9th International Gas Turbine Conference
10-11 October 2018, Brussels, Belgium

DEVELOPMENT OF HYDROGEN AND NATURAL GAS CO-FIRING GAS TURBINE

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~Technology Developments for a Low Carbon Society~

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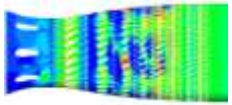
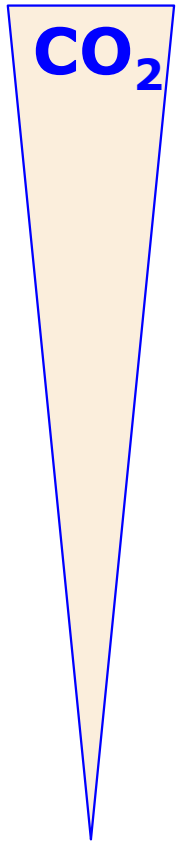
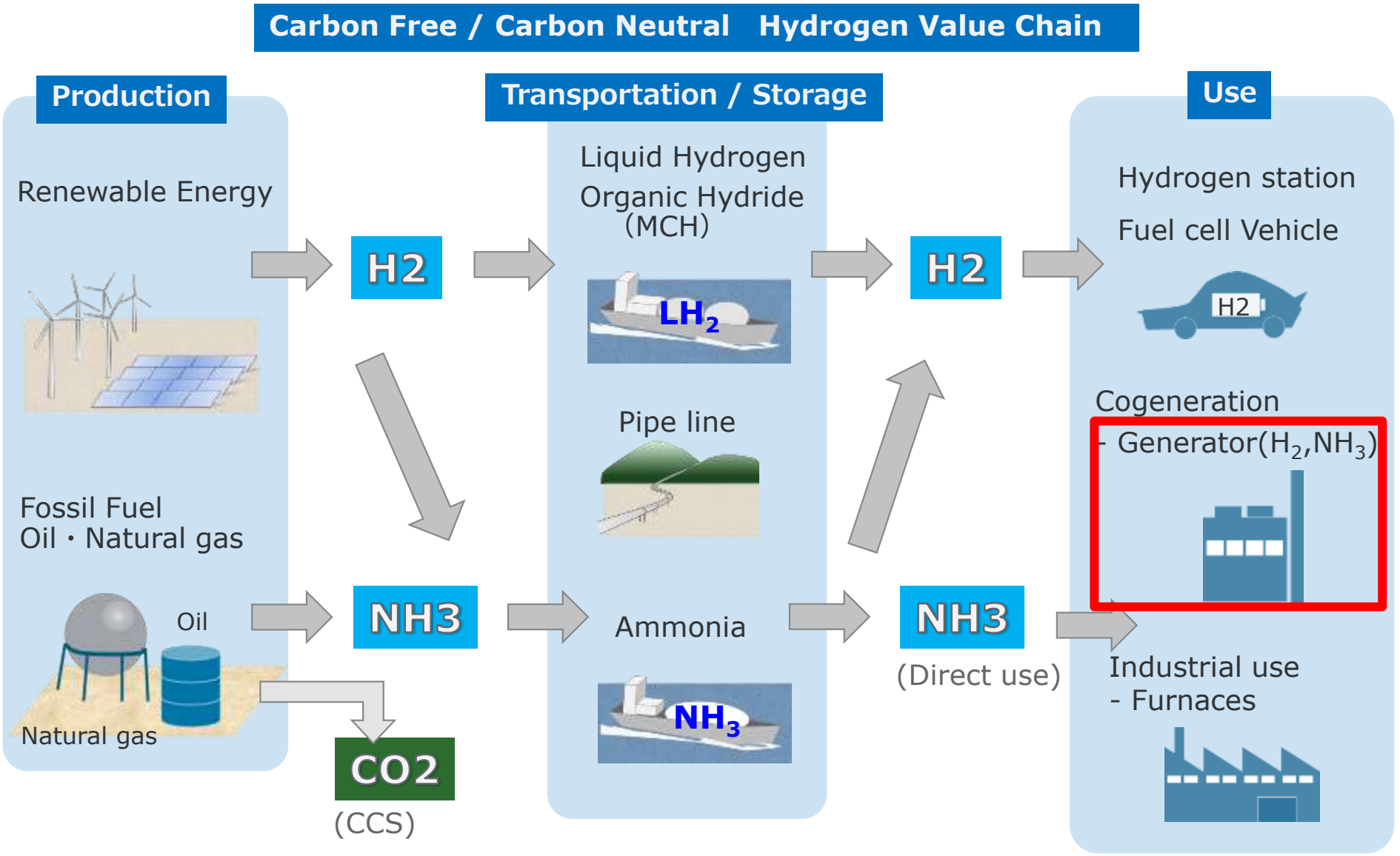
② Rapid Response Gas Turbine



