MOVE THE WORLD FORWARD MITSUBISHI HEAVY INDUSTRIES GROUP

MHI Energy Transition and Ammonia firing Gas Turbine

Presentation at Ammonia Energy APAC 2023

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Senior Manager
GTCC Business Division
Mitsubishi Heavy Industries, Ltd.

August 17th, 2023

MITSUBISHI POWER

Mitsubishi Heavy Industries Group at a Glance

1884 Foundation
over 130 years history

78,486 Employees
(Consolidated)

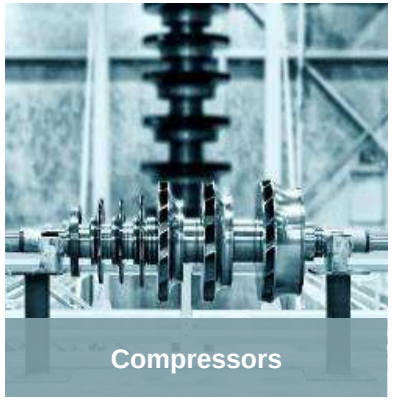
256 Group Companies
(Consolidated)

¥4.2TN ($31.1BN*) Revenue
(FY2022, consolidated)

Diverse **products**
On land, at sea, in the sky, in space

Note: The U.S. dollar revenue figure was converted from Japanese yen using the FY2022 average exchange rate, JPY 134.9/USD.


Gas turbines
MITSUBISHI POWER

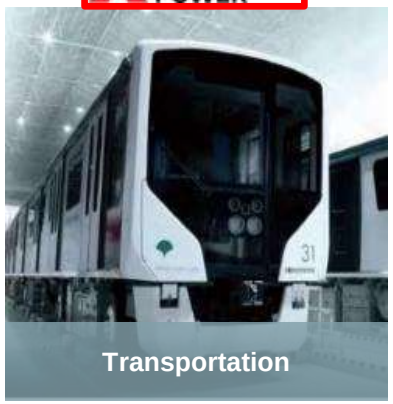

Compressors


Aero engines

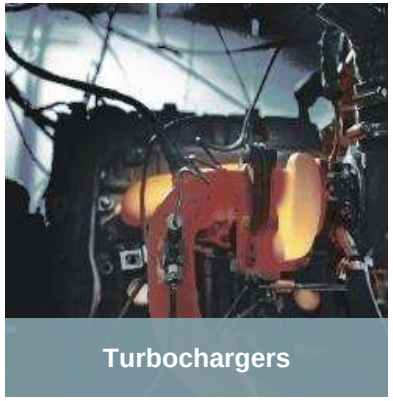

CO_2 capture plants

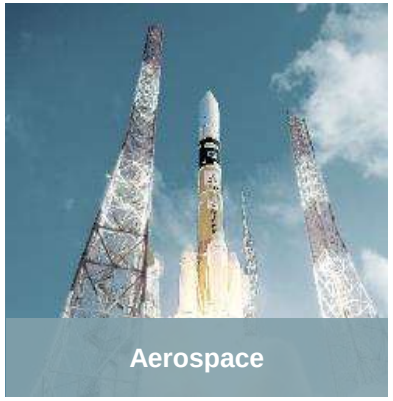

Metals machinery

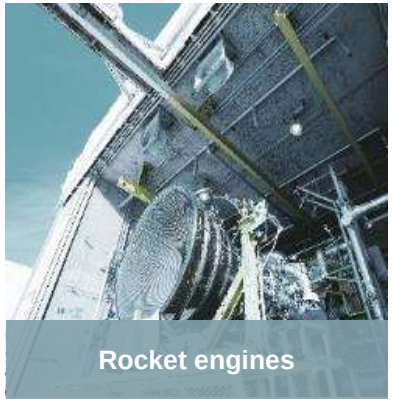

Chemical plants

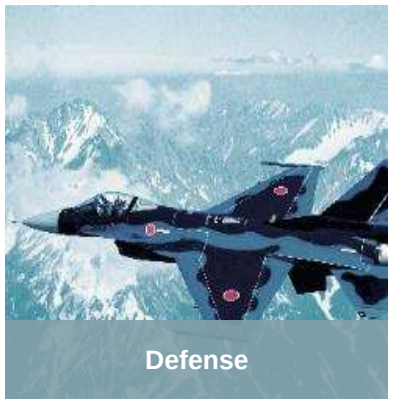

Transportation


Waste-to-energy


Turbochargers


Aerospace


Rocket engines


Defense

2040 Carbon Neutrality Declaration

Path to achieving Carbon Neutrality

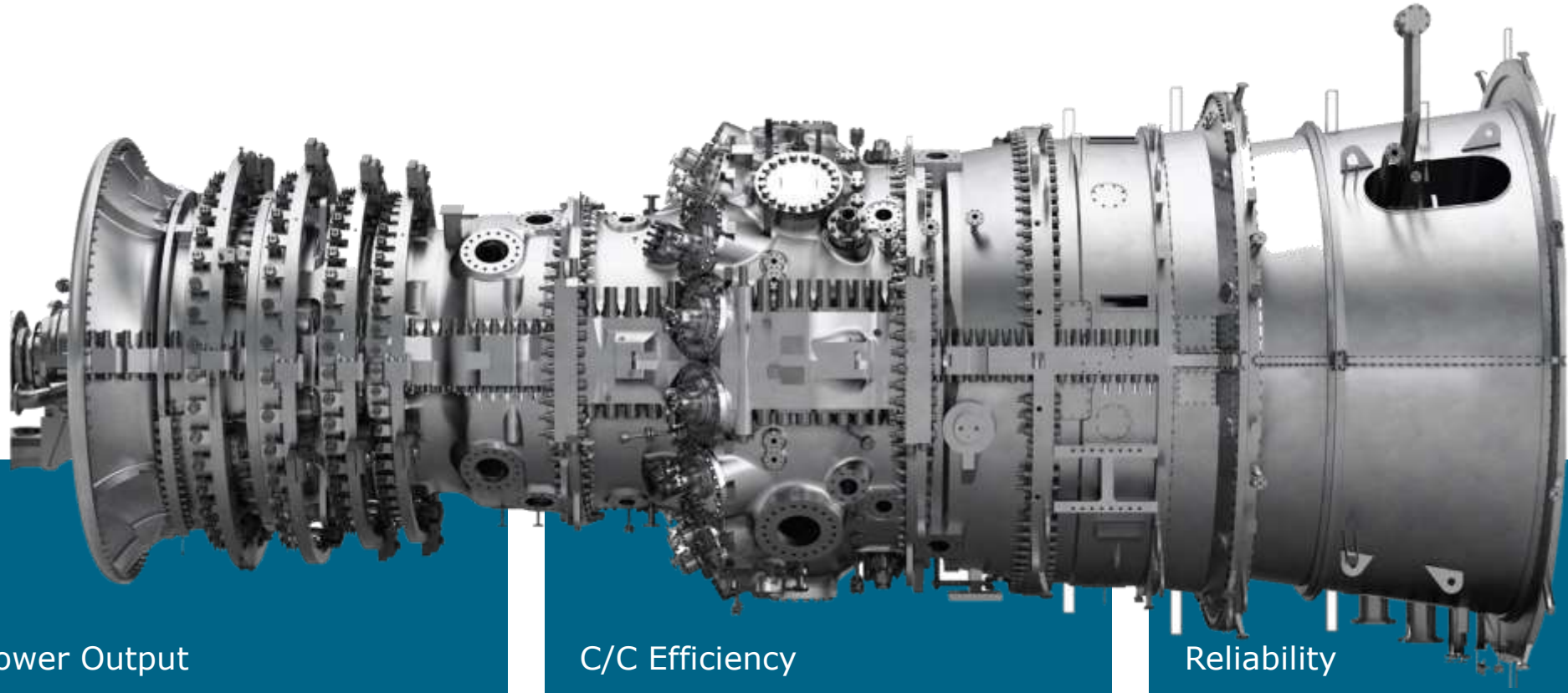
Build an innovative solutions ecosystem to realize a carbon neutral future

