MOVE THE WORLD FORW>RD MITSUBISHI HEAVY INDUSTRIES GROUP

Berlin Energy Transition Dialogue

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

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18th March 2021

Mitsubishi Power Europe GmbH

MITSUBISHI POWER

Content

Company Overview

MITSUBISHI POWER

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

Research & Innovation Centre		
Energy Systems	Plants and Infrastructure	Integrated Defense and Space Systems
		
Jet Engines (Mitsubishi Heavy Industries Aero Engines, Ltd.) **Offshore Wind Turbines** (MHI Vestas Offshore Wind A/S) **Compressor** (Mitsubishi Heavy Industries Compressor Corp.) MITSUBISHI POWER (Mitsubishi Power, Ltd.)	**Iron Making** (Primetals Technologies, Ltd.) **Ammonia & Methanol Co-Production Plants** **CO_2 Capture Plants** (Mitsubishi Heavy Industries Engineering, Ltd.) **Gas Carriers** (Mitsubishi Shipbuilding Co., Ltd.)	**Aircraft** (Mitsubishi Aircraft Corporation) **H-IIA Rocket**

MITSUBISHI HEAVY INDUSTRIES GROUP

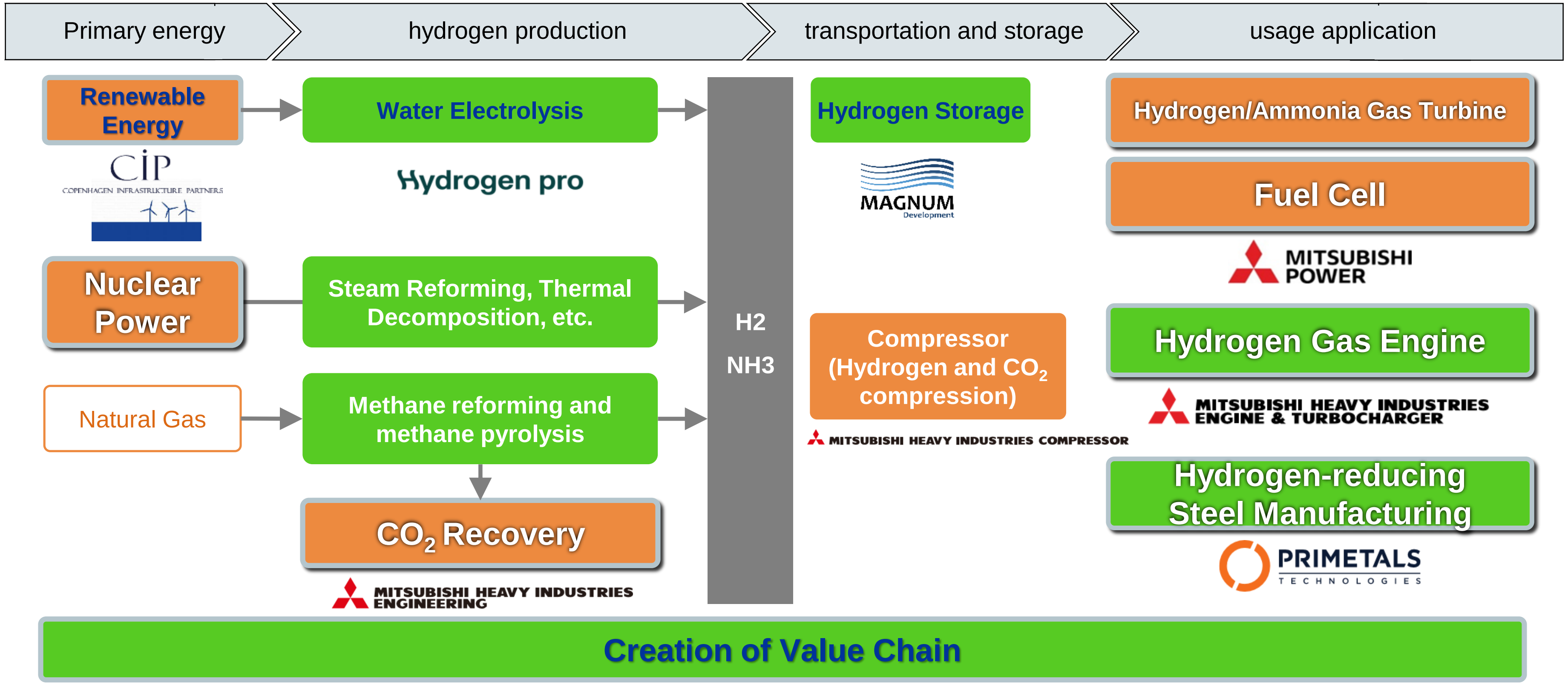
Company Overview

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

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



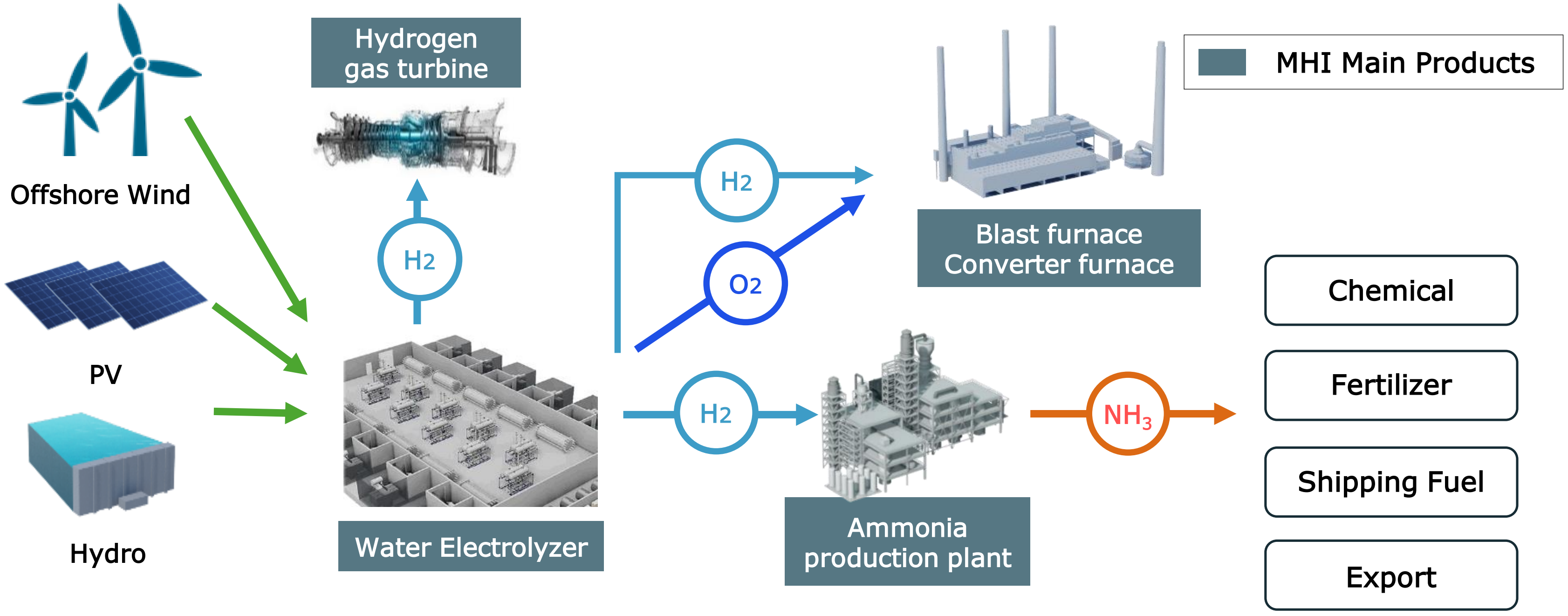
existing products and applications | New entry and development | **White Text: MHI technology** | **Blue Text: Partnering**