③ H2/Ammonia combustion GT

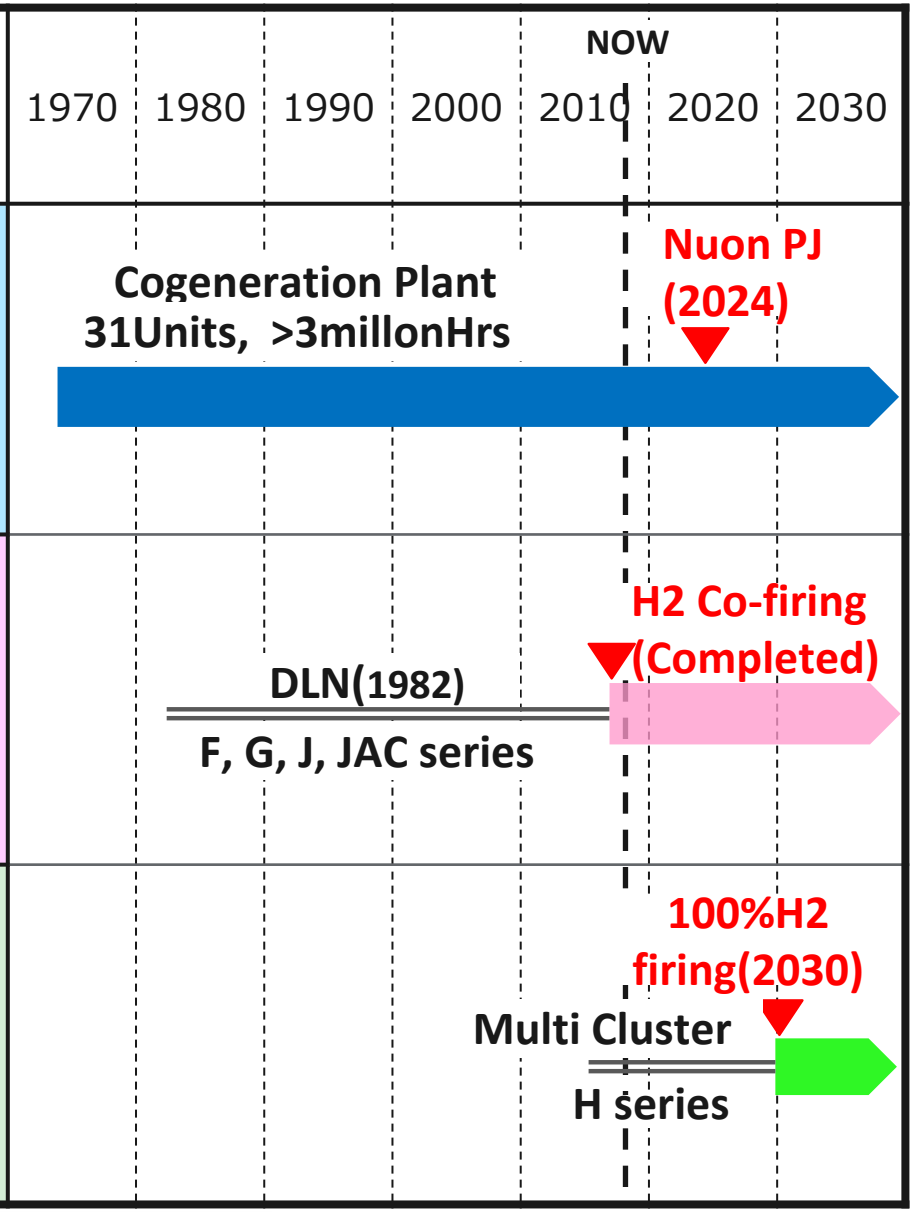


1. Low Carbon Society ~Hydrogen Value Chain~



2. Hydrogen Firing Combustor Development

Combustor Type	Low NOx	Available H2 ratio
Diffusion	Water Injection	100% H2
