Workshop on Non-Electric and Hybrid Applications of Nuclear Energy

WORKSHOP SYNOPSIS AND FINDINGS

Friday, April 26, 2024, from 9:00 – 17:00
205 APEC Hall, BEXCO Convention Hall and Exhibition Hall, Busan, Korea

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Workshop Overview and Key Findings

Workshop Overview

Generation IV International Forum (GIF) Task Force on Non-Electric Applications of Nuclear Heat (NEANH TF) and the Korea Atomic Energy Research Institute (KAERI) co-organised the Non-Electric and Hybrid Applications of Nuclear Energy Workshop on April 26, 2024, in Busan, Korea. The event was hosted by the Korean Nuclear Industry Association (KAIF) and the Korea Nuclear International Cooperation Foundation (KONICOF) on the margins of the 39th Korea Atomic Power (KAP) Annual Conference.

This Non-Electric and Hybrid Applications of Nuclear Energy Workshop included approximately 75 participants from around the world, and featured participation from international organisations collaborating on exploring the opportunity for NEANH, energy end users in hard-to-abate industrial sectors, regulators, and nuclear technology developers targeting non-electric applications. Participants shared information on specific needs, requirements, and potential challenges or concerns associated with coupling nuclear energy to industrial applications in pursuit of advancing technologies toward a net zero future.

In addition to scene-setting remarks, information was primarily provided through presentations, which are available in Appendix A. The event featured the following sessions:

Session 1: Historic context and overview of ongoing international efforts
Session 2: Industrial end user perspectives
Session 3: Operational experience and the challenges associated with operating a co-located system
Session 4: Panel with nuclear technology developers targeting non-electric applications.
Session 5: Interactive discussion on the topics discussed, and next steps.

The day's discussion followed Chatham house rules. Comments are included in this synopsis without attribution to allow anonymity, unless permission was explicitly provided. The event featured simultaneous interpretation between English and Korean, and presentations were delivered in both languages.

This 2024 Workshop follows the first NEANH Workshop held in Toronto, Canada in October 2022 and supports the NEANH Task Force's efforts to enhance the general level of knowledge on non-grid applications of nuclear systems, highlight system configurations that are relevant for further investigation, and develop a network to the high temperature community outside the nuclear field to inform systems analysis on non-electric applications of nuclear heat.

Key Insights

- There is a useful history of nuclear energy use for non-electric applications, but this is limited to lower temperature applications employing LWR technologies. Higher temperature industrial applications have different considerations and may benefit more from GenIV reactor technology.
- At higher temperatures, fuel switching to support industrial processes is challenging and requires significant alterations to existing processes. Integrated systems analysis and financial support are likely required to enable this transition.
- Heat and electricity demand associated with industrial decarbonisation will be significant.
- Reports and tools exist to help end users assess the opportunity to utilise nuclear energy for their operations. Increased engagement between the nuclear and industrial communities is encouraged.
- There is a significant opportunity to use nuclear energy to reduce emissions in industrial sectors, and end users would deploy nuclear energy today if systems were commercially available.
- Hydrogen production is of particular interest, and value chain analysis is required to understand the competitiveness of nuclear energy in producing hydrogen.
- There is regulatory uncertainty for NEANH, and systems will require a case-by-case analysis using a risk-informed and graded approach. There are no obvious technical barriers that cannot be overcome.
- The opportunity for NEANH is geographically distinct due to unique regulatory landscapes, domestic policies, availability of alternative energy options, energy demands of industrial users, and supply chain capabilities.
- Increased collaboration beyond the nuclear sector is essential, including to communicate progress in this area. Communication and transparency are important to build confidence among regulators, investors, and the public.
- Future workshops should include additional end users and other impacted stakeholders such as financiers, investors, and insurers.

Workshop Summary

Opening remarks

Welcome Address - Jin Young CHO, Senior VP, Advanced Nuclear Reactor Laboratory, KAERI

As the Policy Group Member from Korea to GIF and co-organiser of the workshop, Jin Young CHO welcomed international and domestic stakeholders and highlighted the importance of this event given international efforts to reduce emissions, including in industrial sectors.

Jin Young noted that emissions from the industrial sector in many developed countries is a greater contributor to total emissions when compared to electricity generation. He acknowledged the important leadership internationally to demonstrate the opportunity to use nuclear energy to provide process heat for industrial processes, which includes DOW Chemical working with X-Energy to demonstrate the Xe-100 HTGR reactor in the US, and the EU joint research project GEMINI 4.0.

Jin Young CHO noted the role that Korea will play in this emerging area and highlighted the success of the nuclear energy supply chain in Korea to deliver projects on schedule, including the APR1400 technologies deployed both domestically and abroad.

Congratulatory Address - Joon Ho SHIN, Director General, KONICOF

Joon Ho SHIN similarly highlighted the importance of the opportunity to use nuclear energy as a source of non-emitting heat and reliable electricity to support industry and noted that a practical and holistic approach is essential. He noted that nuclear energy is required in energy systems as it is impossible to power economies with 100% renewable energy generation.

Joon Ho noted the declaration to triple nuclear energy generating capacity by 2030, which was committed by many countries during the recent Conference of the Parties (COP) event (COP28) in the United Arab Emirates. Internationally, nuclear energy is also a strategic asset of geopolitical importance as it can power domestic energy security.

