MOVE THE WORLD FORWARD MITSUBISHI HEAVY INDUSTRIES GROUP

10th International Gas Turbine Conference
Gas turbines in a carbon-neutral society
11-15 October 2021

DEVELOPMENT OF HYDROGEN-FIRED GAS TURBINE COMBUSTOR

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Mitsubishi Heavy Industries, Ltd.

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Outline

1. Company Overview
2. Power System Strategies for a Low-Carbon Society
3. Development of Hydrogen Combustion Technology
   - Diffusion combustor
   - Dry Low NOx combustor
   - Multi Cluster DLN combustor
4. Hydrogen GT Project
5. Summary

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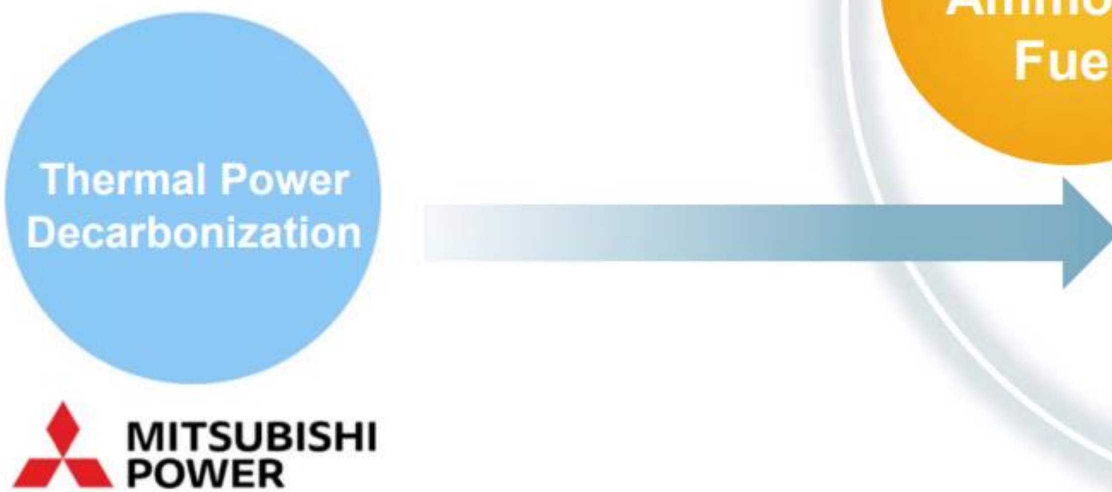
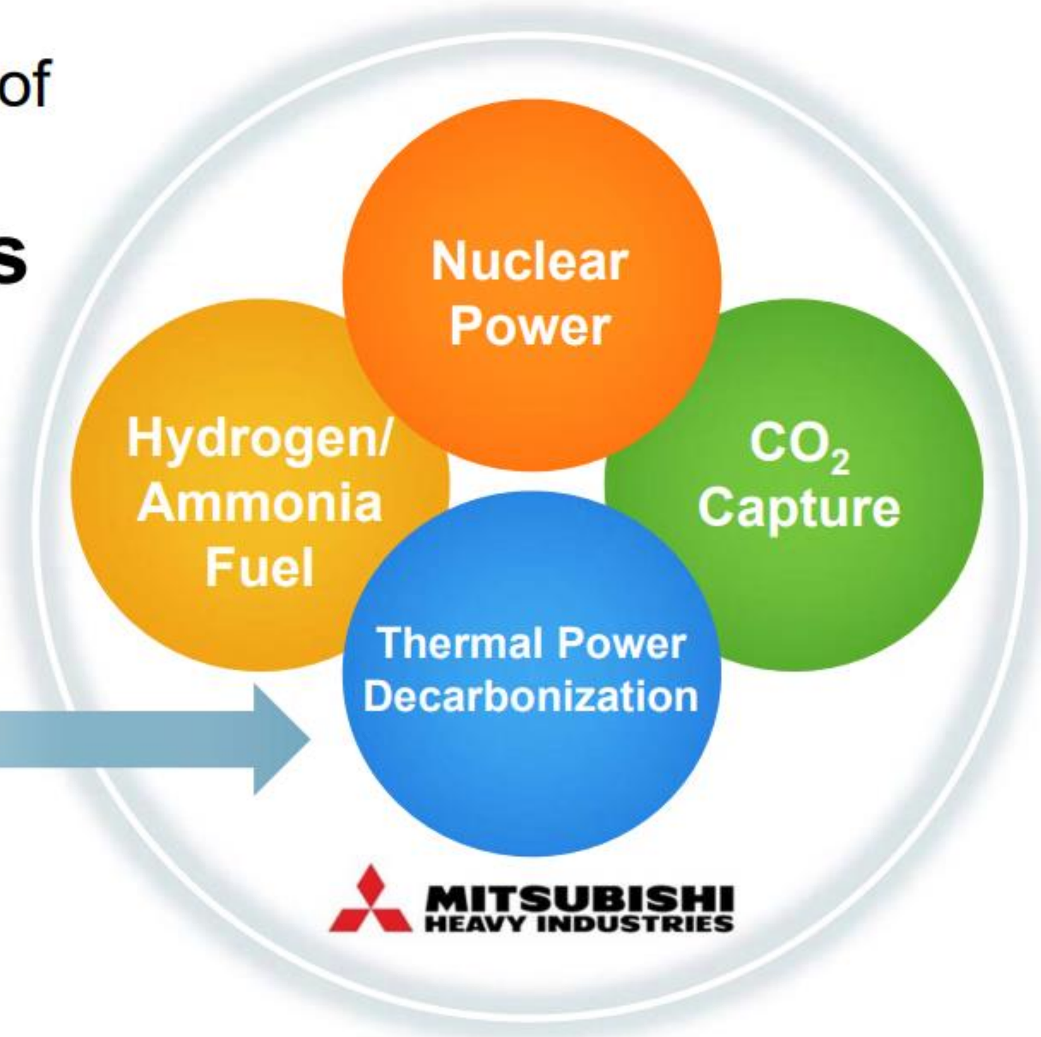
Mitsubishi Power to be integrated into MHI (Oct 2021)

Contribute to the achievement of Carbon Neutrality as a **total energy solutions company**





