Decarbonisation portfolio

Introductory slides

2021.10.25
Mitsubishi Power Europe GmbH
Mitsubishi Power is the thermal power generation company within the MHI Group.

### Company Overview

#### Research & Innovation Centre

<table>
<thead>
<tr>
<th>Energy Systems</th>
<th>Plants and Infrastructure</th>
<th>Integrated Defense and Space Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet Engines (Mitsubishi Heavy Industries Aero Engines, Ltd.)</td>
<td>Ammonia &amp; Methanol Co-Production Plants (Mitsubishi Heavy Industries Engineering, Ltd.)</td>
<td>Aircraft (Mitsubishi Aircraft Corporation)</td>
</tr>
<tr>
<td>Offshore Wind Turbines (MHI Vestas Offshore Wind A/S)</td>
<td>CO2 Capture Plants (Mitsubishi Heavy Industries Engineering, Ltd.)</td>
<td>H-IIA Rocket</td>
</tr>
<tr>
<td>Compressor (Mitsubishi Heavy Industries Compressor Corp.)</td>
<td>Gas Carriers (Mitsubishi Shipbuilding Co., Ltd.)</td>
<td></td>
</tr>
</tbody>
</table>

*This table is not exhaustive. It lists only companies and products related to hydrogen business.*
The MHI Group has a vast range of technologies and end-to-end solutions for the hydrogen supply chain.

In addition, MHI Group has products for iron making, forklift, rocket, etc. that can be fueled by hydrogen.
Overview of Global Hydrogen Supply Chain

Production

Hydrogen from renewable source (with CO₂ capture & storage)

CH₄ + 2H₂O → CO₂ + 4H₂

Hydrogen from renewable source

Transportation

Hydrogen transportation

Liquid Hydrogen / Methylcyclohexane

LH₂ / MCH

Hydrogen

Ammonia

NH₃

Hydrogen

N₂

Nitrogen gas

CO₂ capture & utilization

Synthetic Fuels / Materials

Carbon dioxide

Carbon dioxide capture

Demand

Power

Mobility

Industry

Building
Key technologies for Hydrogen in Power Generation, and Sector Integration (PtX)

Hydrogen in Heat & Power Generation

Solid Oxide Fuel Cell
“MEGAMIE” (1 MW)

Gas turbine in combined cycle power plants: up to GW scale

“hydrogen readiness” is a key requirement for near future in EU market

Hydrogen production & Sector Integration

MW-scale electrolyser (1 to >100MW) + heat pump for waste heat recovery

Electrolyser

Heatpump

Industrial Scale Carbon Capture

“blue hydrogen” and CCU require large scale CO2 capture

Petra Nova Plant, US 4776 t/day CO2 capture
Electrolyser
MHI Group Undertakes Investment in HydrogenPro of Norway, Leading Producer of Advanced Electrolyzers -- Move Will Contribute to Creation of a Sustainable Society through Hydrogen Energy --

2020-10-14

- Investment will make MHI an industrial partner supporting HydrogenPro's business expansion
- Strategic collaboration in hydrogen production will strengthen and diversify MHI's hydrogen value chain

Tokyo, October 14, 2020 - Mitsubishi Heavy Industries, Ltd. (MHI) has made a financial investment in HydrogenPro AS of Norway, a company engaged in the development and manufacture of electrolyzers, devices that produce hydrogen by the process of water electrolysis. MHI subscribed to newly issued shares placed by HydrogenPro in an initial public offering (IPO) undertaken to fund expansion of its business operations. MHI already provides various decarbonization technologies that allow for a realistic path towards net-zero and will form the strategic partnership with HydrogenPro to further expand its portfolio and provide green hydrogen production plants to the market going forward.
HydrogenPro was established in 2013 based in the Norwegian city of Porsgrunn, Telemark County. The history of water electrolysis technology traces back to 1927, when a fertilizer and heavy water plant employing water electrolysis technology was launched in Telemark by Norsk Hydro, a Norwegian state owned conglomerate. HydrogenPro has already developed a 9 megawatt (MW) class hydrogen production system (production capacity: 4.4 tons/day) adopting water electrolysis technology incorporating a pressurized cells with alkaline electrolyte. Plans are now underway toward achieving a 100 MW class plant (capacity: 48 tons/day).