He concluded with an aspirational message that the workshop could be used as a platform to advance this global effort and highlighted the role of KONICOF and GIF Joon Ho noted the Position Paper of the NEANH Task Force as a reference for more information on the importance and the range of non-electric applications that could be decarbonized using nuclear energy.

Session 1: Historic context and overview of ongoing international efforts

Listed Session Speakers

- Shannon BRAGG-SITTON, Director, Integrated Energy and Storage Systems, Idaho National Laboratory (Chair of the GIF NEANH Task Force)
- Francesco GANDA, Technical Lead for Non-Electric Applications, International Atomic Energy Agency (IAEA)
- Brent WILHELM, Nuclear Technology and Economics Analyst, Nuclear Energy Agency (NEA)
- Pierre SERRE-COMBE, Deputy Director, Energy Programs for New Hydrogen Technology, CEA

Key Findings from Session

- There is significant historic precedence for using nuclear fission energy to support heat applications, including for district heating, desalination, and chemicals production.
- It is a priority for governments around the world to explore the opportunity to use nuclear energy for applications beyond grid electricity. There is evidence of good coordination among international initiatives working in this area to share information and leverage complimentary interests.
- There are existing tools that could help industrial end users assess the opportunity, including through research institutions in GIF member countries and the IAEA.
- Engagement with industry is required and encouraged to reduce the overall risk of failure. Mechanisms are being established for industry to better engage the nuclear community and provide information that could support this effort, including informing regulators of the potential risks and requirements associated with nuclear energy integration.
- Hydrogen production from nuclear energy was discussed in depth. Analysis of the overall hydrogen value chain and integrated system operation is needed to identify the competitiveness of nuclear energy to produce hydrogen.
- Confidence is critical to success—whether this is confidence among regulators, investors, or the public. Communication and transparency are important in building confidence.

Session Summary

History of non-electric and hybrid applications of nuclear energy and the NEANH Task Force

- Shannon BRAGG-SITTON provided an overview of GIF and the NEANH TF that she chairs. She discussed the historical and current utilization of nuclear fission for non-grid applications, such as hydrogen production, sustainable fuel production, and district heating. Shannon noted that the industry has over 750 reactor-years of experience in non-electric applications, primarily with light water reactor technologies, including 17 reactors that have supported desalination and 7 providing pressure and steam for industrial needs.
- Since the NEANH Task Force was established, the group has been advancing activities to convene stakeholders in the nuclear community and industrial end users and assess opportunities for NEANH. The TF's ongoing work includes systems analyses, regulatory discussions, and the development of a database of non-electric nuclear applications.

- In conclusion, Bragg-Sitton called for active engagement from industry stakeholders in the collaborative effort to deploy nuclear technologies for decarbonization and highlighted upcoming opportunities for contribution and participation in this field.

IAEA activities related to non-electric applications

- Francesco GANDA noted that a number of tools and toolkits have been produced by the IAEA to support analysis of cogeneration opportunities, including: Hydrogen Economic Evaluation Program (HEEP) for techno-economic assessment of hydrogen generation, Desalination Economic Evaluation Program (DEEP) for desalination, Desalination Thermodynamic Optimization Programme (DE-TOP) on thermodynamic coupling for cogeneration, Hydrogen Calculator (HydCalc) for hydrogen production cost calculations, and FRAmework for the Modelling of Energy Systems (FRAMES) for integrated energy system analysis (this tool currently in the process of being developed and shared with IAEA members).
- Upcoming research projects and events on nuclear cogeneration were highlighted, including a meeting on cogeneration scheduled for December 2024 at the IAEA headquarters in Vienna.
- A particular interest in hydrogen was noted among IAEA member countries, and a number of hydrogen-related publications from the IAEA have been developed. Analysis of hydrogen production is underway, including a roadmap for the commercial deployment of nuclear hydrogen production and two upcoming reports: “Nuclear cogeneration towards climate change mitigation and sustainable development goals” ., and “Advances in High Temperature Processes for Hydrogen Production with Nuclear Energy” (expected 2024 2025).
- The IAEA is engaging with a number of international initiatives on non-electric applications, including the NEA H2 VAL Working Group, GIF NEANH TF, the UN European Commission on Energy’s H2 Task Force, and the Sustainable Nuclear Energy Technology Platform, among others.

NEA activities on hydrogen and industrial case studies for SMR markets

- Brent WILHELM discussed a set of activities underway within the Nuclear Technology and Economics Division of the NEA related to non-electric and hybrid applications of nuclear energy.
- The NEA report on the *Role of Nuclear Power in the Hydrogen Economy* was published in 2022.The report noted that competitiveness for nuclear energy to produce hydrogen is improved when the holistic hydrogen value chain is considered. A new NEA working group, H2 VAL, has been established to progress value chain analysis of nuclear energy produced hydrogen in cooperation with experts across NEA member countries, with a focus on ammonia and synfuel production.
- The NEA is leading a series of industrial case studies to explore markets for SMRs beyond electricity production. Case studies on the applications for SMRs in the mining sector, to replace coal generating assets, for district heating, and industrial cogeneration will be published in 2024. The case studies will identify a potential market size and characterize technical, business, and operational requirements for each application in consultation with industrial end users. There are opportunities for industrial end users to engage in this process to inform the analysis.