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

Establishment of H_2 Energy Value chain

Green Hydrogen — Carbon-free Ammonia Production Project (Australia)

- 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 Project in Germany

Upstream
Midstream
Downstream
Green

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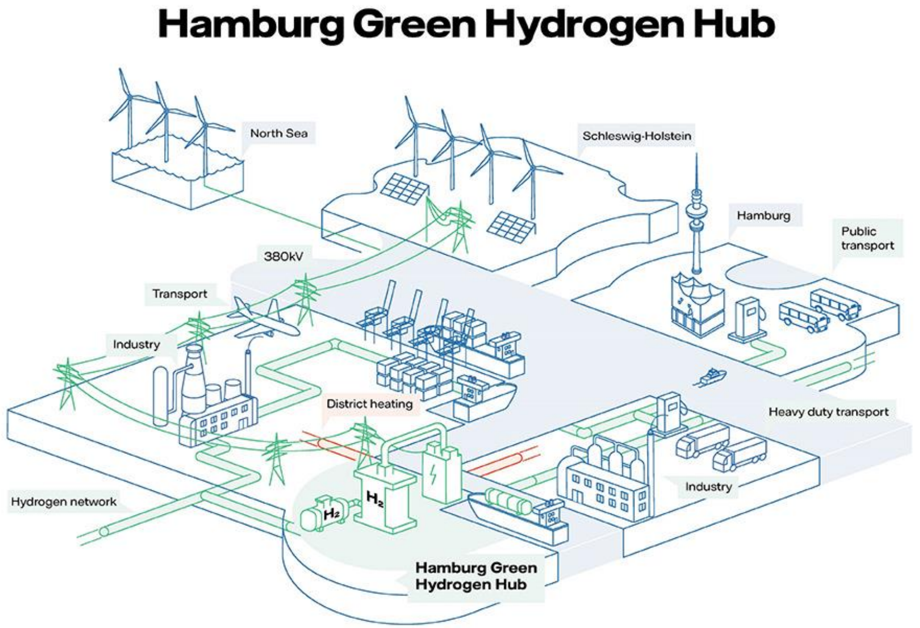
Green Hydrogen | Hamburg Green Hydrogen Hub (Germany)

- 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.

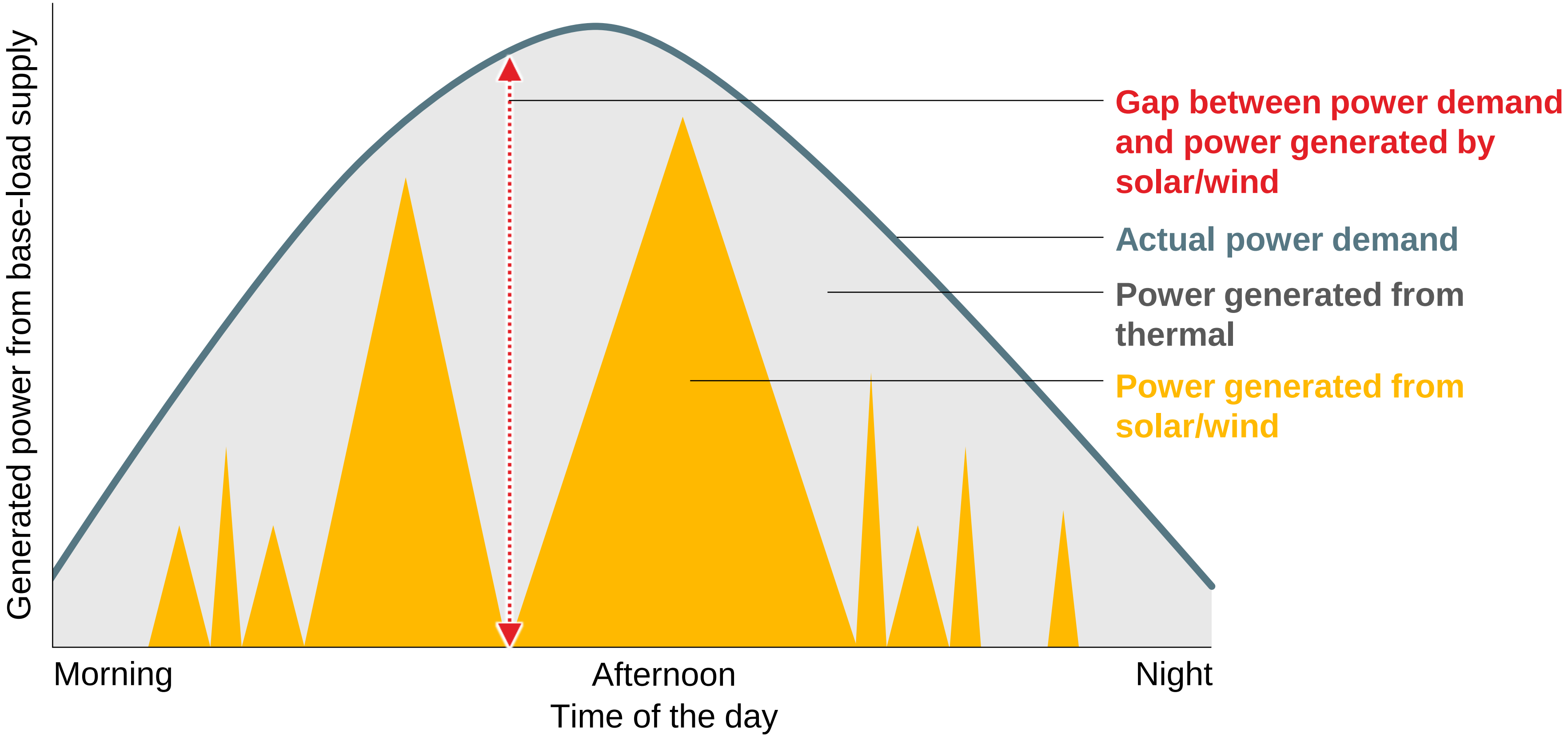


Press Release: https://www.mhi.com/news/210122.html

Content

The Role of Gas Turbines in Energy Transition

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

Benefits of Hydrogen Gas Turbines

Hydrogen Gas Turbines have multiple environmental and economic benefits.

1

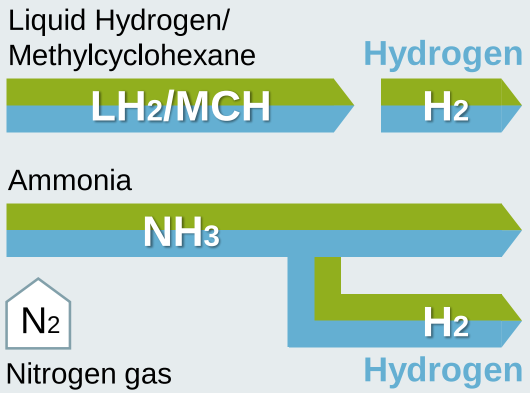
Minimal investment needed to adopt

Power providers can transition to low-CO_2 or CO_2-free systems with minimal modifications*.

