MOVE THE WORLD FORWARD

MITSUBISHI HEAVY INDUSTRIES GROUP

For Cleaner Atmosphere

7 AFFORDABLE AND CLEAN ENERGY

ENSURE ACCESS TO AFFORDABLE, RELIABLE, SUSTAINABLE AND MODERN ENERGY FOR ALL

2022.10.25 Bangkok

Mitsubishi Heavy Industries, Ltd.

Mitsubishi Power is a power solutions brand of Mitsubishi Heavy Industries.

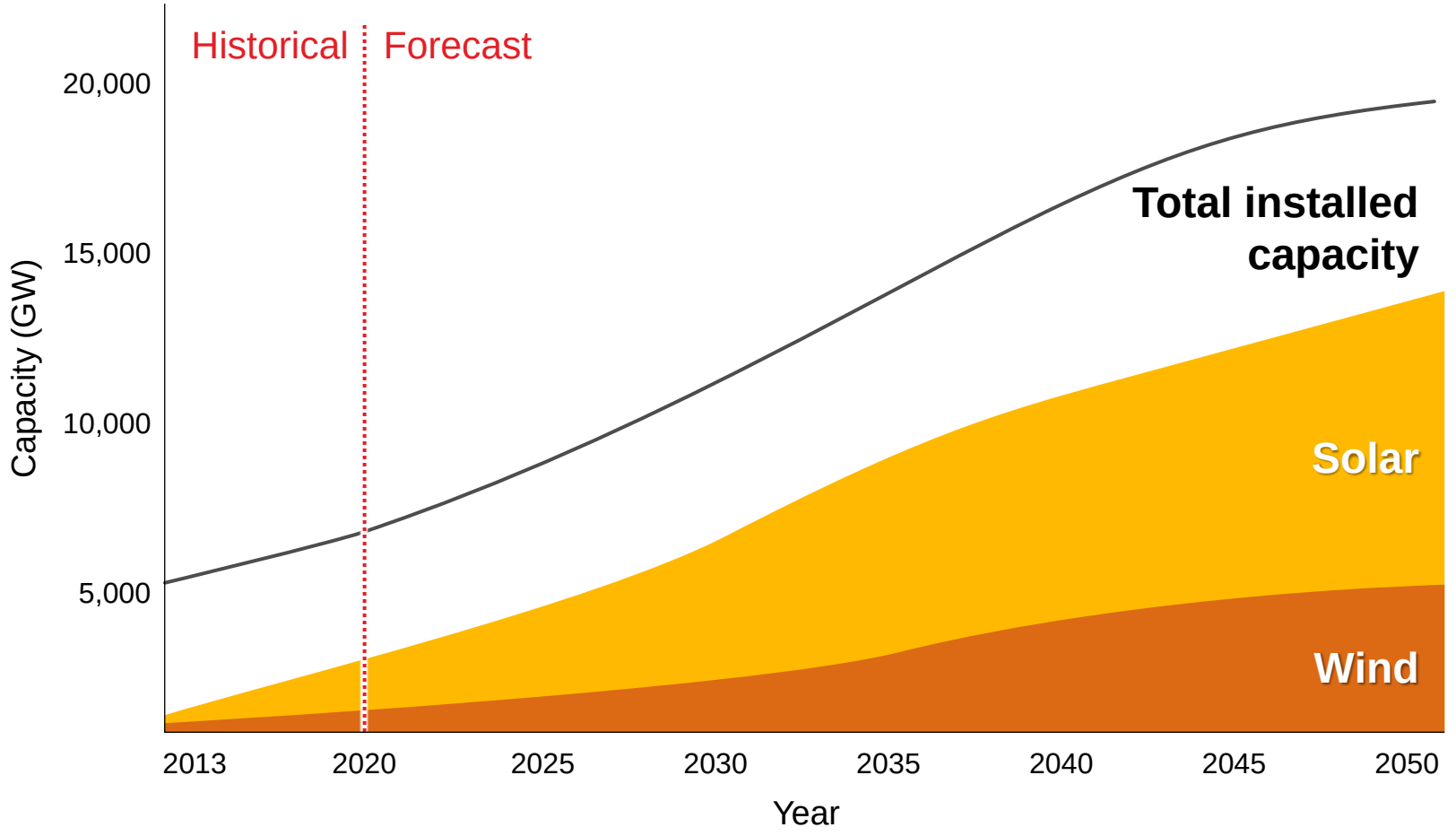
MITSUBISHI POWER

Contents

1. Gas Turbine in Energy Transition

The Role of Gas Turbines in Energy Transition

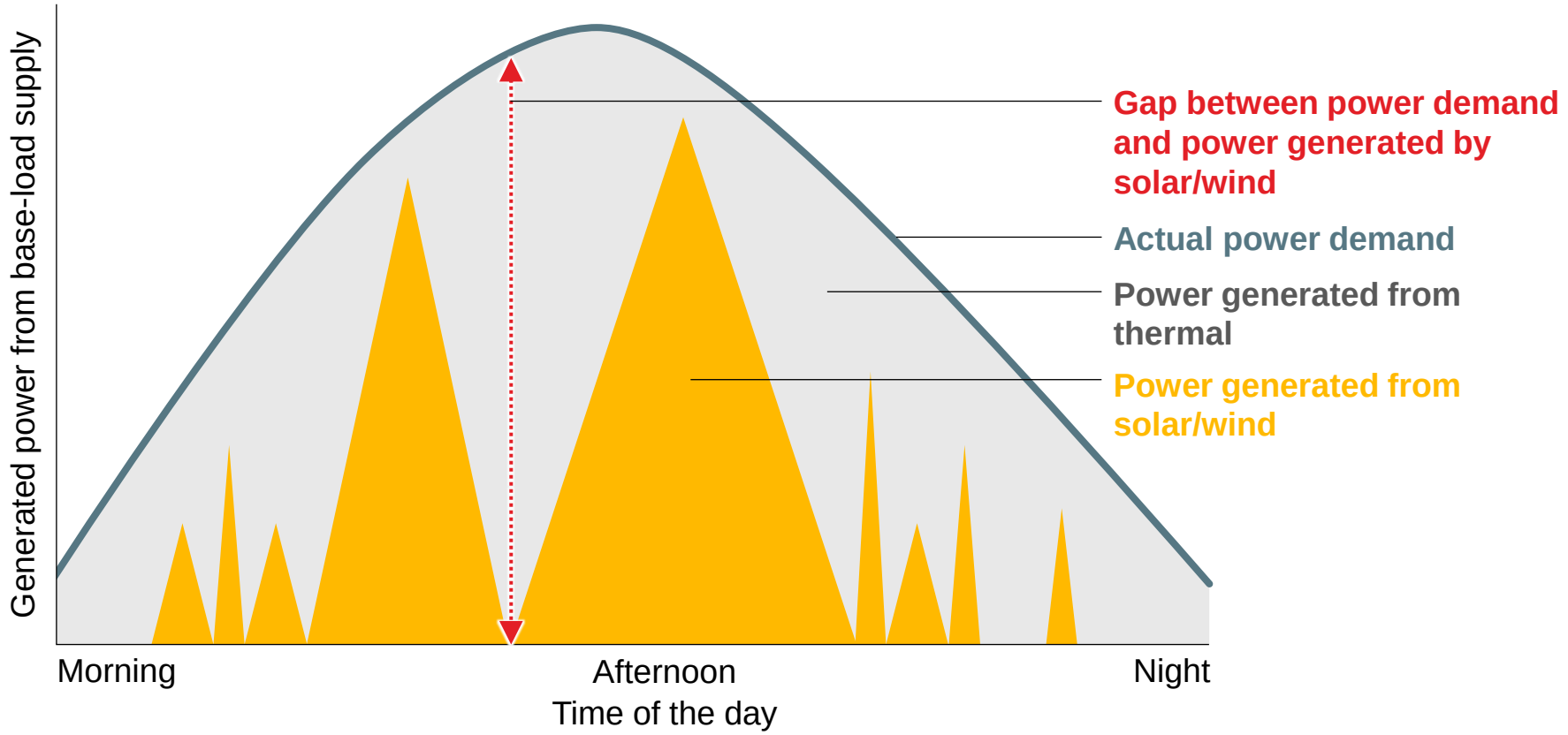
Capacity for renewable energy – primarily wind and solar – will increase over the coming decades.



Source: Bloomberg New Energy Finance, 2019

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.

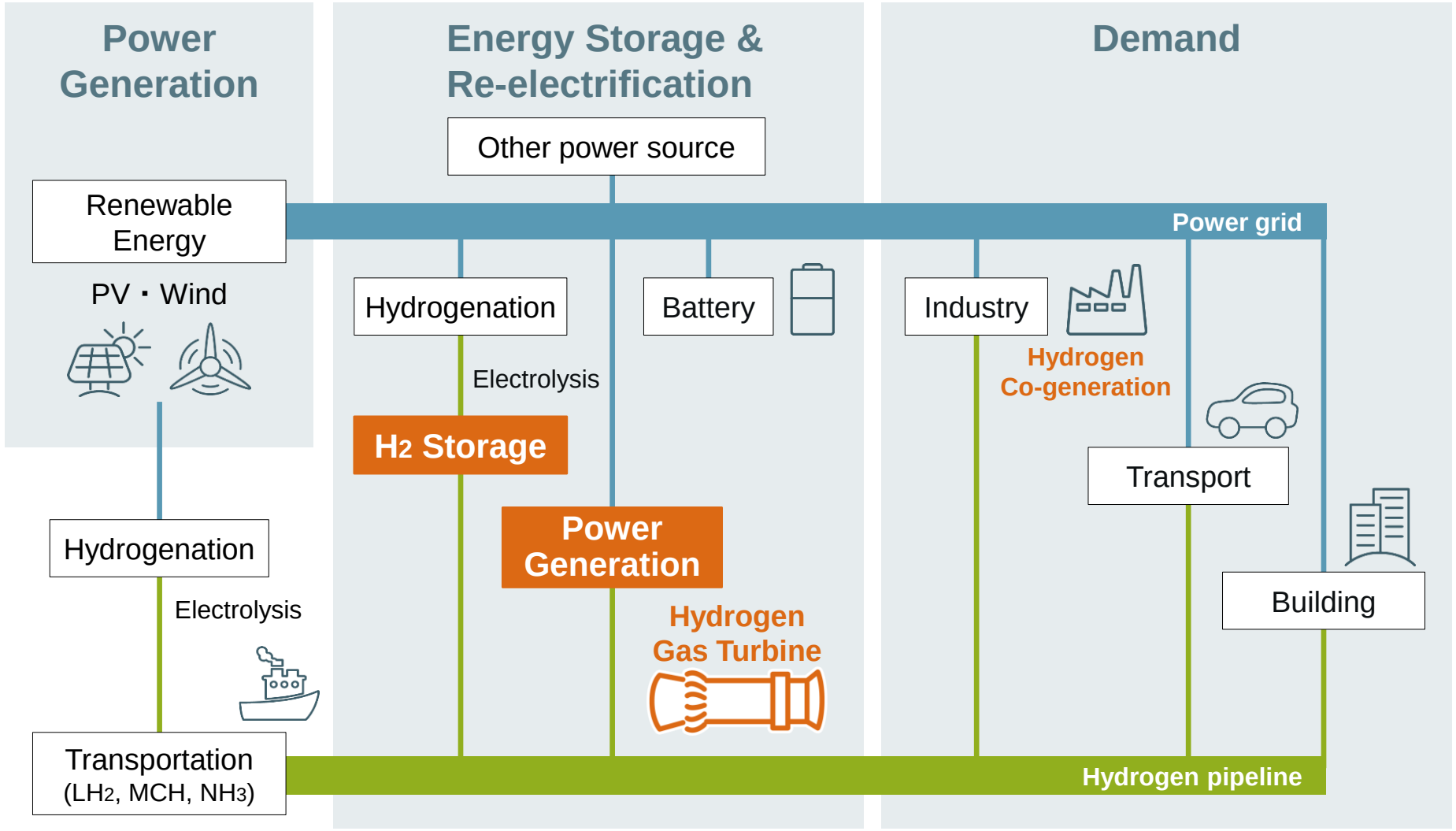


Gas Turbines can address gaps in power demand and renewable supply as a flexible energy source.