International Energy Agency (IEA) Hydrogen Technology Collaboration Programme Task 44 – Hydrogen from Nuclear Energy

- Pierre SERRE-COMBE presented on behalf of Gilles RODRIGUEZ to present on the Hydrogen from Nuclear Energy (HyNE) Task 44 within the IEA Hydrogen Technology Cooperative Program.
- HyNE exists as one of more than 40 tasks within the IEA Hydrogen Technology Collaboration Programme (TCP), which is a network of international experts representing 24 member countries and 250 individual experts. The goal of Task 44 is to explain, clarify, anticipate, analyse, recommend, and advise on the opportunity for nuclear energy to produce hydrogen.
- The group has produced a position paper on the preference to discuss hydrogen in terms of the carbon intensity instead of using the imperfect international standard of hydrogen colours. Another publication has been developed on considerations for funding nuclear hydrogen projects.
- In addition to upcoming workshops related to the safety of coupling nuclear reactors and hydrogen production factories, the IAEA will be hosting the “International Conference on Small Modular Reactors and their Applications 2024” on October 21-25, 2024, with a dedicated track on non-electric applications for SMRs.

GIF Hydrogen Production PMB with overview of work package 4 on integration technologies

- Pierre SERRE-COMBE highlighted planned analysis within the GIF Hydrogen Production Project Management Board (HP PMB), and the emphasis on integration technologies analysis. The

members of the HP PMB develop and optimize high temperature thermochemical and electrolysis processes and validate technologies associated with coupling Gen IV nuclear energy technologies to these processes. While the VHTR HP PMB is within the VHTR System structure of GIF, the scope of this GIF group has been expanded beyond the VHTR reactor class.

- There are four work packages within the VHTR HP PMB programme of work that advance thermochemical hydrogen production methods, high temperature steam electrolysis (HTSE), and hydrogen production coupling technologies. Pierre noted that GIF members are working to scale up and prototype both thermochemical hydrogen production processes and HTSE. The integration technologies work package is a growing area of focus that captures a range of research tasks including safety, simulations, and system integration analysis. The VHTR HP PMB has committed to strengthening relations with the NEANH Task Force and other groups with similar mandates.

Session 2: Industrial end user perspectives

Listed Session Speakers

Moderated by Chan Soo KIM, Principal Researcher at KAERI, participation from industrial end users included:

- Dongil Peter SHIN, Professor of Chemical Engineering, Myongji University
- Il Hwan KANG, Secretary General, Korean Cogeneration Association
- Jin Nam PARK, Clean Hydrogen Program Director, Institute of Energy Technology Evaluation & Planning
- Jang Hoi CHOI, Director, Carbon Neutrality Strategy Sector, POSCO

Key Findings from Session

- There is an immediate opportunity for nuclear energy to support industrial sectors with low temperature heat below 250C, but higher temperature processes require a dedicated effort to develop integration technologies. GenIV reactors with higher usable temperatures might be more suitable as a plug-in solution to many industrial processes.
- There is significant demand for thermal energy and heat quality and reliability of supply are important for industrial processes. The reliable production and delivery of thermal energy at scale is a competitive advantage of nuclear energy.
- Partnerships and transparent information sharing among industrial end users, the nuclear sector, regulators, and other stakeholders is essential to enable the opportunity to use nuclear energy for these processes.
- Government support is likely required to enable this transition as the scale of the process upgrades is significant.
- The amount of power (both thermal and electrical) required to decarbonise industry is significant, and all industries are taking steps towards net zero emissions by 2050.

Session Summary

Session 2 included an opening presentation from Chan Soo KIM of the Alliance for Nuclear Heat Utilization in Korea. Additional speakers during this session represented the perspectives of industry end users of heat and energy from the chemical, petrochemical, steel, and oil and gas sectors, district heating and hydrogen production sectors.

Overview of the Alliance for Nuclear Heat Utilization in Korea

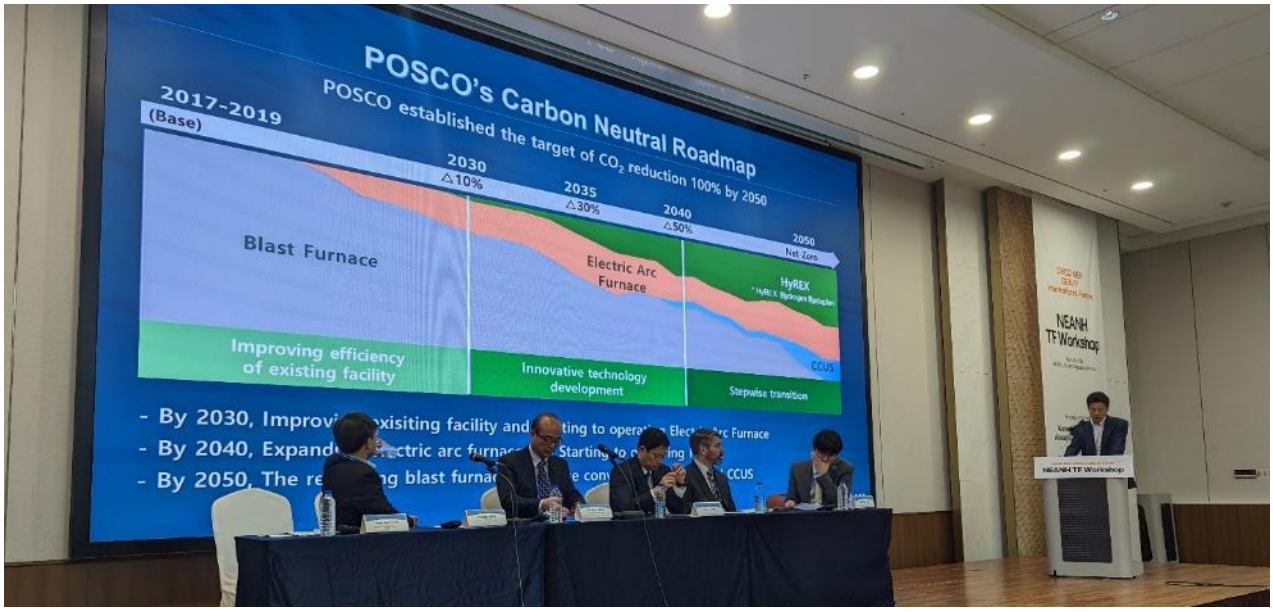
- Chan Soo KIM highlighted the situation in Korea, where progress towards 2030 emissions reduction targets have been primarily in the electricity sector (46% decrease from 2018 levels as of March 2023) but limited in the industrial sector (11% increase). As there is no clear solution to reduce industrial sector emissions, Korea is exploring opportunities to supply nuclear fission generated heat to industrial processes to reduce emissions.
- The Alliance for Nuclear Heat Utilisation was established to develop technologies for nuclear heat supply and utilization, exchange information, and create business connections that could progress a demonstration of a nuclear heat supply system for industry applications. Members of the Alliance include KAERI, the Gyeongsangbuk-do local government, and construction companies in Korea, as well as 4 industry end users in the chemical sector and the POSCO steel-making company.
- Applications such as ammonia cracking, steel production, and hydrogen production are of significant interest to the Alliance. Efforts are underway to establish an industrial complex that could be supplied with nuclear heat to support industries.