*Detailed scope is subject to plant specification

2

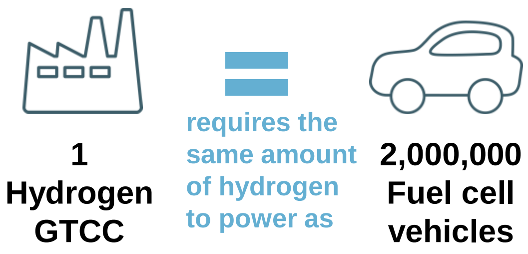
Carrier agnostic



Hydrogen Gas Turbines can be fueled with H_2 transported by any type of carrier as well as less pure forms of H_2 – thus contributing to significant cost reduction.

3

Driver of demand



Increasing demand for hydrogen will drive infrastructure expansion and further cost reduction.

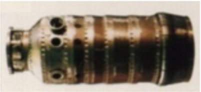
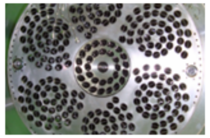
Mitsubishi Power' Hydrogen Gas Turbine Development

Mitsubishi Power' hydrogen combustion technology balances both technical challenges and market needs.

Technical Challenges	Market Requirements
NOx Reduction	Cost
Combustion Dynamics	Efficiency
Unburned Hydrocarbons	Lifetime of Parts
Flashback	Flexibility
	Maintainability

Range of H_2 Combustion Technology

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

Large Frame Gas Turbines					
	Type	**Low NOx tech**	**Turbine inlet temperature (˚C)**	**H2 density (volume %)**	**Schedule**
Ready	**Type 1: Diffusion** 	N2 dilution, Water/ Steam injection	1200~1400	**100%**	1970 Cogen/IGCC → **2027 Magnum H2 conversion**
Ready	**Type 2: Pre-Mix (DLN)** 	Dry	1600	**30%**	1982 DLN → **2018 30% co-firing test completed**
Under development	**Type 3: Multi-Cluster (DLN)** 	Dry	1650	**100% (target)**	**Mar, 2025 Rig test completion target**

*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

Range of H_2 Combustion Technology

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

Middle & Small Gas Turbines					
	Combustor Type		**Low NOx tech**	**H2 density (volume %)**	**Schedule**
Ready	**H-25 Diffusion Combustor**		Water/ Steam injection	**100%**	1990
Under development	**H-25 Multi-Cluster**		Dry	**30%**	2016 Product development completed; 2019 30% co-firing test completed
			Dry	**100% (target)**	**2022 60% co-firing test completion target**; **2024 100% firing test completion target**
Ready	**H-100 Pre-Mix**		Dry	**30%**	2017 Product development completed
Under development	**H-100 Multi-Cluster**		Dry	**100% (target)**	2017 IGCC; **In the late 2020's test completion target**

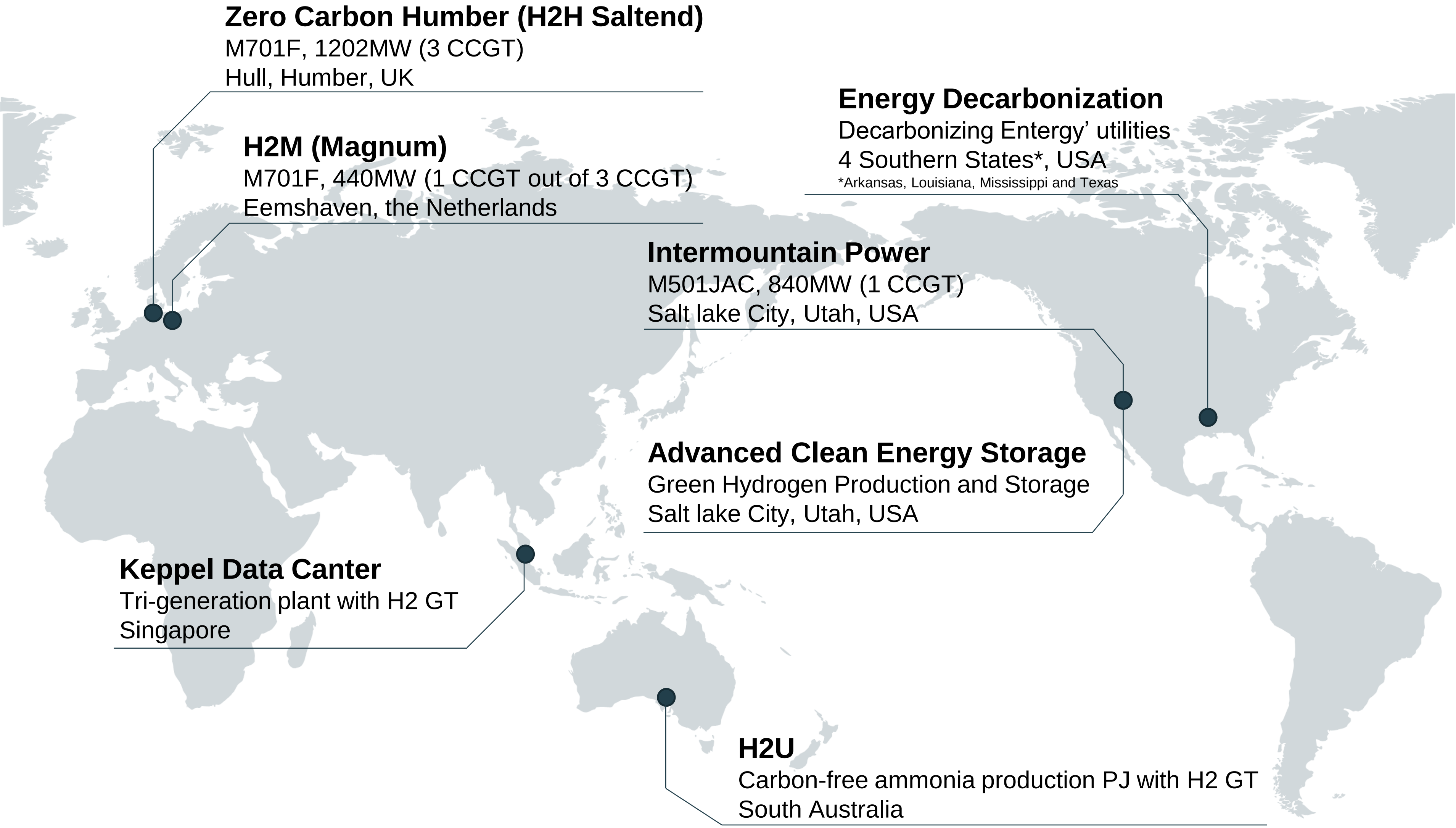
Performance of H_2 Combustors

Mitsubishi Power Gas Turbines can accommodate different proportions of H_2 as fuel.