MHI’s investment in HydrogenPro provides further financial stability and long-term certainty for projects utilizing green hydrogen to decarbonize various sectors. MHI’s investment in HydrogenPro not only signals its confidence in HydrogenPro’s offerings, but more importantly, this investment underscores its confidence in the green hydrogen market which will be supported by a multitude of electrolyzer manufacturers and technologies.

Hydrogen pro
Work in progress,
Preliminary arrangement
100MW(el) class
### H2 electrolyser

<table>
<thead>
<tr>
<th>Type</th>
<th>Op.- Pressure (bar)</th>
<th>Spec. Power (kWh/Nm³)</th>
<th>Turnkey (€/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressurized Alkaline Electrolyzer</td>
<td>15-30</td>
<td>&lt; 4,5 (AC)*</td>
<td>~1000 €/kW*</td>
</tr>
</tbody>
</table>

* 100MW scale, baseload operation proposed solution, for < 4000 full load hours cost optimisation can be done with the same technology by higher current density, lower efficiency (with today’s electrodes) but up to 30% reduced cost
100 MWel scale with traditional technology

Typical large scale hydrogen production process 2018

100MW plant

51 kWh in total to produce 1 kg H2 (already pressurized to 15 bars)
Future plant design for large-scale production processes.

Safety, efficiency and flexibility:

1. Today’s stacks
2. Today’s stacks, higher A/m²
3. Today’s stacks, higher A/m², & new electrodes

Less than 51 kWh in total to produce 1 kg H2 (already pressurized to 15 bars) (operation mode 3)
Hydrogen fired Gas Turbine
Our Advanced Class Gas Turbines are designed for deep decarbonization.

- **High Efficiency**
  - Achieved 64% CC efficiency with
    - High pressure compressor (25:1)
    - Enhanced air-cooled combustor
    - Advanced TBC / Aerodynamics

- **High Reliability**
  - Achieved 99.5% reliability by
    - 60 GT units
    - Over 840k operation hours
      (accumulated hours of all J-class units)

- **Fuel Flexibility**
  - Gas Turbine can be fueled by
    - Fossil fuel (Natural Gas, Oil)
    - Clean fuel (Hydrogen)

<table>
<thead>
<tr>
<th></th>
<th>GT / CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>M701JAC (50Hz)</td>
<td>563MW / 818MW</td>
</tr>
<tr>
<td>M501JAC (60Hz)</td>
<td>425MW / 614MW</td>
</tr>
</tbody>
</table>
Mitsubishi Power has successfully demonstrated more than 3.5 million hours of H₂ co-firing across 29 units since the 1970s.

Hydrogen use in Gas Turbines

Actual Combustion Test for National Project

Syngas
COG
Refinery Gas
M Series
H Series


Mitsubishi Power, Ltd. All Rights Reserved.
Hydrogen use in Gas Turbines

Currently, Mitsubishi Power has 3 types of combustors catering to individual project requirements and hydrogen densities.

<table>
<thead>
<tr>
<th>Type</th>
<th>Low NO\textsubscript{x} tech</th>
<th>Turbine inlet temperature (°C)</th>
<th>H\textsubscript{2} density (volume %)</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1: Diffusion</td>
<td>N\textsubscript{2} dilution, Water / Steam injection</td>
<td>1200 ~ 1400</td>
<td>100%</td>
<td>2025</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnum H\textsubscript{2} conversion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rig test completion target</td>
</tr>
<tr>
<td>Type 2: Pre-Mix (DLN)</td>
<td>Dry</td>
<td>1600</td>
<td>30%</td>
<td>2018</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30% co-firing test completed</td>
</tr>
<tr>
<td>Type 3: Multi-Cluster (DLN)</td>
<td>Dry</td>
<td>1650</td>
<td>100% (target)</td>
<td>Mar, 2025</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>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
Solid Oxide Fuel Cell
• Mitsubishi Power SOFC System Product Line Up

220kW Class (Commercialized)
For Commercial & Industry User
(Building, Hospital, Hotel…)

1MW Class (market launch in 2021)
For Utility, Large Industrial Plant & Micro-grid
Multi-stage power & heat generation

- Mitsubishi Power-SOFC converts various types of fuel to electricity directly while micro gas turbine utilizes excess fuel from SOFC to generate power.

