Mitsubishi Heavy Industries (MHI)

Hydrogen/Ammonia Solution Ecosystem

Ammonia Energy Association Conference 2021

November 10. 2021

Ricky Sakai
Mitsubishi Heavy Industries America, Inc.
### Mitsubishi Group Companies

<table>
<thead>
<tr>
<th>Total Number of Employees</th>
<th>Apx. 570,000</th>
<th>Number of Group Companies</th>
<th>600 +</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Sales Turnover</td>
<td>Apx. US$580 Bil.</td>
<td>Year of Foundation</td>
<td>1870</td>
</tr>
</tbody>
</table>

### Mitsubishi Group

- Mitsubishi Corporation
- ENEOS
- MITSUBISHI CHEMICAL
- Mitsubishi Logistics
- MEIJI YASUDA
- Nikon
- FUSO
- MITSUBISHI MOTORS
- MUFG
- MITSUBISHI PAPER MILLS LIMITED
- MITSUBISHI PLASTICS
- Tokio Marine & Nichido Fire Insurance Co., Ltd.
- Yusen Logistics
- NYK Line
Technology-focused conglomerate company across industries from Energy, Infrastructure, Transportation, Space and Defense for over a hundred years

<table>
<thead>
<tr>
<th>COMPANY HIGHLIGHTS</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$36.7BN</strong></td>
<td><strong>54%</strong></td>
<td><strong>83,000</strong></td>
<td></td>
</tr>
<tr>
<td>Annual revenue (*)</td>
<td>Sales outside Japan</td>
<td>Employees worldwide</td>
<td></td>
</tr>
<tr>
<td>Americas</td>
<td>$ 7.7 Bil.</td>
<td>More than</td>
<td>130+</td>
</tr>
<tr>
<td>Japan</td>
<td>$ 17.7 Bil.</td>
<td>24,600 Patents</td>
<td>Years</td>
</tr>
<tr>
<td>Asia Pacific</td>
<td>$ 6.6 Bil.</td>
<td></td>
<td>240+</td>
</tr>
<tr>
<td>EMEA</td>
<td>$ 4.7 Bil.</td>
<td></td>
<td></td>
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</tbody>
</table>

(FY2019 Results @110JPY/$)
MHI Group Technologies and Domain

**Energy Systems**

- Thermal Power Generation Systems
- Compressors
- Renewable Energy & Storage
- Nuclear Energy Systems Division

**Aircraft, Defense & Space**

- Commercial Airplanes
- Regional Aviation MRO
- Space Systems Division
- Aircraft Division

**Plant & Infrastructure Systems**

- Chemical Plants
- Environmental Protection Systems
- CO2 Capture System
- Shipbuilding & Ocean Development
- Land Transportation Systems

**Logistics, Thermal & Drive Systems**

- Material Handling Equipment / Engine & Energy / Turbocharger
- Metals Machinery
- Air-Conditioning & Refrigeration
MHI’s strategy to achieve Carbon Neutrality

Build an innovative solutions ecosystem to realize a carbon neutral future

Decarbonize existing infrastructure

Build a hydrogen solutions ecosystem

Build a CO₂ solutions ecosystem

Highly Efficient Turbomachinery

Renewable Energy & Storage

Hydrogen GT

CO₂ Carrier

CO₂ Capture and Utilization
The MHI Group has a vast range of technologies and end-to-end solutions for hydrogen value chain.

- **Expanding value chain by R&D activities and Strategic partnership**
- **Developing flagship projects all over the world**
MHI’s Global Green & Blue Hydrogen / Ammonia Project: Developing Flagships

- **Vattenfall Magnum**: Existing GTCC Conversion to Blue Hydrogen
  - Eemshaven, Netherlands

- **HySTRA CO₂-free Hydrogen Usage**: Japan

- **Green Energy Hub**: 100MW Green Hydrogen Production
  - Hamburg, Germany

- **H2@Scale Texas**: Renewable Hydrogen network

- **ACES**: World’s Largest Green Hydrogen Production and Storage
  - Salt Lake City, Utah

- **Intermountain Power**: 840 MW Green Hydrogen Power
  - Salt Lake City, Utah

- **H2U**: Green Ammonia Project
  - South Australia

- **HySTRA CO₂-free Hydrogen from Coal**: Latrobe, Australia

- **Entergy Decarbonization**: Multiple Green H₂ Project Across Four Utilities
  - TX, LA, MS, AK

- **Bakken Energy**: Clean Hydrogen Hub
  - Bismarck, North Dakota

- **Harrison Energy Center**: 1,200 MW Green Hydrogen Power
  - Harrison County, Ohio

- **Danskammer Energy Center**: 600 MW Green Hydrogen Power
  - Newburgh, NY

- **Chickahominy**: 1,500 MW Green Hydrogen Power
  - Charles City, VA

- **Keppel Data Centers**: Tri-generation from Blue Hydrogen
  - Singapore

- **Global Hydrogen Experiences**

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Establishing Hydrogen Energy Value Chain

**Partnership / Project**  
**Carbon-free Ammonia Production Project**

- 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

Offshore Wind

PV

Hydro

Hydrogen gas turbine

Water Electrolyzer

Ammonia production plant

Blast furnace

Converter furnace

MHI solution

Chemical

Fertilizer

Shipping Fuel

Export
The use of ammonia fuel for ships reduces CO2 emissions throughout the Supply chain.
MHI group is a leading EPC contractor for Ammonia, and CCS plant
Business development of Blue / Green Ammonia undergoing