Target Year	Reduce CO_2 emissions across MHI Group Scope 1&2	Reduce CO_2 emissions across MHI's value chain Scope 3 + reductions from CCUS
2030	-50% (compared to 2014)	-50% (compared to 2019)
2040	Net Zero	Net Zero

Scope 1&2: The calculation standard is based on the GHG Protocol.
Scope 3: The calculation standard is based on the GHG Protocol. However, we also account for reductions achieved by CCUS as an MHI original index.

GHG: Greenhouse Gas CCUS: Carbon dioxide Capture, Utilization and Storage

JAC Series Gas Turbine (50Hz)



Power Output

840 MW

C/C Efficiency

> 64 %

Reliability

99.5 %

CO2 Zero power generation technology Roadmap

Reduce CO_2 by High Efficiency Gas Turbine ➡ ZERO CO_2 by Hydrogen Gas Turbine

CO_2 Reduction -65%

1 High Efficiency Natural Gas-fired Gas Turbine

JAC series

Co-firing

2-1 Ammonia Biomass Co-firing Boiler

Ammonia co-firing

CO_2 Capture

2-2 Gas Turbine Combined Cycle plant **+CCUS**

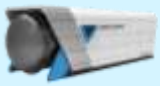
CO_2 Zero

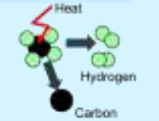
3 Hydrogen Gas turbine Development

Hydrogen Gas turbine

Ammonia Gas Turbine Development

3 Hydrogen Production





water electrolyser *SOEC* *Turquoise H_2*

Base*1

2-1 *Ammonia Biomass co-firing*

Toward CO_2 Zero

1 ***Reduce CO_2***

-65%down (2020-)

64% High Efficiency Gas Turbine Combined Cycle Power Plant (Commercial Operation in 2020)

2-2 ***-90%***

3 ***CO_2 Zero Ammonia Hydrogen***

CO_2 Emission (%)

Base

50%

0%

Technology Road Map 2020 2030

*1 :Based on Sub-C CO_2 Emission

Ammonia Power Technology Roadmap

- Gas turbine: Working on combustor development, aiming for commercial unit operation and commercialization in 2025
- Boiler: Working on burner development, targeting commercialization of ≥50% mixed firing in early 2030s

GT

-2024 → 2025-

100% firing

Combustor development → Validation testing, commercialization

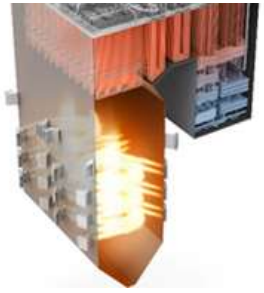
Current hydrocarbon fuel

Ammonia (combustion test)