<table>
<thead>
<tr>
<th></th>
<th>PEFC Polymer Electrolyte Fuel Cell</th>
<th>PAFC Phosphoric Acid Fuel Cell</th>
<th>MCFC Molten Carbonate Fuel Cell</th>
<th>Mitsubishi Power-SOFC Solid Oxide Fuel Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>60～100</td>
<td>150～200</td>
<td>600～650</td>
<td>750～1000</td>
</tr>
<tr>
<td>Fuel</td>
<td>Hydrogen</td>
<td>Hydrogen</td>
<td>Natural Gas</td>
<td>Flexible</td>
</tr>
<tr>
<td>Efficiency (%LHV)</td>
<td>35～40</td>
<td>38～42</td>
<td>~45</td>
<td>~55</td>
</tr>
</tbody>
</table>

- Due to multi-stage power generation, our SOFC system has proved to have the highest efficiency in all other Distributed Energy Resources at same capacity range.

Efficiency Comparison Chart
220kW Class SOFC Specification (Commercialized)

<table>
<thead>
<tr>
<th>Expected Specification</th>
<th>Mitsubishi Power 250kW Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Output</td>
<td>220kW class</td>
</tr>
<tr>
<td>Electrical Efficiency</td>
<td>55 %</td>
</tr>
<tr>
<td>(LHV)</td>
<td></td>
</tr>
<tr>
<td>Hot water/Steam Output</td>
<td>86kW/50kW</td>
</tr>
<tr>
<td>Total Efficiency (LHV)</td>
<td>73%/65%</td>
</tr>
<tr>
<td>Electrical + Thermal</td>
<td></td>
</tr>
<tr>
<td>Unit Size</td>
<td>W 3.2m x L 12.4 m x H3.3 m</td>
</tr>
<tr>
<td>Weight</td>
<td>37ton</td>
</tr>
<tr>
<td>Noise Level</td>
<td>≤65dBA</td>
</tr>
<tr>
<td>(Estimated value)</td>
<td>(at 10m far distance)</td>
</tr>
<tr>
<td>NOx (16% O2)</td>
<td>Low Concentration</td>
</tr>
<tr>
<td></td>
<td>(Depends on the fuel)</td>
</tr>
<tr>
<td>SOx emission</td>
<td>Low Concentration</td>
</tr>
<tr>
<td></td>
<td>(Depends on the fuel)</td>
</tr>
</tbody>
</table>

Diagram:
- LNG
- H2 GAS
- BIO GAS
- SOFC (Fuel cell)
- MICRO GAS TURBINE
- 1st stage
- 2nd stage
- 3rd stage
- Heat
1MW-Class SOFC specification *(Under Development)*

<table>
<thead>
<tr>
<th>Expected Specification</th>
<th>1MW Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Output</td>
<td>1,200kW</td>
</tr>
<tr>
<td>Electrical Efficiency (LHV)</td>
<td>Approx. 55%</td>
</tr>
<tr>
<td>Hot water/Steam Output</td>
<td>Detail to be discussed</td>
</tr>
<tr>
<td>Total Efficiency (LHV) Electrical + Thermal</td>
<td>Later</td>
</tr>
</tbody>
</table>
| Unit Size               | W: 8.0 m  
L: 25 m  
H: 4.0 m |
| Weight                  | Approx. 160 ton |
| Noise Level (Estimated value) | ≦65dBA (at 10m far distance) |
| NOx (16% O₂)            | Low Concentration (Depends on the fuel) |
Mitsubishi Power SOFC Supply Record

**Overseas: 1 Unit**
- Germany / GWI
  - Co-generation / Hot water
- J Power
  - Mono-generation
- Kyushu Univ.
  - Mono-generation
- 1MW demonstration
  - Mono generation

**Japan: 10 Units**
- Commercial Operation @2022
- ASAHI BREWERIES
  - Co-generation / Steam
- TAISEI Corp.
  - Co-generation / Hot water
- NGK Spark Plug
  - Co-generation / Steam
- Toyota Motor
  - Co-generation / Steam
- Tokyo gas
  - Co-generation / Hot water
- HAZAMA ANDO Corp.
  - Co-generation / Hot water
- MITSUBISHI ESTATE
  - Co-generation / Steam