Perspectives from the chemicals and petrochemicals sectors

- Globally, the petrochemicals sector accounts for 5% of CO2 emissions, and the oil and gas sector accounts for 6% of emissions.
- In Korea, the petrochemical sector is a significant contributor to economic strength. Korea accounts for 3.4% of global petrochemical sales with exports expected to exceed $45B in the coming years.

- Across the petrochemical sector value chain, the greatest near-term opportunity to reduce emissions is to replace the supply of required steam with non-emitting fuel alternatives, and to improve process efficiency. Other processes will require a dedicated effort to identify integration opportunities, which is especially true for high temperature processes.
- For a given chemical plant, energy requirements are primarily thermal, requiring low temperatures (<250C) for many and higher temperatures for others, ranging from 250-350°C for heating oil, 350-1000°C for select furnaces, and up to 1500°C for blast furnaces and gasifiers.
- There is a strong preference for these industries to continue using thermal energy (versus electrifying processes) to utilize their existing processes to the extent possible, and to reduce costs. Electricity is considered relatively expensive for these industry applications and is minimized. The competitive advantage of nuclear energy is that it reliably produces heat at scale, which aligns well with industrial process that do not have many other opportunities to decarbonise.
- End users expect nuclear energy to be useful for some applications but unsuitable for others. In particular, heat inputs for endothermic processes less than 800°C could use heat generated from nuclear fission, while higher temperature processes could be supported by non-nuclear alternatives (potentially including hydrogen combustion).
- While there is a long history of nuclear energy being used for NEANH, this experience is limited to low temperature applications. Plug-in solutions are not available for high temperature processes. GenIV reactors with temperatures exceeding 500°C are expected to be more suitable as a plug-in solution in the chemicals sector compared to LWRs.
- It was noted that in the 1970s the chemicals sector in the US was considering nuclear energy but it was not deemed economical at the time. Today, chemical processes are still thermal energy dominated. Carbon taxes and other policy impacts could make nuclear energy may be competitive in the future.
- While both the nuclear industry and the chemicals industry may have mature components, the integration of these components is a gap. It is important to have industries and stakeholders from both the nuclear and end user sectors working together to communicate both industry requirements and the capabilities of the nuclear energy technologies so that integration technologies can be developed, and confidence in their viability and performance can grow.

Perspectives from the steel sector and on the emerging hydrogen economy



- The POSCO steel making company is the world leading steelmaker in competitiveness. POSCO aims to achieve net zero emissions by 2050 through the immediate use of electric arc furnaces, with their HyREX (Hydrogen Reduction) process starting in the late 2020s and CCUS starting in late 2030s.
- The POSCO HyREX process is based on a "fluidized bed reactor" process combined with an electric smelting furnace. The process requires significant quantities of hydrogen which is consumed with iron oxide in an endothermic reaction. POSCO is already demonstrating lab scale engineering of the concept and aims to develop a commercial HyREX plant in the 2020s in

partnership with other steel producers. Government support is required to make this innovation possible, as it will cost an estimated 30 billion USD (CAPEX) by 2050 and will require 3.7 million tons of hydrogen.

- Policies in Korea suggest expectations for a very large hydrogen economy, requiring a significant increase in hydrogen production. According to the national hydrogen strategy, end use applications are articulated for industry and the transportation sector, but not for power generation. Korea's November 2021 hydrogen roadmap includes a plan to develop the necessary infrastructure for a hydrogen economy and to increase hydrogen applications. Less than 2M tonnes of hydrogen is currently produced in Korea, and there is a target is to have 3.9M tonnes of hydrogen produced in 2030. Korea is targeting 30% of hydrogen production from clean energy sources by 2030 and 60% by 2050.
- Demonstration of a low-temperature electrolysis system coupled to a nuclear power plant is being developed with support from KHNP. There is a possibility to use HTSE in a system like this in the future, but more time is required to determine how to utilize both heat and electricity from a nuclear power plant.
- Decarbonizing industrial processes will require innovation and significant process alternations. Industry end users acknowledge that they need to work together, and that collaboration should extend to the government, community, academia, and other stakeholders to enable this significant change.