GT Model		Output (MW)* SC	Output (MW)* CC	Combustor Type	H_2 (vol%)
H-25	60/50Hz	41/41	60/60	Diffusion	100
				Multi-Cluster (DLN)	30→100 (target)
H-100	60/50Hz	106/116	150/171	Pre-Mix (DLN)	30
				Multi-Cluster (DLN)	100 (target)
M501F	60Hz	185	285	Diffusion	100
				Pre-Mix (DLN)	30
				Multi-Cluster (DLN)	100 (target)
M501GAC	60Hz	283	427	Pre-Mix (DLN)	30
				Multi-Cluster (DLN)	100 (target)
M501J M501AC	60Hz	330 435	484 630	Pre-Mix (DLN)	30
				Multi-Cluster (DLN)	100 (target)
M701F	50Hz	385	566	Diffusion	100
				Pre-Mix (DLN)	30
				Multi-Cluster (DLN)	100 (target)
M701J M701JAC	50Hz	478 448-574	701 650-840	Pre-Mix (DLN)	30
				Multi-Cluster (DLN)	100 (target)

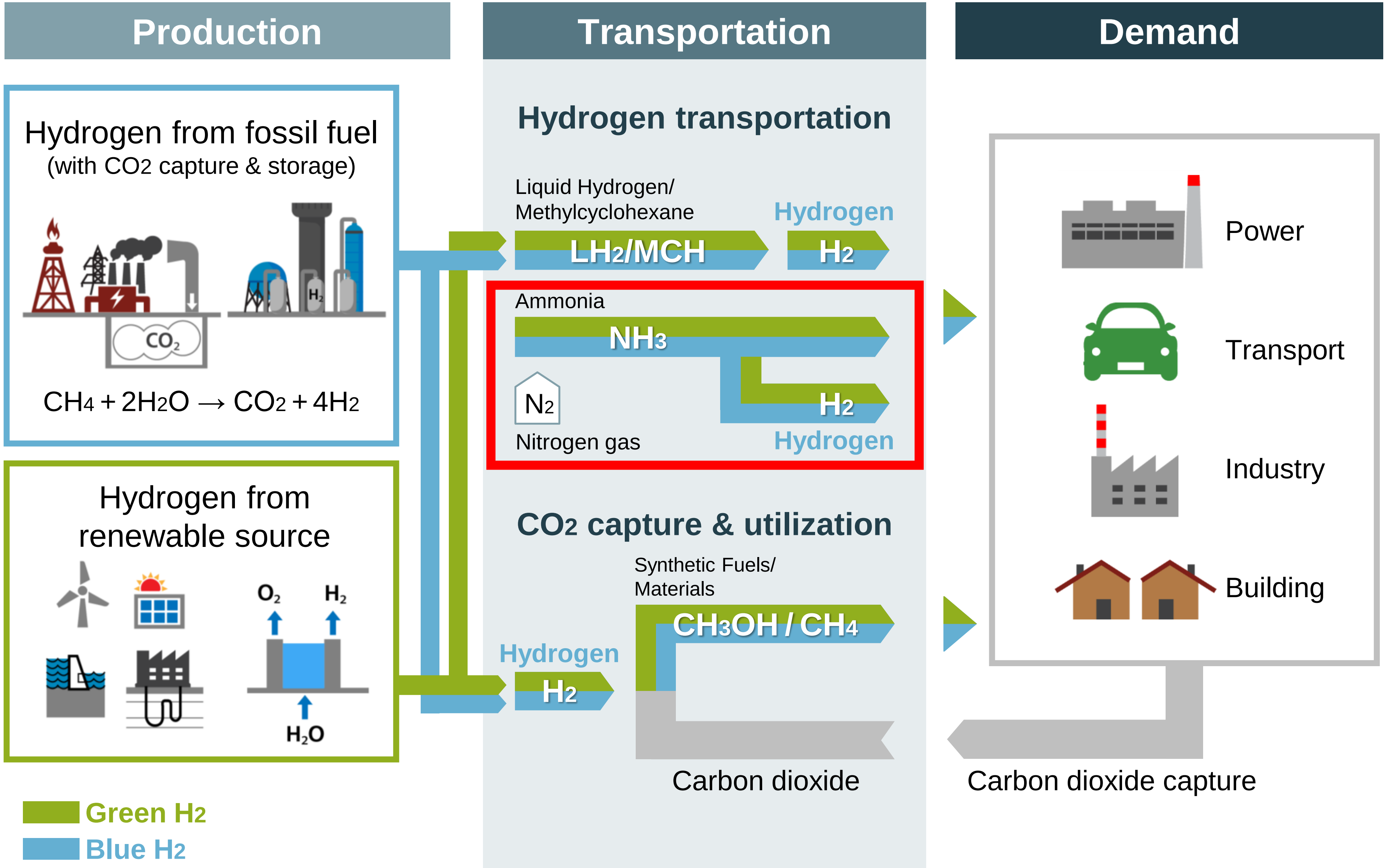
* Output is reference at natural gas firing

Mitsubishi Power' H_2 GT Projects



Content

Overview of Global Hydrogen Supply Chain



Start development of Ammonia Direct Combustion

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.

・Development begins of 40MW GT (H25) with Ammonia (100%) direct combustion for zero CO_2 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)

Product		Detail	Status
Ammonia Mixed Boiler		20-30% ammonia mix for coal firing boiler	2023 verification
H2 GT	30% H2	30% hydrogen mix for current LNG GT combustor or with minimum modification	2018 completion
	100% H2	100% hydrogen combustor (multi cluster)	completion M：2025 H：2023
Ammonia Cracking GTCC		Ammonia cracking and conversion to H2 by GT exhaust heat (good for high temperature large GT)	2026-2029
Ammonia Direct Combustion GT		No need of ammonia cracking system, higher NOx due to ammonia direct combustion and deNOx in HRSG required	2024 completion

New!

Ammonia co-firing existing (coal) boilers

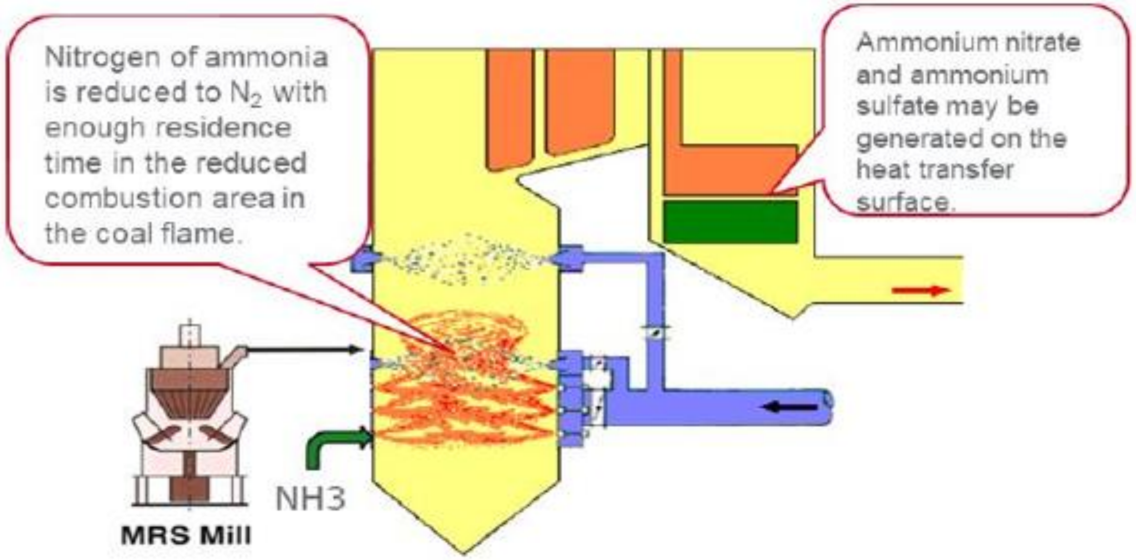
Ammonia co-firing ratio will be depended on the regulation of NOx emission

