Workshop between Clean Hydrogen Partnership and NEDO on H2/Ammonia Combustion Technologies
2nd Information Exchange

Date: Wednesday, 26 March 2025
Location: Kobe (Japan)
Invited speakers and attendees: 8 participants from NEDO/METI and 17 from Japanese companies and research institutes; 4 participants from the Clean Hydrogen Partnership and 14 from EU companies and research institutes.

Introductions

This second workshop between NEDO and the Clean Hydrogen Partnership (CH JU) has been an opportunity to discuss activities for potential collaboration in the field of hydrogen and ammonia combustion. This area was identified as a mutual area of interest following the signature of the collaboration agreement concluded between the Clean Hydrogen Partnership (CH JU) and NEDO on 3rd June 2024.

The event was opened by **Ms Akiko Iimura, Executive Director of NEDO,** and by **Ms Valerie Bouillon-Delporte, Executive Director at the Clean Hydrogen Partnership.**

Ms Iimura welcomed all the participants, and highlighted the work done since the formulation of the Japan's Basic Hydrogen Strategy, published in 2017, and the strategic importance of the city of Kobe, which became an important Hub for demonstrations of hydrogen technological solutions.

Ms Bouillon-Delporte emphasised the strategic importance of the NEDO/CH JU MoU, which is consolidating an existing strong and productive bilateral partnership. The decarbonisation of gas turbines through the use of hydrogen and ammonia is now critical and supported by several European policies enabled in the past years.

Ms Mirei Isaka, Director of Hydrogen and Ammonia Dept., NEDO, was the Master of Ceremony. She presented a framework of the policies supported and implemented by NEDO, including the collaboration with CH JU. In particular, she illustrated the "support focusing on price gap" scheme, for which subsidies are awarded for low-carbon hydrogen and its derivatives which are supplied in Japan, focusing on the price gap between the costs for domestic or overseas hydrogen production and transportation and the price of conventional fuels.

Later, she provided an overview of the key achievements on hydrogen and ammonia combustion, and their integration in energy plants and hubs in Japan.

Ms Mirela Atanasiu, Head of Unit Operations and Communication at the Clean Hydrogen Partnership, presented the CH JU activities, including the composition of the portfolio of projects. She provided an overview of the hydrogen and ammonia combustion portfolio within the CH JU. It contains 8 projects for a total of 33.15Million EUR in JU contribution, with a focus on gas turbines, burners and boilers. It represents a mix of low TRL research activities on combustion physics of hydrogen and ammonia and higher TRL solutions for retrofitting existing cogeneration plants, and it sees the participations of the most important OEMs in the sector.

Both parties emphasised the importance of this workshop, as a unique initiative to facilitate knowledge-sharing across scientific and industrial domains, with the objective of cultivating a productive and tangible cooperative relationship between Japanese and European entities, both in the short and long term.

Keynotes

Professor Hideaki Kobayashi, from Tohoku University, and Mr. Andrea Gruber from Sintef were invited to set the scene with a keynote speech.

Professor Kobayashi made a keynote illustrating the background of choosing ammonia as fuel within the last decades in Japan. Despite technical challenges of this fuel (slow flame speed, narrow ignition range, high NO_x and a potential reduction of efficiency) there are certain solutions that make it viable, such as using two-stage combustion, a swirling flow, or using it in combination with hydrogen. In some cases, Japan has already reached demo scale or commercial scale for some applications using ammonia, such as in power generation plants or maritime applications.

Mr Andrea Gruber highlighted the strategic importance of gas turbines applications, and their role in balancing the electricity grid thanks to their fast startup and possibility to variate load. He described the challenges of thermo-diffusive instabilities, together with the effect of high-pressure combustion on the intensity of the instabilities. Their comprehension remains an open issue for the scientific community.

However, he also emphasised the challenge of these turbomachinery's today: to be, at the same time, fully fuel-flexible (switching between 100%H_2 and 100%NG in operation) with a stable combustion (no flashback or instabilities) at all load conditions maintaining high efficiency and low NO_x.

He also illustrated latest activities on ammonia combustion with rich-quench-lean strategy and a related ongoing project (ADONIS) which sees a cooperation between Japan and Europe.

To conclude, he provided some points of reflection for areas of cooperation on fundamental and/or low/medium TRL topics.

Session 1: Combustion Technologies for Gas Turbines

Summary of presentations:

This section saw a wide range of solutions and applications presented by Japanese (KHI, MHI, IHI) and European (Ansaldo, Baker Hughes, TUD, Siemens) stakeholders.