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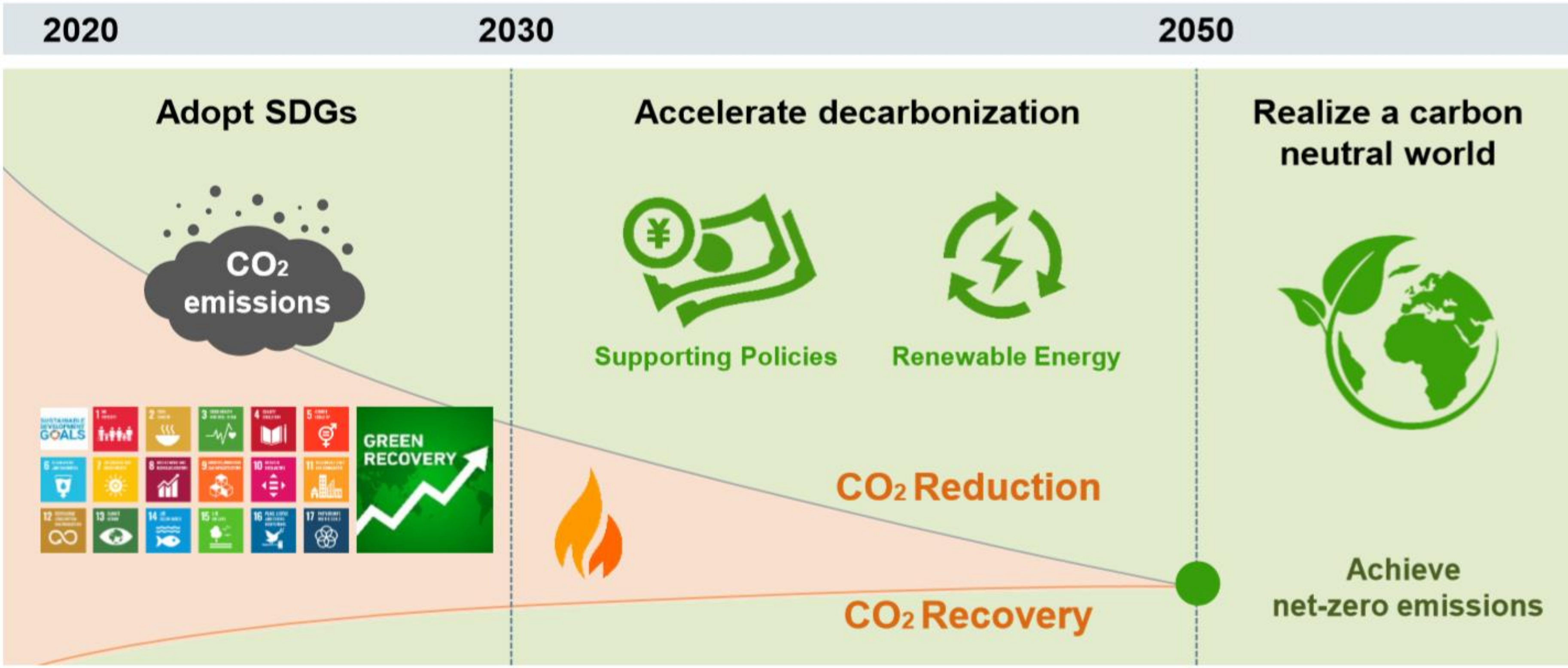
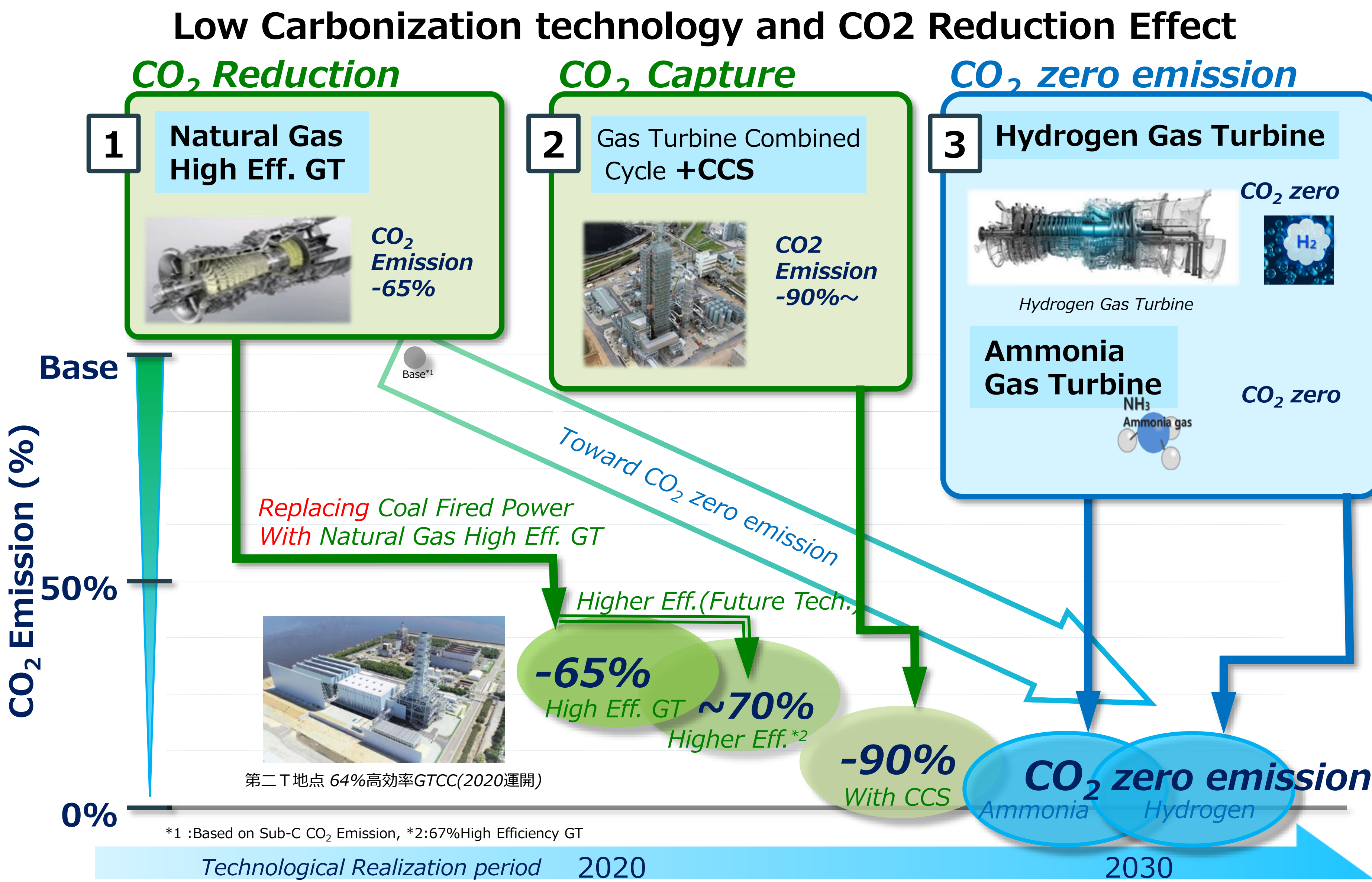
Global Trends

- The world is shifting to a carbon-neutral society
- Reducing and recovering CO_2, net-zero carbon society is to be achieved by 2050