Perspectives on district heating and co-generation

- The options to improve district heating technology is very limited, and the only option to reduce emissions using a district heating network is to replace the source of power with a sustainable option. A viable option may be nuclear energy, but district heating networks could also utilize thermal energy from the digestion of waste using a bio-generator or waste heat from other applications such as data centers. Using electricity to satisfy the energy needs for district energy results in significant inefficiencies.
- Reliability of heat for district heating networks is important, and there is a requirement for near continuous warm and cool water supplies.
- There are 74 companies and 105 workplaces connected to district heating networks in Korea. There are notable differences between residential and industrial district heating needs. Residential customers use hot water, have a distribution radius of 20 km, and have demand seasonality associated with home heating requirements. In contrast, industrial processes that utilize district heating networks use steam at higher temperatures and pressures, have a 2 km radius, and have very constant demand without seasonal variation.

Session 3: Operational experience and the challenges associated with operating a co-located system

Listed Session Speakers

- Seok-Bin PARK, Seoul National University, Nuclear Energy Policy Center, and member of the Senior Industry Advisory Panel (SIAP) to GIF
- Shannon BRAGG-SITTON, Director, Integrated Energy and Storage Systems, Idaho National Laboratory
- Tetsuo NISHIHARA, Director General, HTGR Research and Development Center, Sector of Fast Reactor and Advanced Reactor Research and Development, Japan Atomic Energy Agency (JAEA)
- Sun Jae Kim, Principal Researcher of Senior Advisory Committee, Korea Institute of Nuclear Safety
- Young Jo RYU, Director, Safety Technical Standards Division, Korea Gas Safety Cooperation

Key Findings from Session

- Nuclear energy is being used for non-grid applications today. Existing and planned demonstrations of coupled systems are needed to inform the safety of larger scale and more complex planned systems.
- Passive safety features associated with GenIV reactor technologies have been demonstrated and should be considered when determining the safety case for an integrated system.
- There are regulatory processes and guidelines already in place to enable nuclear energy regulators to assess the risks associated with coupling a NPP with non-electric applications.
- There is uncertainty in understanding safety impacts of integrating nuclear energy with process applications, and the level of analysis and verification required to prove the safety of the integrated system will require a case-by-case process using a risk-informed and graded approach.
- Hydrogen regulation is well established and leverages safety processes from the natural gas sector. There are requirements for permitting, operations, inspections, and safety management that will be considered when co-locating nuclear energy with hydrogen production. There are no obvious barriers.

Session Summary

- Seok-Bin PARK (SIAP) remarked on the significant use of non-electric energy in Korea, including for higher temperature process heat applications. He highlighted the potential role of hydrogen, and the political situation in Korea that will drive technologies that can ensure domestic security of supply. Seok-Bin concluded by commenting on the importance of advancing discussion with regulators as an important step to increase confidence in projects, including public confidence.

Presentation on operational experience on hydrogen production and district energy

- Shannon BRAGG-SITTON presented on past experience in operational nuclear cogeneration, noting that the history primarily involves lower temperature applications. This includes previous examples for fuel production (UK Calder Hall Magnox), steam supply for the pulp and paper industry (Norway Halden BWR and Switzerland Gosgen PWR), desalination (mostly Japan, India, Kazakhstan, and Pakistan), and other examples in Germany and Canada.
- In Switzerland, the Beznau NPP is currently being used to provide 170 GWh of thermal energy per year of district heat to over 2600 customers. Heat is extracted from the turbine at a temperature of 127°C and routed to the heat exchanger where heat is transferred to the district heating network as 120°C hot water. Two power plants are connected to this system allowing district heating to be available at all times, even during scheduled outages.
- In the US, the utility Constellation began producing hydrogen from the Nine Mile Point NPP in March 2023. This demonstration integrates a 1.25 MWe Polymer Electrolyte Membrane (PEM) electrolyzer behind the NPP grid interconnect to demonstrate the economics of using behind-the-meter pricing, regulatory impacts, and overall proof of concept of hydrogen co-located with nuclear power.
- Shannon also highlighted the work being done at Idaho National Laboratory to develop an Energy Technology Proving Ground to combine clean energy systems to build capabilities and support the maturation of integrated energy system technologies. She highlighted that this type of integration work is a critical next step to improve the overall technical readiness level (TRL) of coupling energy technologies.

Operational experience coupling hydrogen production with an advanced reactor system

- Tetsuo NISHIHARA discussed work being performed through the HTGR Research and Development Center at JAEA to develop the HTTR (High Temperature Engineering Test Reactor) technology. HTTR is a 30 MWth prismatic type HTGR with an outlet temperature of 950°C. He highlighted recent loss of forced cooling tests that demonstrated the passive safety of the technology and noted plans to connect the HTTR to hydrogen production using steam methane reforming. JAEA has developed a safety design philosophy for coupling the HTTR with hydrogen production based on previous JAEA R&D in this area. Safety design will be confirmed through engagement with the Nuclear Regulatory Authority in Japan.
- Tetsuo noted that policy in Japan is supporting the development of a commercial HTGR technology that will be suitable for hydrogen production in the 2040s and will have capabilities to support industrial heating requirements. Basic design is underway, and detailed design is expected to begin in late 2020s.