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

15 Ammonia plants
with HTAS technology
built Globally

<table>
<thead>
<tr>
<th>Plant location</th>
<th>NRG WA Parish Power Plant (Thompsons, TX)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project owner</td>
<td>Petra Nova – partnership between NRG Energy and JX Nippon Oil &amp; Gas</td>
</tr>
<tr>
<td>Plant scale</td>
<td>240 MW$_{eq}$</td>
</tr>
<tr>
<td>CO$_2$ capacity</td>
<td>4,776 TPD (1.4 MMtonne/year)</td>
</tr>
<tr>
<td>CO$_2$ conc.</td>
<td>11.5 mol% -wet</td>
</tr>
<tr>
<td>CO$_2$ removal</td>
<td>90%</td>
</tr>
</tbody>
</table>

Mitsubishi Heavy Industries Engineering, Ltd. is an authorized licensee of Haldor Topsoe Ammonia Technology

CO$_2$ Used for CO$_2$-EOR

<table>
<thead>
<tr>
<th>Pipeline</th>
<th>12 in diameter, ~ 81 miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection Site</td>
<td>West Ranch Oil Field</td>
</tr>
</tbody>
</table>

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Utilization of ammonia is a path to H₂ society mitigating economical impact

**Hydrogen Carrier**
- Utilize ammonia as a carrier of voluminous hydrogen
- Exhaust heat from GT used for ammonia cracking

**As Fuel**
- Use ammonia as low CO₂ emission or carbon-free fuel

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**Ammonia as Fuel - Technology Development**

- Ammonia combustion boiler
- Ammonia co-firing Boiler power generation
- Ammonia Gas Turbine power generation
- Shipping fuel

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**Ammonia Powered Ammonia Carrier**

- Ammonia Cracking GTCC
- Exhaust heat
- Hydrogen GT
- H₂

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**Ammonia Gas Turbine**

- Ammonia Co-Firing Boiler
- Shipping Fuel
- Participate in Maersk Mc-Kinney Møller Center for Zero Carbon Shipping

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Ammonia Fuel Gas Turbine

Ammonia Cracking GTCC

Apply to large frame GTs with high combustion temp. and high efficiency operation.

Ammonia Direct Combustion GT

Ideal for small frame GT due to low combustion temperature operation.

High efficiency large frame GT

Ammonia Direct Combustion GT

Low combustion temp. allow NOx control by two stage burner system. SCR is mandatory for NOx reduction.
Ammonia Direct Combustion GT Development

- Commenced development of gas turbine fueled by 100% ammonia. (30- 40MW, H-25)
- Utilizing combustion technology to reduce NOx emissions generated from nitrogen in fuel
- Expanding lineup of carbon-free power generation options.

**H-25 Gas turbine**
- Output : 41.0MW
- Efficiency : 36.2% (SC)
- 80% + (Cogen)
- Delivered fleet : 189 units

**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

- 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.

TOKOHAMA, JAPAN (March 1, 2021) - Mitsubishi Power, a subsidiary of Mitsubishi Heavy Industries (MHI) Group, has commenced development of a 40-megawatt (MW) class gas turbine that is fueled by 100% ammonia (NH₃). The project
Combustion stability is maintained by using “Diffusion Combustion Method”.
Fuel-NOx formation is controlled by using “Two-stage Combustion Technology”;
Rapid mixing of lean air enables switching from Fuel rich zone(1) to Fuel lean zone(2) without passing through the Fuel-NOx formation zone.

**Solution**
Rich-Lean Two Stage Combustor

<table>
<thead>
<tr>
<th>Model</th>
<th>Fuel</th>
<th>GT modification</th>
<th>Other modifications</th>
<th>Performance</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard H-25 (Base spec.)</td>
<td>LNG / NG</td>
<td>Base spec.</td>
<td>Base spec.</td>
<td>Base spec.</td>
<td>Existing</td>
</tr>
<tr>
<td>Ammonia Direct Combustion GT</td>
<td>100% Ammonia</td>
<td>Combustor only</td>
<td>Fuel Gas System Add./Improve. of De-NOx system</td>
<td>Same level as base spec.</td>
<td>New</td>
</tr>
</tbody>
</table>
Ammonia Co-Firing Boiler Development

- NOx emission minimized with appropriate firing system (including burners)

- Modification scope is limited to fuel supply and burner since the combustion speed of ammonia and pulverized coal is almost same. (Modification/addition of DeNOx system may be required, depending on NOx restriction/regulation.)

- Power generation can be maintained by coal even if ammonia supply is unstable.

Target : 20〜50cal% Ammonia co-firing ratio
Modification scope : Burner and fuel/ammonia supply system.

Ammonia combustion test
MHI’s strategy to achieve Carbon Neutrality

Build an innovative solutions ecosystem to realize a carbon neutral future

Decarbonize existing infrastructure

Build a hydrogen solutions ecosystem

Build a CO₂ solutions ecosystem

Highly Efficient Turbomachinery
Renewable Energy & Storage
Hydrogen GT
CO₂ Carrier
CO₂ Capture and Utilization
Build CO₂ Solution Ecosystem

- Expanding our advantage in CO₂ recovery through further technology development
- Enter into the value chain of CO₂ conversion and utilization

**CO₂ NTAIN**
- Power plants (GTCC, Coal-fired, or biomass)
- SMR furnace exhaust
- LNG liquefaction Plant
- Cement and Steel plants
- Commercial facilities

**CO₂ NNNECT**
- CO₂ Recovery

**CO₂ NVERT**
- Distribution
- Storage in earth layer: EOR, CCS
- Fuel synthesis: carbon recycled methanol, Jet Fuel
- Valuable products synthesis: carbon recycled Chemicals
- Industrial use: food and welding

**Solving CO₂ for Good**
- LCO₂ carrier (CO₂L-Blue)
- CO₂ to X

**PétroNova World Largest**
- From coal fire power in TX US

**Biomass Power In UK**
- On-Board

**CO₂ Capture**
- MHI Over 70%
MOVE THE WORLD FORWARD