DLN	Multi nozzle	Premix	30vol% H2 (NEDO)
DLN	Multi Cluster	Premix	100% H2 (NEDO)



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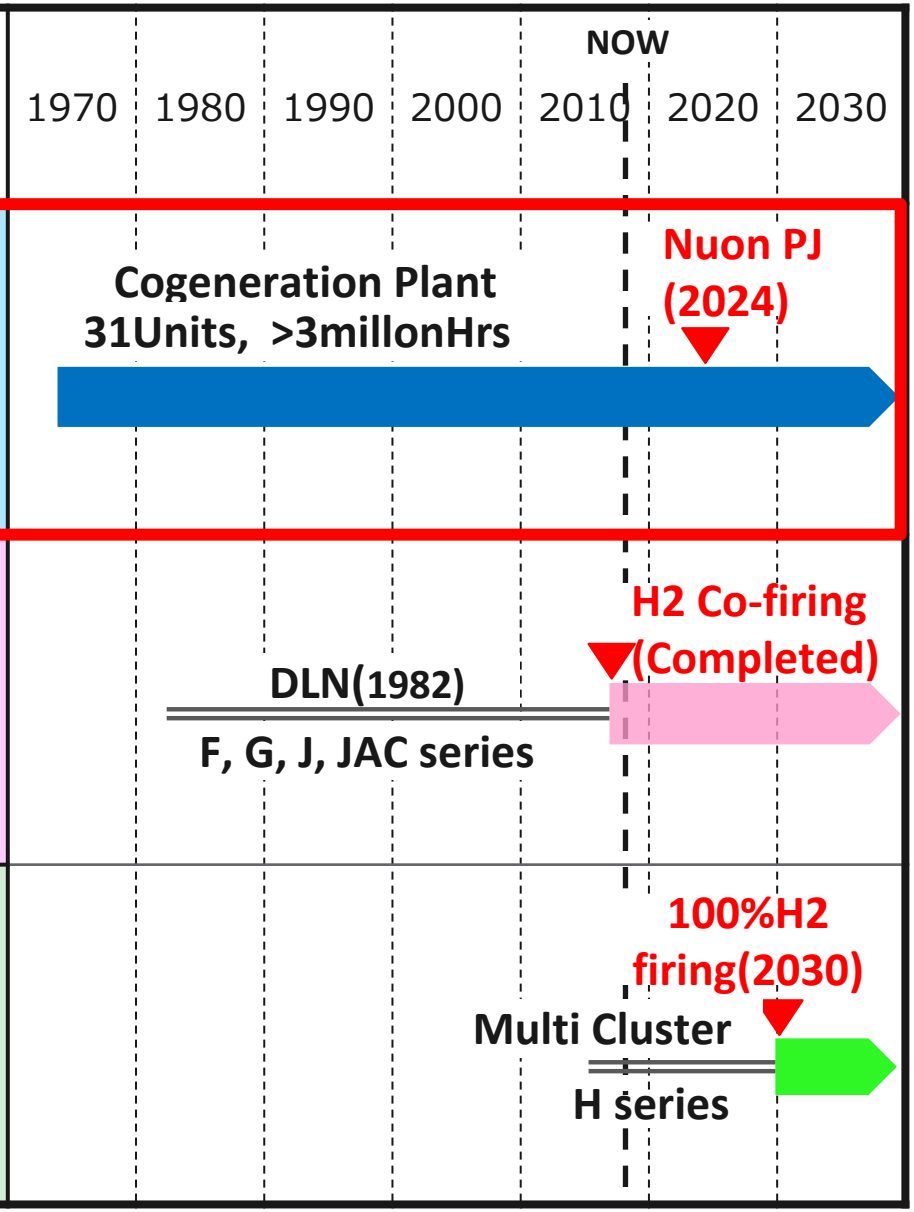
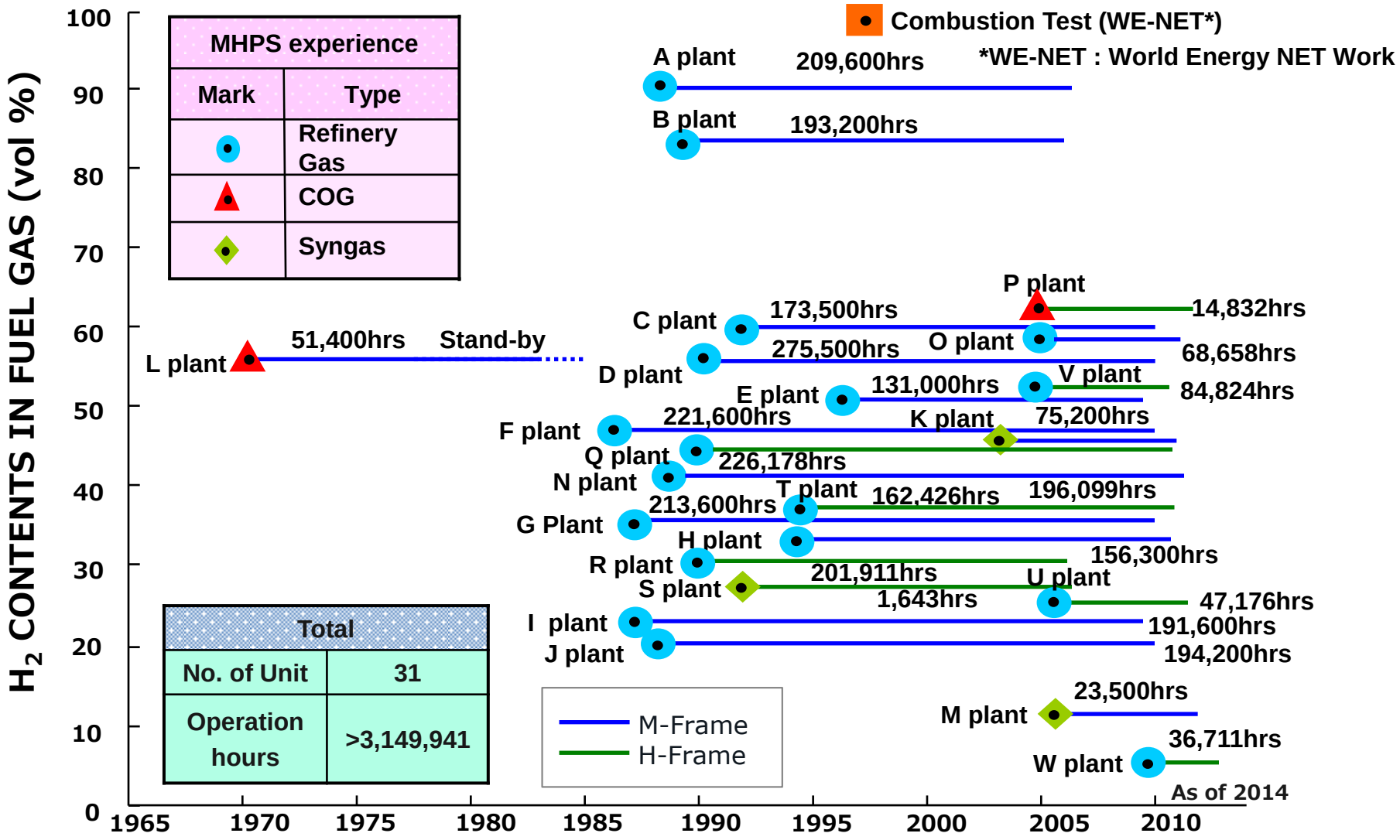