Japan:
- 10 Units
- 1MW class
- 210kW class
  - with H2 Rich Fuel
  - with Biogas Fuel

Overseas:
- 1 Unit
  - Commercial Operation @2022
- Germany / GWI
  - Co-generation / Hot water

ASAHI BREWERIES
- Co-generation / Steam

Tokyo gas
- Co-generation / Hot water

HAZAMA ANDO Corp.
- Co-generation / Hot water

MITSUBISHI ESTATE
- Co-generation / Steam

Germany / GWI
- Co-generation / Hot water

J Power
- Mono-generation

Kyushu Univ.
- Mono-generation

1MW demonstration
- Mono generation
Ammonia use in Gas Turbines and boilers
Development program for ammonia utilisation in GTs

**Ammonia cracking system**
- **NH₃** → **H₂ + N₂**
- **NH₃ Decomposition**
- Higher CET / higher efficiency (typically applicable for large GTs)
- NH₃ decomposition by GT high temp exhaust → higher exhaust temp needed

**Ammonia Direct combustion system**
- **NH₃** → **NH₃(Gas)**
- Need lower CET & deNOx system to reduce Fuel–NOx
- Lower CET / simple system (typically good for small GTs)

**H-25 Series gas turbine**

**PRESS RELEASE**
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
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>

Output: 41.0MW
Efficiency: 36.2% (SC)
>80% (Cogeneration)
Sales: 190 GTs
Development program on ammonia firing in boilers

- Development program for 100% ammonia firing in retrofitted industrial boilers ongoing. Pilot tests carried out

- Ammonia co-firing already feasible in existing boilers after retrofit

Benefits of Ammonia co-firing/ 100% firing

- Reduced / zero CO₂ emissions
- Higher operating flexibility (better load change rate)
Integrated Projects (Examples)
Hydrogen for multi-sectoral approach, storage, grid services

- Hydrogen compression & storage
- Electrolyser: (20-100%) waste heat
- CHP: (GT, SOFC, gas engines) (0-100%) waste heat
- Battery Container: (+/-)
- Electric Heater: (0-100%) heat
- Heat pump: electricity, heat, flue gas heat
- Heat storage

>80% total energy efficiency for electrolysis by waste heat utilisation

Services & Income streams:
- Multiple grid services (flexible operation)
- H₂ sales
- Heat sales
- O₂ sales
- "storage"
Mitsubishi Power Hydrogen approach: Learning by doing

Global Hydrogen Experience Highlights
- 4 Continents
- 3 Hydrogen Source Fuels
- JAC Dry Low NOx Combustion
- F-Class Diffusion Combustion
- Coal Gasification
- CO₂ Sequestration

Intermountain Power
840 MW Green Hydrogen Power
Salt Lake City, Utah

Advanced Clean Energy Storage
World's Largest Green Hydrogen Production and Storage
Salt Lake City, Utah

Vattenfall Magnum
Existing GTCC Conversion to Blue Hydrogen
Eemshaven, Netherlands

Green Hydrogen Hub, Hamburg
100 MWe
Hamburg, Germany

Zero Carbon Humber (H2H Saltend)
Existing GTCC Conversion
Blue, Green H₂
Hull, Humber, UK

HySTRA
CO₂-free Hydrogen Usage
Japan

HySTRA
CO₂-free Hydrogen from Coal
Latrobe, Australia

Salt Dome Storage
Marine Transport
Pipeline Transport
Feasibility study bid under UK funding. 30% H2 co-firing in Saltend GTCC is the starting point of the project.

Turbine Model M701F
Power Output 1202 MW (3 GTCC)
Location Hull, Humber UK

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.
Hamburg Green Hydrogen Hub

Shell, Mitsubishi and Vattenfall partner on Hamburg hydrogen project

Targets
- 100MW(el) electrolyser as first stage, 11500Nm³/h H2 transport & storage via pipeline to users (85bar)
- Supply to industrial customers, transport
- Later extension to X*100MW
- Site: Moorburg PP, Hamburg

Shell, Mitsubishi Heavy Industries (MHI), Vattenfall and municipal company Wärme Hamburg are exploring a plan to jointly produce hydrogen from wind and solar power at the Hamburg-Moorburg power plant site and utilise it in its vicinity.
The Advanced Clean Energy Storage Project is the world’s largest renewable energy storage project. 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.

