Berlin Energy Transition Dialogue

Current picture of co-firing and future prospects for hydrogen-rich fuels

Prof. Emmanouil Kakaras
e_kakaras@eu.mhps.com

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Mitsubishi Power Europe GmbH
Content

1. Company Overview
2. As Mitsubishi Heavy Industry group
3. Hydrogen in Energy Transitation
4. Ammonia in Energy Transitation
Mitsubishi Power, as one of the core subsidiaries of Mitsubishi Heavy Industries group, offers generation technologies and solutions.

* This table is not exhaustive. It lists only companies and products related to hydrogen business.
Mitsubishi Power is creating a future that works for people and the planet by developing innovative power generation technology and solutions to enable the decarbonization of energy and deliver reliable power everywhere.
Content

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Our approach to a Hydrogen Society

- Contributing to the establishment of infrastructure and cost reduction through the provision of technologies, products, and services from hydrogen production to utilization
- Creating a value chain by our unique technologies and active cooperation with partners
- Transition towards utilization of ammonia

![Diagram showing the value chain from primary energy to usage application](image)

- **Primary energy**
- **hydrogen production**
- **transportation and storage**
- **usage application**

## Creation of Value Chain

- **Renewable Energy**
- **Water Electrolysis**
- **Hydrogen Storage**
- **Hydrogen/Ammonia Gas Turbine**
- **Fuel Cell**
- **Hydrogen Gas Engine**
- **Hydrogen-reducing Steel Manufacturing**

### Technologies and Partners:
- **CIP**
  - Development of Offshore Wind Turbines in Hokkaido
- **Hydrogen Pro**
  - Investing in Hydrogen Production Plant Supply
- **Magnum**
  - Green Hydrogen Production, Storage and Supply Business Development in Utah, USA

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Capital participation in H2U Investments conducting carbon-free ammonia production project in South Australia

Making use of abundant renewable energy in the area, producing hydrogen and ammonia. Contributing to the region’s industries such as nearby steel mills, and export carbon-free ammonia
Green Hydrogen

Hamburg Green Hydrogen Hub (Germany)

- The consortium consists of 4 companies MHI, Royal Dutch Shell, Vattenfall, Wärme Hamburg signed a letter of intent to promote green hydrogen project in Hamburg, Germany.

- This project aims to construct a scalable electrolyser with an initial output of 100MW in Moorburg, close to the Port of Hamburg, in order to produce green hydrogen and contribute to decarbonization of local business such as steel mills. From a long-term perspective, this project aims to supply carbon-free fuels to vessels anchored at the Port of Hamburg.

- The consortium will conduct feasibility studies on the project and the operation of the hydrogen plant is anticipated in the course of 2025.

- MHI is responsible for the technologies and engineering fields related to hydrogen production and the optimization service of a hydrogen utilization process.

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On its own, renewable energy cannot meet actual power demand because it is dependent on weather and other natural phenomena.

Gas Turbines can address gaps in power demand and renewable supply as a flexible energy source.

Source: METI
Hydrogen Gas Turbines have multiple environmental and economic benefits.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimal investment needed to adopt</strong></td>
<td><strong>Carrier agnostic</strong></td>
<td><strong>Driver of demand</strong></td>
</tr>
<tr>
<td>Power providers can transition to low-CO2 or CO2-free systems with minimal modifications*.</td>
<td>Hydrogen Gas Turbines can be fueled with H2 transported by any type of carrier as well as less pure forms of H2 – thus contributing to significant cost reduction.</td>
<td>Increasing demand for hydrogen will drive infrastructure expansion and further cost reduction.</td>
</tr>
</tbody>
</table>

*Detailed scope is subject to plant specification

- Liquid Hydrogen/ Methylcyclohexane
- NH3
- N2
- Hydrogen
- Hydrogen
- Hydrogen
- Hydrogen

1 Hydrogen GTCC
2,000,000 Fuel cell vehicles

1 requires the same amount of hydrogen to power as

H2
NH3
LH2/MCH
Mitsubishi Power’ hydrogen combustion technology balances both technical challenges and market needs.