Regulatory perspectives (nuclear energy regulation)

- Sun Jae KIM shared regulatory considerations for a NPP coupled to non-grid applications as a representative of Korea Institute of Nuclear Safety, the Technical Support Organization for the Korean regulator. Sun Jae highlighted the situation of nuclear energy development in Korea and the organizational structure of agencies involved in nuclear energy and safety. He shared details of the legal framework and licensing process in place in Korea, which aligns with IAEA frameworks.
- Sun Jae shared an assessment of regulatory oversight of human induced external events (HIEE) in the Site Evaluation for NPPs and the process to perform a hazard analysis for a HIEE scenario. Preliminary screening uses both the distance from a facility beyond which potential sources of an event can be ignored (Screening Distance Value), as well as the value of the annual probability of occurrence of a particular type of event below which such an event can be ignored (Screening Probability Level). If there are conflicts among these two parameters, it is still possible to co-locate hazards but additional detailed assessment is triggered.
- With regard to particular regulatory challenges associated with the coupling non-electric and hybrid applications with a SMR, there are uncertainties regarding:
    - An understanding of safety implications related to interconnections between nuclear assets and associated process applications (e.g., hydrogen production, process heat for chemicals, mining)
    - The level of analysis, verification, documentation, regulation, activities, and procedures that is required and applied to comply with a safety requirement. He noted that the level of detail should be commensurate with the associated radiation risk and use a graded approach.
- Sun Jae noted that high-level, non-prescriptive regulations that are rooted in existing LWR regulations could be an efficient way to quickly establish a regulatory base for novel reactors.

Regulatory perspectives (industrial regulation and certification)

- Young Jo RYU's presentation provided information to the nuclear energy community on considerations for co-locating hydrogen production with nuclear power based on the perspectives from the Korean regulator for natural gas and hydrogen.
- Ryu outlined the legal and regulatory frameworks governing gas safety in Korea, primarily under the High-Pressure Gas Act, Hydrogen Act, Urban Gas Act, and other related legislation. He noted technical specifications of hydrogen at pressure thresholds and emphasized the necessity of safety and inspection protocols in the handling of high-pressure gases including hydrogen, which is considered both a high-pressure and a liquefied gas under specific conditions.
- The structured regulatory process involving permits, inspections, and safety management systems are mandatory for facilities handling high-pressure gases. Young Jo highlighted the inspection regimes required for hydrogen fuel use facilities and the distinctions drawn between HTSE and LTE systems.
- Finally, Young Jo discussed the broader implications of these safety standards in supporting the transition to a hydrogen economy, reflecting on the potential synergies between nuclear and hydrogen technologies in terms of safety and regulatory compliance. He commented that the nuclear energy community should consider these detailed regulatory frameworks early when planning to co-locate hydrogen production facilities with nuclear reactors.

Session 4: Panel with nuclear technology developers targeting non-electric applications.

Session Panelists

- (Moderator) Dr. Dong Wook JERNG, Professor of Energy System Engineering, Chung-Ang University
- Sang Jin HAN, Director, KHNP
- Mikal BØE, Chief Executive Officer, Core Power
- Chan Soo KIM, Principal Researcher, KAERI
- Han Ok KANG, Vice President for SMART development, KAERI

Key Findings from Session

- Both LWR technologies and GenIV reactors are suited for NEANH; the specific opportunity depends on the characteristics of the specific technology. Passive safety of advanced reactor systems helps enable their use for NEANH.
- There is real progress towards using existing NPPs and SMRs for industrial applications, with projects moving forward internationally. Partnerships beyond the nuclear sector are important to manage the risks of first-of-a-kind deployment and to remove commercialisation barriers.

Session Summary

Existing LWRs:

- Sang Jin HAN, Director of KHNP, highlighted the opportunity to utilize existing LWRs for non-electric applications, specifically focusing on hydrogen production. The presentation detailed how integrating hydrogen production with nuclear technology aligns with global energy trends and can leverage the consistent energy output of LWRs to provide a stable supply of low-carbon hydrogen.
- Sang Jin provided an overview of the current energy landscape, both globally and in Korea, and the important role of large-scale LWRs. He described both LTE and HTSE that could be coupled with LWRs. For KHNP he noted that the integration of these technologies with nuclear facilities is a strategic decision to enhance the value chain of nuclear energy beyond electricity generation. Sang Jin presented case studies where LWRs are being used or planned to be used for hydrogen production, illustrating practical implementations and the potential scalability of such projects.
- The presentation also covered safety considerations for integrating hydrogen production at nuclear sites. It highlighted ongoing efforts to align these operations with international safety standards and regulatory practices.
- Sang Jin HAN emphasized the importance of partnerships and innovative regulatory approaches to facilitate the integration of nuclear technologies into the broader clean energy landscape.

Molten Salt Reactor and opportunity for off-grid applications of SMRs:

- Mikal BØE of Core Power presented their Molten Chloride Fast Reactor (MCFR) concept, emphasizing its suitability for non-grid applications, particularly in maritime settings. This includes MCFR deployment in offshore industrial settings such as deep-sea oil and gas extraction.
- The company has agreements with entities like TerraPower, Southern Co., Hyundai Heavy Industries, Orano, and INL to develop the MCFR and is backed by commercial customers and shareholders who control over 4,000 ships.
- Mikal noted that although naval reactors have demonstrated the feasibility of maritime nuclear power since the 1950s in submarines and icebreaker ships, commercial insurance and regulatory acceptance remain challenges. He highlighted the importance of industry input to regulatory bodies, and encouraged the audience to engage if they wish to join the newly established trade association: Nuclear Energy Maritime Organization (NEMO).