Source: METI

Hydrogen GT in Green H_2 network

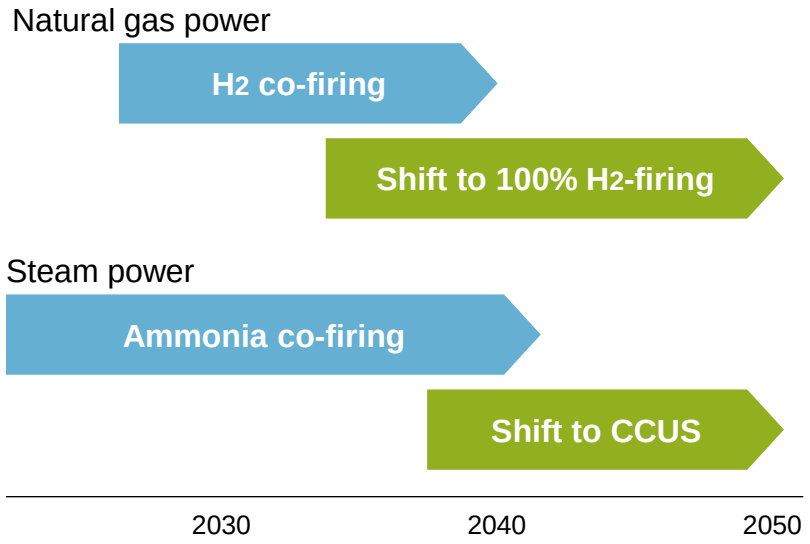
Zero emission society realized by renewable energy and hydrogen.



The Role of Gas Turbines in Energy Transition

Power sector will gradually increase the proportion of clean fuel following the global trend of decarbonization, and growth of the supply chain.

Scenario in Power Sector



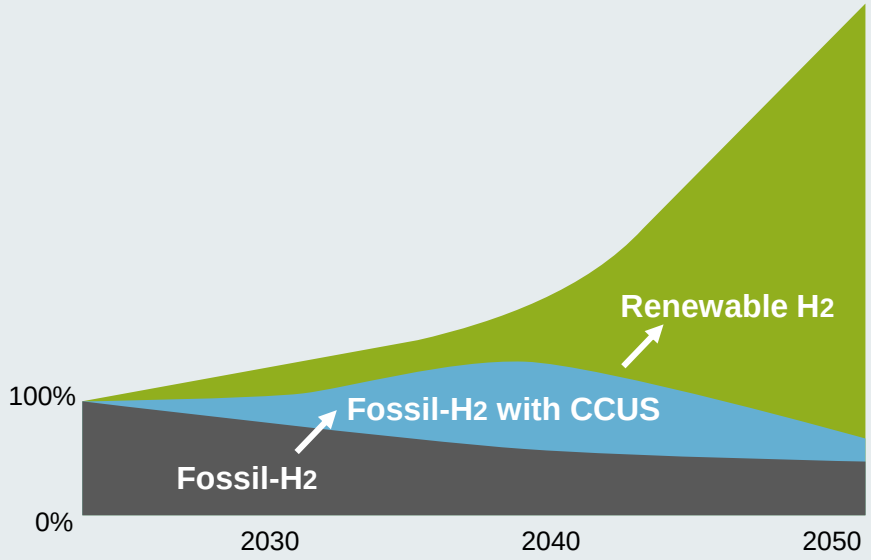
Horizon 1 (medium term)

Co-firing with CO_2-free hydrogen and ammonia

Horizon 2 (long term)

100% H_2-firing and CCUS with net zero CO_2 emissions

Source of Hydrogen



Horizon 1 (medium term)

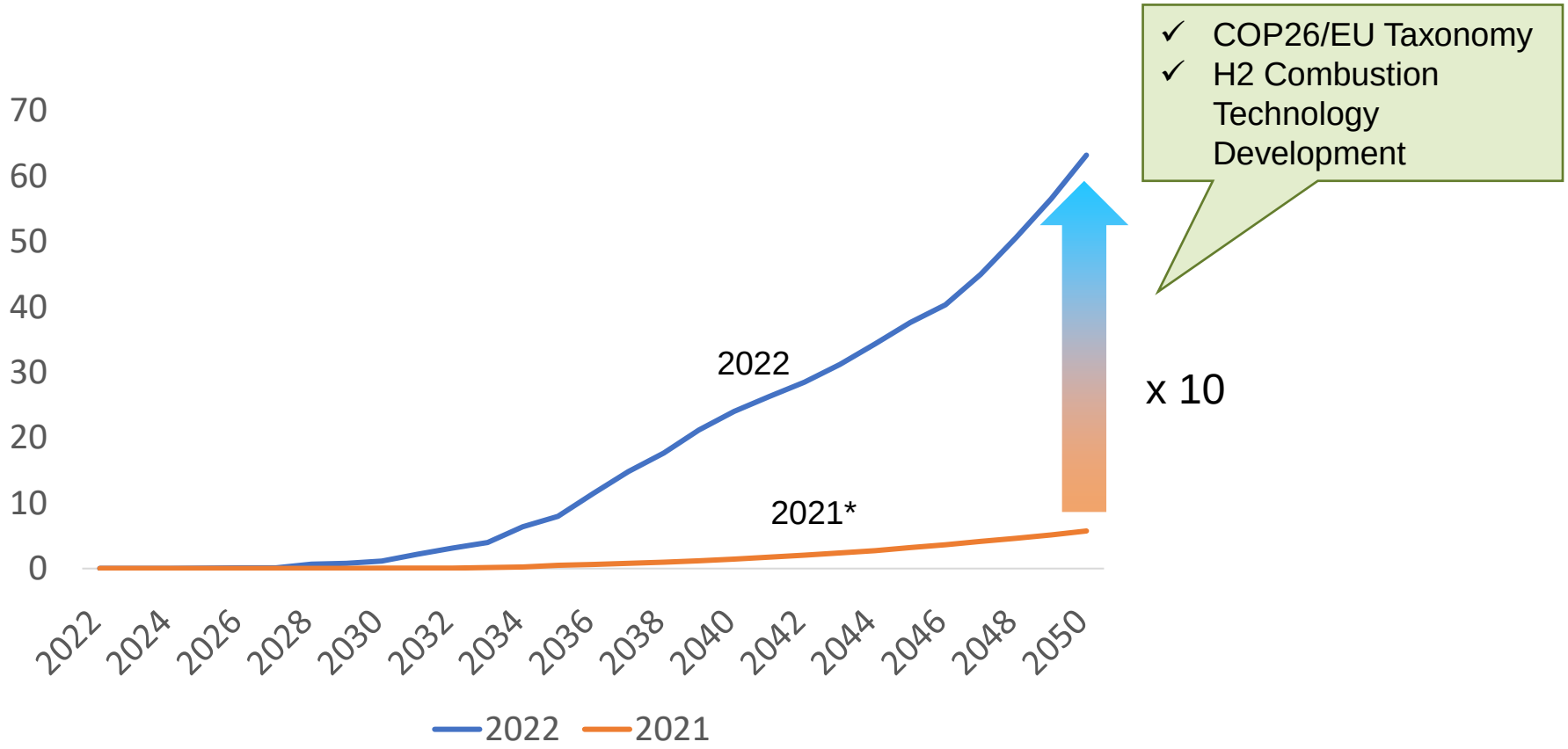
Fossil-H_2 with CCUS will initiate and accelerate adoption of hydrogen as a fuel

Horizon 2 (long term)

With innovation and significant cost reduction, renewable H_2 will be the main source of hydrogen

Comparison of H2 demand forecast (for power gen)

Hydrogen demand is increasing rapidly
Hydrogen is not future story. It may come earlier than expected.



Source ; Wood Mackenzie, Hydrogen Strategic Planning Outlook (March, 2022)
*Wood Mackenzie, 2050 The Hydrogen Possibility (January. 2021)

2. Zero Carbon Emission by Hydrogen Gas Turbine

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

Liquid Hydrogen/ Methylcyclohexane

LH_2/MCH → Hydrogen H_2

Ammonia

NH_3 → Hydrogen H_2

N_2 Nitrogen gas

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

1 Hydrogen GTCC

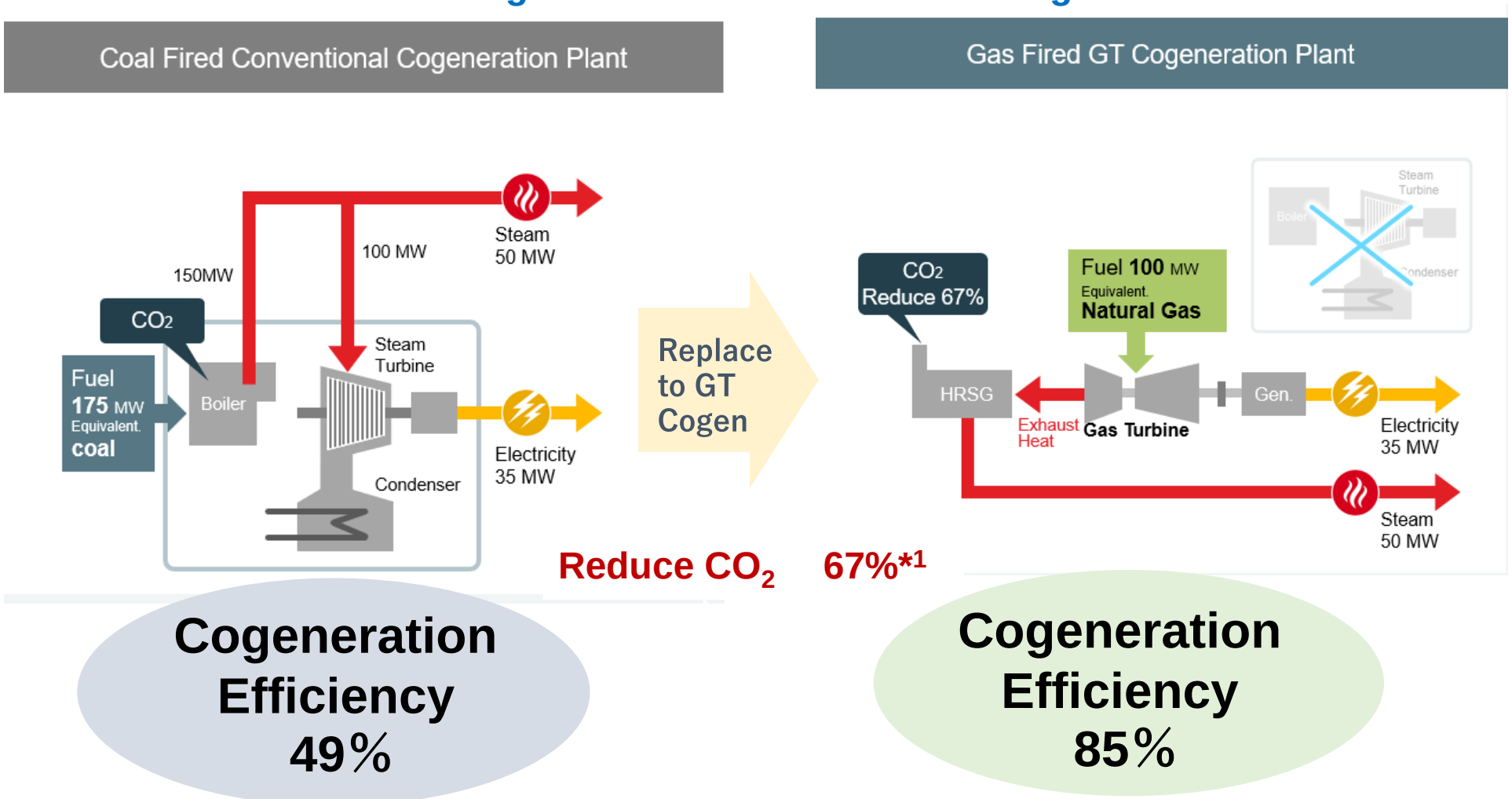
requires the same amount of hydrogen to power as