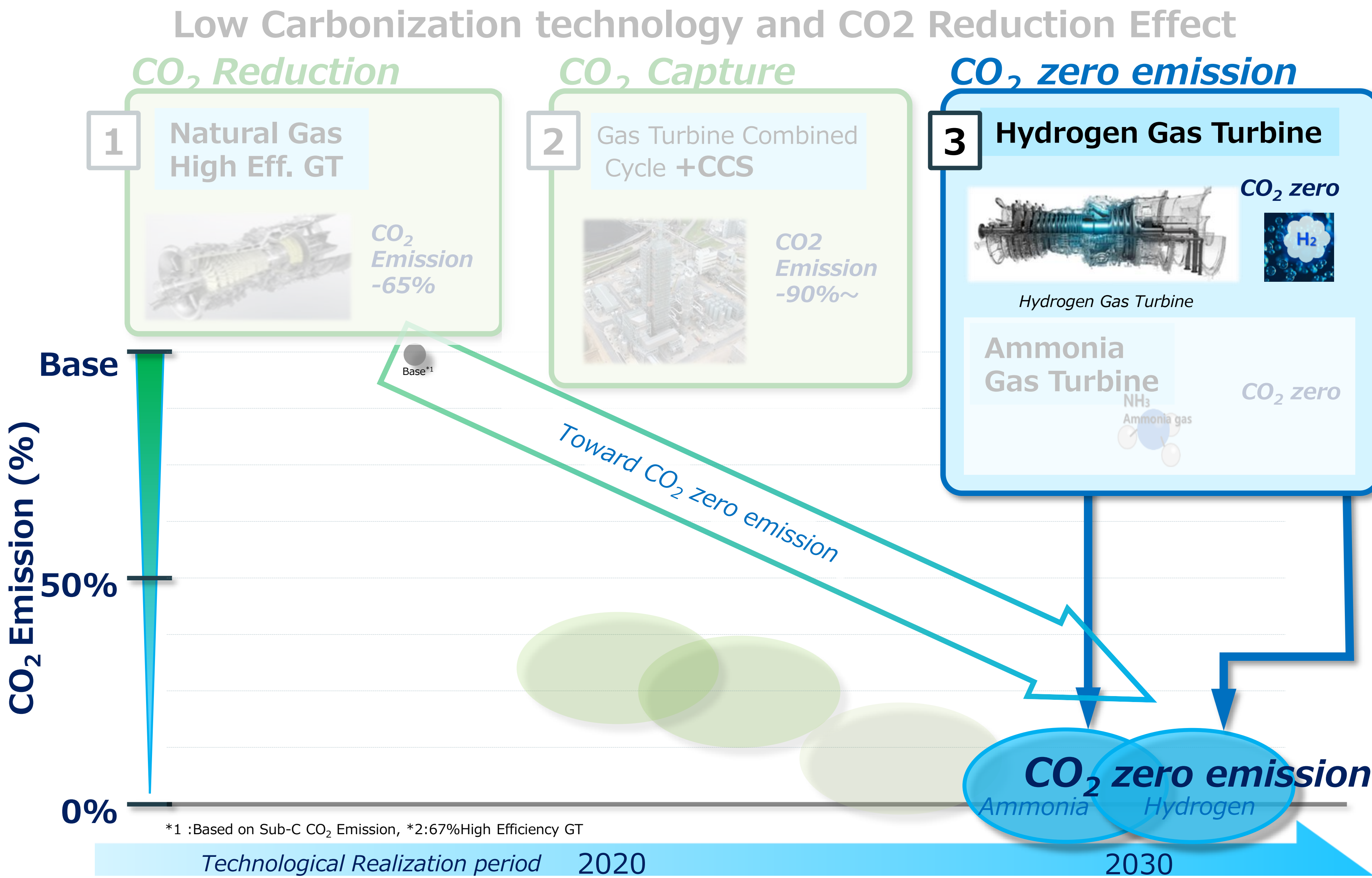


Reference : Energy Transition -New Frontier for MHI Group -

Technology Development for CO_2 zero emission



Technology Development for CO_2 zero emission



*1 :Based on Sub-C CO_2 Emission, *2:67%High Efficiency GT

Benefits of Hydrogen Gas Turbines

Hydrogen Gas Turbines have multiple environmental and economic benefits.

1

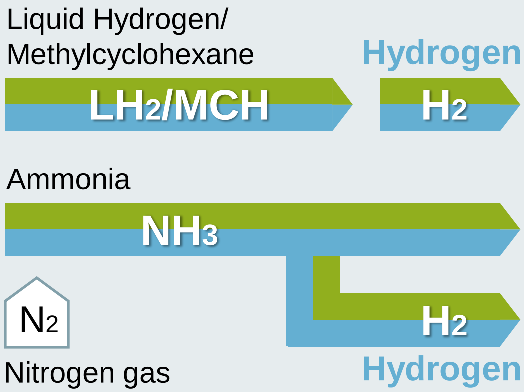
Minimal investment needed to adopt

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

*Detailed scope is subject to plant specification

2

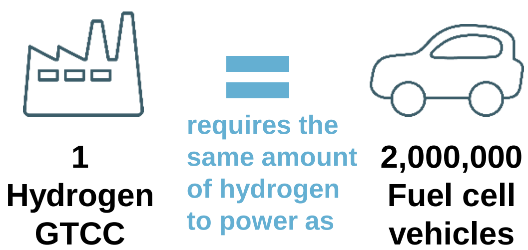
Carrier agnostic



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.

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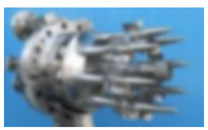
Range of H_2 Combustion Technology

MHI 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)	H_2 density (volume %)	Schedule
Ready	**Type 1: Diffusion** 	N_2 dilution, Water/ Steam injection	1200~1400	100%	1970 Cogen/IGCC
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

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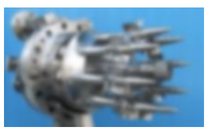
Ready	**Type 2: Pre-Mix (DLN)** 	Dry	1600	**30%**	1982 DLN; **2018** **30% co-firing** **test completed**
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**DLN：Dry Low NOx