Boiler

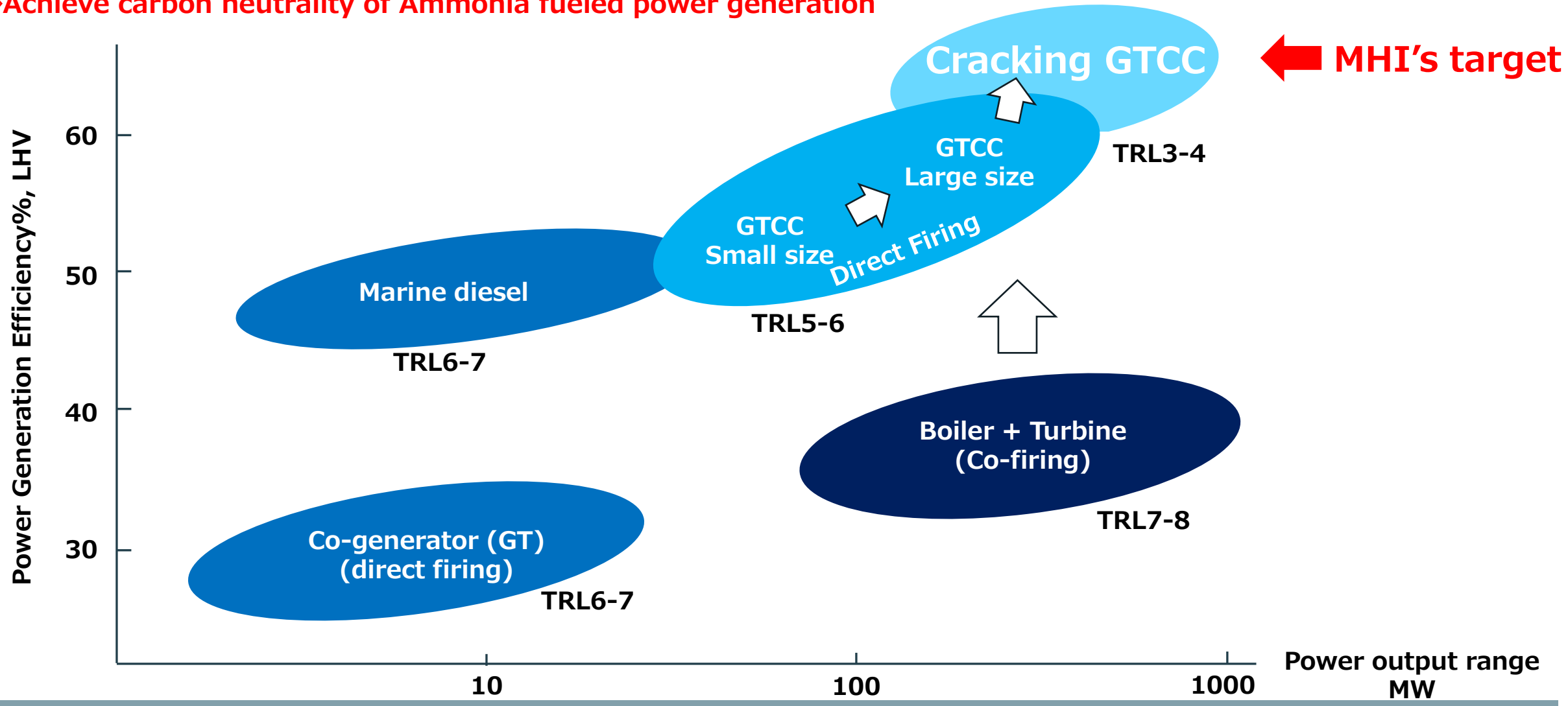
-2024 → -2030 → -2035 → -2050

		-2024	-2030	-2035	-2050
MHI	20% mixed firing	Burner development → Validation preparation → Validation testing			
MHI/ JERA	≥50% mixed firing (Green Innovation Fund)	Burner development, validation preparation	2027-2028: Validation testing	Early 2030s: Commercialization	



Ammonia Fueled Gas Turbine

Cover large power output / high efficiency areas
⇒Expand range of use
⇒Achieve carbon neutrality of Ammonia fueled power generation



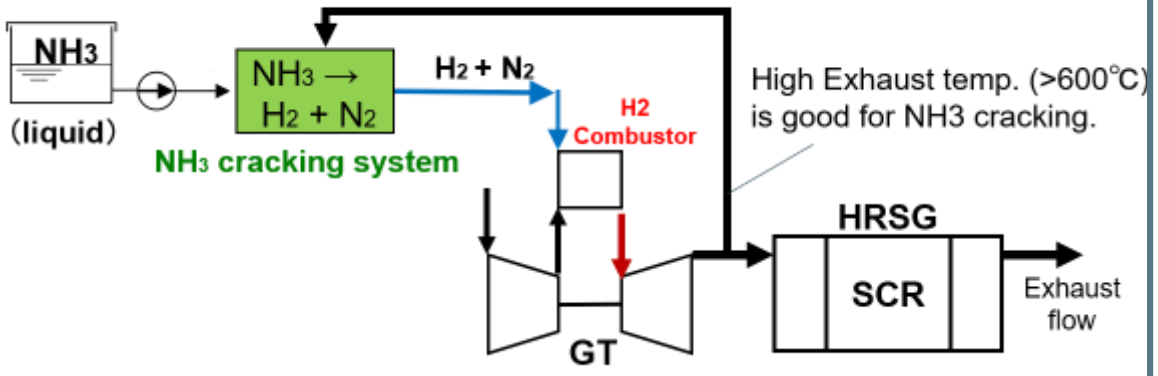
Ammonia Fueled Gas Turbine

Ammonia(NH3)

- Good H2 Carrier
- Fuel use available (No CO2)
- Combustion emit high N0x (Fuel N0x)