2,000,000 Fuel cell vehicles

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

First step for Decarbonization

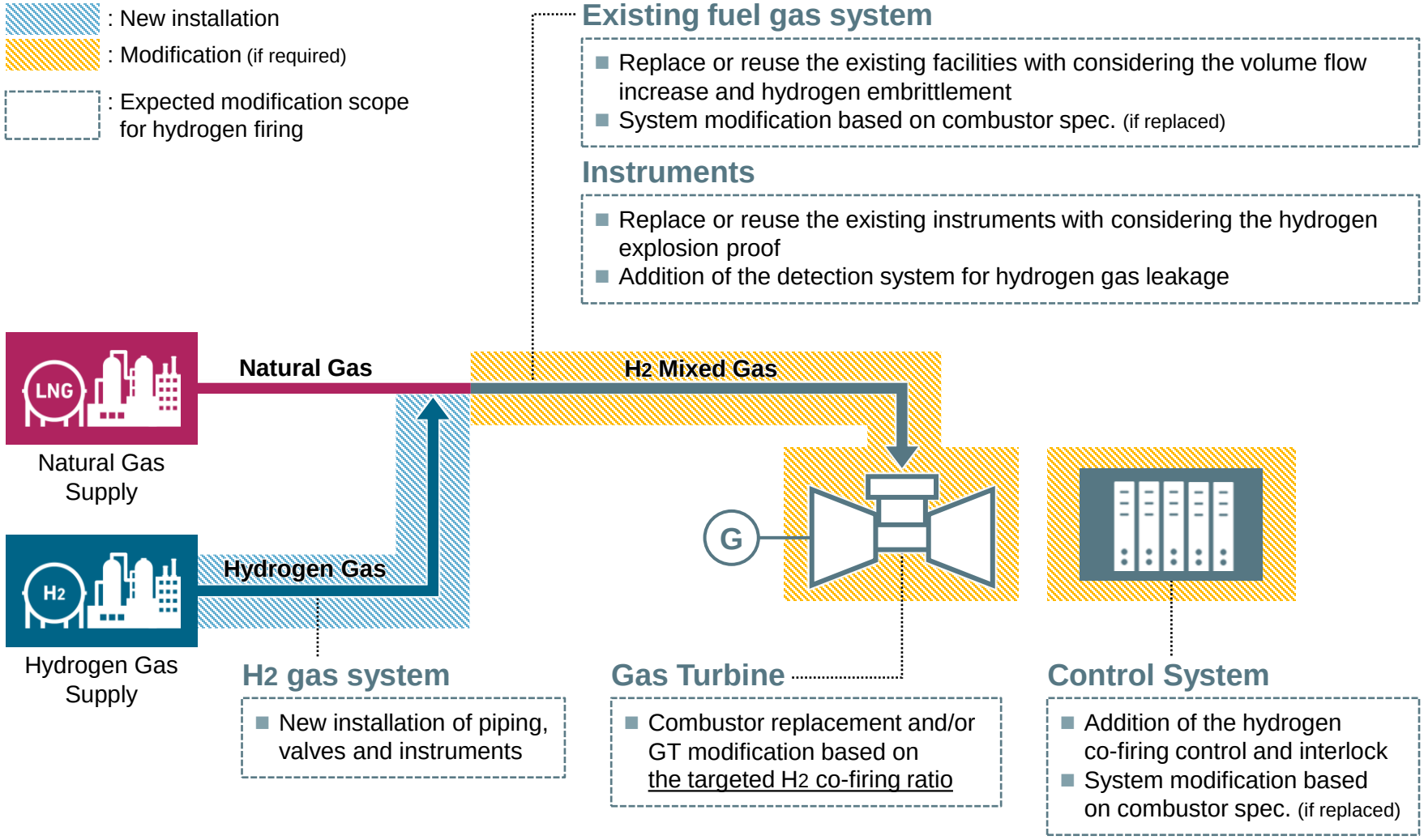
Example:
Coal fired Conventional Cogeneration VS Gas fired GT cogeneration



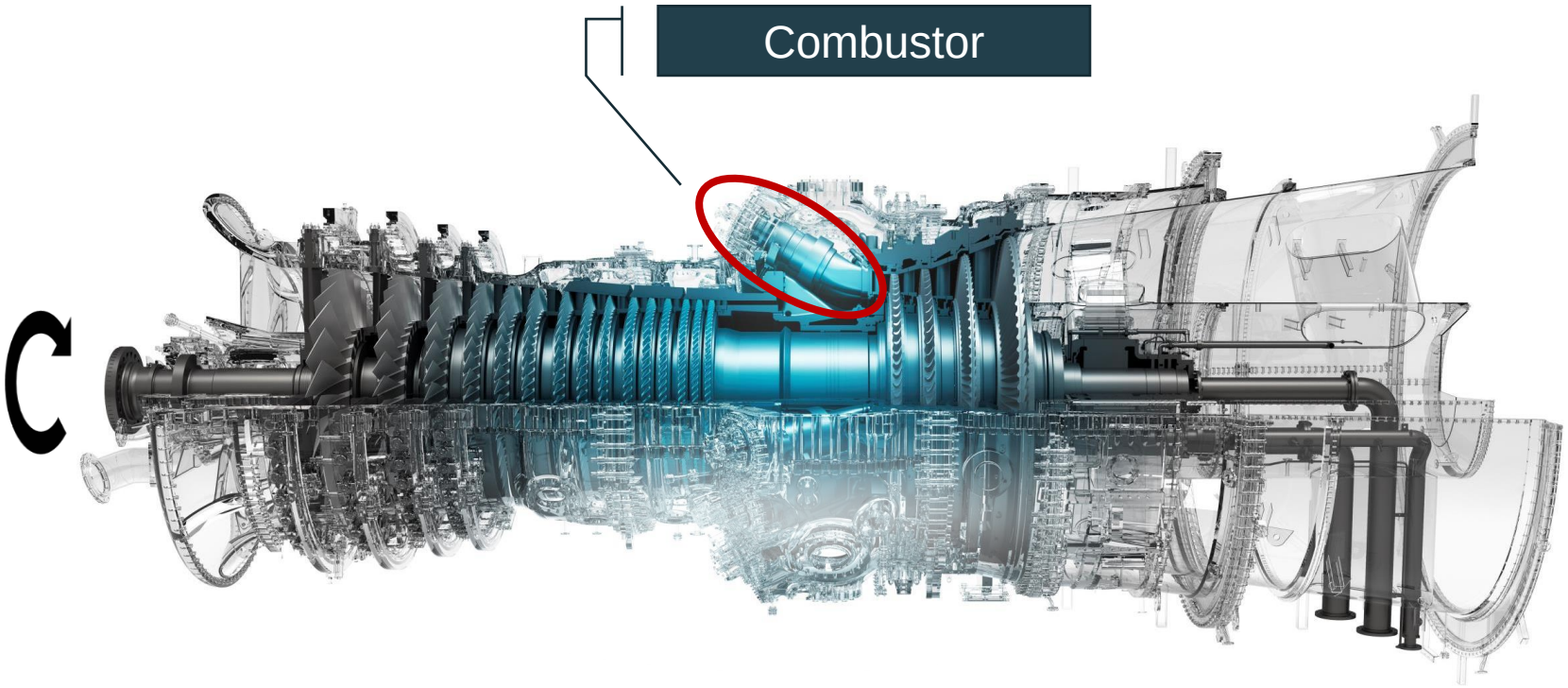
*1 CO2 Emission Factor Data Reference: Thailand Greenhouse Gas Management Organization
https://ghgreduction.tgo.or.th/th/download-tver/120-tver-gwp-emission-factor/2372-2021-08-09-08-16-31.html
CO2 Emission Factor: Coal (Anthracite): 98.3kg/TJ, Natural Gas: 56.1kg/TJ

Expected Modification Scope for Hydrogen Firing

Necessary to evaluate the modification scope for each plant individually.



Minimal Investment



Rotating Main Body is basically same even in case of Hydrogen.
Combustor needs to be fit for Hydrogen.
Mitsubishi Power offers suitable Hydrogen combustor depending on the customer’s plan.