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

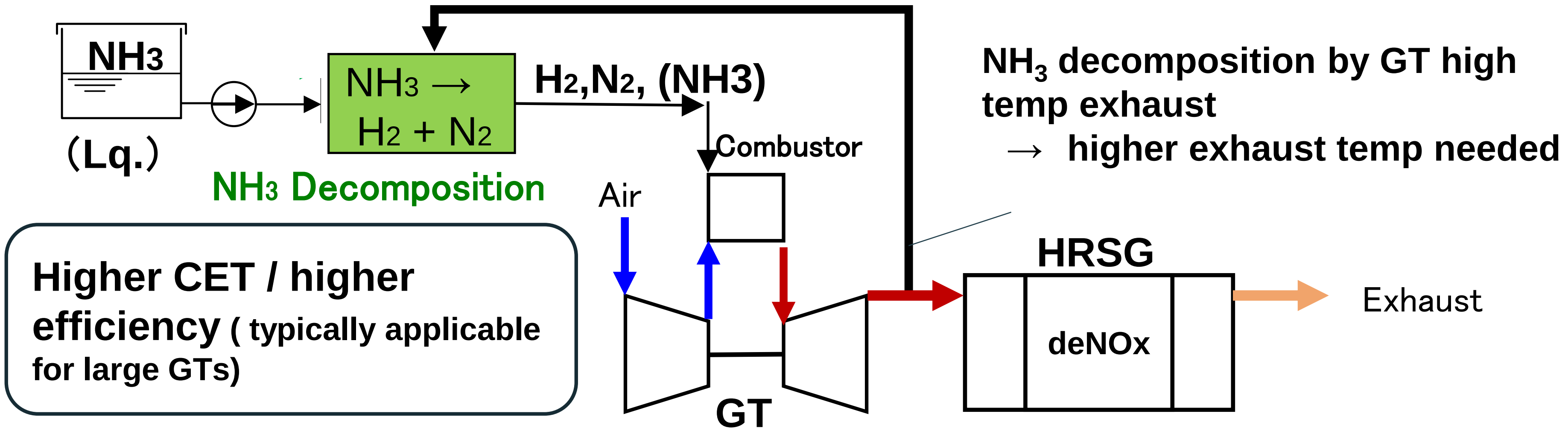
Co-firing concept

- 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

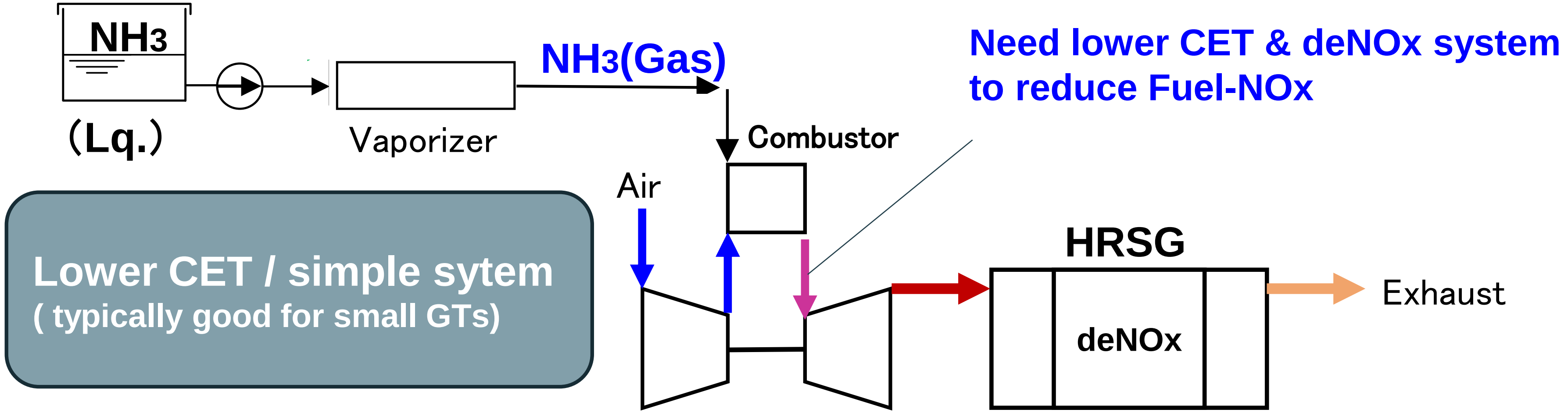


Ammonia combustion systems

Ammonia cracking system



Ammonia Direct combustion system



Development Schedule

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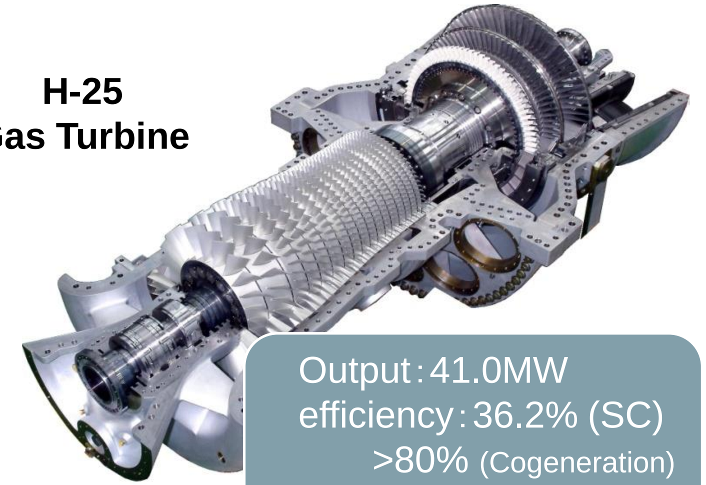
Mitsubishi Power is now expanding the line-up of carbon free combustion system, not only hydrogen combustion but also ammonia direct combustion.