**Technical Challenges**
- NOx Reduction
- Combustion Dynamics
- Unburned Hydrocarbons
- Flashback

**Market Requirements**
- Cost
- Efficiency
- Lifetime of Parts
- Flexibility
- Maintainability
Mitsubishi Power has **3 types** of combustors catering to individual project requirements and hydrogen densities.

<table>
<thead>
<tr>
<th>Type</th>
<th>Low NOx tech</th>
<th>Turbine inlet temperature (°C)</th>
<th>H₂ density (volume %)</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ready</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1: Diffusion</td>
<td>N₂ dilution, Water/ Steam injection</td>
<td>1200~1400</td>
<td>100%</td>
<td>1970 Cogen/GCC, 2027 Magnum H₂ conversion</td>
</tr>
<tr>
<td>Type 2: Pre-Mix (DLN)</td>
<td>Dry</td>
<td>1600</td>
<td>30%</td>
<td>1982 DLN, 2018 30% co-firing test completed</td>
</tr>
<tr>
<td>Under development</td>
<td>Dry</td>
<td>1650</td>
<td>100% (target)</td>
<td>Mar, 2025 Rig test completion target</td>
</tr>
</tbody>
</table>

*This presentation is based on results obtained from a project commissioned by NEDO that is a government organization in Japan. (NEDO: New Energy and Industrial Technology Development Organization) **DLN**: Dry Low NOx*
Mitsubishi Power has **3 types** of combustors catering to individual project requirements and hydrogen densities.

<table>
<thead>
<tr>
<th>Mitsubishi Power has 3 types of combustors catering to individual project requirements and hydrogen densities.</th>
</tr>
</thead>
</table>

**Middle & Small Gas Turbines**

<table>
<thead>
<tr>
<th>Combustor Type</th>
<th>Low NOx tech</th>
<th>H₂ density (volume %)</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-25 Diffusion</td>
<td>Water/ Steam injection</td>
<td>100%</td>
<td>1990</td>
</tr>
<tr>
<td>Combustor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-25 Multi-Cluster</td>
<td>Dry</td>
<td>30%</td>
<td>2016 Product development completed, 2019 30% co-firing test completed</td>
</tr>
<tr>
<td>Under development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-100 Pre-Mix</td>
<td>Dry</td>
<td>100% (target)</td>
<td>2022 60% co-firing test completion target, 2024 100% firing test completion target</td>
</tr>
<tr>
<td>Ready</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-100 Multi-Cluster</td>
<td>Dry</td>
<td>30%</td>
<td>2017 Product development completed</td>
</tr>
<tr>
<td>Under development</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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## Performance of H₂ Combustors

Mitsubishi Power Gas Turbines can accommodate different proportions of H₂ as fuel.

<table>
<thead>
<tr>
<th>GT Model</th>
<th>Output (MW)* SC CC</th>
<th>Combustor Type</th>
<th>H₂ (vol) %</th>
<th>Current</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-25</td>
<td>41/41 60/60</td>
<td>Diffusion</td>
<td>100</td>
<td>30–100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-Mix (DLN)</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-Cluster (DLN)</td>
<td>100 (target)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-100</td>
<td>106/116 150/171</td>
<td>Diffusion</td>
<td>100</td>
<td>30–100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-Mix (DLN)</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-Cluster (DLN)</td>
<td>100 (target)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M501F</td>
<td>185 285</td>
<td>Diffusion</td>
<td>100</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-Mix (DLN)</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-Cluster (DLN)</td>
<td>100 (target)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M501GAC</td>
<td>283 427</td>
<td>Diffusion</td>
<td>100</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-Mix (DLN)</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-Cluster (DLN)</td>
<td>100 (target)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M501J</td>
<td>330 484</td>
<td>Diffusion</td>
<td>100</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-Mix (DLN)</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-Cluster (DLN)</td>
<td>100 (target)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M501AC</td>
<td>300 435</td>
<td>Diffusion</td>
<td>100</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-Mix (DLN)</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-Cluster (DLN)</td>
<td>100 (target)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M701F</td>
<td>385 566</td>
<td>Diffusion</td>
<td>100</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-Mix (DLN)</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-Cluster (DLN)</td>
<td>100 (target)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M701J</td>
<td>478 701</td>
<td>Pre-Mix (DLN)</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>448-574 650-840</td>
<td>Multi-Cluster (DLN)</td>
<td>100 (target)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Output is reference at natural gas firing