2. Hydrogen Firing Combustor Development ~Hydrogen rich fuel operating experiences~

H2 fuel experiences by diffusion combustor in 31units, 3mil hours since 1970's.



2. Hydrogen Firing Combustor Development
~Hydrogen conversion project with diffusion combustor~

MHPS joins in a hydrogen conversion project at Nuon's Magnum power plant in the Netherlands.

PJ organization

Statoil — Energy supplier

Vattenfall / Nuon — Owner of Nuon Magnum

Gasunie — Gas infrastructure and transporter

MHPS — GTCC OEM

Gas Turbine Combined Cycle(GTCC):440MW×3

Vattenfall's gas power plant Magnum. (Photo: Koos Boertjens / Vattenfall)

Schedule

~July 2018:
Feasibility Study

~2019
Permit approval by
the Netherlands Government

2019~2021
Modification work starts

2024
H2 firing (440MW GTCC)

2. Hydrogen Firing Combustor Development

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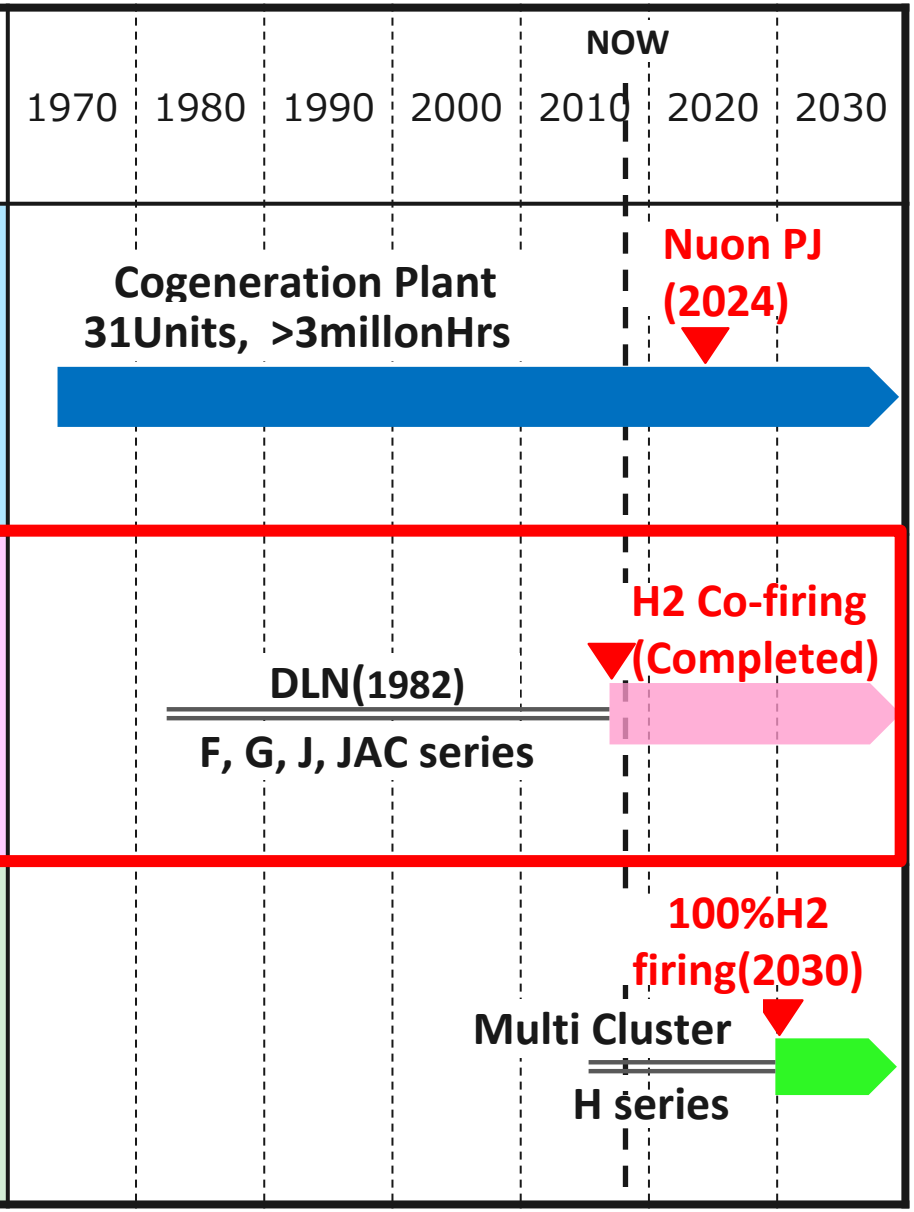
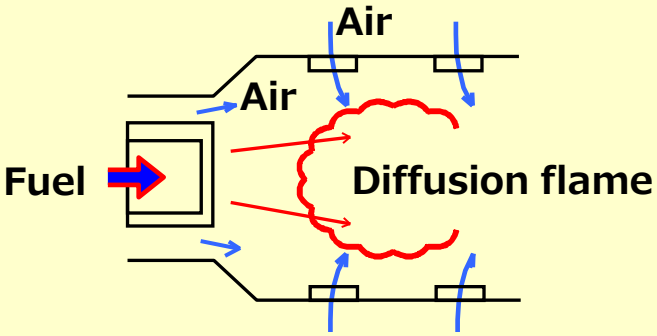
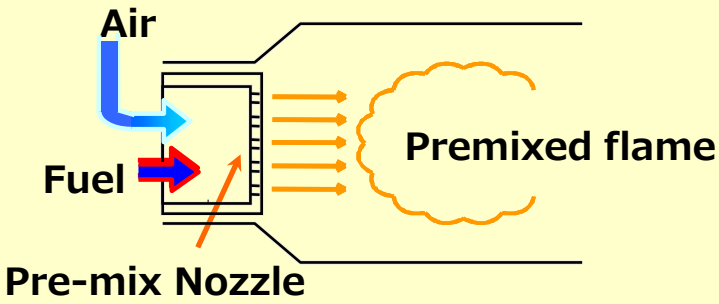
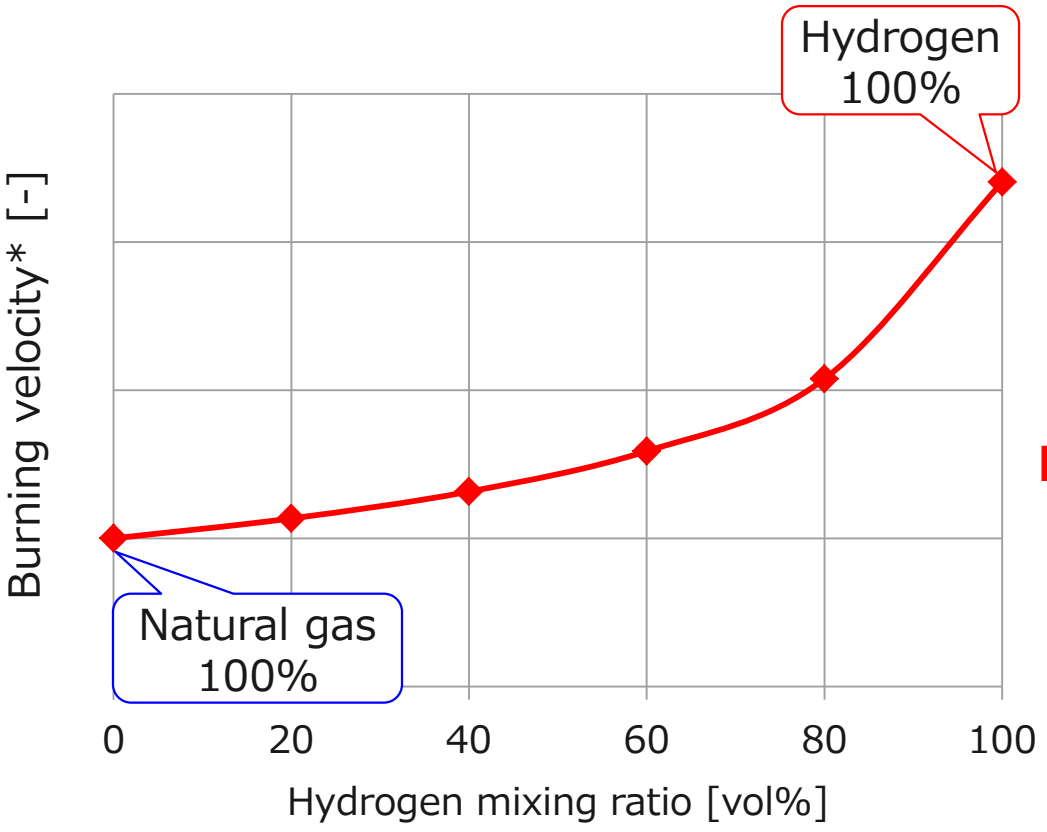


2. Hydrogen Firing Combustor Development
~Comparison of diffusion and premixed combustion~

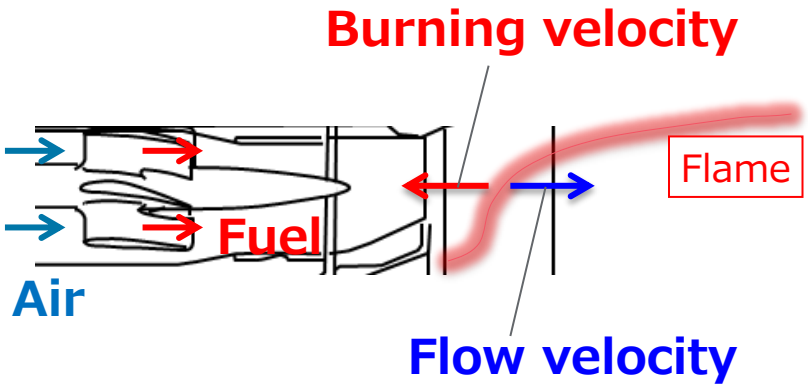
Type	Diffusion Combustion	DLN(Premixed Combustion)
Configuration		
Combustion method	• Fuel and Air are injected individually.	• Fuel and Air are mixed before combustion.
Characteristics	• **Water injection** required due to High NOx	• Low NOx **without water**
	• **Stable flame** for wide H2 mixing ratio	• Unstable flame **Flashback**