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	Turbine inlet temperature	H_2 density (volume %)	Schedule (1990 – 2020 – 2025 – 2030)
Ready	**H-25 Diffusion Combustor**		Water/ Steam injection	1260~1300ºC class	100%	
Under development	**H-25 Multi-Cluster**		Dry	1300ºC class	60%	Product development completed; H2 30% combustion test; H2 60% combustion test
			Dry	1300ºC class	100%	**H2 100% commercialization**
Ready	**H-100 Pre-Mix**		Dry	1380ºC class	30%	Product development completed
Under development	**H-100 Multi-Cluster**		Dry	1300ºC class	100%	IGCC H2 80% verification; **H2 100% commercialization**

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

	Combustor Type	Low NOx tech	Turbine inlet temperature	H_2 density (volume %)	Schedule (1970 ‥ 2020 2025 2030)
Ready	**Type 1: Diffusion** 	N_2 dilution, Water/ Steam injection	1200~1400ºC class	100%	Cogen/IGCC
Ready	**Type 2: Pre-Mix (DLN)** 	Dry	1650ºC class	30~50%	H2 50% combustion test; H2 30% combustion test; DLN; **H2 30%~ validation**; **H2 30%~ commercialization**
Under development	**Type 3: Multi-Cluster (DLN)** 	Dry	1650ºC class	100%	**H2 100% combustion test**; **H2 100% commercialization**

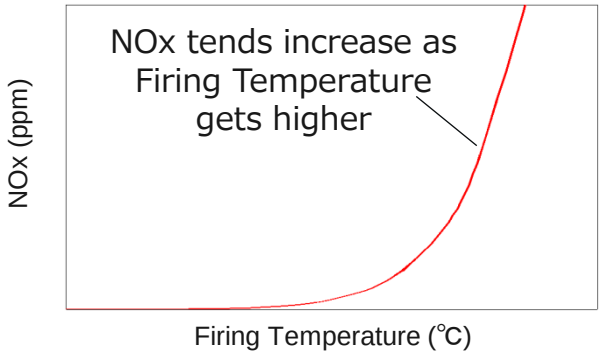
*This presentation is based on results obtained from a project commissioned by NEDO that is a government organization in Japan.
(NEDO: New Energy and Industrial Technology Development Organization)
**DLN：Dry Low NOx

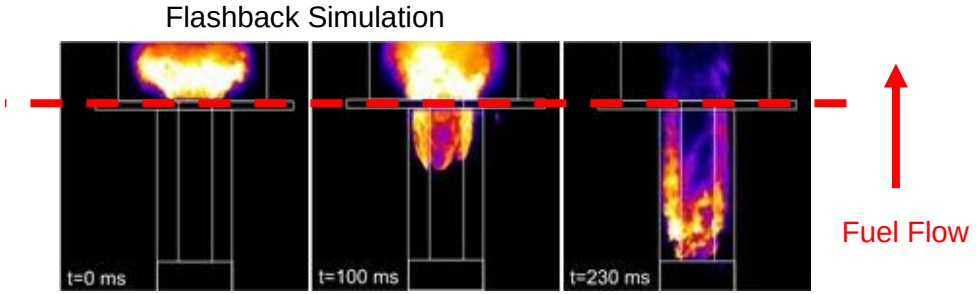
Challenges of Hydrogen Combustion

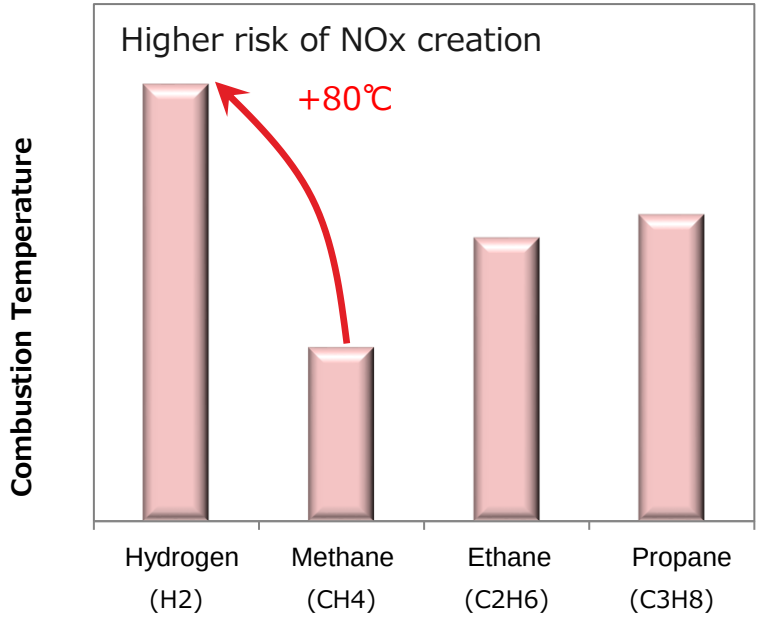
Hydrogen is very flammable fuel and accompanies following risks.

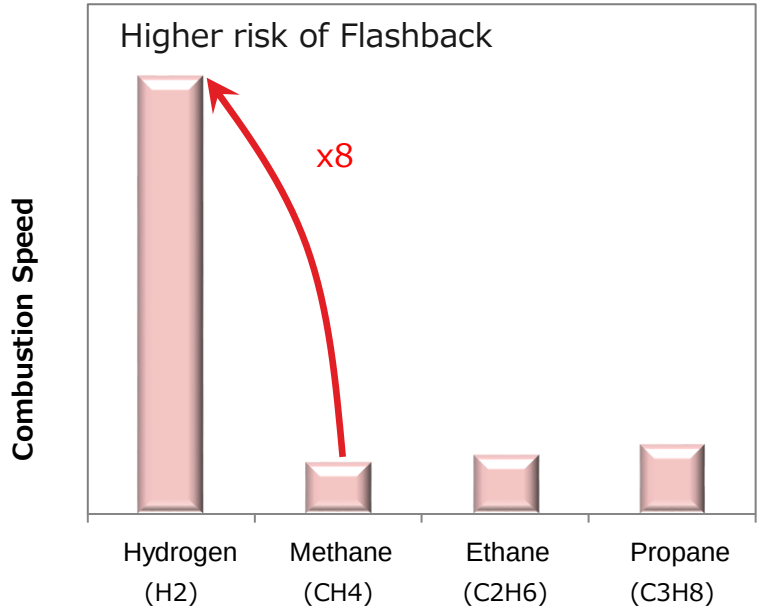
①Increase Combustoion Temperature ⇒ Risk of higher NOx emission

②Increase Combustion Speed ⇒ Risk of Flashback ocurrance



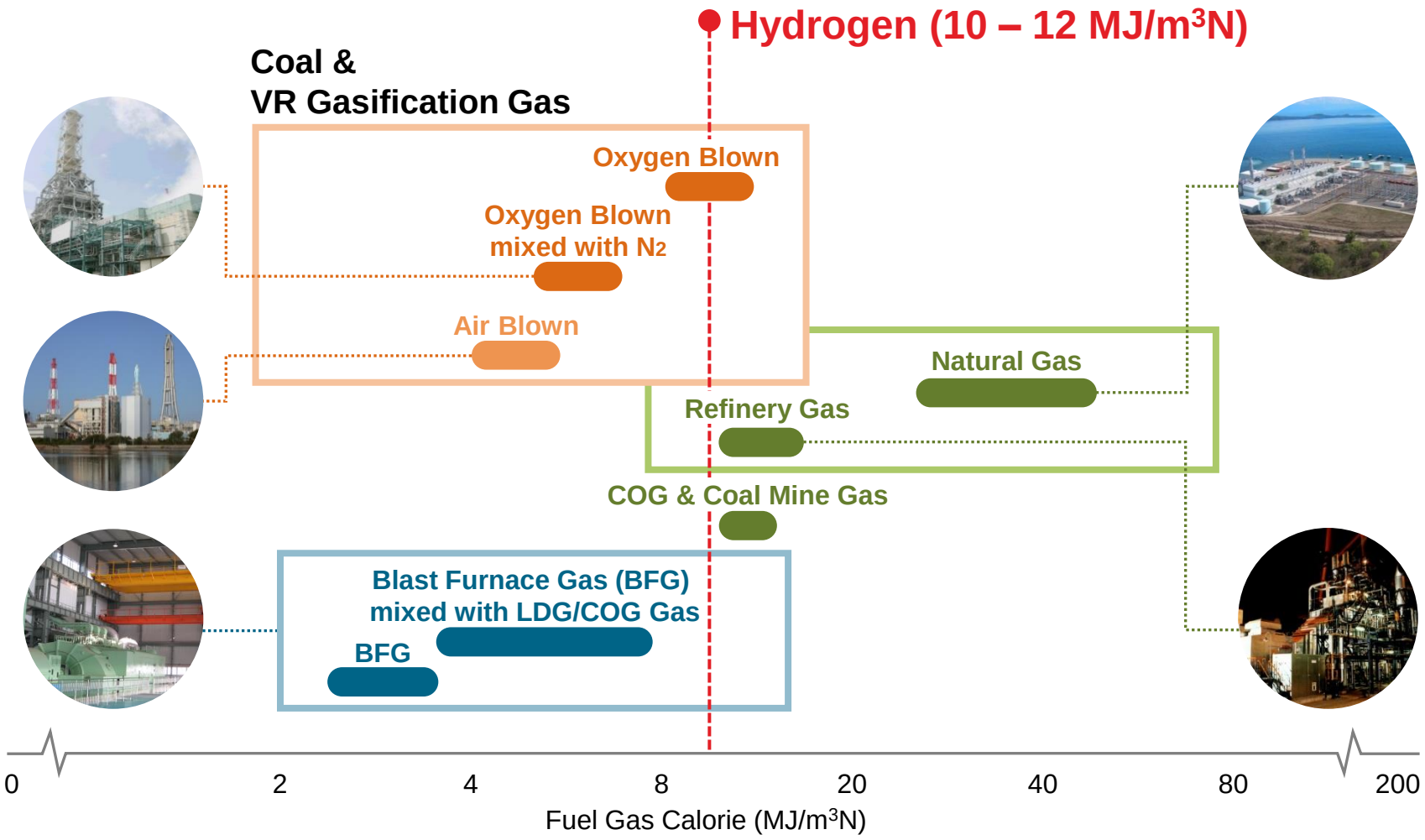






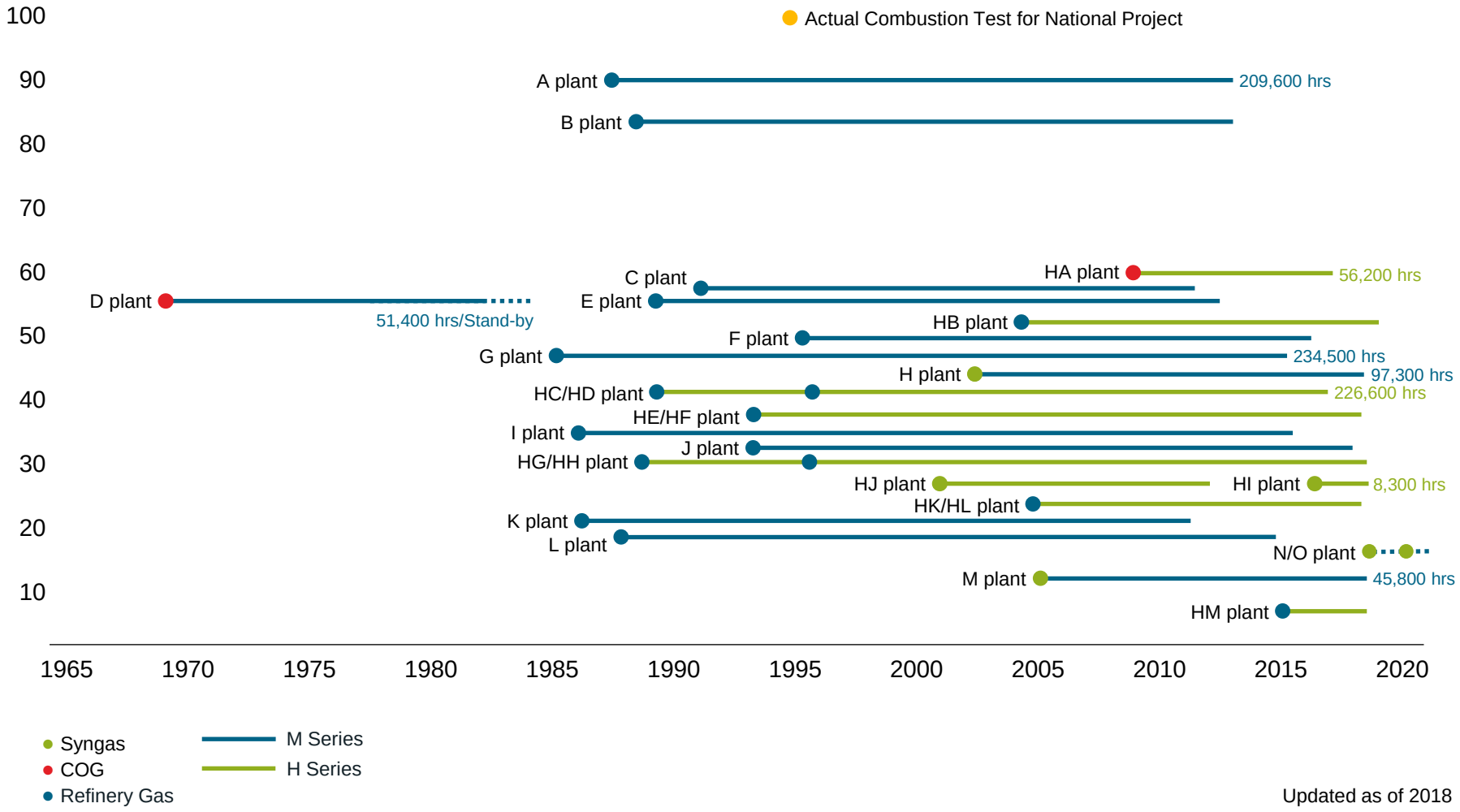
Type 1: Diffusion Combustor

Mitsubishi Power has experience in using fuels from a wide range of calorific values by Diffusion Combustor.