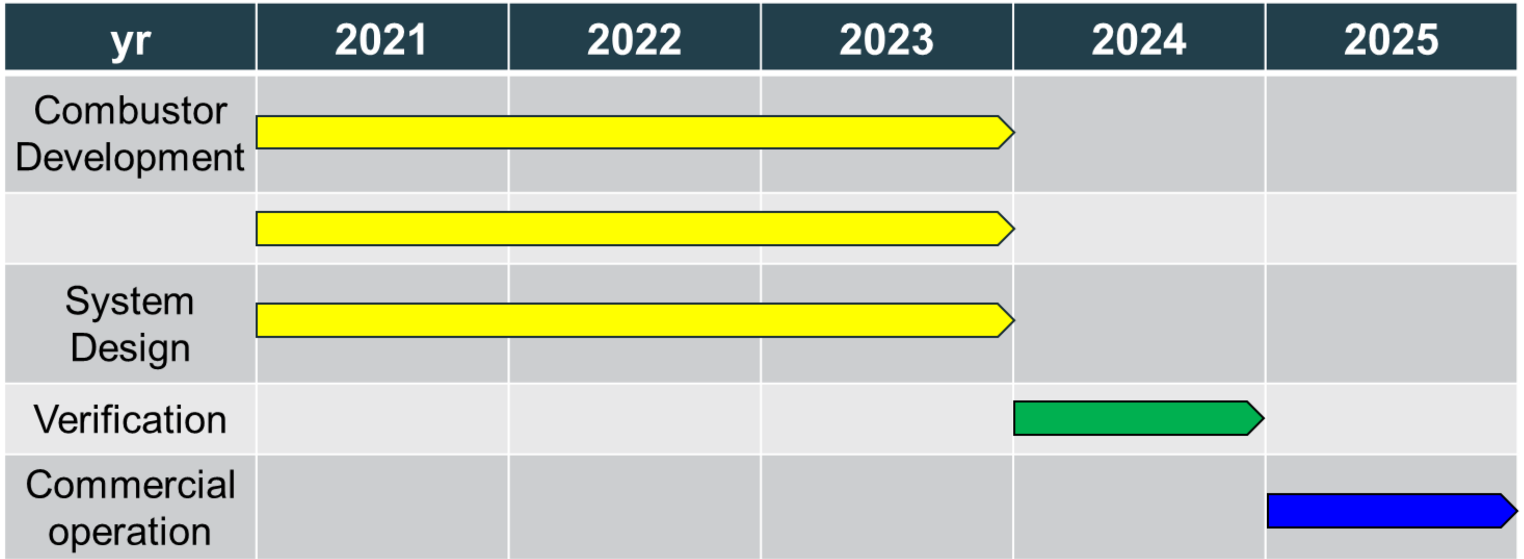
- ☞ start development of ammonia direct combustor
- ☞ plan to verify the system in 2024
- ☞ start commercial operation from 2025

H-25 Gas Turbine



Output : 41.0MW
efficiency : 36.2% (SC)
>80% (Cogeneration)
Sales : 190 GTs

Development Schedule



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MOVE THE WORLD FORWARD

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Partnership in Wind Turbine

Wind Turbine — Strengthening partnership in offshore wind power business

Strengthening the relationship with Vestas

- Strengthening competitiveness by integrating offshore and onshore wind turbine manufacturing business
- Strategic investment in Vestas as an industrial partner
- Consistent efforts to expand the Japanese offshore wind turbine market


©MHI VESTAS OFFSHORE WIND A/S

Participation in the development of wind power generation 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

CIP
COPENHAGEN INFRASTRUCTURE PARTNERS

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

Partnership in Electrolyser

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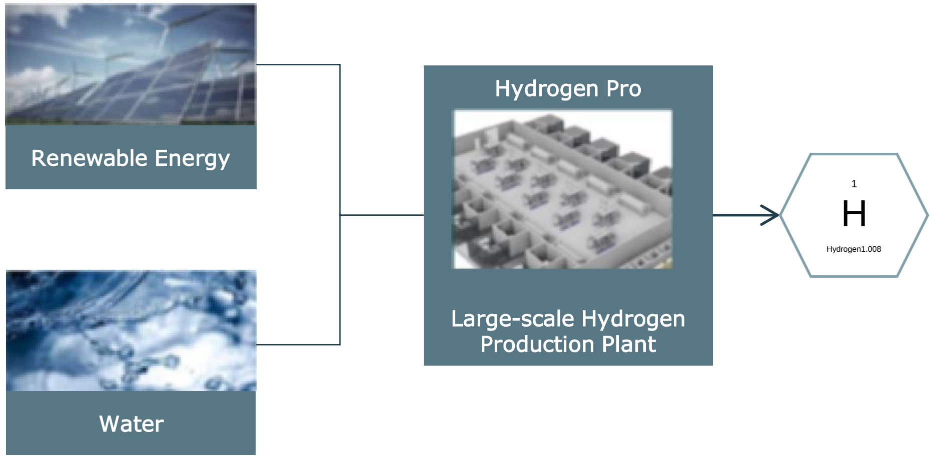
Electrolyser | Investment in HydrogenPro

- MHI Group Undertakes Investment in HydrogenPro of Norway, on October, 2020.
- 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.

Hydrogen pro

Middle-size Electrolysis
(10-20MW)



https://www.mhi.com/news/201014.html

CO_2 reduction by Blue Ammonia

Upstream
Midstream
Downstream
Blue

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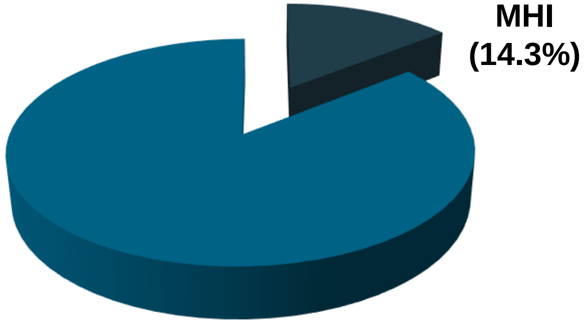
Blue Ammonia

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

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



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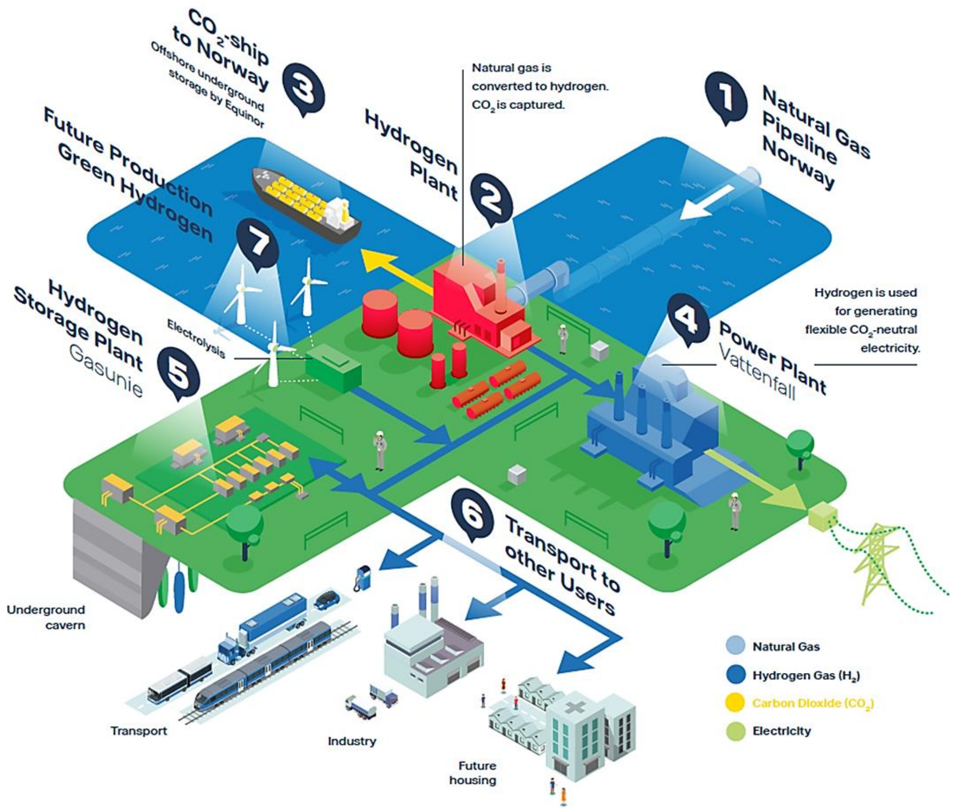
Mitsubishi Heavy Industries Engineering, Ltd. is a authorized licensee of Haldor Topsoe Ammonia Technology

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}
CO_2 capacity	4,776 TPD (1.4 MMtonne/year)
CO_2 conc.	11.5 mol%-wet
CO_2 removal	90%

CO_2 Used for CO_2-EOR	
Pipeline	12 in diameter, ~ 81 miles
Injection Site	West Ranch Oil Field

H2M Project (The Netherlands)

The H2M (Hydrogen to Magnum) project is a key first step in the development of a low-carbon H_2 economy.