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Mitsubishi Power’ H₂ GT Projects

Zero Carbon Humber (H2H Saltend)
M701F, 1202MW (3 CCGT)
Hull, Humber, UK

H2M (Magnum)
M701F, 440MW (1 CCGT out of 3 CCGT)
Eemshaven, the Netherlands

Energy Decarbonization
Decarbonizing Entergy’ utilities
4 Southern States*, USA
*Arkansas, Louisiana, Mississippi and Texas

Intermountain Power
M501JAC, 840MW (1 CCGT)
Salt lake City, Utah, USA

Advanced Clean Energy Storage
Green Hydrogen Production and Storage
Salt lake City, Utah, USA

Keppel Data Canter
Tri-generation plant with H2 GT
Singapore

H2U
Carbon-free ammonia production PJ with H2 GT
South Australia
Content

1. Company Overview
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Overview of Global Hydrogen Supply Chain

**Production**

- **Hydrogen from fossil fuel** (with CO2 capture & storage)
  \[ \text{CH}_4 + 2\text{H}_2\text{O} \rightarrow \text{CO}_2 + 4\text{H}_2 \]

- **Hydrogen from renewable source**

**Transportation**

- **Liquid Hydrogen/Methylcyclohexane**
  - LH2/MCH

**Demand**

- **Power**
- **Transport**
- **Industry**
- **Building**

**Hydrogen transportation**

- **Ammonia** \( \text{NH}_3 \)
  - **N\text{2}** Nitrogen gas

**CO2 capture & utilization**

- **Synthetic Fuels/Materials**
  - CH3OH/CH4
- **Carbon dioxide**

- **Carbon dioxide capture**
Mitsubishi Power Commences Development of World's First Ammonia-fired 40MW Class Gas Turbine System
-- Targets to Expand Lineup of Carbon-free Power Generation Options, with Commercialization around 2025 --

2021-03-01

- Utilizing technology that enables 100% direct combustion of ammonia will contribute to formation of ammonia fuel supply chain
- Commercialization will also support decarbonization systems for small to medium-scale power plants in industrial applications, on remote islands, etc.

- Development begins of 40MW GT (H25) with Ammonia (100%) direct combustion for zero CO₂ emissions
- Expansion of line-up of carbon free power generation
## Carbon Free Combustion System Development

Several development of combustion system for carbon free (=CO$_2$ zero)

<table>
<thead>
<tr>
<th>Product</th>
<th>Detail</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia Mixed Boiler</td>
<td>20-30% ammonia mix for coal firing boiler</td>
<td>2023 verification</td>
</tr>
<tr>
<td>H2 GT</td>
<td>30% H2 30% hydrogen mix for current LNG GT combustor or with minimum modification</td>
<td>2018 completion</td>
</tr>
<tr>
<td></td>
<td>100% H2 100% hydrogen combustor ( multi cluster )</td>
<td>completion M: 2025 H:2023</td>
</tr>
<tr>
<td>Ammonia Cracking GTCC</td>
<td>Ammonia cracking and conversion to H2 by GT exhaust heat ( good for high temperature large GT)</td>
<td>2026-2029</td>
</tr>
<tr>
<td>Ammonia Direct Combustion GT</td>
<td>No need of ammonia cracking system, higher NOx due to ammonia direct combustion and deNOx in HRSG required</td>
<td>2024 completion</td>
</tr>
</tbody>
</table>
Ammonia co-firing ratio will be depended on the regulation of NOx emission