High Temperature Gas Reactor for hydrogen production in Korea

- Chan Soo KIM provided an overview of the HTGR technology, which uses TRISO fuel, graphite moderators, and helium as a coolant. The reactors are capable of producing usable temperature of 950°C suitable for a wide range of industrial applications, including hydrogen production, and feature inherent safety features that make them suitable for siting near demand centres.
- Chan Soo highlighted several international HTGR projects aimed at non-electric applications, such as the GEMINI 4.0 in Europe, Xe-100 in the US, and HTR600C in China, all of which focus on high-temperature steam supply for industrial uses.
- The presentation detailed the Korean nuclear R&D plans to develop HTGRs and the integration with hydrogen production technologies. Korea has designed a high-temperature helium loop for testing these systems and proposed collaboration using this testing equipment.
- The importance of collaboration was underscored with mentions of partnerships with various institutions and industries, including POSCO Holdings, for the development and testing of modules for high temperature steam electrolysis integrated with helium loops.

LWR SMR for industrial applications

- Han Ok KANG opened with a reference to the COP28 agreement to triple nuclear energy generating capacity by 2050, which will support both electricity and industrial demands.
- Han Ok noted that KAERI is developing the SMART SMR for export applications, a 365 MWth LWR with a 60 year design life and 360°C outlet temperature with passive safety. The presentation highlighted the versatility of SMRs to supplement the intermittency of variable renewable energy and overcome geographic transmission limitations. SMART reactors are poised to replace coal plants, provide energy for heavy industry, support off-grid mining, enable district heating, and facilitate hydrogen production and desalination.
- KAERI is pursuing the deployment of the SMART reactor in Canada, targeting first-of-a-kind deployment in Chalk River at Canadian Nuclear Laboratories. KAERI intends to deploy the SMR commercially to provide steam to support emissions reductions in Canada’s industrial sector, including for in-situ oil sands production.

Session 5: Interactive discussion on the topics discussed, and next steps.

Session Summary

Shannon BRAGG-SITTON provided an overview of the day's discussion emphasizing the complexities and opportunities of integrating nuclear technology into non-electric applications as well as the urgency and necessity to find solutions. She noted that there are a number of reports and tools that already exist and can be leveraged and encouraged participants to actively engage with these materials.

Reflecting on feedback from various industries such as steel, Shannon noted significant energy demands that will be required to decarbonise industry as they consider fuel switching to lower carbon sources.

While acknowledging the critical role of hydrogen as a versatile energy carrier, Shannon cautioned against an overly narrow focus on hydrogen alone.

Shannon discussed the diverse temperature requirements of different applications, ranging from 200-350°C, 800°C, to as high as 1500°C. She noted the potential to use lower temperature waste heat for district energy systems and other plug-in industrial processes, but she noted that integration technologies need further development for higher temperature applications. While modelling is an essential first step for systems integration, actual demonstration projects using this technology are crucial.

An open discussion was held among the audience participants on the opportunity and challenges of NEANH:

- ***"Opportunity Cost" of evaluating HTSE coupling***: The complications of integrating hydrogen production with a NPP was discussed and compared to using the simplicity of LTE using grid-electricity.
- ***Opportunities are geographically distinct***: Unique regulatory landscapes were noted, emphasizing that countries like Korea do not have licensing pathways for non-LWR SMRs, which contrasts with more flexible frameworks in countries like Canada. Opportunities to use GenIV technologies to support the decarbonisation of higher temperature processes are limited.
- ***Demand for process heat***: End users noted that they would buy these technologies today if they were commercially available due to the difficulty of producing heat without concurrent emissions. Commercialisation timelines need to be accelerated for timely integration with industrial processes.
- ***Need for collaboration:*** A call for increased collaboration beyond the nuclear sector is essential. There is a need for honest communication about the readiness and timelines of these technologies to build confidence among potential industrial users.
- ***Need to communicate progress:*** The nuclear sector needs to continue to communicate global progress on integration technologies, but they also need to communicate progress to identify regulatory pathways for NEANH.
- ***Need for investment:*** Bold investment in demonstration projects will likely be needed to capture the opportunity given the scale of the transition that is required, and the large risks associated with implementing nuclear technologies.
- ***Who was missing:*** Participants noted that future workshops should include representation from additional end users who are new to nuclear energy, including data centres. They also noted that financiers, investors, and insurers need to be engaged in parallel to understand the risks and impact of nuclear technologies.