2. Hydrogen Firing Combustor Development
~Characteristics of Hydrogen Co-firing~

The risk of the flashback due to higher Burning velocity



*calculated by GRI3.0

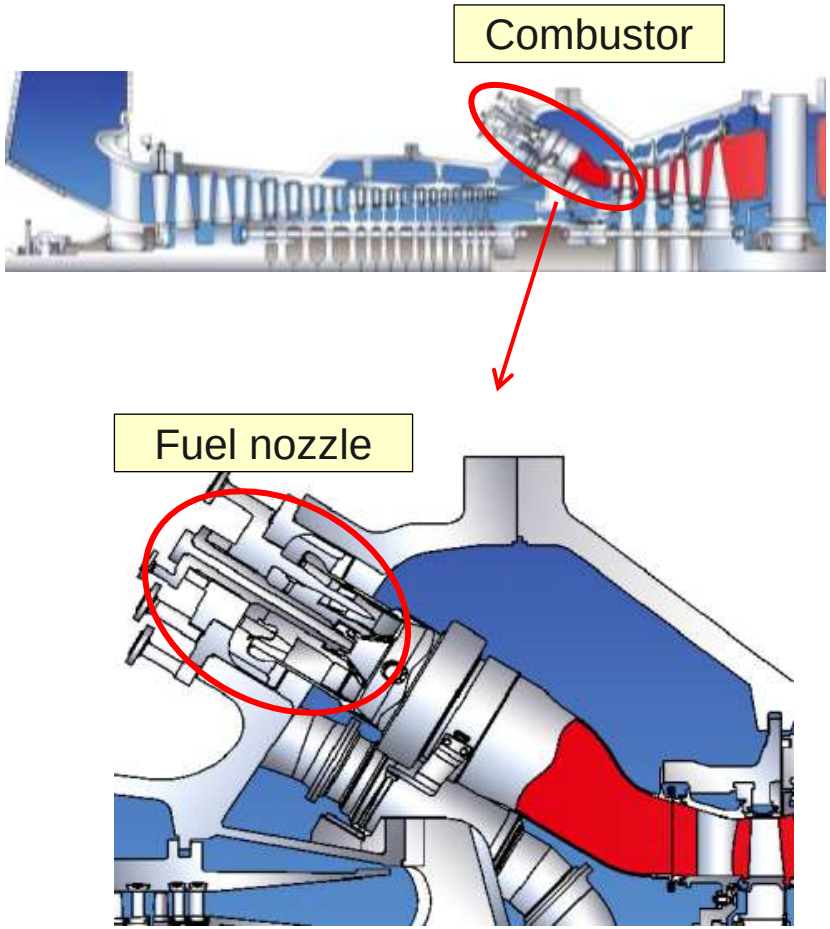


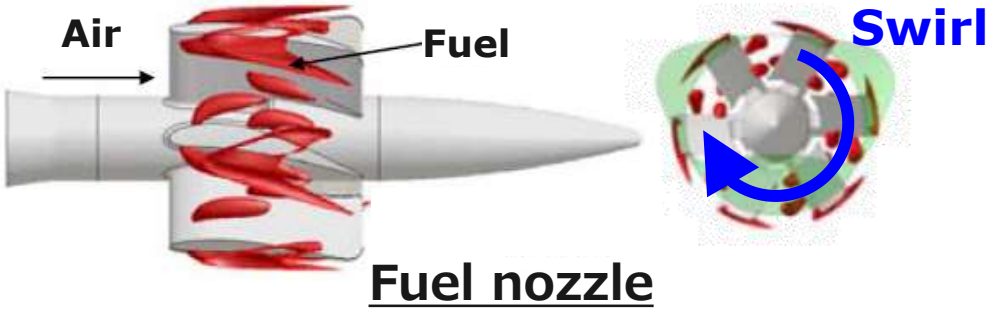
Burning velocity > Flow velocity

⇩

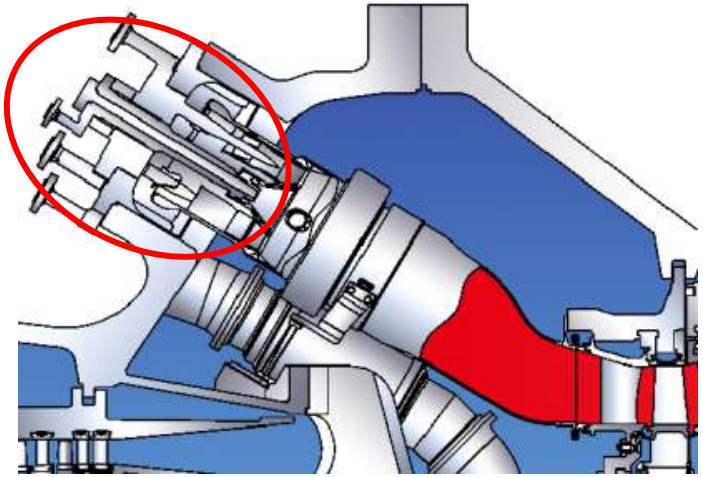
Flashback

2. Hydrogen Firing Combustor Development
~DryLowNOx combustor~

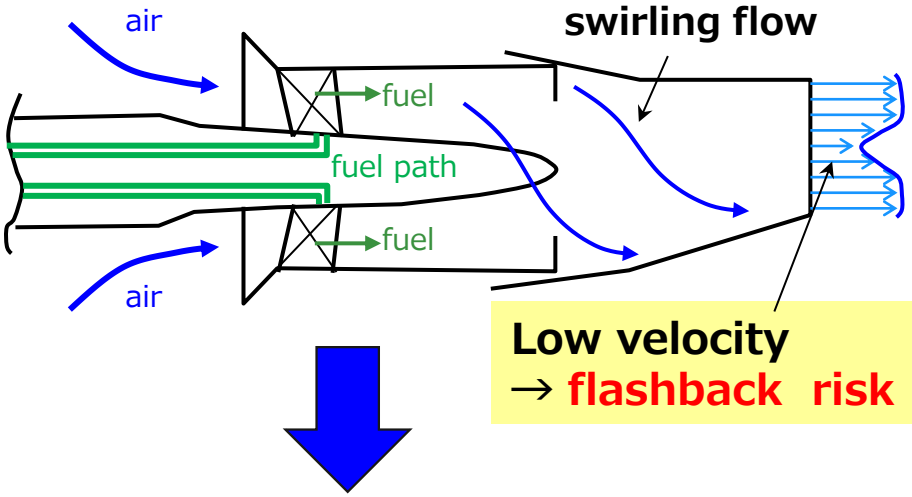




2. Hydrogen Firing Combustor Development