According to the number of burner stage of existing boiler, it would be changed the possible ratio of co-firing

Concept of ammonia co-firing is shown below

Co-firing concept
- Ammonia has almost same burning rate as coal
- The stable flame made by the coal burners, and Nox generated by ammonia combustion is reduced in the deduced area up to AA in the furnace
- Ammonia is supplied from the bottom burner area by jet
Ammonia combustion systems

Ammonia cracking system

\[ \text{NH}_3 \xrightarrow{\text{Lq.}} \text{NH}_3 \rightarrow \text{H}_2, \text{N}_2, (\text{NH}_3) \]

**NH\(_3\) Decomposition**

Higher CET / higher efficiency (typically applicable for large GTs)

NH\(_3\) decomposition by GT high temp exhaust → higher exhaust temp needed

Ammonia Direct combustion system

\[ \text{NH}_3 \xrightarrow{\text{Lq.}} \text{NH}_3(\text{Gas}) \]

**Vaporizer**

Lower CET / simple system (typically good for small GTs)

Need lower CET & deNO\(_x\) system to reduce Fuel-NO\(_x\)

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Mitsubishi Power is now expanding the line-up of carbon free combustion system, not only hydrogen combustion but also ammonia direct combustion.

☞ start development of ammonia direct combustor  
☞ plan to verify the system in 2024  
☞ start commercial operation from 2025

### Development Schedule

<table>
<thead>
<tr>
<th>yr</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustor Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verification</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**H-25 Gas Turbine**

- Output: 41.0MW  
- Efficiency: 36.2% (SC)  
- >80% (Cogeneration)  
- Sales: 190 GTs
MOVE THE WORLD FORWARD
## Partnership in Wind Turbine

### Wind Turbine

<table>
<thead>
<tr>
<th>Strengthening the relationship with Vestas</th>
<th>Participation in the development of wind power generation business</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Strengthening competitiveness by integrating offshore and onshore wind turbine manufacturing business</td>
<td>- Agreement signed with Danish company CIP for cooperation in the development of offshore wind power projects in Hokkaido in July, 2020</td>
</tr>
<tr>
<td>- Strategic investment in Vestas as an industrial partner</td>
<td>- Contributing to the growth of offshore wind power generation in Japan through joint development projects in Hokkaido, where it is blessed with favorable wind conditions</td>
</tr>
<tr>
<td>- Consistent efforts to expand the Japanese offshore wind turbine market</td>
<td></td>
</tr>
</tbody>
</table>

---

**Strengthening partnership in offshore wind power business**

- Agreement signed with Danish company CIP for cooperation in the development of offshore wind power projects in Hokkaido in July, 2020
- Contributing to the growth of offshore wind power generation in Japan through joint development projects in Hokkaido, where it is blessed with favorable wind conditions

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CIP: Danish fund management company specializing in investment in the renewable energy infrastructure sector

©MHI VESTAS OFFSHORE WIND A/S

HydrogenPro aims to be a world leading designer and supplier of alkaline electrolyser technology plants and solutions that meet the highest standards for safety, reliability and long lifetime.

HydrogenPro was established in 2013.

MHI group is a leading EPC contractor for Ammonia, and CCS plant
Business development of Blue / Green Ammonia under go

Blue Ammonia

Contractors Share for Ammonia Plant
(2008 – 2018 / Capacity-Based)

- MHI (14.3%)

Plant location
- NRG WA Parish Power Plant
  (Thompsons, TX)

Project owner
- Petra Nova – partnership between
  NRG Energy and JX Nippon Oil & Gas

Plant scale
- 240 MW eq

CO₂ capacity
- 4,776 TPD
  (1.4 MMtonne/year)

CO₂ conc.
- 11.5 mol% - wet

CO₂ removal
- 90%

CO₂ Used for CO₂-EOR
- Pipeline 12 in diameter,
  ~ 81 miles
- Injection Site West Ranch
  Oil Field

Mitsubishi Heavy Industries Engineering, Ltd. is a authorized
licensee of Haldor Topsoe Ammonia Technology
The H2M (Hydrogen to Magnum) project is a key first step in the development of a low-carbon H2 economy.