High efficiency large frame GT

Ammonia cracking cycle gas turbine system

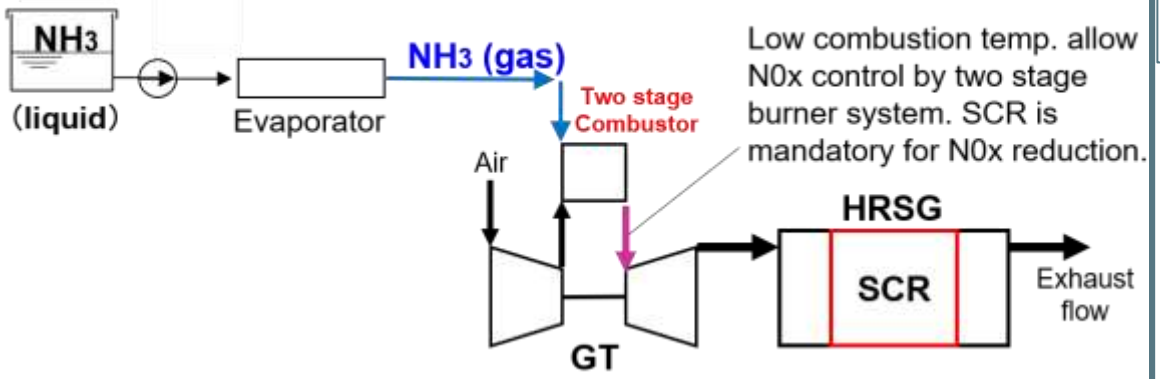


Cracking System
Standalone
Verification Test : 2025～

GTCC Combination

Middle&Small Frame GT

Ammonia direct combustion gas turbine system



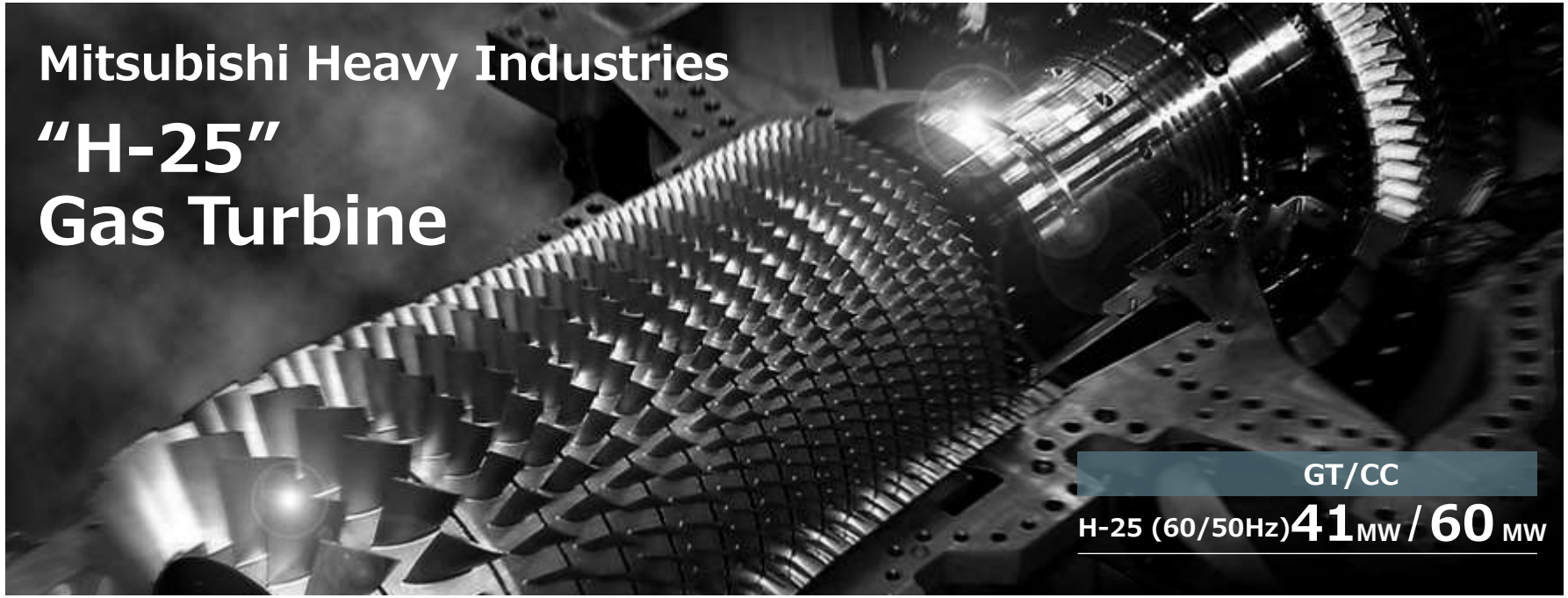
Small Frame

Combustor Test : 2023～
Engine Verification: 2025～

Large Frame GT combustor development

Mitsubishi H-25 Gas Turbine

Our Advanced Class Gas Turbines are designed for deep decarbonization.



High Efficiency

More than 80% Co-generation Overall Efficiency

- Simple cycle 36.2%
- Combined Cycle 54.0%
- Cogeneration Over 80.0%
  79 ton/h (Heat Output)

High Reliability

Cumulative total operating time exceeds 11.0 million hours

- Over 11.0 million operation hours
- Ordered: 193 GT units
  (H-25 as of 2023)

Fuel Flexibility

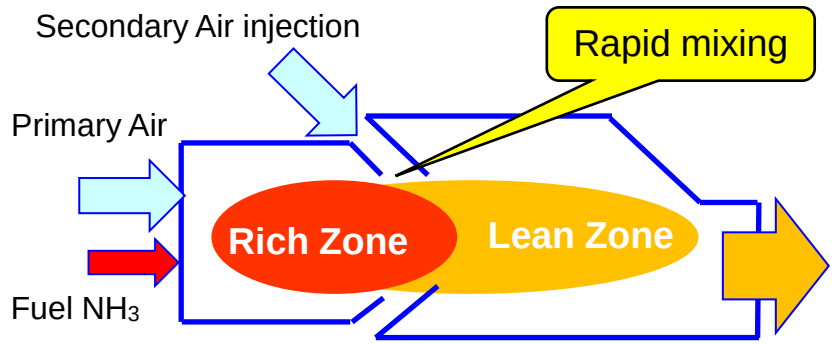
Gas Turbine can be fueled by

- Fossil fuel (Natural Gas, Oil)
- Clean fuel (**Hydrogen, Ammonia**)

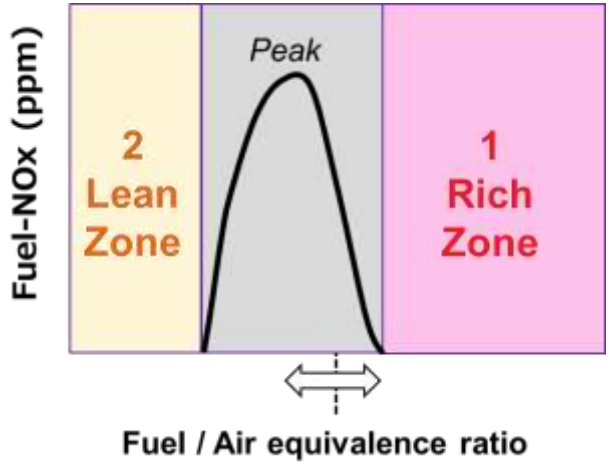
Ammonia Direct Combustion Gas Turbine

Key challenges of Ammonia combustion
- Flame is unstable
- Higher NOx (Fuel NOx)

Solution
Rich/Lean 2-stage combustion



Combustor (Schematic)



H25 gas turbine

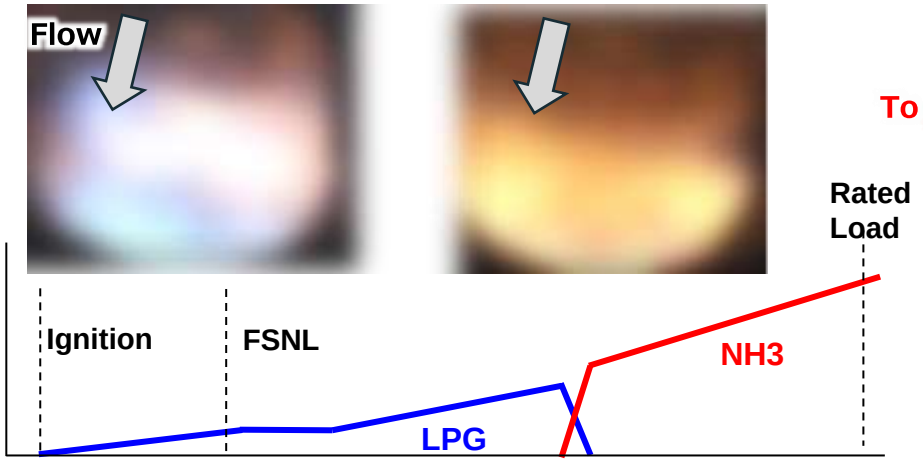
- 41MW (Output)
- 36.2% (SC efficiency)
  80%+ (Cogeneration)
- ~191 units orders

High efficiency SCR (Selective Catalytic Reduction) Required

Ammonia Firing Combustor Development Status

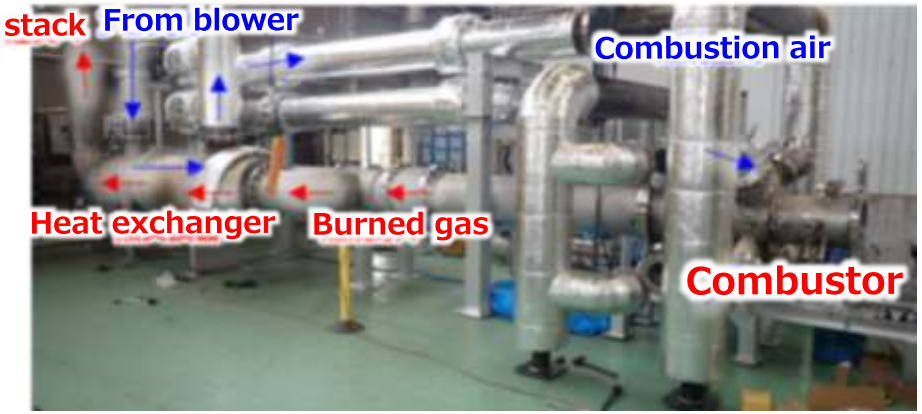
Rich-lean combustion technology based on the matured standard diffusion combustor is applied. Combustion tests are on going.