~DryLowNOx combustor~

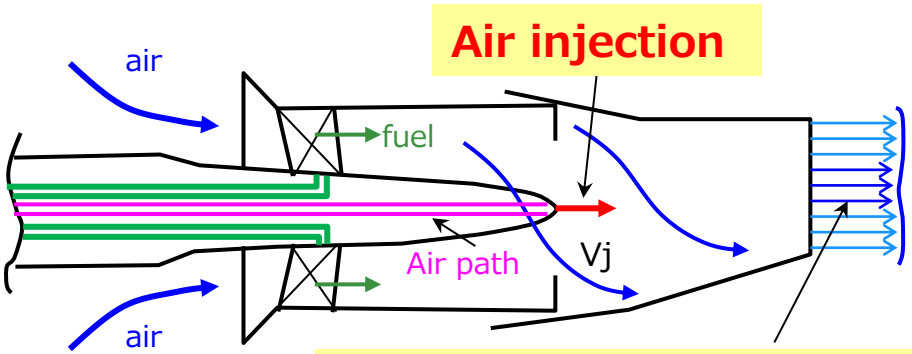


~Conventional nozzle~



Low velocity
→ flashback risk

~Advanced nozzle~

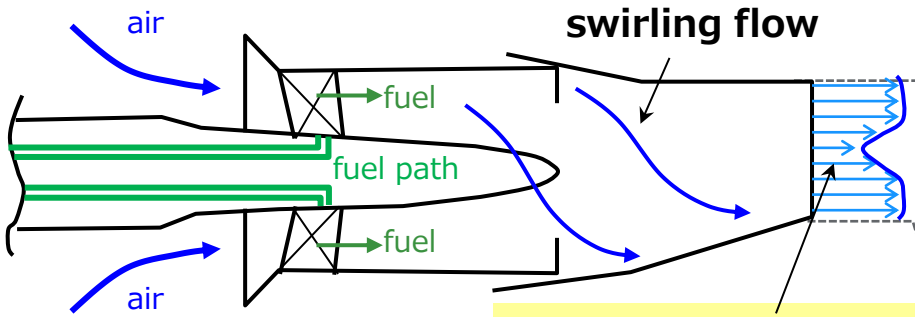


High velocity
→ Reduce flashback risk

2. Hydrogen Firing Combustor Development
~DryLowNOx combustor~

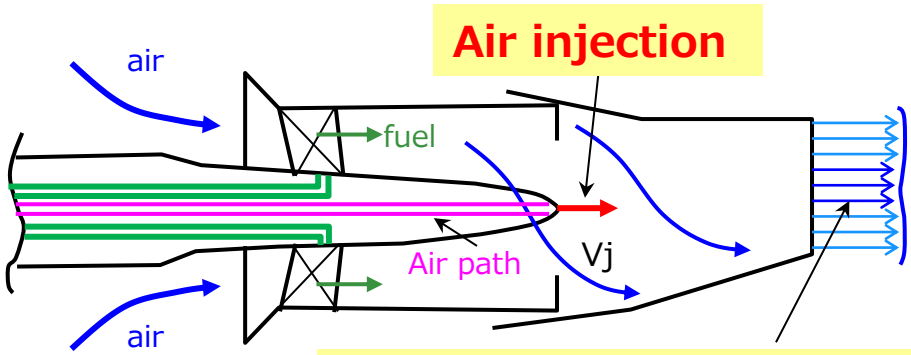
Verification by air flow test

~Conventional nozzle~

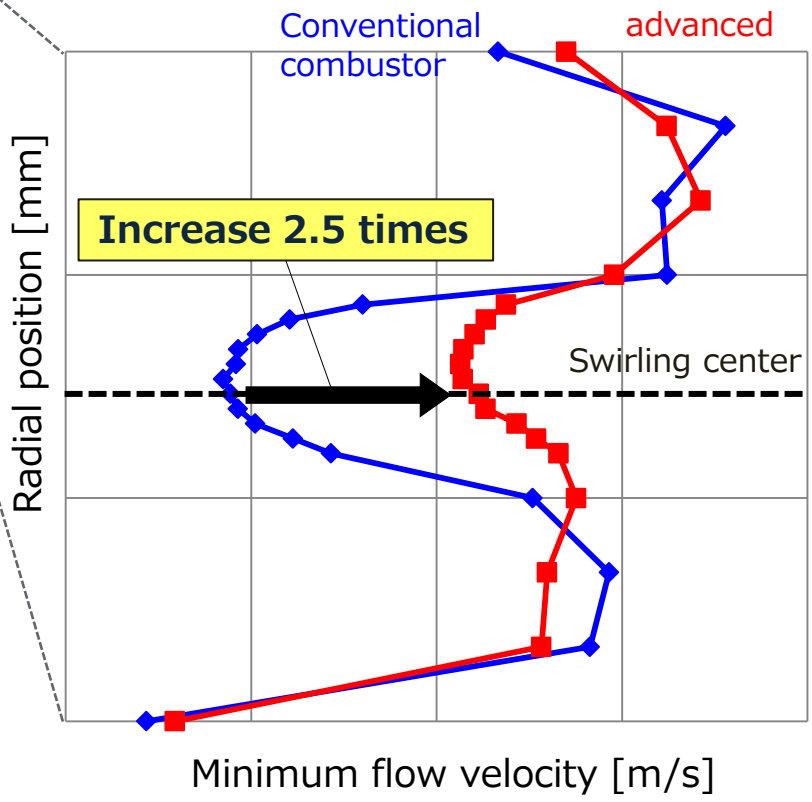


Low velocity
→ flashback risk