The goal is to Kick-start H2 economy by using Blue H2 for Hydrogen (100%) firing in CCGT by 2027, and gradual transition to Green H2.

Development of hydrogen demand by H2M will assist realisation of hydrogen infrastructure.

*Expected CO2 emission reduction reaches up to 2Mt/year including use of Hydrogen in Transport, Industry and Housing.

Source and courtesy Vattenfall
Zero Carbon Humber, H2H Saltend (UK)

Feasibility study bid under UK funding. 30% H₂ Co-firing in Saltend GTCC is the starting point of the project.

<table>
<thead>
<tr>
<th>Turbine Model</th>
<th>M701F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Output</td>
<td>1202 MW (3 GTCC)</td>
</tr>
<tr>
<td>Location</td>
<td>Hull, Humber UK</td>
</tr>
</tbody>
</table>

Zero Carbon Humber: a partnership to build the world’s first net zero industrial cluster and decarbonise the North of England

30% H₂ co-firing in Saltend GTCC by using Blue H₂, named H2H Saltend is the starting point of the project.

Source and courtesy Equinor
The Advanced Clean Energy Storage Project is the world’s largest renewable energy storage project.

<table>
<thead>
<tr>
<th>Storage Capacity</th>
<th>150GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Utah, USA</td>
</tr>
</tbody>
</table>

This project was launched in May 2019 by Mitsubishi Power, Magnum Development and the Governor of Utah.

This project using storage technology such as renewable hydrogen (Green H2), compressed air, large scale flow batteries and solid oxide fuel cells. Green H2 and/or compressed air is planned to be stored in underground salt caverns in Utah.
Intermountain Power Agency orders Mitsubishi Power JAC Gas Turbine Technology for Renewable-Hydrogen Energy Hub. This utility-scale project shows a path to 100% renewable power no later than 2045.

<table>
<thead>
<tr>
<th>Gas Turbine Model</th>
<th>M501JAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Output</td>
<td>840 MW (by 2 CCGT)</td>
</tr>
<tr>
<td>Location</td>
<td>Utah, USA</td>
</tr>
</tbody>
</table>

This transition will start in 2025 using a mix of 30% hydrogen and 70% natural gas fuel.

This fuel mixture will reduce CO₂ emissions by more than 75% compared to the retiring coal-fired technology.

Between 2025 and 2045, the hydrogen capability will be systematically increased to 100% renewable hydrogen, enabling carbon-free utility-scale power generation.

Power plant is connected to the Los Angeles power grid by an existing high voltage direct-current (HVDC) transmission line.
### Fundamentals of Ammonia Direct Combustion

#### Issues

**NOx production from fuel Ammonia**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>N products</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG etc</td>
<td>N2 in air oxidized in high temp combustion</td>
</tr>
<tr>
<td></td>
<td>N2 (Air) + O2 → NOx</td>
</tr>
<tr>
<td>Ammonia (NH3)</td>
<td>NH3 in fuel oxidized (Fuel-NOx)</td>
</tr>
<tr>
<td></td>
<td>NH3(Fuel) + O2 → N2 + H2O + NOx</td>
</tr>
</tbody>
</table>

#### Fuel-NOx Production

- Higher CET produces more NOx
  - → H-25GT: lower CET, lower NOx
due to lower LNG,
  - need to keep the stable combustion

**CET**: combustor exhaust temperature

### Control fuel NOx production in H25 combustor

To control NOx production,
- ① Rich combustion,
- ② Lean Combustion