APPENDICES

APPENDIX A – Presentation Slides

Session 1: Historic context and overview of ongoing international efforts

- History of non-electric and hybrid applications of nuclear and the NEANH Task Force, Shannon BRAGG-SITTON, Director, Integrated Energy and Storage Systems, Idaho National Laboratory
- IAEA activities related to non-electric applications, Francesco GANDA, Technical Lead for Non-Electric Applications, IAEA
- NEA activities on hydrogen and industrial case studies for SMR markets, Brent WILHELM, Nuclear Technology and Economics Analyst, NEA
- IEA Hydrogen Technology Collaboration Programme Task 44 – Hydrogen from Nuclear Energy, Pierre Serre-Combe on behalf of Gilles RODRIGUEZ, CEA
- GIF Hydrogen Production PMB with overview of WP4 on integration technologies, Pierre SERRE-COMBE, Deputy Director, Energy Programs for New Hydrogen Technology CEA

Session 2: Industrial end user perspectives

- Overview of the alliance for nuclear heat utilization in Korea, Chan Soo KIM, Principal Researcher, KAERI
- Chemical sector, Dongil Peter SHIN, Professor of Chemical Engineering, Myongji University
- District Energy, Il Hwan KANG, Secretary General, Korean Cogeneration Association
- Hydrogen production and hydrogen policies in Korea,, Jin Nam PARK, Clean Hydrogen Program Director, Institute of Energy Technology Evaluation & Planning
- Steel: Jang Hoi CHOI, Director, Carbon Neutrality Strategy Sector, POSCO

Session 3: Operational experience and the challenges associated with operating a co-located system

- Presentation on operational experience on hydrogen production and district energy. Shannon BRAGG-SITTON, Director, Integrated Energy and Storage Systems, Idaho National Laboratory
- Operational experience coupling hydrogen production with an advanced reactor system, Tetsuo NISHIHARA, Director General, HTGR Research and Development Center, Sector of Fast Reactor and Advanced Reactor Research and Development, JAEA
- Nuclear energy Technical Support Organisation, Sun Jae KIM, Principal Researcher of Senior Advisory Committee, Korea Institute of Nuclear Safety
- Industrial sector regulator, Young Jo RYU, Director, Safety Technical Standards Division, Korea Gas Safety Cooperation

Session 4: Nuclear technology developers targeting non-electric applications.

- Existing LWR, Sang Jin HAN, Director, KHNP
- MSR, Mikal BØE, Chief Executive Officer, Core Power
- HTGR, Chan Soo KIM, Principal Researcher, KAERI, and member of VHTR SSC and NEANH-TF
- LWR SMR, Han Ok KANG, Vice President for SMART development, KAERI

APPENDIX B – Information on organisers and host organisations

About the Generation IV International Forum, and the Non-Electric Application of Nuclear Heat (NEANH) Task Force (Organiser)

Established in 2001, the Generation IV International Forum (GIF) is a co-operative international endeavour bringing together 13 countries, as well as Euratom (representing the 27 European Union members), to co-ordinate research and development on advanced nuclear energy systems and make them available for industrial deployment by 2030. GIF provides a forum for collaborative R&D on six reactor concepts and a variety of cross-cutting issues. The six reactor concepts, also known as Generation IV (Gen IV) concepts, are: gas-cooled fast reactor, lead-cooled fast reactor, molten salt reactor, sodium-cooled fast reactor, supercritical water-cooled reactor, and very-high-temperature reactor. The priorities for GIF in the near-term focus on accelerating the readiness of fourth generation nuclear systems to meet net zero targets.

In 2002, GIF released the Gen IV Roadmap, which identifies potential applications for these reactors in addition to electricity production, including desalination, district heating, hydrogen production, and high-temperature process heat. A collaborative research and development project focused on hydrogen production using the VHTR system began in 2008, and a dedicated cross-cutting Task Force was established in October 2021 to address non-electric applications of nuclear energy broadly. This Non-Electric Applications of Nuclear Heat Task Force (NEANH TF) aims to provide its members and other stakeholders with the appropriate knowledge and access to innovative energy system design, analysis, and optimisation tools to allow decision makers to find optimal energy system solutions for different socio-economic and geographical contexts.

The NEANH TF is currently working to advance a number of initiatives to explore the opportunity for non-electric applications and hybrid systems, which leverage and integrate multiple energy sources with multiple energy demands. This has included developing and maintaining a database of relevant studies and activities and developing a network of energy end users beyond the nuclear sector who may benefit from fission-generated heat and electricity. The Task Force is currently working to advance techno-economic analysis of coupled systems to understand the economic opportunity, readiness, and timelines for these systems.

About the Korea Atomic Energy Research Institute (Organiser)

The Korea Atomic Energy Research Institute (KAERI) is a government-funded research institute established to contribute to academic advancement, energy acquisition, and utilization of nuclear energy through active research and development in related fields.

Since its establishment in 1959, KAERI has been the only research institute in Korea dedicated to research and technology development of nuclear energy. Over the past 60 years, it has concentrated its resources on the development of nuclear technology and made significant achievements, including the localization of PHWR and PWR reactors, the design of a Nuclear Steam Supply System (NSSS) - applied to Uljin Units 3 & 4 - and the design and construction of the multi-purpose research reactor HANARO.

As one of the leading nuclear science and technology research institute in the world, KAERI is building a safe society centered on people and the environment. It will continue its efforts to expand research scopes into new fields such as improving quality of life while attaining higher standards in safety and reliability.

About the Korean Nuclear Industry Association (Host)

The Korean Nuclear Industry Association (KAIF) was established in 1972 to promote cooperation between related organizations; build networks between Korea and overseas countries; and strengthen nuclear educational programs.

About the Korea Nuclear International Cooperation Foundation (Host)

The Korea Nuclear International Cooperation Foundation (KONICOF) is dedicated to enhancing international cooperation in nuclear energy through strengthening global partnerships and knowledge exchange in the nuclear sector, providing systematic education and training for nuclear professionals, and consolidating Korea's leadership in nuclear technology and expanding into international markets.