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.
Carbon Capture, CCU
The world's most energy efficient post combustion process was commercialized 1999 for various flue gas sources (natural gas, heavy oil, biomass, coal) to a variety of usages such as Urea, Methanol or other CO₂ use cases.

- Carbon Capture from Flue Gases with 3% of CO₂ or more
- Purity of CO₂ > 99.9%
- Carbon capture rate over 90%, up to 99.5% possible
- Solvent KS-1™ is negligible corrosive with low consumption
- Over a dozen commercial references

MHI KM CDR™ Carbon Capture Process for Carbon Capture from Flue Gases

- Proprietary hindered amine solvent KS-1™ with low energy, low solvent degradation
- High energy efficiency system
- Amine emission reduction system
- Automatic Load Adjustment (ALAC) System
CO₂ scrubbing - sound reference - key equipment also for PtX (e-fuels)

World’s leading large scale post – combustion CO₂ capture technology licensor

13 plants in operation and 1 under construction, from a variety of natural gas, heavy oil and coal flue gas sources

European Market started
Mitsubishi Power Europe GmbH, well prepared as licensee of MHI-ENG Technology for present tenders
CO₂ Capture and Utilisation (CCU)

CO₂ - Scrubber Reference

**Petra Nova**: Texas – USA
World biggest CO₂-scrubber

Start-up: end 2016
4.776 t/day CO₂ production
(flue gas stream of 240 MW hard coal)
90% capture rate

Utilisation:
Enhanced Oil Recovery (EOR)

Flue gas slip stream scrubbing of Boiler #8
(654 MW) W.A. Parish Power Plant / USA

MHI is No. 1 in the world
with over 15 years of experiences
having more than 10 reference plants
for CO₂ scrubbing (PCC technology) in operation
Multi-sectoral Approach: H₂ Conversion to MeOH and DME

Strong engagement by Mitsubishi Power Europe GmbH*
in EU funded multi-party demonstration plants, projects successful and almost completed

**MefCO2**: EU SPIRE2 – Horizon 2020  
Grand Agreement no.: 637016  
- 9 Project partners  
- MHPS-EDE as system integrator  
- Production of 1 t of Methanol per day  
- Project Volume: 11 Mil. EUR

**ALIGN-CCUS**: EU SPIRE2 – Horizon 2020  
Grand Agreement no.: 691712  
- 31 partners from 5 EU countries working on 6 topics  
- WP CO₂ utilization: RWE, AsahiKasei, FEV, FZ Jülich, MHPS-EDE, RWTH; associated partner: BOSCH  
- Production of 48 kg of DME mixture per day  
- Project Volume: 23 Mil. EUR  
- Construction to be completed

*former MHPS-EDE
65MW(el) Synthetic methanol

Harbour of Gent/BE
Electrolyser in Rodenhuize PP
Synthesis in harbour area
CO₂ source options
- From nearby ammonia plant
- From bioethanol
- From AM steel mill
Summary
MHI Group Hydrogen Portfolio  Capabilities across the Hydrogen Value Chain

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

### Hydrogen Production

- **Water Electrolysis**
- **Steam Reforming, Thermal Decomposition, etc.**
- **Methane reforming and methane pyrolysis**

### Transportation and Storage

- **CO₂ Recovery**
- **Compressor (Hydrogen and CO₂ compression)**

### Usage Application

- **Hydrogen Gas Turbine**
- **Fuel Cell**
- **Hydrogen Gas Engine**
- **Hydrogen-reducing Steel Manufacturing**
- **SynFuels**

#### Current products and applications

- **Renewable Energy**
  - Water Electrolysis
  - Hydrogen pro

- **Nuclear Power**
  - Steam Reforming, Thermal Decomposition, etc.

- **Natural Gas**
  - Methane reforming and methane pyrolysis

- **CO₂ Recovery**

- **Hydrogen Storage**

**White Text: MHI technology**  **Blue Text: Partnering**

- 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