Hydrogen-mixed Fuel Operating Experiences

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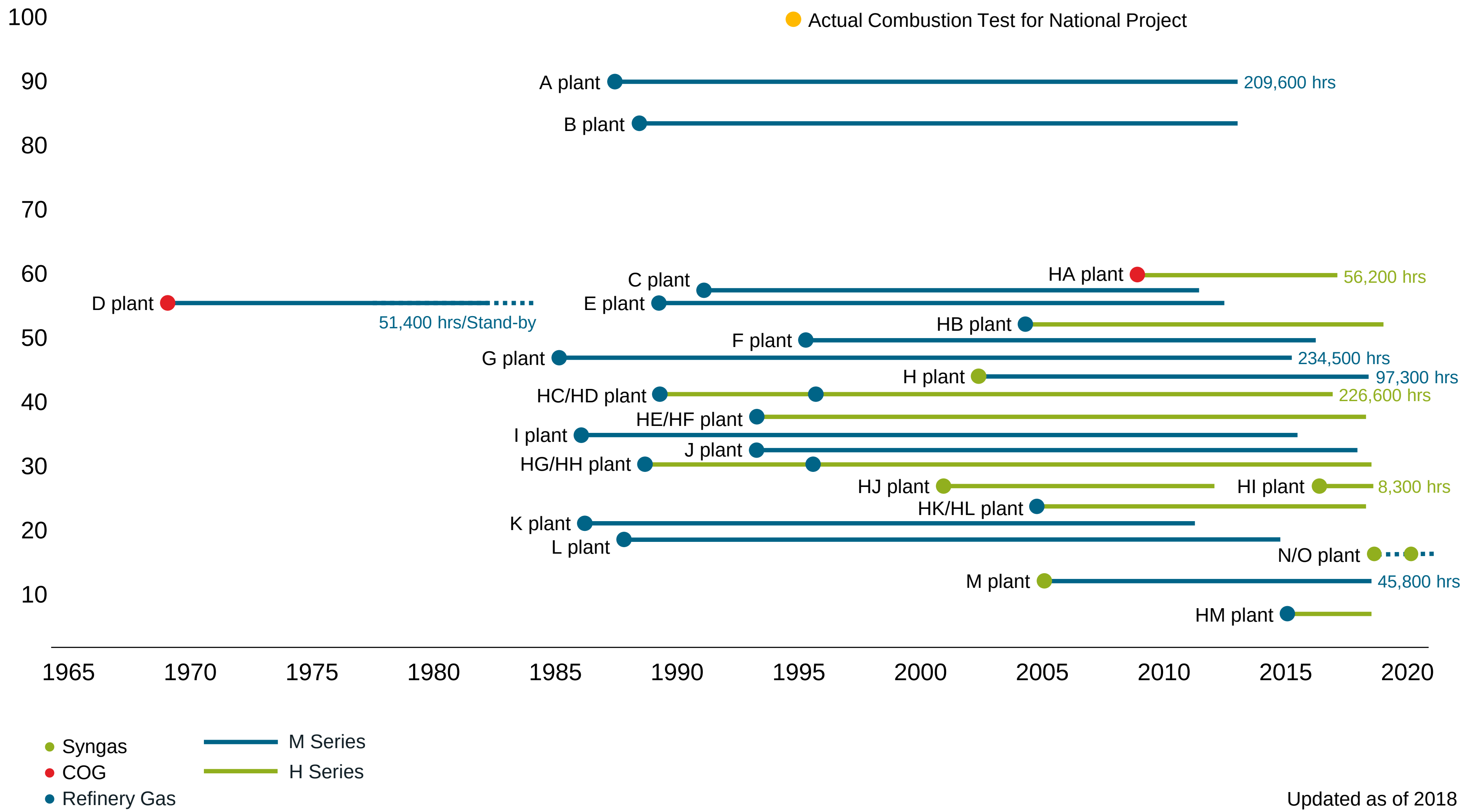
MHI has successfully accumulated more than 3.5 million hours of H_2 co-firing across 29 units since the 1970s.



Updated as of 2018

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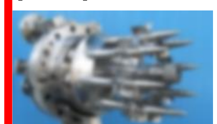
Ready	**Type 2: Pre-Mix (DLN)** 	Dry	1600	30%	1982 DLN; **2018 30% co-firing test completed**
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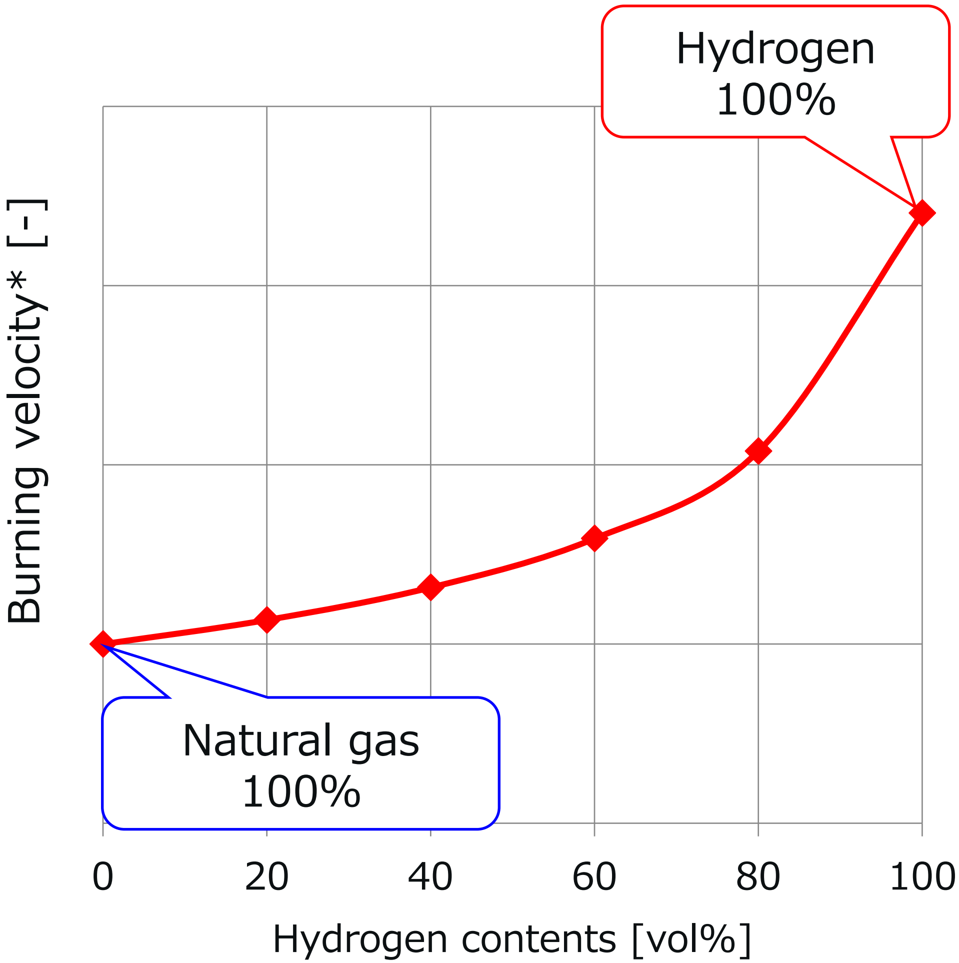
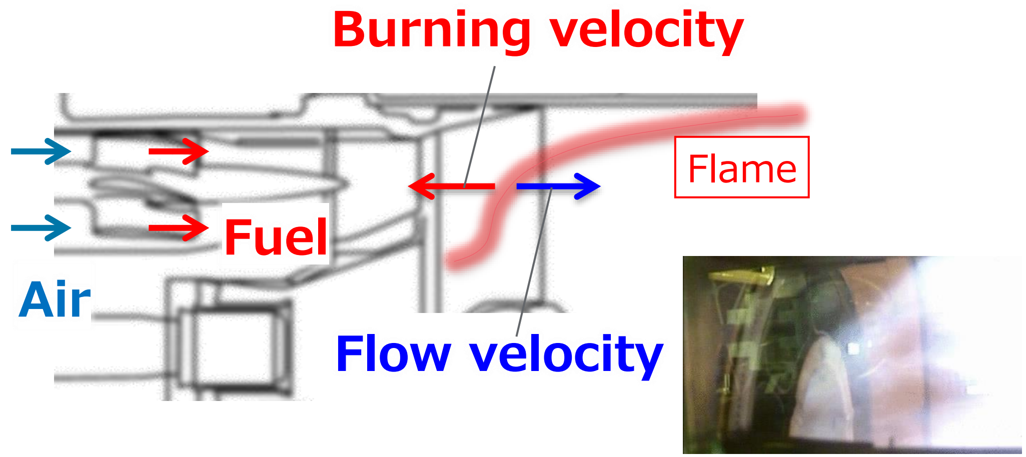
**DLN：Dry Low NOx

Characteristics of Hydrogen Co-firing

The risk of the flashback increases due to the higher burning velocity.