Turbine Model	M701F
Power Output	440 MW
CO_2 reduction	Up to 2 Mt/year*
Location	Eemshaven, The Netherlands

The goal is to Kick-start H_2 economy by using **Blue H_2** for Hydrogen (100%) firing in CCGT by 2027, and gradual transition to **Green H_2**.

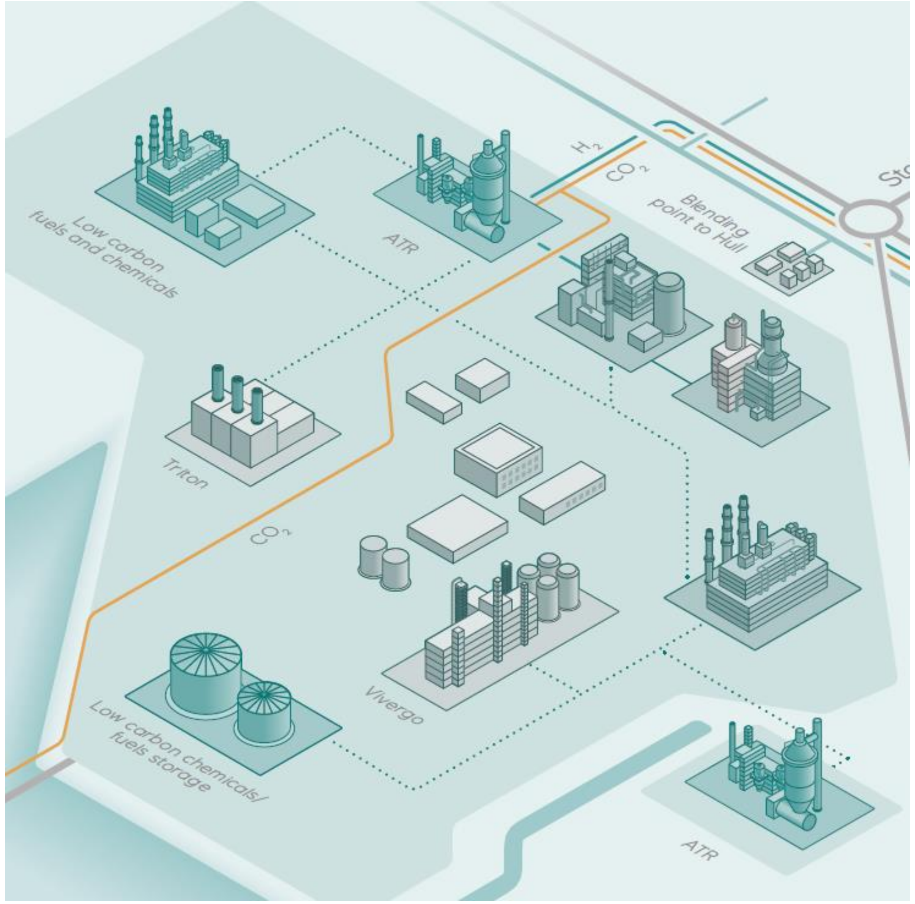
Development of hydrogen demand by H2M will assist realisation of hydrogen infrastructure.

*Expected CO_2 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% H_2 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.

Source and courtesy Equinor

Advanced Clean Energy Storage Project (United States of America)

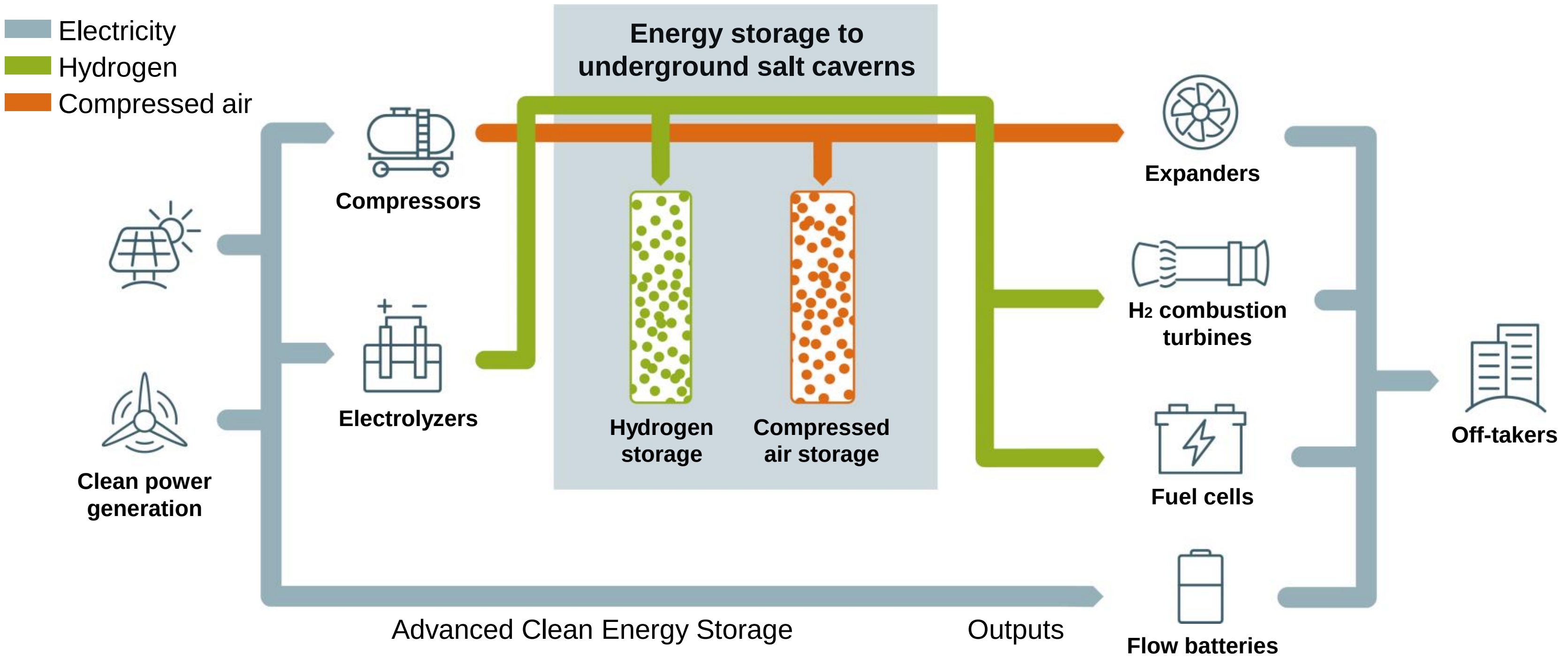
The Advanced Clean Energy Storage Project is the world's largest renewable energy storage project.