~Advanced nozzle~

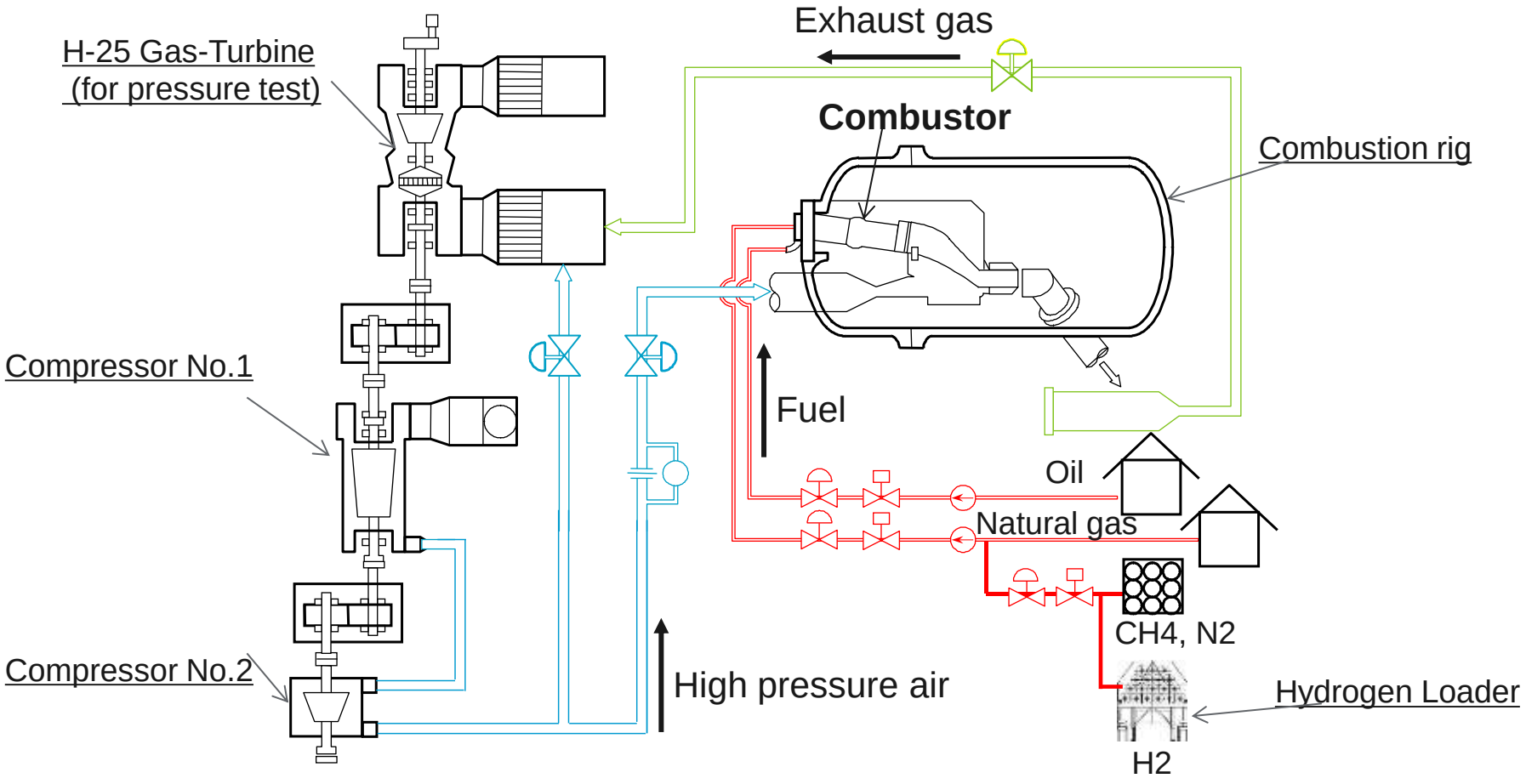


High velocity
→ Reduce flashback risk



2. Hydrogen Firing Combustor Development ~DryLowNOx combustor~

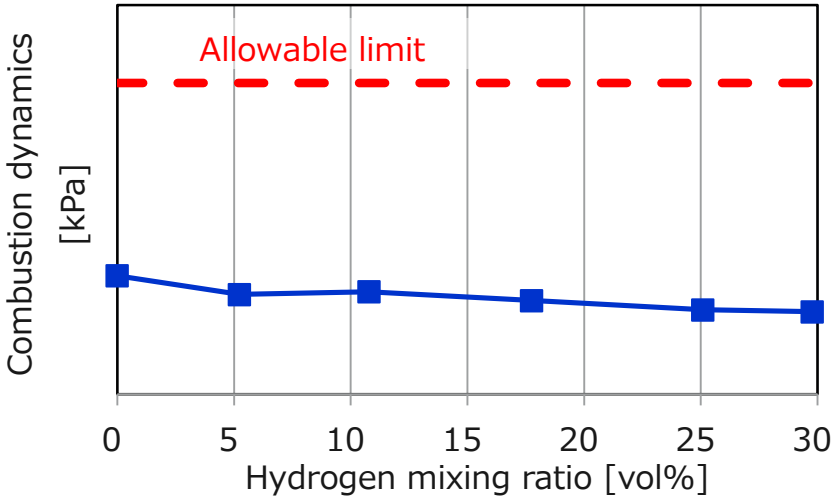
High pressure combustion rig test facility

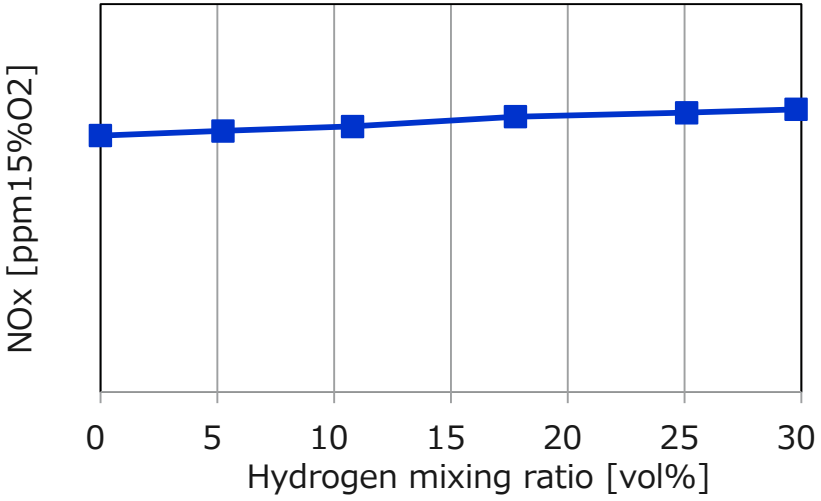


2. Hydrogen Firing Combustor Development ~DryLowNOx combustor~

Combustion test was successfully carried out **up to 30% without flashback** and combustion dynamics.