Combustor



Test Facility

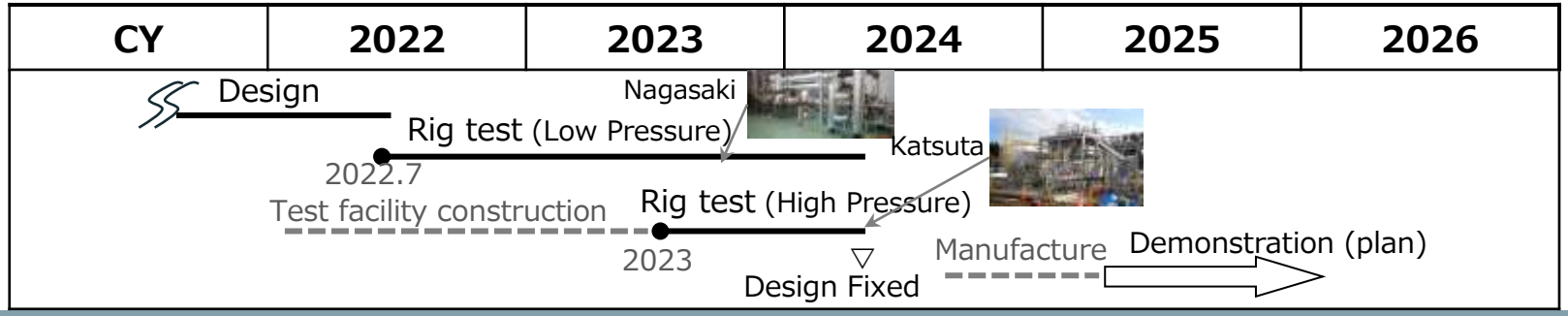
Combustion test@Nagasaki



Combustion test@Katsuta

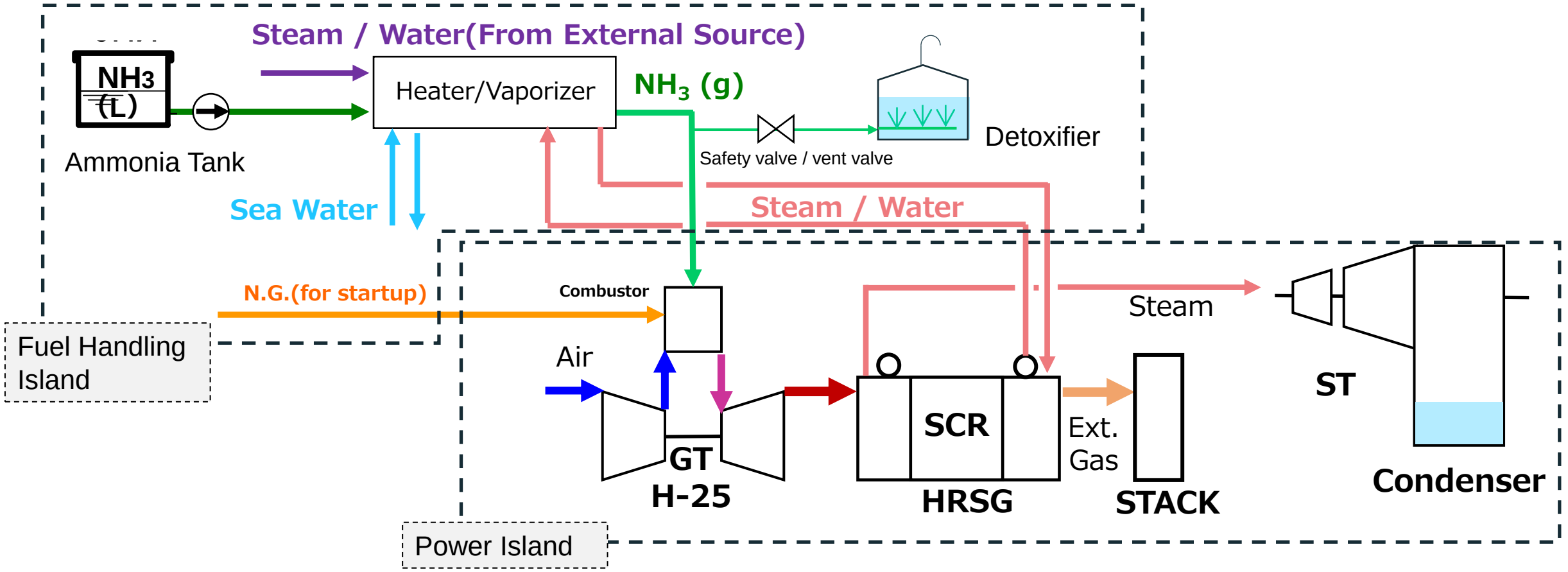
Combustor

Schedule

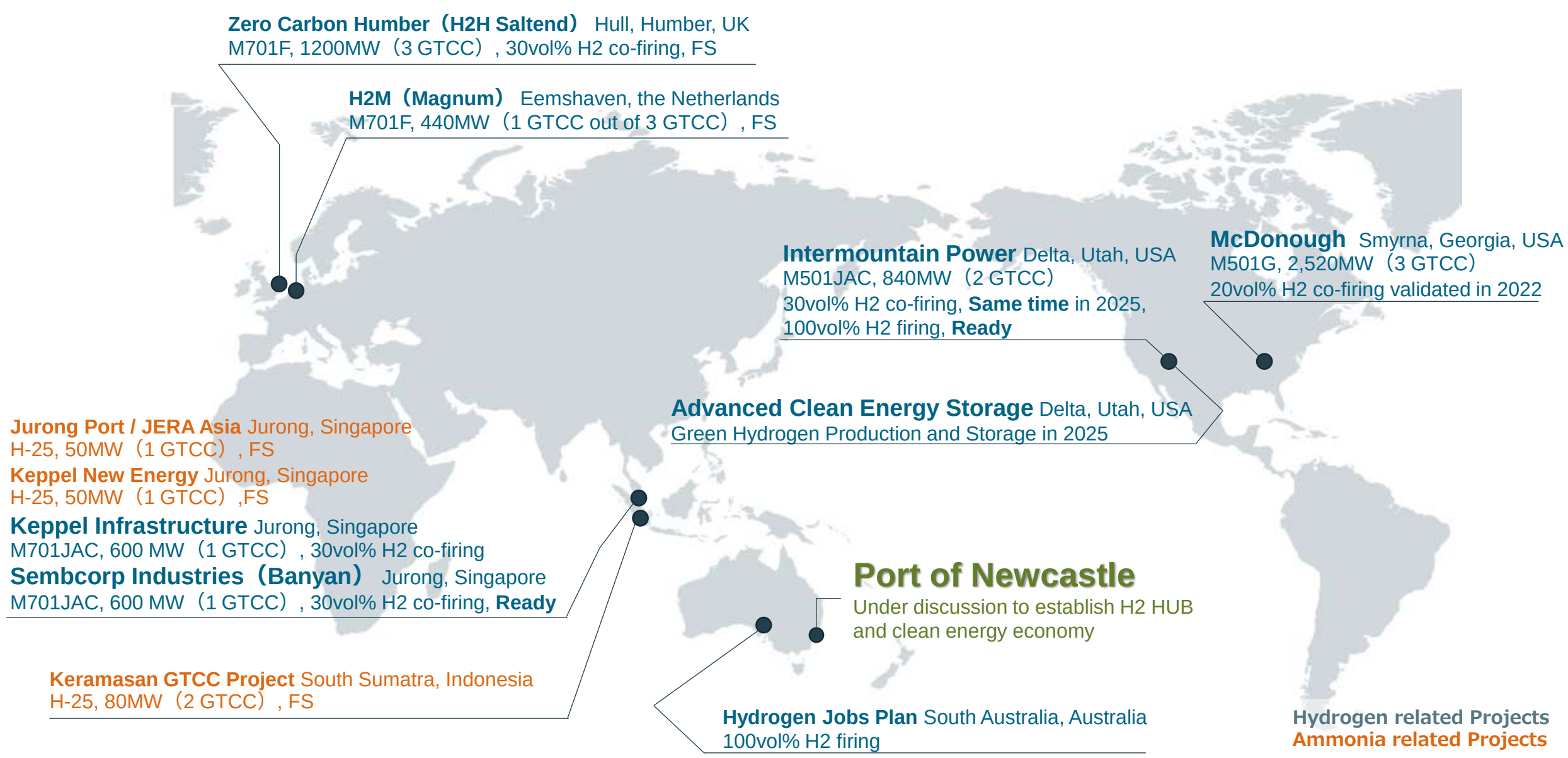


Ammonia GTCC Plant System

Conceptual Scope of Each Island (Fuel Handling Island/ Power Island) shown below



MHI Ammonia / Hydrogen Gas Turbine Combined Cycle projects



Zero Carbon Humber（H2H Saltend） Hull, Humber, UK
M701F, 1200MW（3 GTCC）, 30vol% H2 co-firing, FS

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

Intermountain Power Delta, Utah, USA
M501JAC, 840MW（2 GTCC）
30vol% H2 co-firing, **Same time** in 2025,
100vol% H2 firing, **Ready**

McDonough Smyrna, Georgia, USA
M501G, 2,520MW（3 GTCC）
20vol% H2 co-firing validated in 2022

Advanced Clean Energy Storage Delta, Utah, USA
Green Hydrogen Production and Storage in 2025

Jurong Port / JERA Asia Jurong, Singapore
H-25, 50MW（1 GTCC）, FS

Keppel New Energy Jurong, Singapore
H-25, 50MW（1 GTCC）,FS

Keppel Infrastructure Jurong, Singapore
M701JAC, 600 MW（1 GTCC）, 30vol% H2 co-firing

Sembcorp Industries（Banyan） Jurong, Singapore
M701JAC, 600 MW（1 GTCC）, 30vol% H2 co-firing, **Ready**

Port of Newcastle
Under discussion to establish H2 HUB
and clean energy economy

Keramasan GTCC Project South Sumatra, Indonesia
H-25, 80MW（2 GTCC）, FS

Hydrogen Jobs Plan South Australia, Australia
100vol% H2 firing

Hydrogen related Projects
Ammonia related Projects

Projects

PRESS INFORMATION

Keppel, MHI and DNV Sign Agreement to Explore Adoption of Ammonia-fired Gas Turbine on Jurong Island

2022-09-27

Mitsubishi Heavy Industries, Ltd.
DNV