Type 1: Diffusion Combustor

Mitsubishi Power has successfully demonstrated more than 3.5 million hours of H_2 co-firing across 29 units since the 1970s.



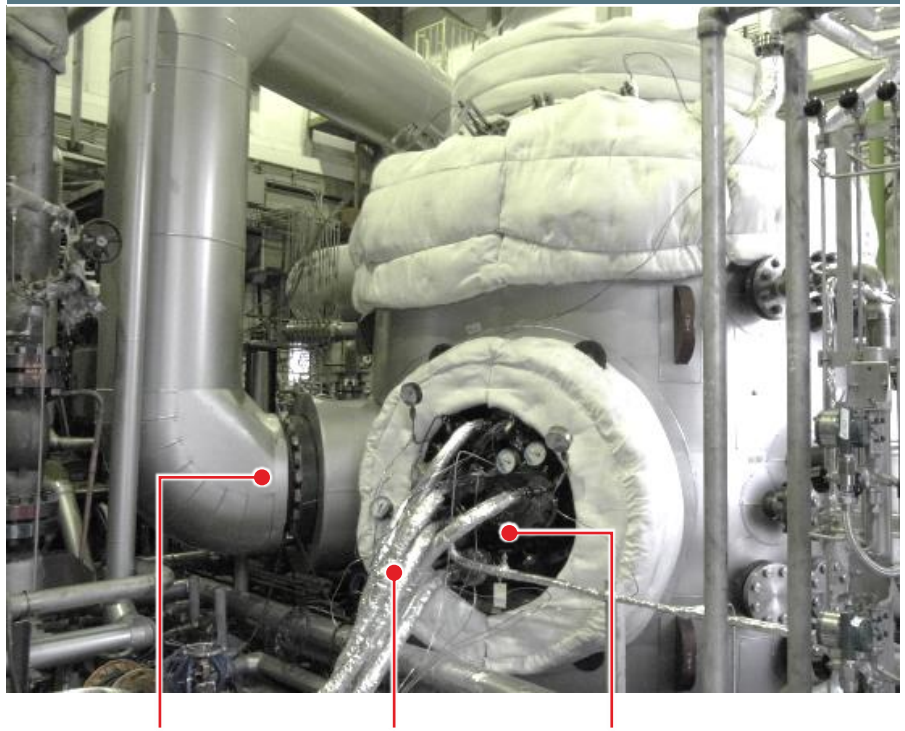
Updated as of 2018

Type 2: Pre-Mix (DLN) Combustor

In 2018, Mitsubishi Power completed test trials for 30% H_2 co-firing using DLN combustion technology.

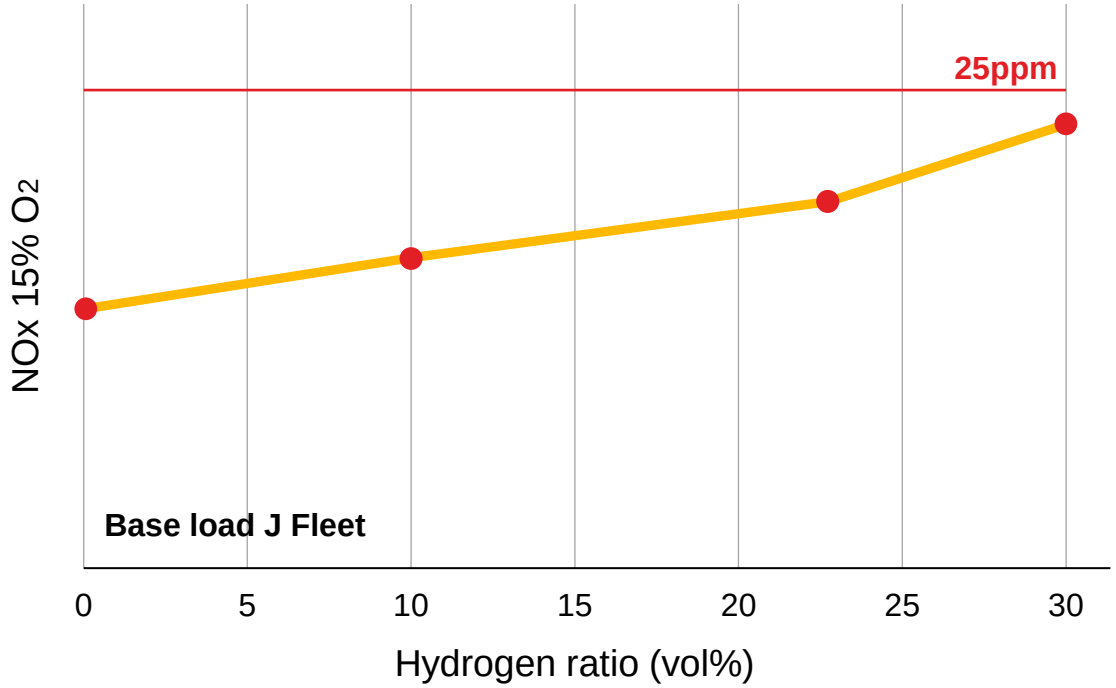
Takasago Test Facility

Combustion Test Shell

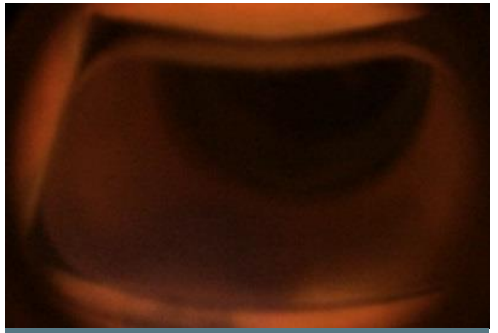


Type 2: Pre-Mix (DLN) Combustor

The test trial successfully used a stable flame with no occurrence of flashback and emitted less NOx than 25ppm threshold.



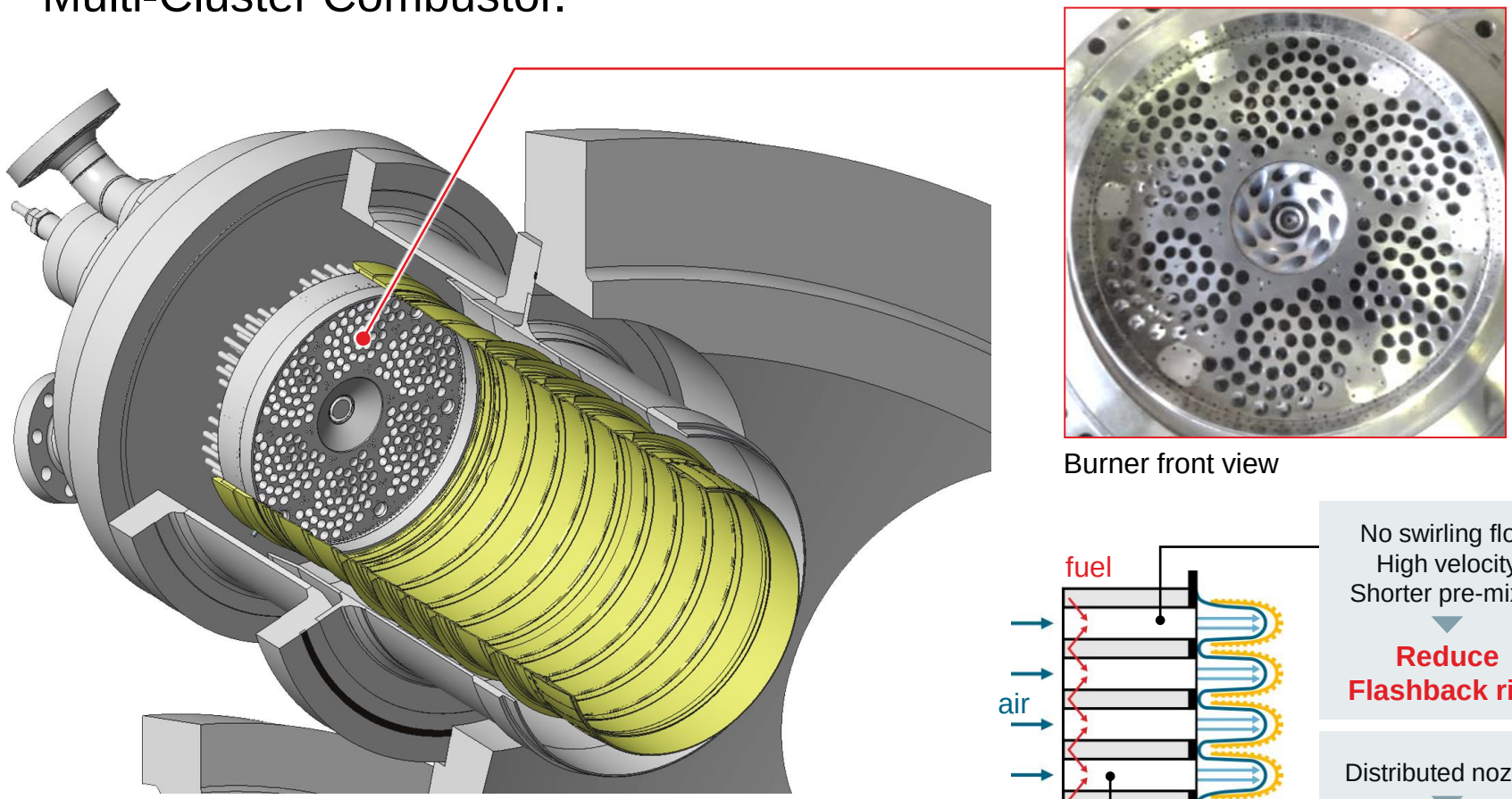
Flame Image
(LNG only)



Flame Image
(LNG + 20% H_2)

Type 3: Multi-Cluster (DLN) Combustor

Mitsubishi Power is currently developing DLN combustion technology for 100% H_2 firing and targets to complete the rig test for the Multi-Cluster Combustor.