Concerning the **small to mid-sized gas turbines**, there is a wide range of technical solutions available for obtaining H_2 combustion. Partially premixed solutions, or diffusion combustor solution represent a first step to achieve 100% H_2 combustion. However, they also come with certain disadvantages such as higher NO_x or lower efficiency because of the use of water to reduce NO_x.

The vision for the future in Japan is the use of a Micromix combustor, which has been presented by KHI and it is now implemented at 1MW class in a cogeneration system in the Kobe Smart Community Project in the port area. It can run from 50% to 100% H_2, however it has difficulties in running 100% at natural gas

Among the European manufacturers, focus area is now the achievement of TRL7 for new combustion technologies such as the fully premixed combustion, able to run at 100% H_2. At the same time, there are solutions such as the aerodynamic stabilisation with trapped vortexes which has also allowed to obtain 100% H_2 combustion, and it is now investigating its operation at higher temperatures.

Concerning **the large turbines** (> 100's MW), 30% H_2 co-firing operation was successfully carried out in 2023 in Japan. At the same time, parallel development of 100% H2 firing capabilities in plant

operation and 100% NH_3 firing test in rig test facility has been achieved in 2024 and 2023, respectively in Japan.

Other technological solutions are being investigated in Europe such as the Constant Pressure Sequential Combustion, which also has achieved 100% H_2 combustion capability in test rig at TRL6, despite some derating.

Integration of 100%H_2 gas turbines into industrial power-to- H_2-to-power has been also demonstrated in Europe, where a gas turbines developed by Siemens has been installed and connected to electrolysers, storage solutions and local plan power network in France.

Concerning the **ammonia combustion**, the solutions investigated by the Japanese OEM for direct combustion of ammonia foresee either the use of an ammonia evaporator, or an ammonia cracking system as standalone, with the first one being more advanced that the other. The plan is to have these solutions demonstrated in 2026 at plant level.

The use of liquid ammonia directly injected into the turbine is also under study because of its simplicity of equipment and easiness in managing the supply of liquid ammonia, despite loss due to latent heat of evaporation and combustion stability. In Japan, durability test at engine level at 2MW scale is ongoing for 100% ammonia combustion with the intention of pursuing a long-term effects of ammonia combustion.

In Europe, the works on ammonia are rather at scientific and lower TRL level. The focus is on studying the fundamentals of ammonia combustion, also when blend with hydrogen, in different type of reactors at lab scale. Models and algorithms to replicate flame structure, chemistries and pollution mechanisms are also under investigation.

Discussion and Potential Areas of cooperation:

In conclusion, we could observe a very wide range of technical solutions adopted and pursued between the various OEMs.

It can be stated that the results shown are encouraging towards the target of reaching 100% H_2 combustion in stable, efficient and with low pollutant manner. Fuel flexibility remains paramount for all OEMs.

In terms of potential cooperation, the participants agree that the area of low TRL research activity remains of high interest, especially when it comes to fundamental research of hydrogen and ammonia combustion.

Particularly important research topics for potential cooperation could be:

- Combustion behaviour of ammonia, including chemical reactions kinetics, (rich-condition, high pressure).
- Fundamental insights and improved CFD for high pressure H_2 flames.
- Atomisation and vaporisation of ammonia
- Experiments and characterisation of NH_3 burners/spray for Gas turbines
- Study of material embrittlement, corrosion and nitridation.

Another comment raised by the speakers is on the maturity of the supply chain. Since these applications consume huge quantities of H_2 (up to 1.5tons H_2 per hour of testing, depending on the power range), it has been noticed that availability and cost of H_2 is a determining and blocking factor for the development of the sector. This makes it even more important to have a turbine flexible enough to accept lower quantities of H_2, when they are not available, until the H_2 economy fully develops, and scale economies become applicable.

Safety standards and certifications procedure could also be investigated jointly, the participant agree.

In view of future cooperation, in case of multiple funded topics issues by NEDO/CH JU, it will also be important to synchronise the availability of funds to guarantee continuity of research operations.

Session 2: Combustion Technologies for Gas Engines

Summary of presentations:

Concerning the **Internal Combustion Engines (ICEs),** current solutions in the Japanese market are addressing stationary power generation using hydrogen blends up to 30% vol H_2 in the mixture at full rate. Some of them will be market ready within 2025.

In Europe, some of the solutions presented are already available at 25% vol H_2 and, for one specific product in the 1MW scale already available at 100% vol H_2. Operation with ammonia, after cracking it, area also under investigation during 2025. Several applications have been demonstrated and implemented for these power generators as part of data centres, renewable energy sources balancing, demo projects, etc.

