL)
16:10	**DISCUSSION ON KEY FINDINGS** *Moderated discussion opened to participants and supported by a panel.* **Moderator:** • Shannon Bragg-Sitton, INL **Support panel:** • Aiden Peakman, NIRO • Michael Fütterer, EC JRC • Gilles RODRIGUEZ, CEA
16:40	**WRAP UP/ADJOURN**

Annex 2: List of participants

12 JULY 2022

Speakers

- Shannon Bragg-Sitton, Task Force Chair (INL)
- Michael Fütterer (EC-JRC)
- Han Ok Kang (KAERI)
- Paul Lucchese (IEA TCP)
- Lucas Mir (NEA)
- Aiden Peakman (NIRO)
- Gilles Rodriguez (CEA/IRE)
- Olli Soppela (VTT)
- Bronwyn Hyland (Suncor)
- David Shropshire (INL)
- Mijin Kim (Ulsan National Institute Science and Technology)
- Seokbin Park (Seoul National University)
- KyungSoo Yoon (KAERI)
- Joe Tortorelli (NRCan)
- Jeff Holliday (NIRO)
- Daniel Mikkelson (INL)
- Ekaterina Rodionova (Kurchatov Institute)
- Aaron Epiney (INL)

Participants

- Rob Arnold (BEIS)
- Brent Dixon (INL)
- Paul Gauthé (CEA)
- Peter Fomichenko (NRC KI)
- Aleksandr Lazarev (OKBM)
- Ramakant Sadhankar (NRCan)
- Seokbin Park (Seoul National University)
- David Holcomb (ORNL)
- Marisol Garrouste (INL/University of Michigan)
- Nawal Prinja (Jacobs)
- Chan Soo Kim (KAERI)
- Hyeonil Kim (KAERI)
- Taiju Shibata (JAEA)
- Haydn C. Bryan (INL)
- Sung Nam Lee (KAERI)
- Han Kang (HEC)
- Will Jenson (INL)
- Ilia Pakhomov (IPPE)
- Grol AV (Kurchatov Institute)
- Dawn Scates (INL)

- Jewhan Lee (KAERI)
- Anna Wrobel (INL)
- Andrey Balanin (KurchatovI Institute)
- Hidemasa Yamano (IAEA)
- Megan Moore (CNL)
- Karl Verfondern (Institute of Energy and Climate Research)

NEA/NTE

- Gina Abdelsalam
- Wendy Houët
- Seoyeong Jeong
- Youngjoon Lee
- Franco Michel-Sendis
- Masahiro Nishimura
- Vladislav Sozoniuk

13 JULY 2022

Speakers

- Shannon Bragg-Sitton, Task Force Chair (INL)
- Richard Boardman (INL)
- Alina Constantin (IAEA)
- Aaron Epiney (INL)
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