Multi-Cluster (DLN combustor)

Burner front view

No swirling flow
High velocity
Shorter pre-mixer

Reduce Flashback risk

Distributed nozzle

Reduce NOx

Takasago Hydrogen Park

Begin operation in FY2023

A one-stop-shop for validating hydrogen-related technologies from hydrogen production to power generation

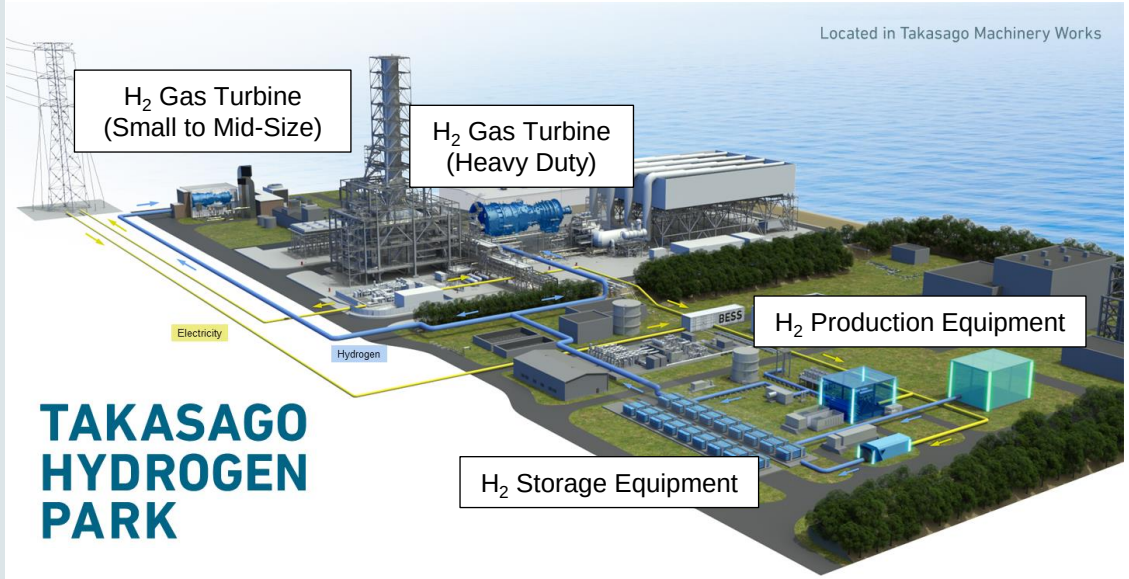
- **Add hydrogen production and storage equipment to existing demonstration plant**
  Test and validate water electrolysis, turquoise hydrogen*, SOEC** and other technologies in-house and improve product reliability

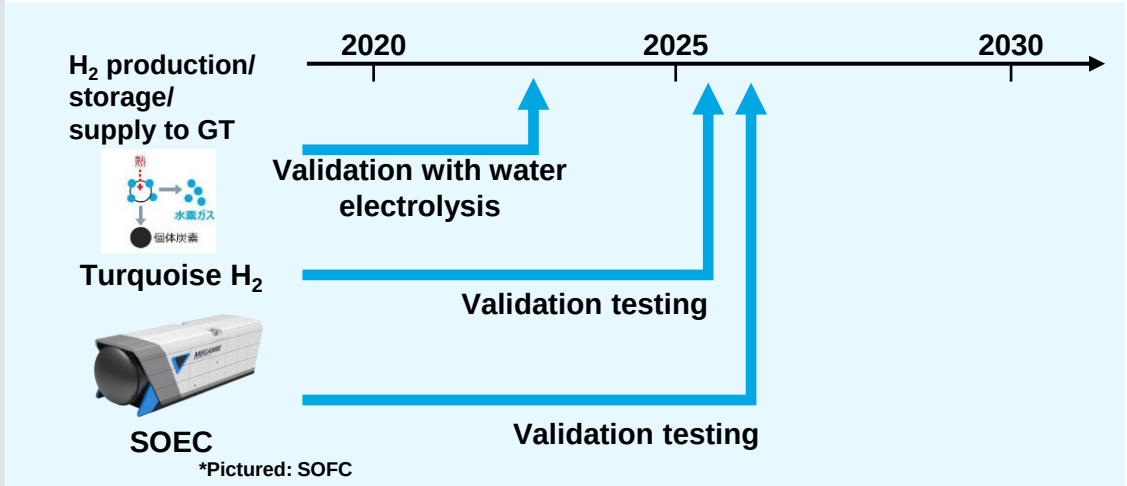
  *Turquoise hydrogen: H_2 obtained through pyrolysis of methane into H_2 and solid carbon

  **SOEC (Solid Oxide Electrolyzer Cell): High temperature steam electrolysis

- **Validate hydrogen gas turbine technology**
  Validate technology in lead up to commercialization of 30% mixed firing in heavy duty gas turbines and 100% hydrogen firing in small to mid-size gas turbines by 2025

- **Combine and evolve energy infrastructure and hydrogen technologies**
  Make progress toward establishing a hydrogen solutions ecosystem, which will help achieve a sustainable society by linking various industries with hydrogen technologies





3. Zero Carbon Emission by Ammonia Gas Turbine

Ammonia Gas Turbine Development

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.

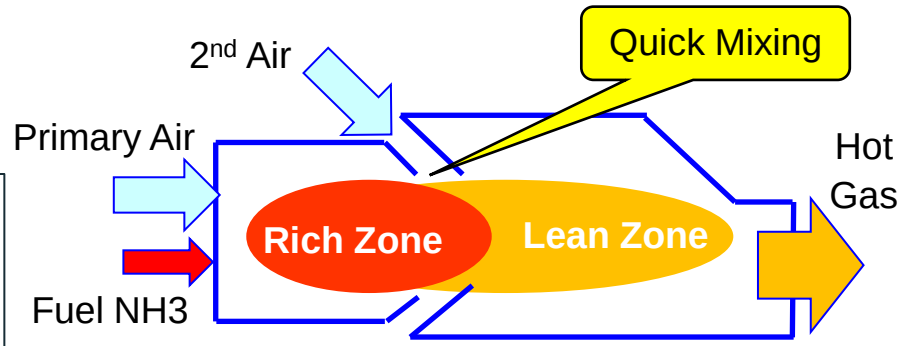
YOKOHAMA, JAPAN (March 1, 2021) - Mitsubishi Power, a subsidiary of Mitsubishi Heavy Industries (MHI) Group, has commenced development of a 40-megawatt (MW) class gas turbine that is fueled by 100% ammonia (NH_3). The project

H-25 Gas turbine

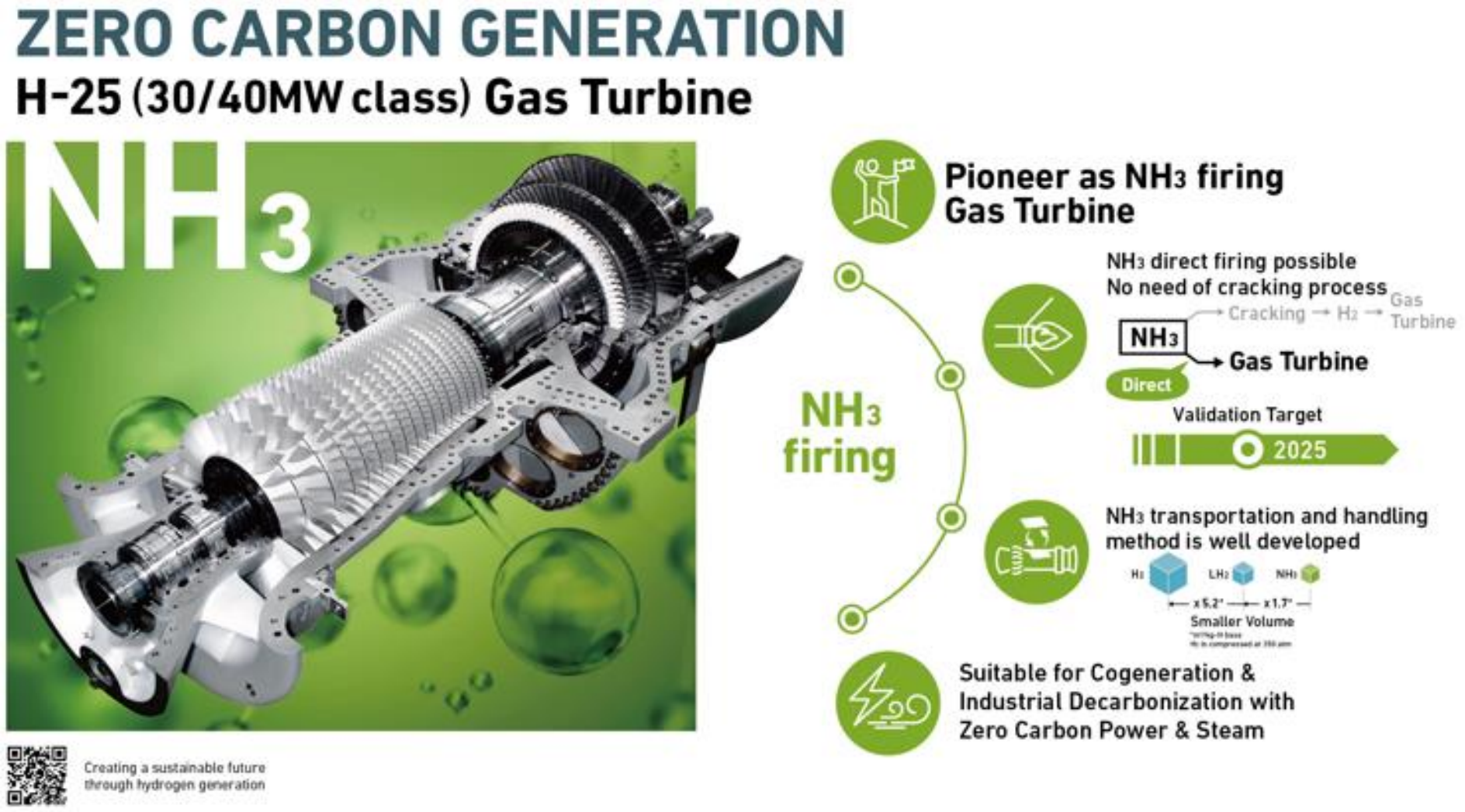
- Output: 41.0MW
- Efficiency:
  36.2% (SC)
  More than 80% (Cogen)
- Received orders: 189 units

NH3 Combustion Challenge
Poor flammability
High N0x (Fuel N0x)

Solution
Rich-Lean
Two Stage Combustor



Ammonia Gas Turbine Features



Ammonia direct combustion gas turbine can contribute to future ZERO carbon.