Tokyo, September 27, 2022 – In a Memorandum of Understanding (MoU) signed yesterday, Keppel New Energy Pte Ltd, a wholly owned subsidiary of Keppel Infrastructure; Mitsubishi Heavy Industries, Ltd. (MHI); and DNV, a global independent energy expert and assurance provider, announced a strategic collaboration to explore the feasibility and implementation of an ammonia-fired gas turbine on Jurong Island, Singapore.

The MoU will see the three companies work together to perform a high-level Quantitative Risk Assessment to explore the use of 100% ammonia as a fuel for a gas turbine or com development of an Ammonia Power Plant.

Under the MoU, Keppel will study the feasibility of an am solutions brand, Mitsubishi Power, will develop an ammo pursue the expansion of the ammonia fuel supply chain management expertise to prepare and present a QRA an

Takao Tsukui, General Manager, International Sales and "Ammonia is a potential key component to building a hyd turbine and hydrogen fuel combustion technologies for dedication to pursue cutting-edge solutions that can sup towards a more sustainable energy future in Asia Pacific

"DNV is proud to use our well established advisory and assessment for this impactful project. We believe that ar path to a more sustainable energy future. This MoU offers us an exciting opportunity to share our extensive industry experience to support this important contribution to Singapore's net zero and energy transition goals," said Brice Le Gallo, Vice President and Regional Director-Asia Pacific, Energy Systems, DNV.

https://www.mhi.com/news/220927.html

PRESS INFORMATION

Port of Newcastle and MHI Announce Clean Energy Partnerships Enabling Port of The Future in Newcastle

2023-07-12

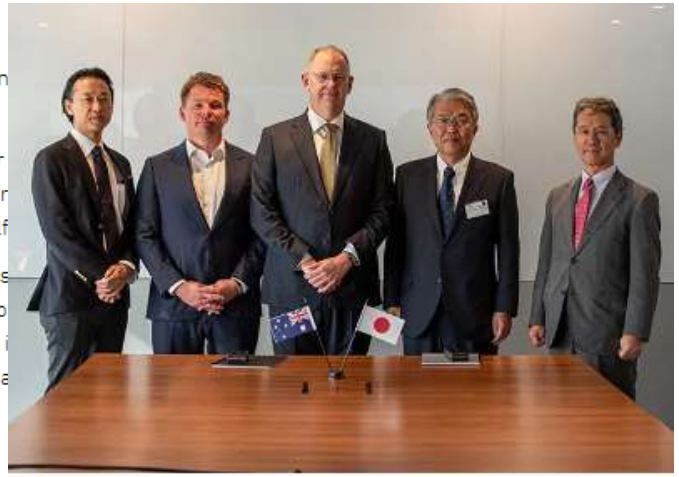
Port of Newcastle
Mitsubishi Heavy Industries, Ltd.