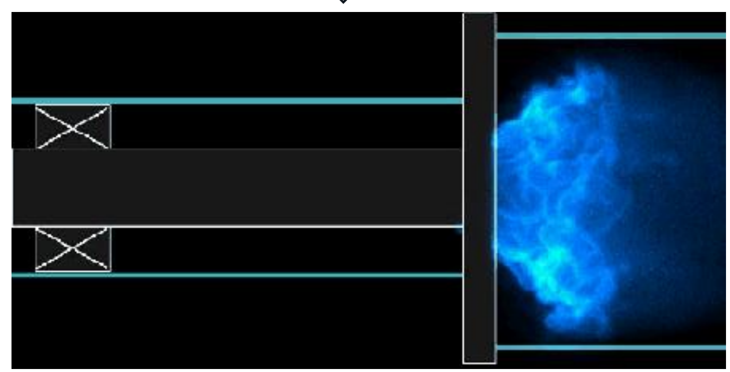


*calculated by GRI3.0



Burning velocity > Flow velocity

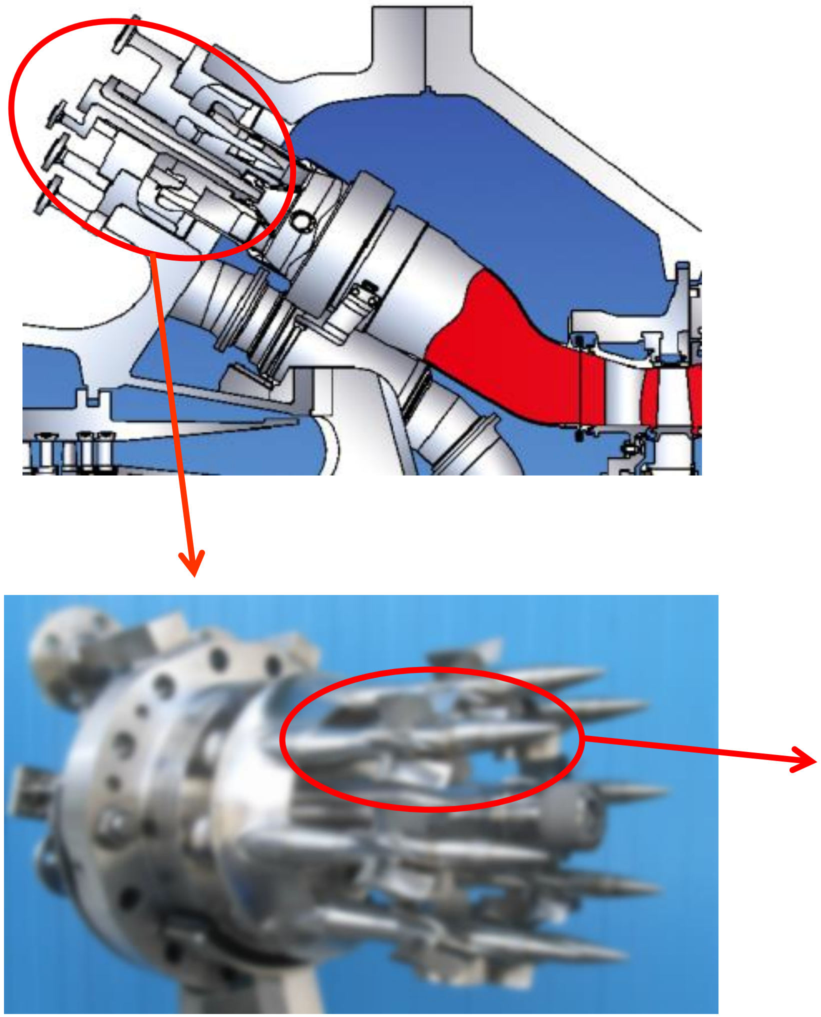
Flashback

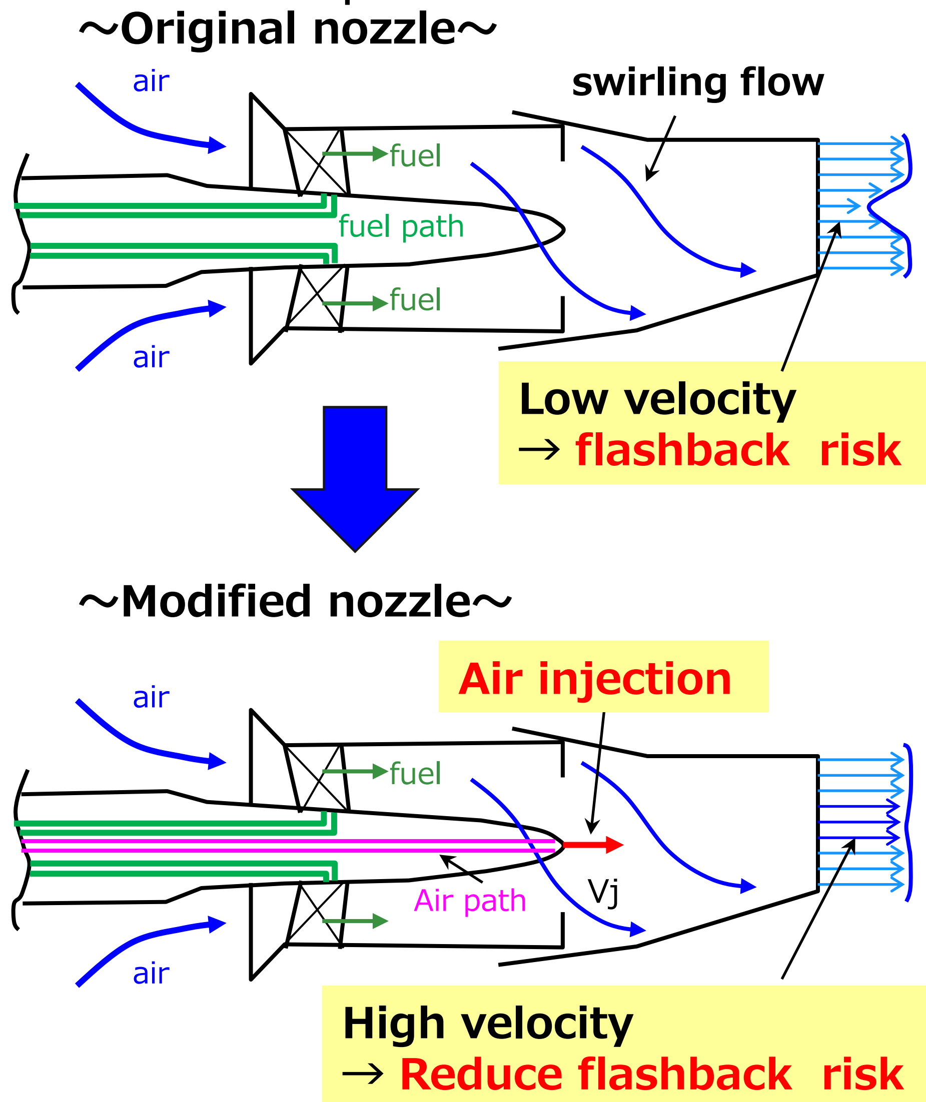


Source: Texas University Flow field Imaging Laboratory

Dry Low NOx combustor

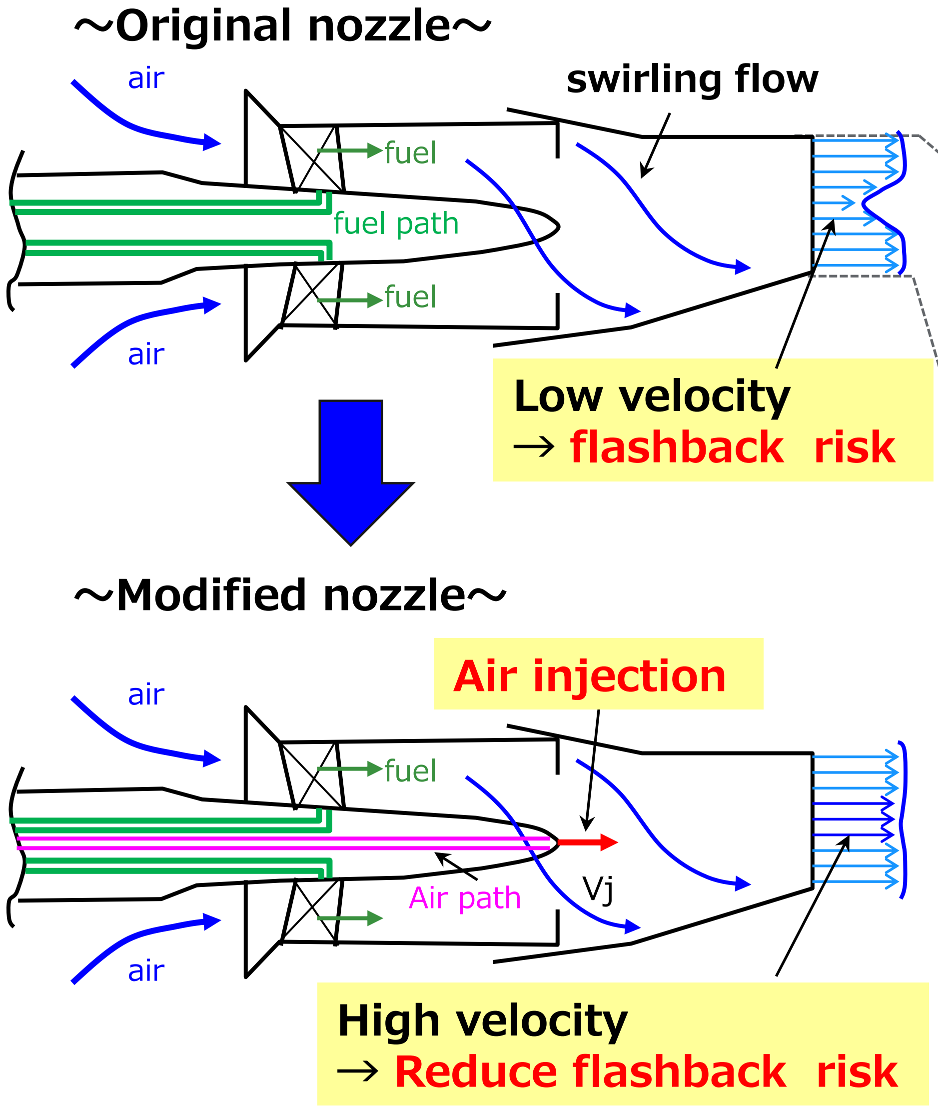