Latest Collaboration on Ammonia Gas Turbine

Jurong Port, Mitsubishi Heavy Industries Asia Pacific and JERA Asia come together to explore establishing an ammonia direct combustion power plant. The project aims to accomplish the twin goals of supplying green electricity and developing an ammonia bunkering terminal

Singapore, August 19, 2022 – Jurong Port, Mitsubishi Heavy Industries Asia Pacific (MHI-AP), a subsidiary of Mitsubishi Heavy Industries, and JERA Asia, a subsidiary of JERA, today concluded a Memorandum of Understanding (MoU) to jointly explore establishing a 100% ammonia direct combustion power plant on Jurong Island, Singapore, which houses the country's chemical and energy industries.

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

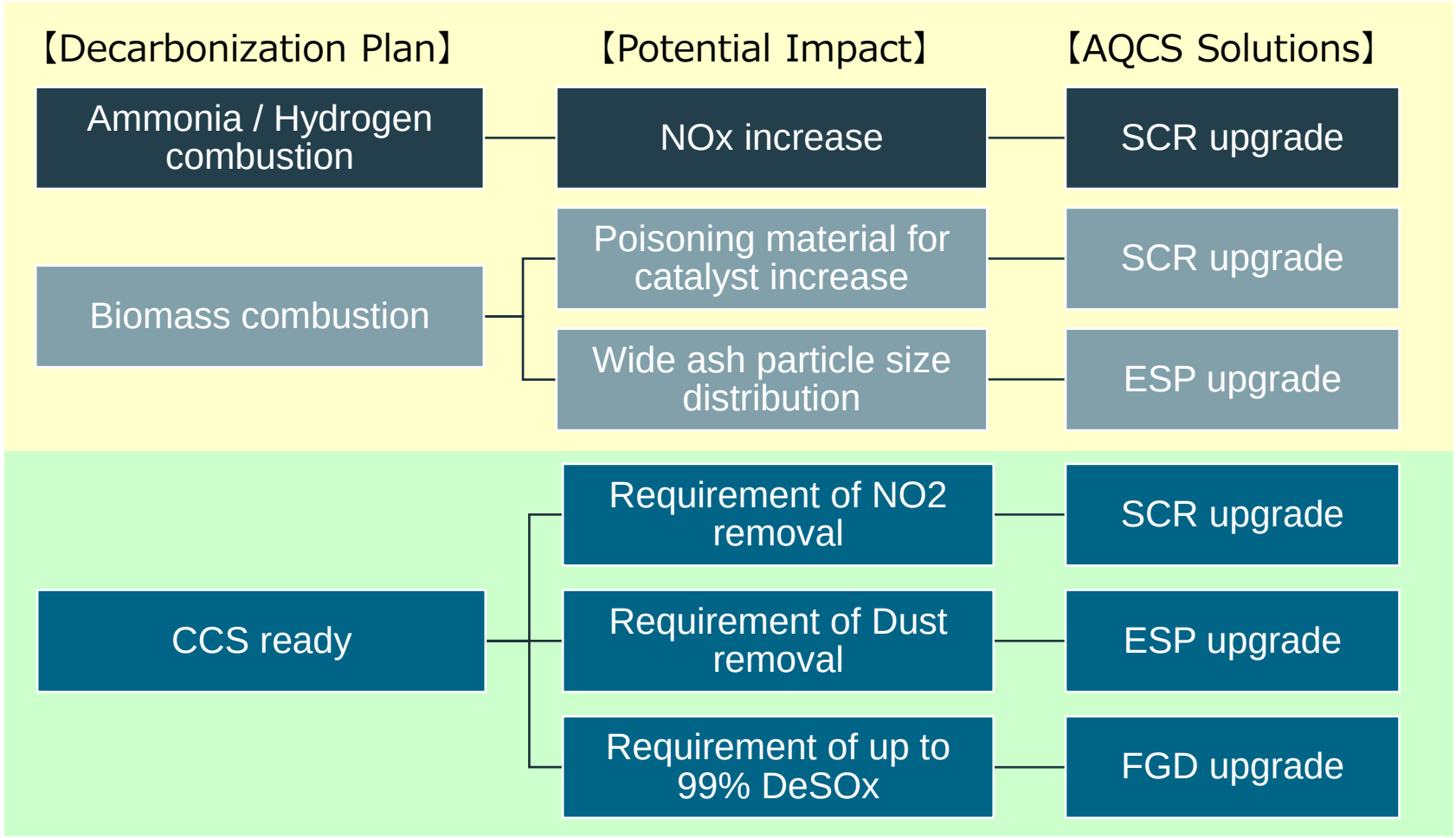
Tokyo, September 27, 2022 – In a Memorandum of Understanding (MoU) signed yesterday, Keppel New Energy Pte Ltd, a wholly owned subsidiary of Keppel Infrastructure; Mitsubishi Heavy Industries, Ltd. (MHI); and DNV, a global independent energy expert and assurance provider, announced a strategic collaboration 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 combined cycle gas turbine (CCGT) – towards the potential development of an Ammonia Power Plant.

4. AQCS for Decarbonization Society

***AQCS : Air Quality Control Systems**

AQCS Role for Decarbonization Technology

➢ AQCS, the solution for strict emission regulation and human health, also has important role for Decarbonization Society.



✓ **AQCS optimization** is necessary for decarbonization technology application

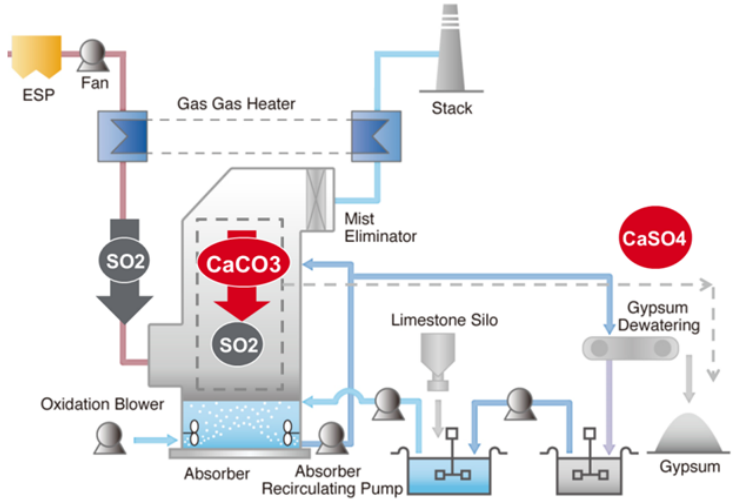
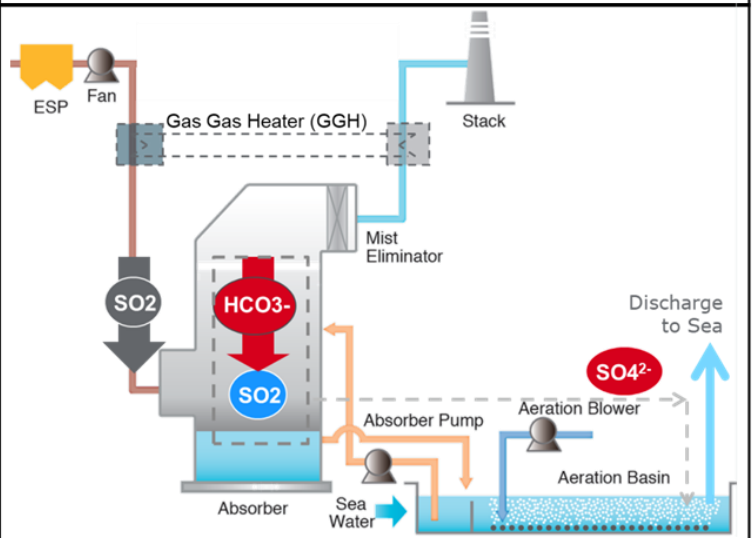
DeNOx Technology

- ✓ Catalyst Replacement for stable operation.
- ✓ SCR system modification for higher performance

* SCR : Selective Catalytic Reduction system

DeSOx Technology

✓ **Solution for 1) Strict regulation with retrofit & 2) CCS ready with upgrade. (for both OEM / o-OEM FGD, up to 99% DeSOx %)**

	Limestone Gypsum	Seawater
Process		
Absorbent	Limestone：$CaCO_3$	Seawater：HCO_3^-
DeSOx %	~ 99 %	~99%
Absorber Module	up to 1,000MW equivalent	up to 1,000MW equivalent
Byproduct	Gypsum, Salable byproduct	NONE

5. Summary

About Mitsubishi Power

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.