Port of Newcastle and Mitsubishi Heavy Industries, Ltd. have unveiled, during a visit by Mr. Chris Bowen, Minister for Climate Change and Energy, to the Port today, an MOU setting out a pathway towards the enablement of a world-class clean energy economy in the Hunter Region through the Port's Clean Energy Precinct, which secured a $100-million Commonwealth funding grant in the 2022 Federal Budget.

Port of Newcastle CEO Craig Carmody said the once in a gen diversification strategy.

"Our dedicated 220-hectare Clean Energy Precinct will offer which will be supported by common user, open access, shar export facilities servicing production from the Precinct itself

Dr. Hitoshi Kaguchi, Senior Executive Vice President at MHI s project for the Port of Newcastle, a promising hydrogen hub considered necessary for the realization of a hydrogen hub power generation and CO_2 capture technologies, ammonia a



Signing Ceremony

https://www.mhi.com/news/23071201.html

CO2 Zero power generation technology Roadmap

Reduce CO_2 by High Efficiency Gas Turbine ➡ ZERO CO_2 by Hydrogen Gas Turbine

CO_2 Reduction -65%

1 High Efficiency Natural Gas-fired Gas Turbine

JAC series

Co-firing

2-1 Ammonia Biomass Co-firing Boiler

Ammonia co-firing

CO_2 Capture

2-2 Gas Turbine Combined Cycle plant **+CCUS**

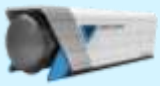
CO_2 Zero

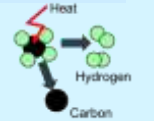
3 Hydrogen Gas turbine Development

Hydrogen Gas turbine

Ammonia Gas Turbine Development

3 Hydrogen Production





water electrolyser *SOEC* *Turquoise H_2*

CO_2 Emission (%)

Base

50%

0%

Base*1

2-1 *Ammonia Biomass co-firing*

Toward CO_2 Zero

1 *Reduce CO_2*

-65%down (2020-)

64% High Efficiency Gas Turbine Combined Cycle Power Plant (Commercial Operation in 2020)

2-2 ***-90%***

3 ***CO_2 Zero Ammonia Hydrogen***

Technology Road Map 2020 2030

*1 :Based on Sub-C CO_2 Emission

Development status of Hydrogen Gas turbines

	Combustor type	Low NO_X technology	Turbine inlet temperature	H_2 density (volume %)	Schedule
Ready	**Type1 Diffusion** 	N_2 dilution, Water/ Steam injection	1200~1400ºC class CC efficiency 50%	100%	MHI has over 50years (3.5 million hours) experience in Hydrogen firing 1970 — Hydrogen 82%(1989-) — Magnum 100% Hydrogen
Ready	**Type2 Pre-mix(DLN)** 	Dry	1650ºC class CC efficiency 64%	30~50%	Natural gas DLN: 2018 30%H_2 co-firing test completed; 2022 50%H_2 co-firing test completed; 2025 30~50%H_2 co-firing Commercial operation 20%H_2 co-firing operation in Large Frame GT completed
Under development	**Type3 Multi-cluster(DLN)** 	Dry	1650ºC class CC efficiency 64%	100%	H_2 co-firing is under commercial operation in Osaki Cool Gen 80%H_2 co-firing test completed; (Small-Middle frame) 100%H_2 firing Commercial operation; (Large frame)

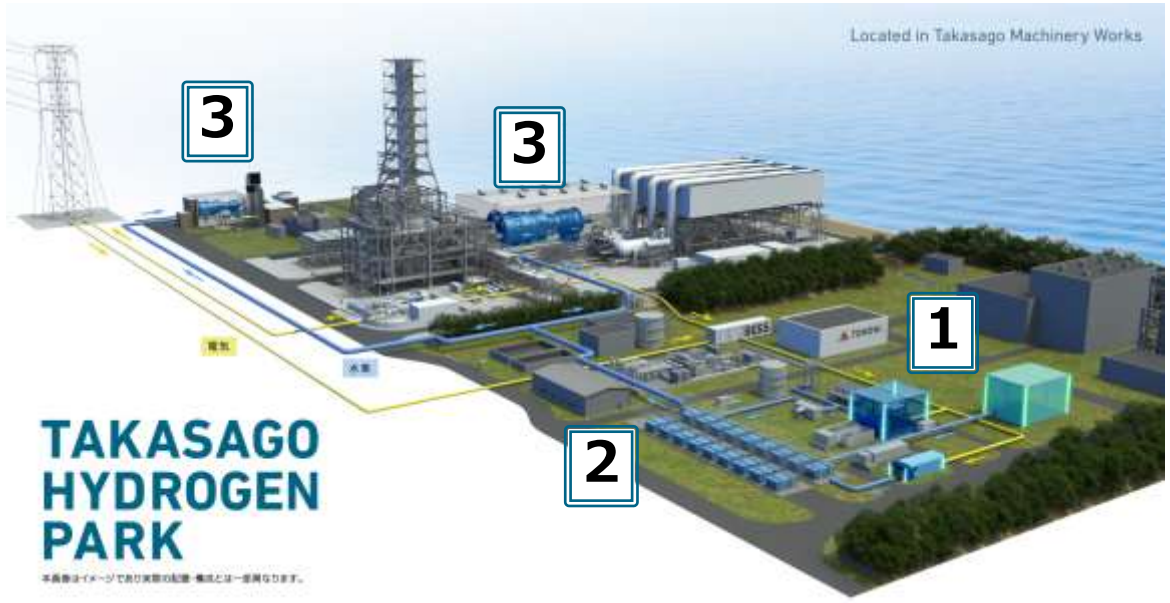
Type1	**100% H_2 firing**	**Ready/Development completed**
Type2	**30% H_2 co-firing**	**Ready/Development completed**
	50% H_2 co-firing	**To be verified in actual engine**
Type3	**100% H_2 firing**	**Ready by 2025**