DLN combustor requires countermeasures to prevent Flashback.

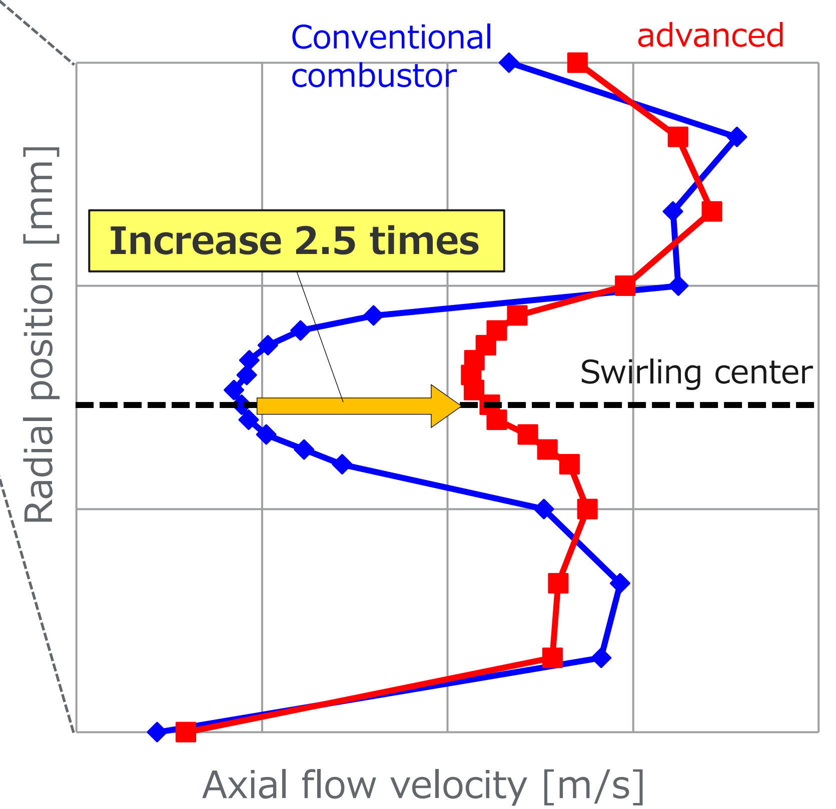




Dry Low NOx combustor

The Axial flow velocity is increased 2.5 times.





Dry Low NOx combustor

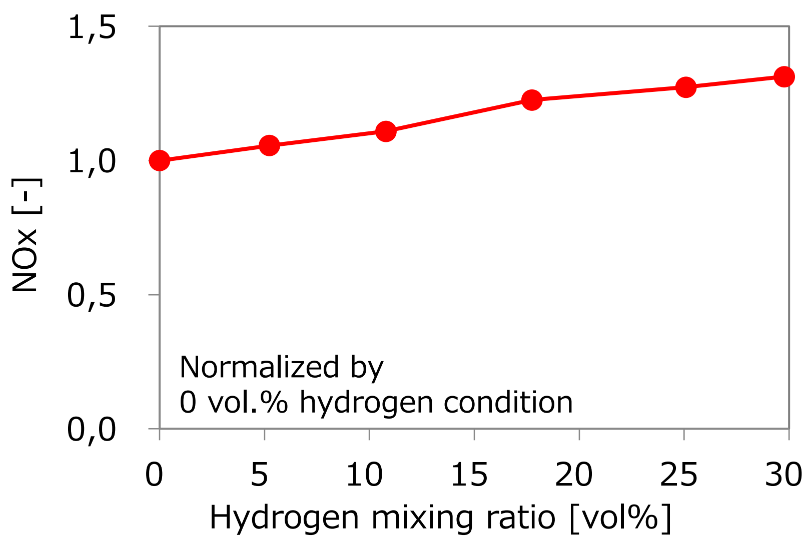
Under the condition of 30% hydrogen in the fuel,
no flashback occurred and the combustion was stable.