Storage Capacity	150GWh
Location	Utah, USA

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 H_2**), compressed air, large scale flow batteries and solid oxide fuel cells.

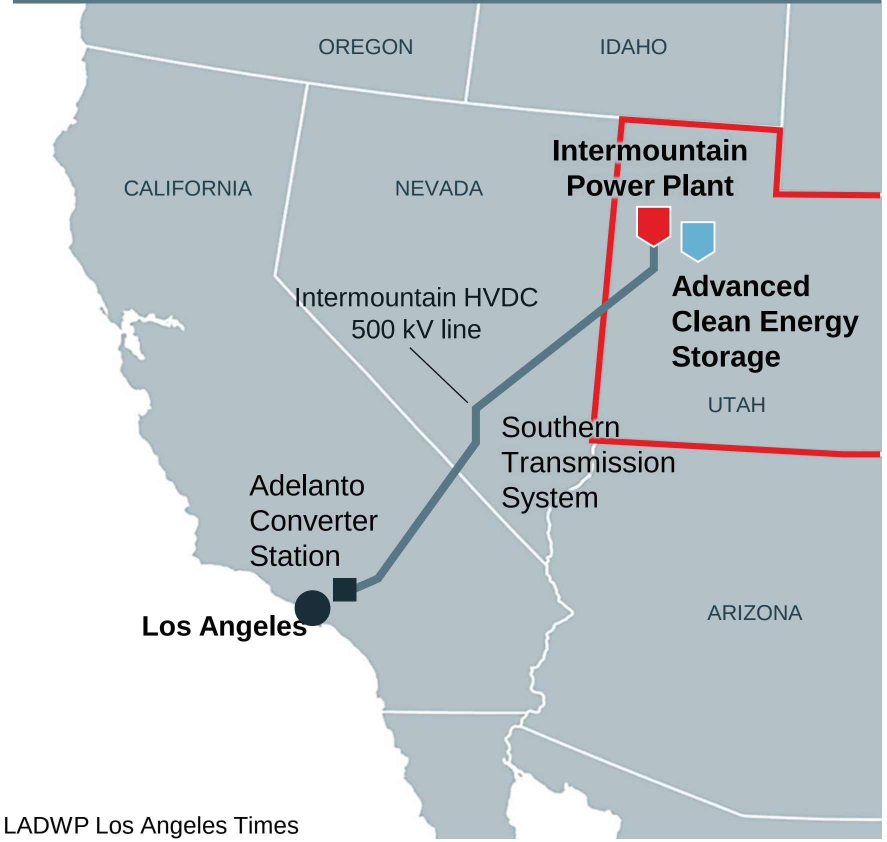
Green H_2 and/or compressed air is planned to be stored in underground salt caverns in Utah.



Intermountain Power Plant (United States of America)

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.

Location of Projects



Source: LADWP Los Angeles Times

Gas Turbine Model	M501JAC
Power Output	840 MW (by 2 CCGT)
Location	Utah, USA

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

This fuel mixture will reduce CO_2 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

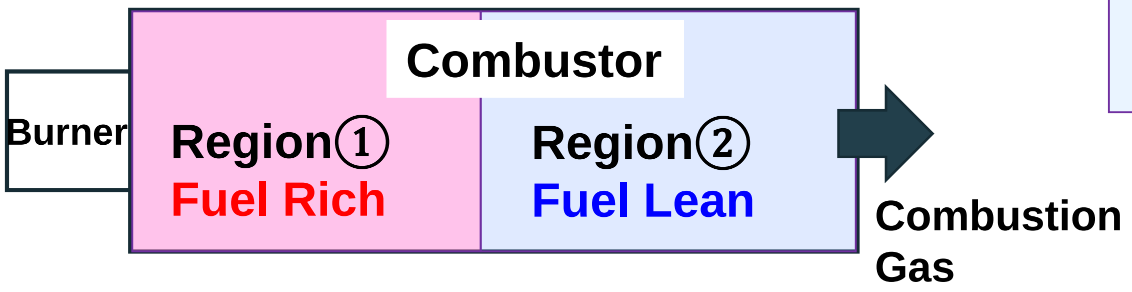
【Issues】
NOx production from fuel Ammonia

Fuel	N products
LNG etc	N2 in air oxidized in high temp combustion N2 (Air) + O2 → **NOx**
Ammonia (NH3)	NH3 in fuel oxidized **(Fuel-NOx)** NH3(Fuel) + O2 → N2 + H2O + **NOx**

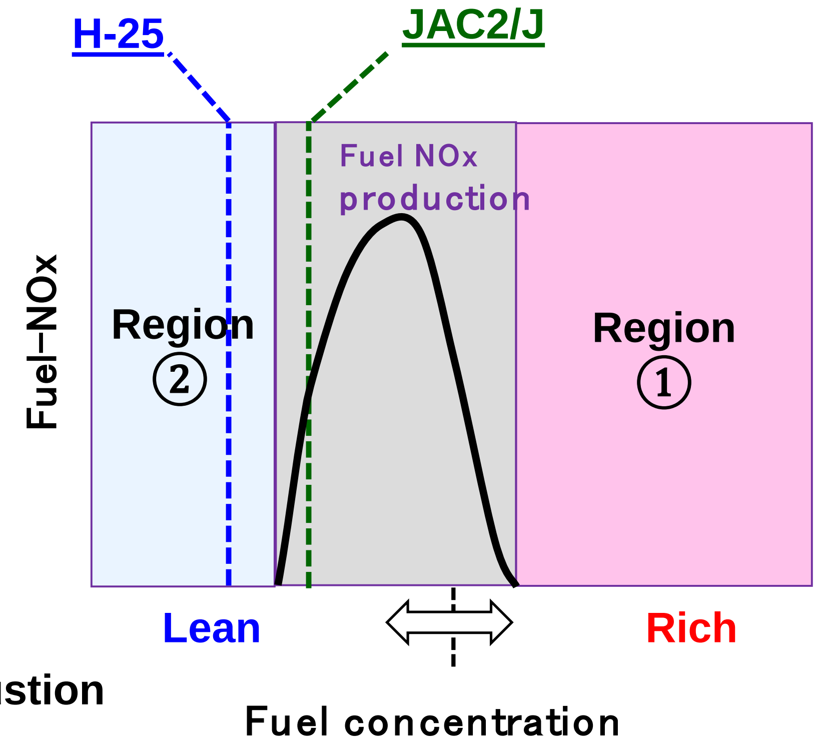
【Fuel-NOx Production】
Higher CET produces more NOx
→ H-25GT : lower CET, lower NOx
due to lower LNG,
need to keep the stable combustion

CET : combustor exhaust temperature

【Control fuel NOx production in H25 combustor】
To control NOx production,
①Rich combustion, ②Lean Combustion



H25 Combustor



Fuel-NOx production