Test facility





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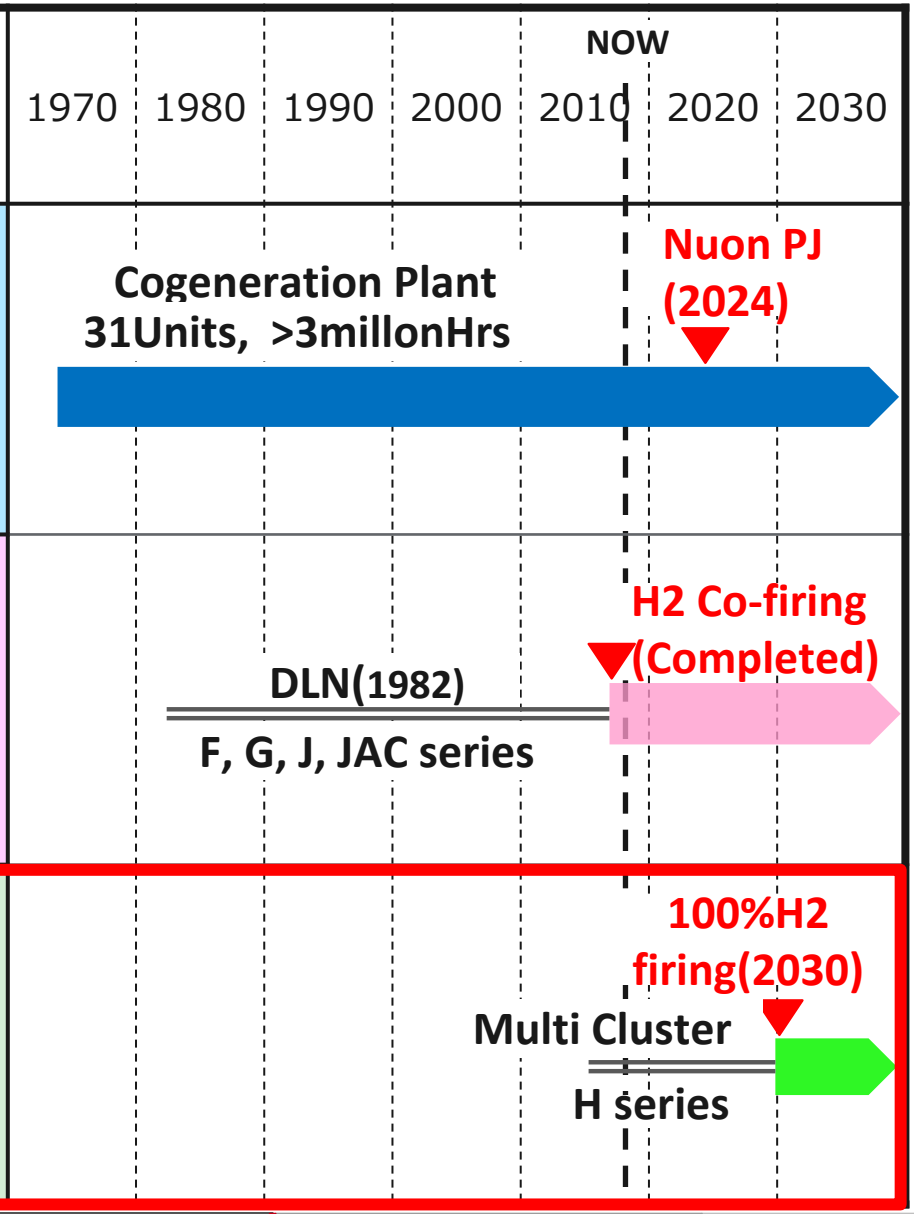
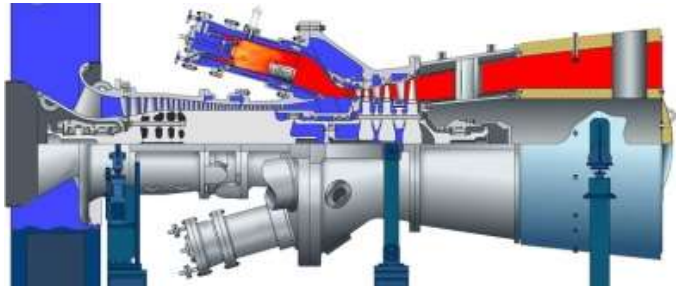


2. Hydrogen Firing Combustor Development
~Multi Cluster DLN combustor~

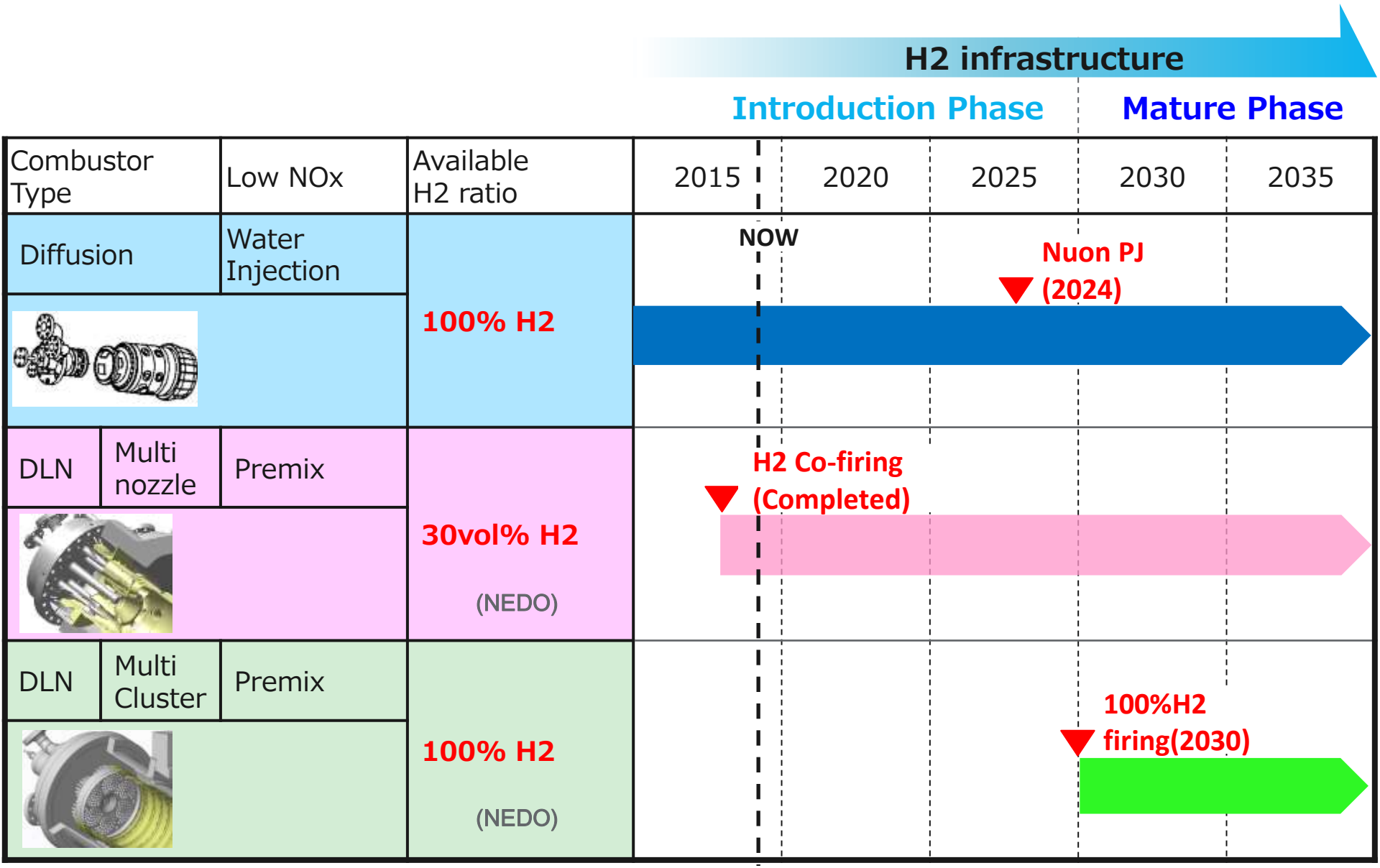
Multi Cluster with H2 mixing fuel experiences in H-series gas turbine.



GT type	H-15
Load	10MW

GT type	H-100
Load	170MW

3. Summary
~Hydrogen Road Map~



3. Summary

MHPS is actively developing new technology on hydrogen fuel for gas turbine.

1. MHPS joins in a hydrogen conversion project at **the first commercial hydrogen-fired Nuon GTCC**.
2. Combustion test was **successfully carried out 30vol% hydrogen** co-firing at turbine inlet temperature of 1600℃.
3. We are continuously **developing 100% hydrogen firing** using Multi cluster DLN combustor.

Thank You For Your Attention