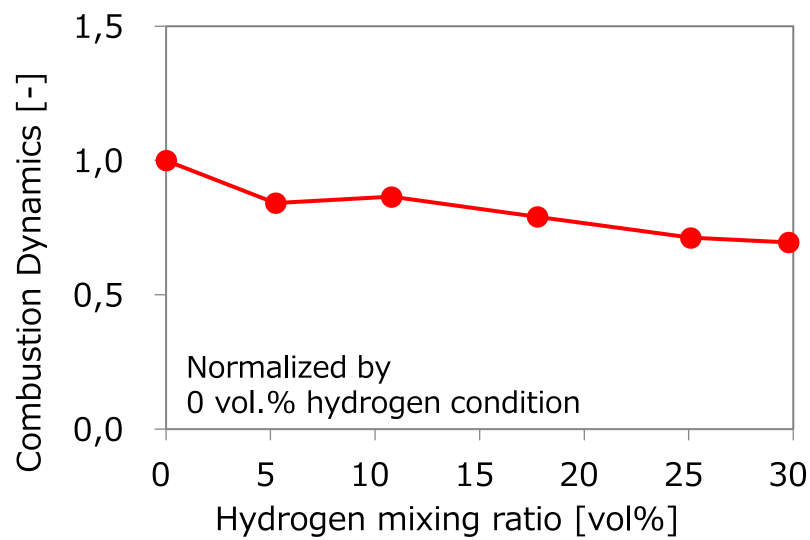
Test facility

T1T=1600degC condition

Combustion rig

Hydrogen loader





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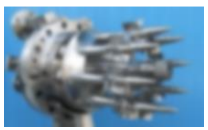
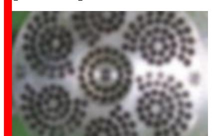
Ready	**Type 2: Pre-Mix (DLN)** 	Dry	1600	**30%**	1982 DLN; **2018 30% co-firing test completed**
Under development	**Type 3: Multi-Cluster (DLN)** 	Dry	1650	**100% (target)**	**Mar, 2025 Rig test completion target**

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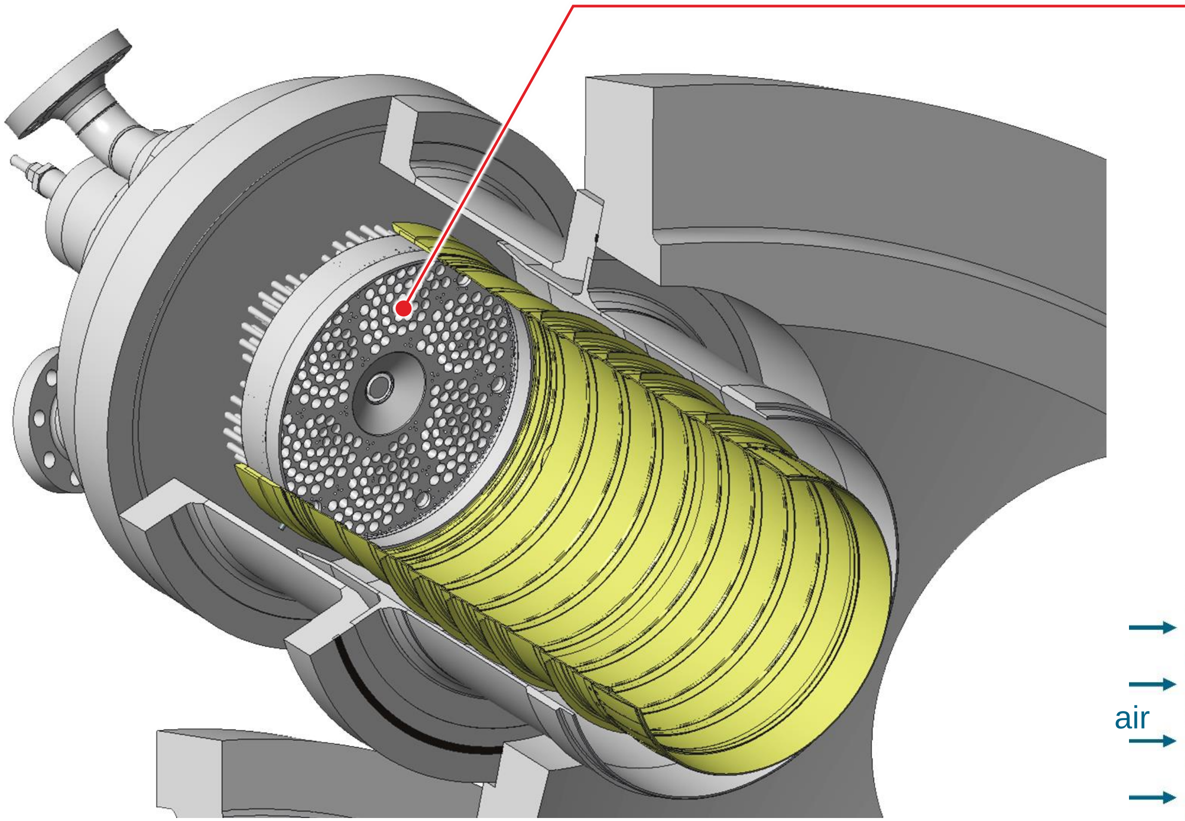
**DLN：Dry Low NOx

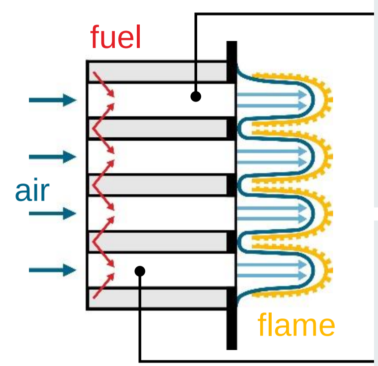
Multi Cluster DLN combustor

MHI is currently developing DLN technology called Multi-Cluster Combustor for 100% H_2 firing.



Multi-Cluster (DLN combustor)