Large Frame Gas Turbines	Middle & Small Gas Turbines	Power Plants






Line-up

Power Plant Solutions

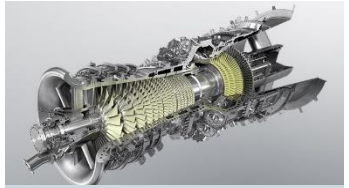

GTCC


Steam Power


IGCC

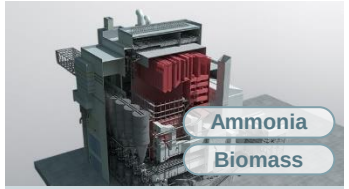
Geothermal

Products & Equipment

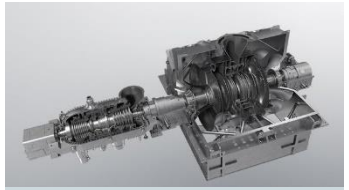

Gas Turbines

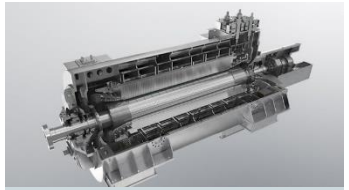

Hydrogen fuel for GT


Boilers



Mixed- Combustion

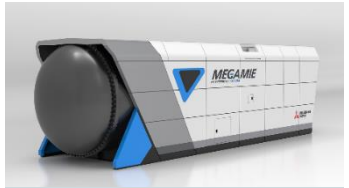

Steam Turbines


Generators

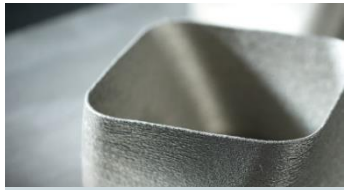

Air Quality Control Systems


Control Systems

Energy Storage



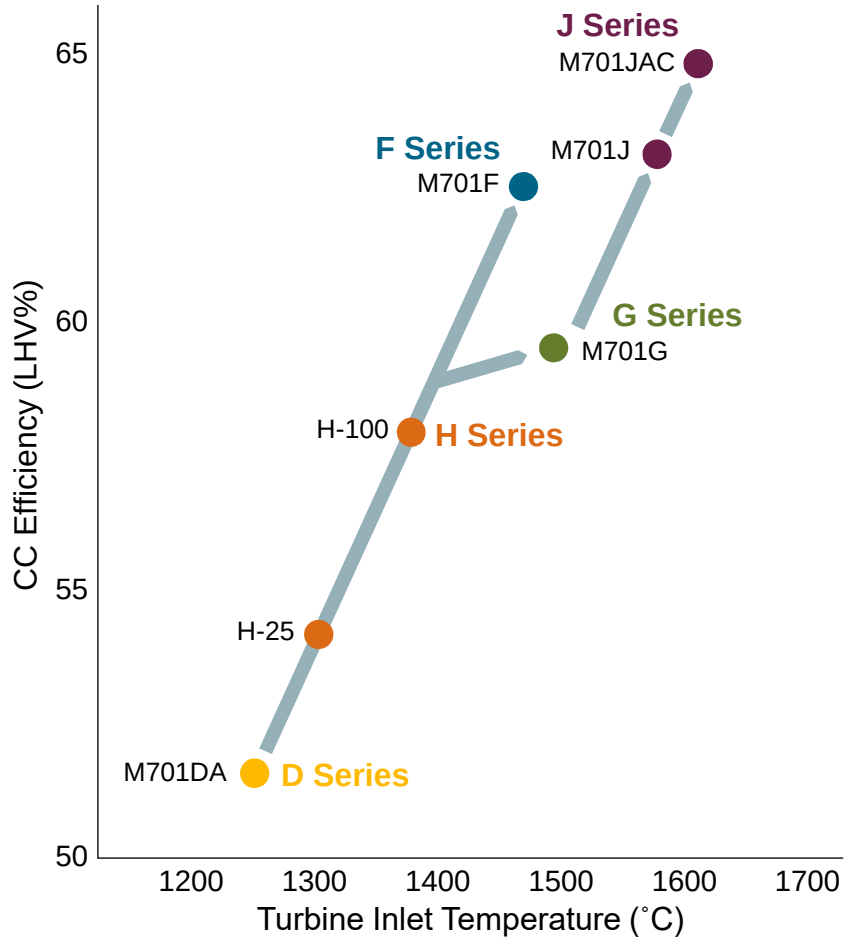
Fuel Cells


Additive Manufacturing

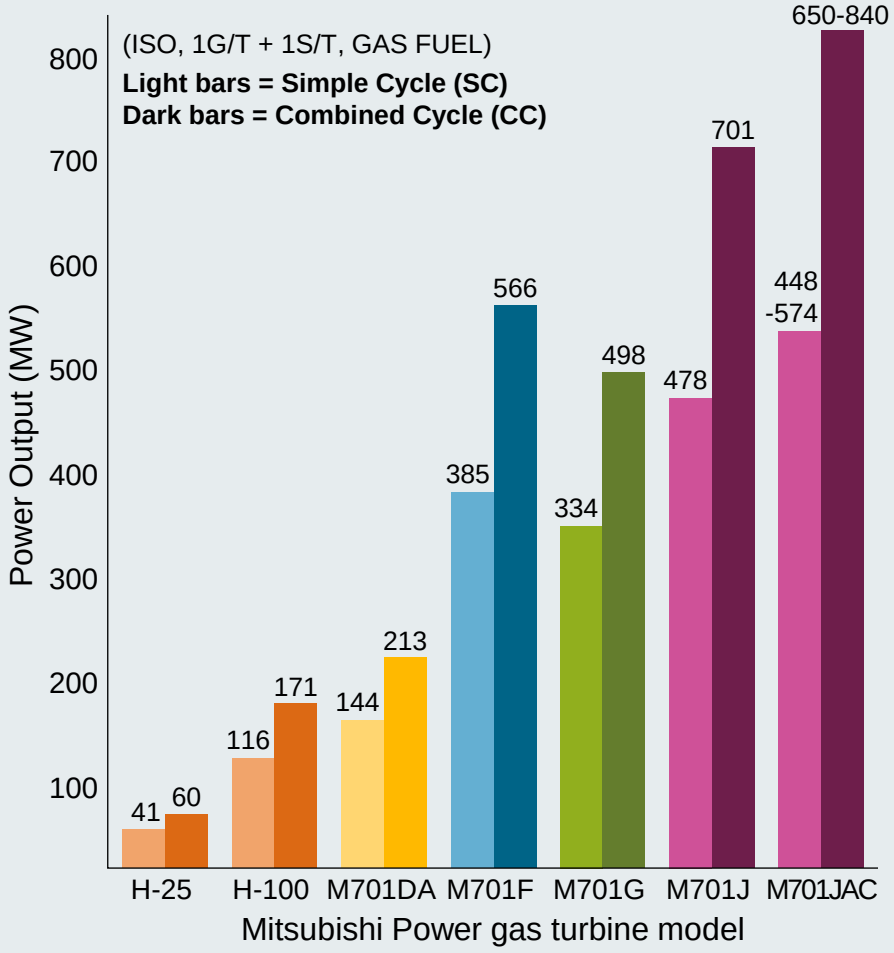
Mitsubishi Power' Gas Turbine Technology (50Hz)

Mitsubishi Power offers a wide range of Gas Turbines
— from small frame to large frame.

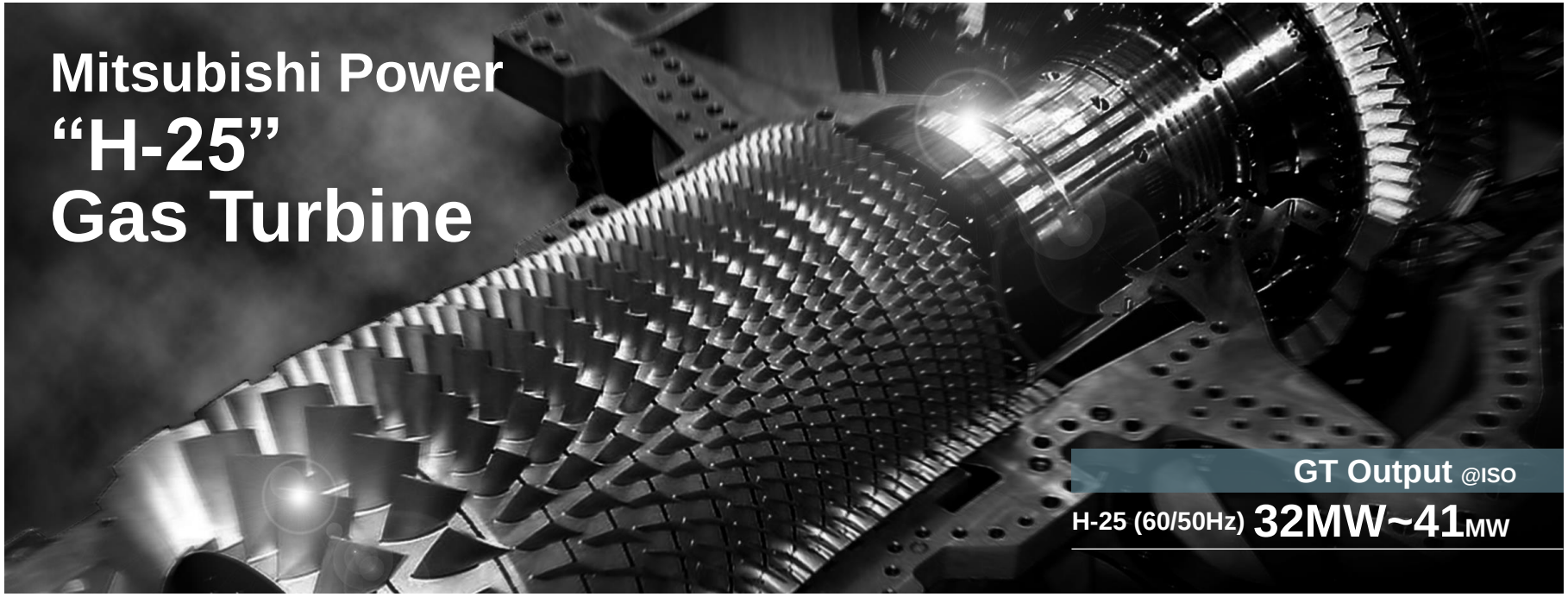
Range of Efficiency



Range of Output



H-25 Gas Turbine



ROBUST

Heavy Duty Single Shaft

RELIABLE

More than 99%

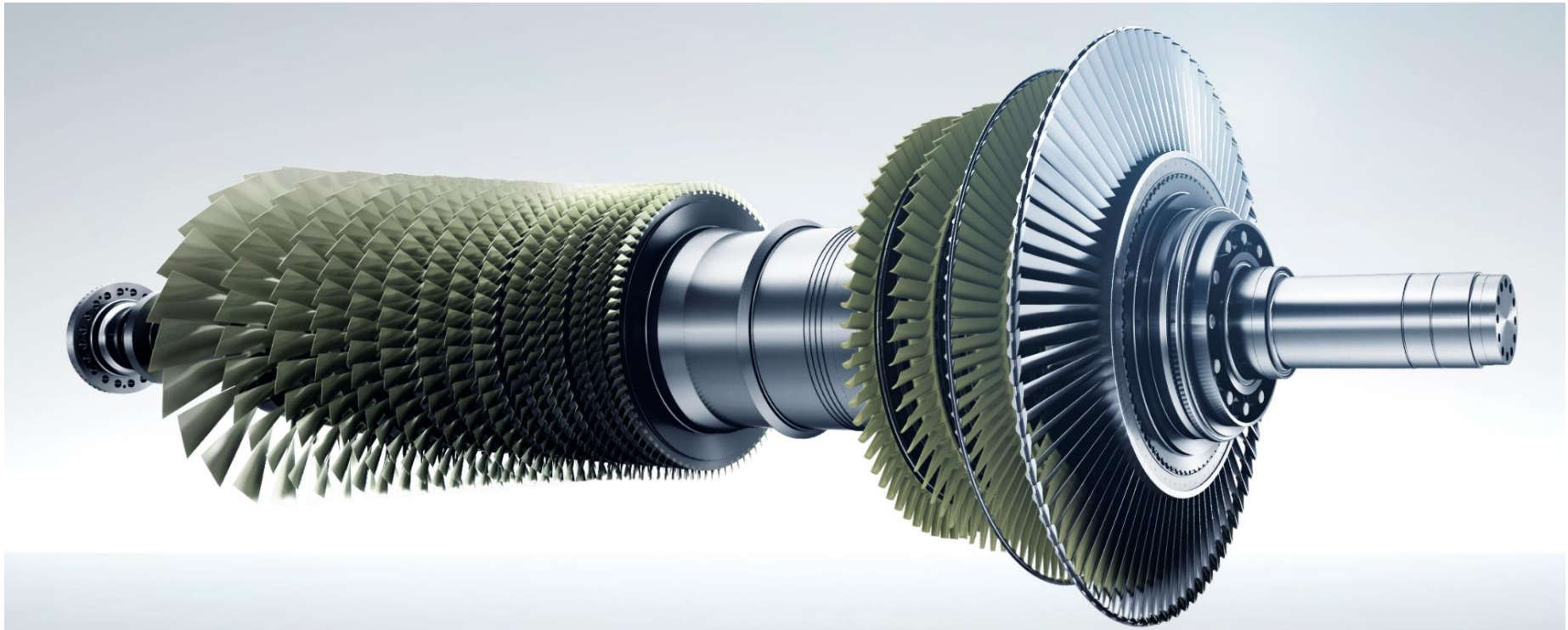
- Over 11.0 million operation hours
- Ordered: 192 GT units
  (H-25 as of October 2022)

READY

100% H_2 Firing

- Available in Diffusion Combustor
- DLN will be soon available by 2025
- Ideal for Retrofit of old conventional cogeneration

Towards a Hydrogen Society



Gas Turbines are essential to stabilize power supply in energy transition

Hydrogen Gas Turbines are key to deep decarbonization

MHI Group can contribute to a future hydrogen society


MITSUBISHI
POWER

MOVE THE WORLD FORWARD

MITSUBISHI
HEAVY
INDUSTRIES
GROUP