Applications of ICEs for maritime propulsion will also be developed soon, depending on the hydrogen market readiness. The intention is to develop dual fuel gas 4 stroke and 2 stroke engines for propulsion in the range of 3MW/5MW.

Some of the physical properties of hydrogen creates also challenges for ICEs, leading to engine knocking, higher temperatures, backfire.

In order to study and investigate them, a hydrogen single-cylinder gas engine test facility has been built in Japan as part of a NEDO project.

Discussion and Potential Areas of cooperation:

- Similarly to the previous session, safety and regulations have been identified as potential areas of cooperation among stakeholders.
- Similarly, the fundamental research on ammonia combustion applied to ICE's engines could also be of interest.
- Specific issues related to ICEs, such as spark ignition (ignition delays, flashback) and use of compression ignition (autoignition, emission control) could also be of common interest.

Concerning the field applications, the ICEs powered by H_2 is demonstrated to be a versatile solution because of its quick startup time after long shutdowns (and act as backup for power operations, if needed).

Even without current Clean Hydrogen JU Strategic Research and Innovation Agenda (SRIA) funding, these field could be investigated and researched jointly by the participants through direct cooperation agreements, if willing to do so.

Session 3: Combustion Technologies for Industrial Furnaces, Boilers

Summary of presentations:

It has been shown that an existing boiler of a thermal power station in Japan has been retrofitted and equipped with ammonia burners, running at 20% NH_3 in gaseous phase, to replace coal fire. The test for this first experimental phase has shown positive results, with reduction in CO_2, NO_x, SO_x, N_2O etc. This result encourages toward achieving stable combustion in the future with higher percentages of ammonia such as 60% and 100%, eventually.

An important solution for industrial furnaces has been shown based on ammonia combustion with pure oxygen (instead of air). This is currently being tested in a glass furnace in Japan. Oxygen combustion is a mean to increase temperature, increase speed flame and improve combustion efficiency. It has been demonstrated that is possible to burn pure ammonia, in stable conditions, when mixed with a higher concentration of oxygen. Similarly to gas turbine applications, combustion staging in necessary to reduce NO_x. Testing on this type of application will continue for higher levels of power.

The combustion of H_2 (in combination with Natural Gas) and Oxygen is also under investigation in Europe, in this case within the aluminium industry. In this case, the burner is composed by 2 main melting burners of 2MW joined by one flame holding burner of 150kW.

Discussion and Potential Areas of cooperation:

- Looking at the results from the Japanese manufactures, it would be encouraging for the European manufacturers to start looking at ammonia also for this type of heat generation applications, especially when combined with higher concentration of oxygen. This has been identified as an opportunity for EU market.
- On the other hand, safety concerns and the need for specific safety devices is even higher when it comes to ammonia burnt in oxygen (pure, or higher concentration). Therefore, also for the technologies of burners and boilers, safety represents a potential area of cooperation for all participants.

A comment has been raised concerning the scale of the demonstration in Japan, which require, again very high quantities of hydrogen and the question is on how they succeed to secure such high quantities of hydrogen for longer periods at cheap price. Among their feedback, is their capability to diversify the import of energy from different suppliers and different sources of energy (hydrogen and ammonia and other forms of hydrogen carriers even). This diversification helps them securing long term supplies at stable prices and allows them having such a testing capability.

Closing remarks:

Ms Marta Olender, Counsellor in the delegation of the European Union to Japan, welcomed the initiative very much, praising this workshop as positive example of spark of cooperation between EU and Japan. She also reminded of other existing frameworks between the two regions that are representing successful cooperations. These are:

- Memorandum of Cooperation (MOC) between METI and the European Commission signed in 2023.
- EU/Japan Green Alliance, a real expression of EU intention to create a global coalition working towards net zero goal.

In the closing remark **Mr Luigi Crema, President of Hydrogen Europe Research**, placed a note on the challenges that have been mentioned during the day, such as:

- infrastructure and economic challenges related to the hydrogen supply and price,
- technical challenges related to the hydrogen combustion such as flame instabilities, understanding of chemical reaction mechanisms and safety.

He confirmed that these areas are priorities for Hydrogen Europe Research too and that soon they would welcome cooperation in the area of ammonia/ammonia blends in gas turbine applications.

He concluded by wishing that the existing framework of cooperation between Europe and Japan act as enablers for a concrete cooperation.

Finally, **Ms Iimura, NEDO Executive Director** officially closed the meeting, thanking all participants and presenters and wishing them a continued fruitful cooperation.