Applicable to commercial engines

*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

Hydrogen / Ammonia Gas Turbine Development schedule



1 Production

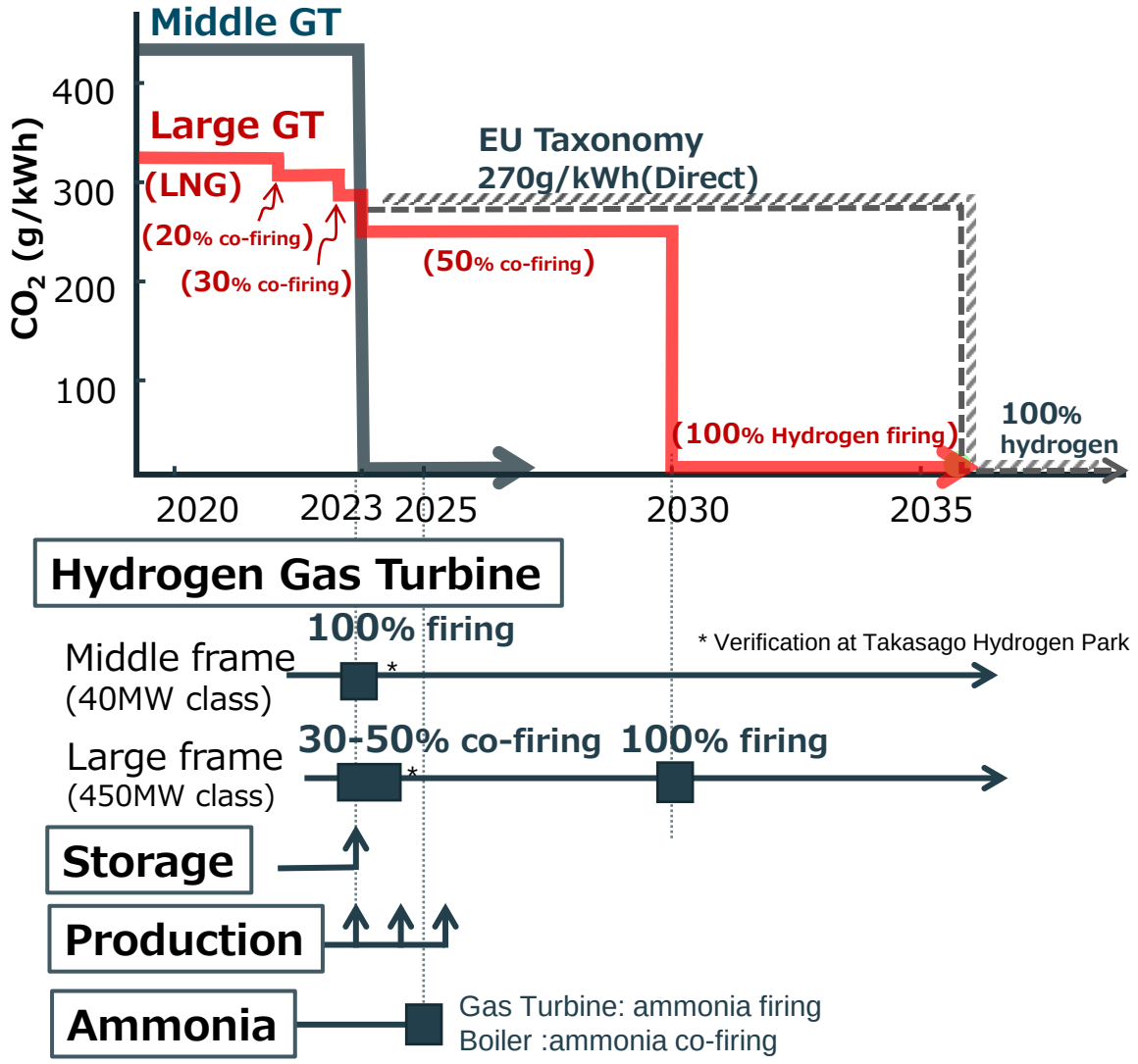
2 Storage

3 Utilize

Power generation

Integrated demonstration from hydrogen production to hydrogen power generation from 2023

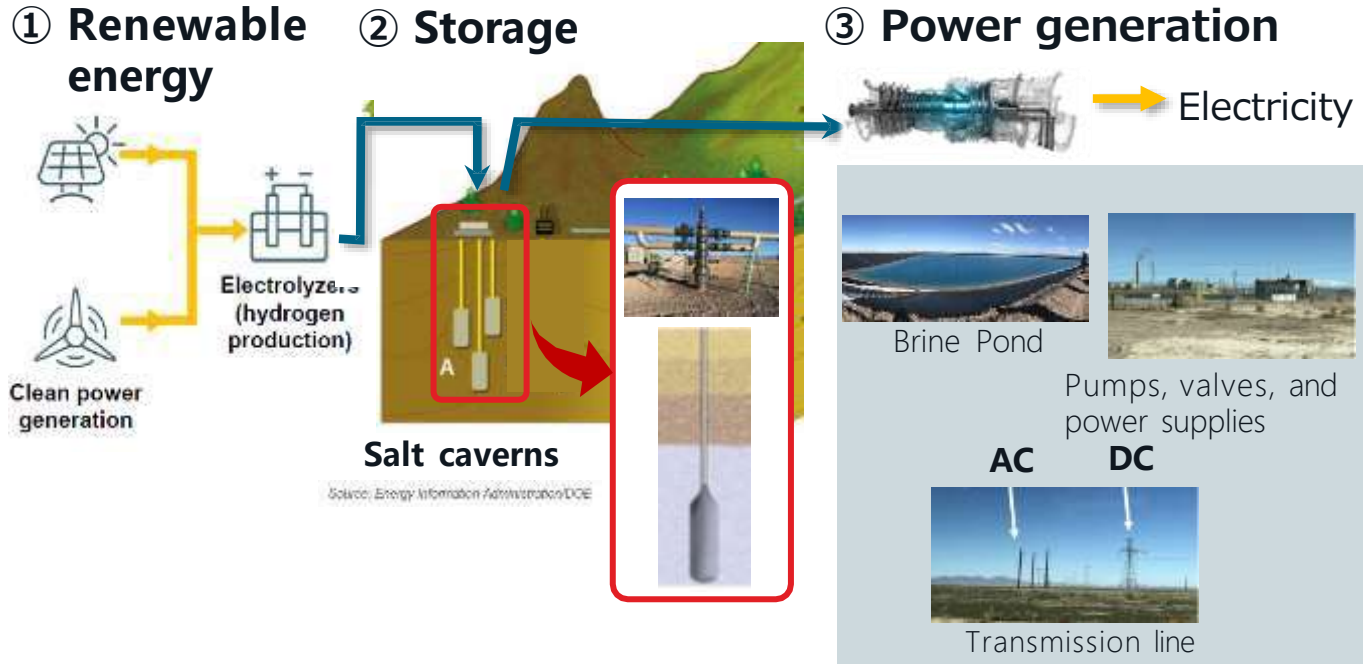
In combustion test, EU Taxonomy has already been achieved in our Type -2 combustor with 50% hydrogen co-firing.
Engine verification starts at Takasago Hydrogen park in 2023.



MHI Hydrogen-Fired GTCC Projects

Advanced Clean Energy Storage Project (USA)

1. Green hydrogen production by electrolyzers using renewable energy from the West Coast.
2. Storage in salt caverns in North America.
3. Power generation by gas turbine on demand.
4. DOE Loan application submitted for up to $595 million



Mitsubishi Power to supply two hydrogen-capable M501JAC gas turbine power trains (1X1) to Intermountain Power Agency. Plans to co-fire 30% Hydrogen in 2025 and operate on 100% Hydrogen no later than 2045.

MITSUBISHI HEAVY INDUSTRIES | MISSION NET ZERO