Burner front view



No swirling flow
High velocity
Shorter pre-mixer

Reduce Flashback risk

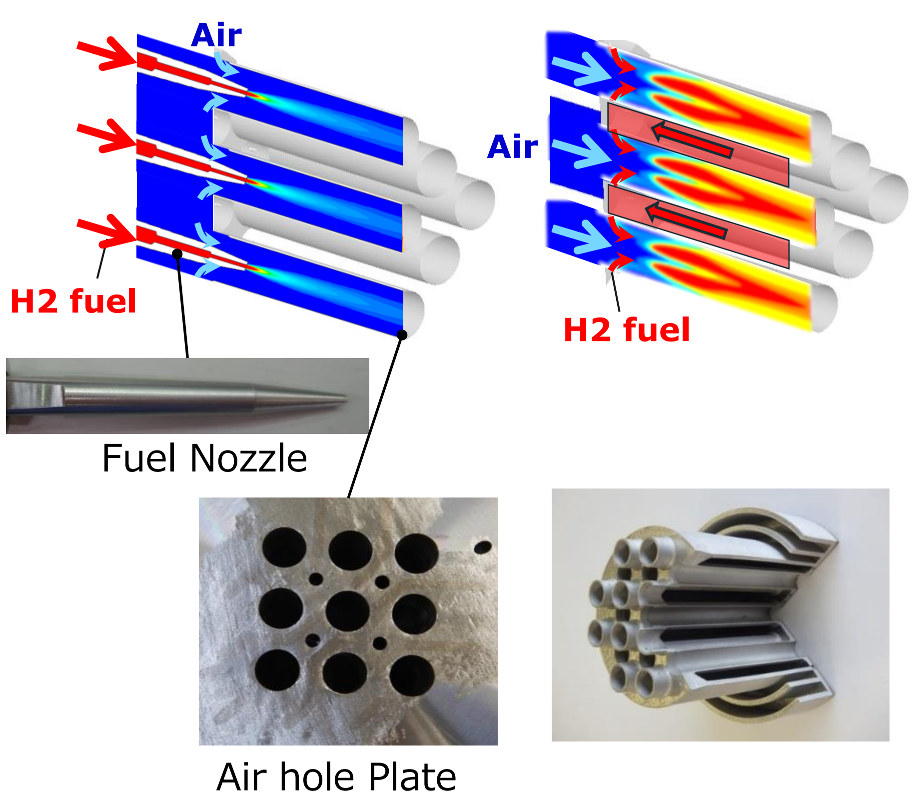
Distributed nozzle

Reduce NOx

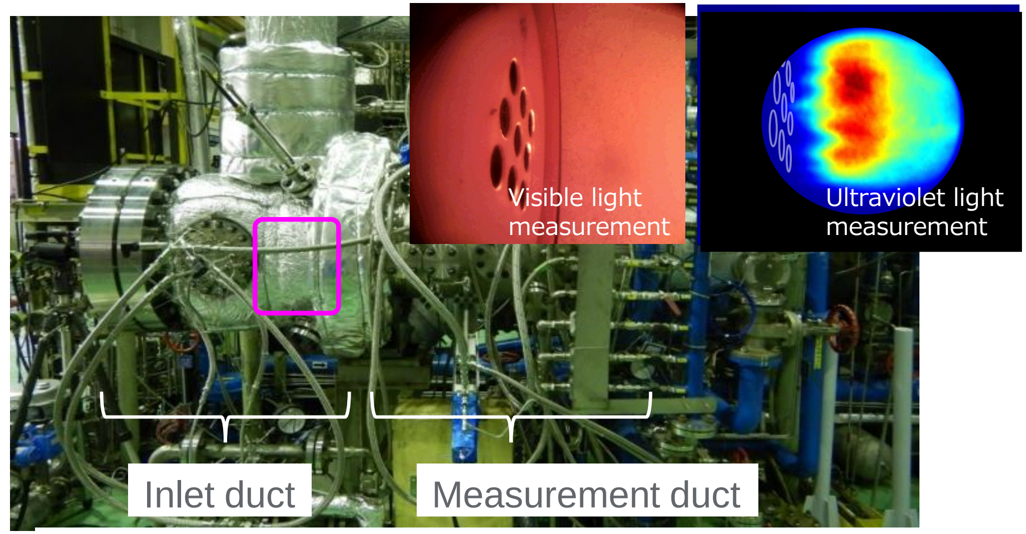
Multi Cluster DLN combustor

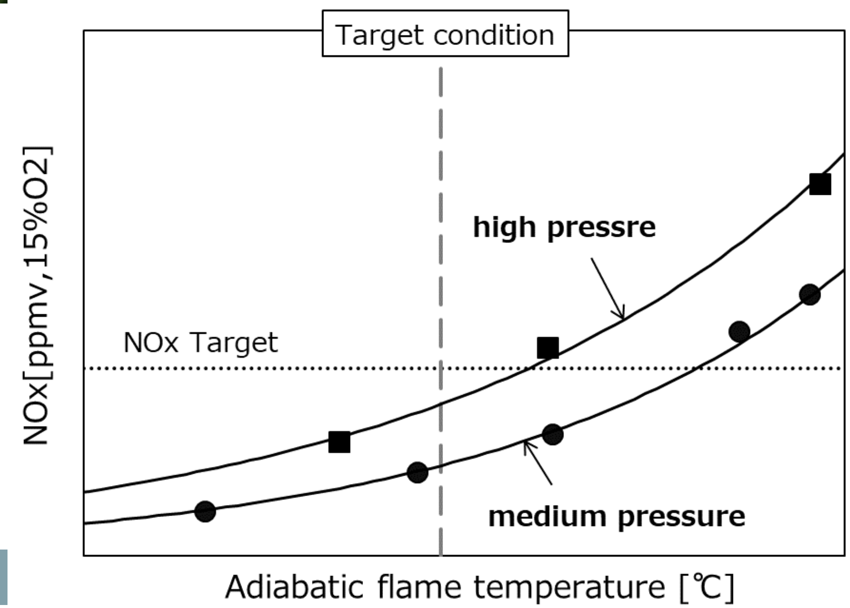
100% H_2 combustion test under the actual gas turbine pressure successfully demonstrated without flashback at the elemental test facility.

Co-axial type　Cross follow type



Burner for element test





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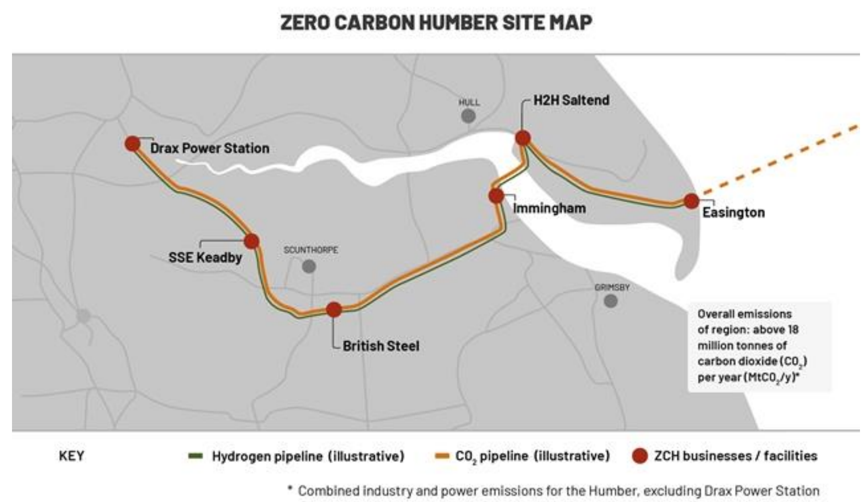
Zero Carbon Humber, H2H Saltend (UK)

MHI has been participating Zero Carbon Humber Partnership in the UK to create the world's first net zero industrial cluster by 2040.

Saltend power plant in the UK (Humber)



Hydrogen to Humber (H2H) Saltend project:
a partnership to build the world's first net zero industrial cluster and decarbonize the North of England.

Feasibility study bid under UK funding.
30% H2 co-firing in Saltend GTCC is the starting point of the project.

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Summary

MHI is actively researching and developing new technologies on hydrogen fuel utilization in gas turbine.

1. Combustion test was **successfully carried out 30vol% hydrogen** co-firing at turbine inlet temperature of 1600℃.
2. Using Multi cluster combustor, **100% H_2 combustion test under the actual gas turbine pressure successfully demonstrated** without flashback at a test facility.
3. MHI has been participating **Zero Carbon Humber Partnership in the UK** to create **the world's first net zero industrial cluster by 2040.**

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