8th International Gas Turbine Conference
The Future of Gas Turbine Technology

Development of Gas Turbine Combustors for Fuel Flexibility

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Outline

1. MHPS Line-up of Gas Turbines
2. Addressing Fuel Flexibility
3. GT Combustors for Natural Gas & Low Btu Fuels
4. Multi-Cluster Combustor for IGCC Syngas Fuels
5. Multi-Cluster Combustor for Dual Gaseous Fuels (Natural Gas/Petroleum Gas)
6. Summary and Next Steps

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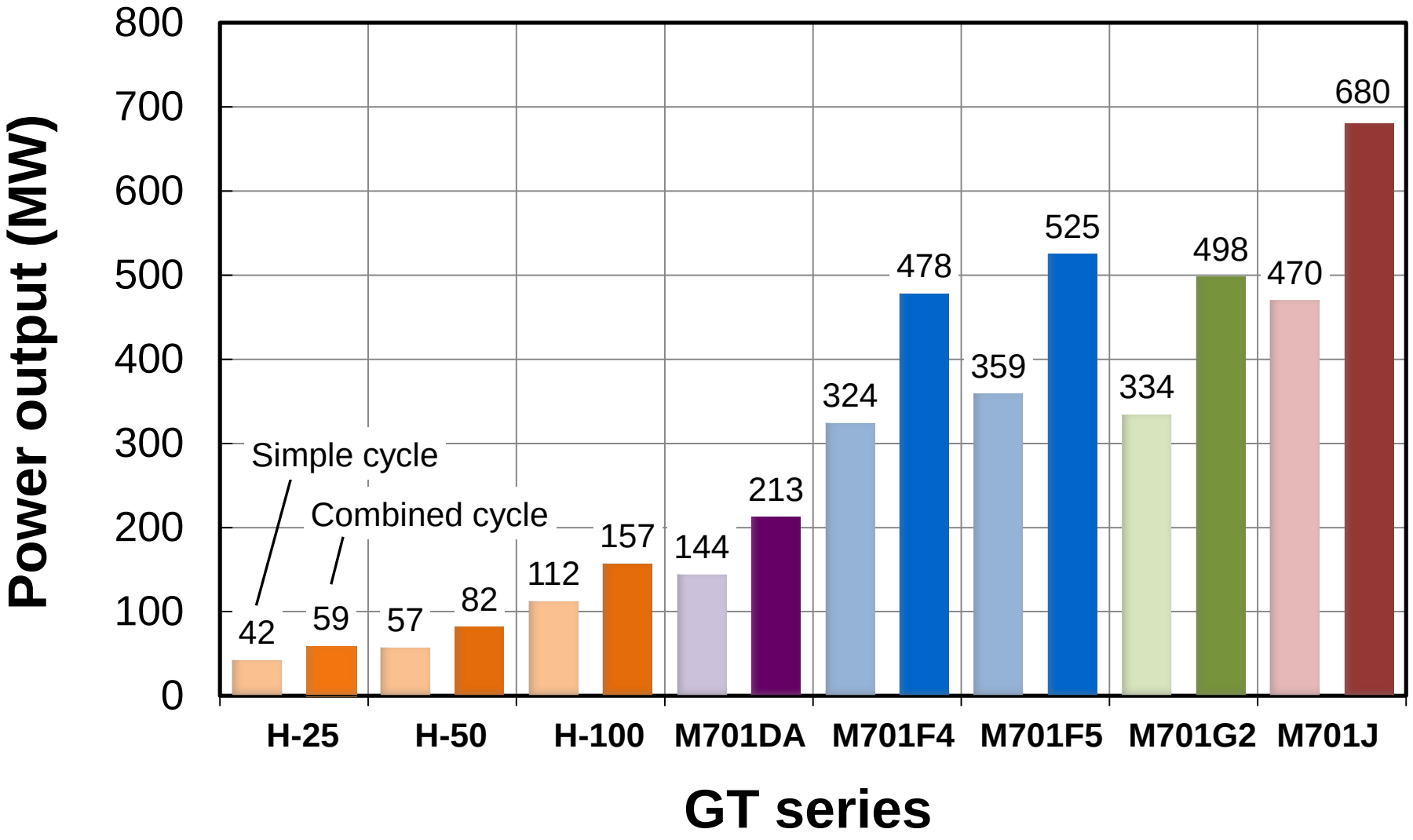
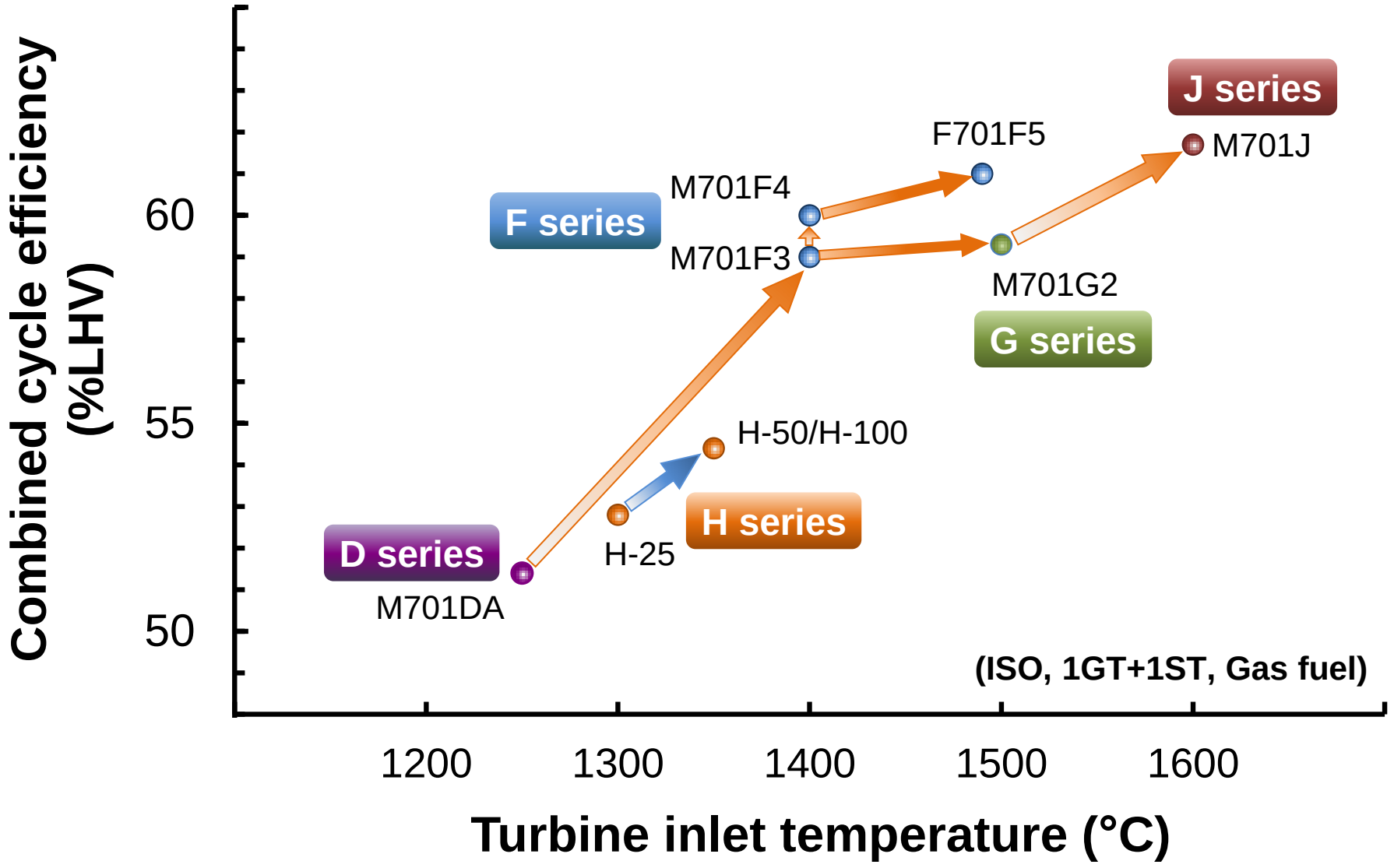
1-1 MHPS GT Line-up (50 Hz) - Power Output



1-2 MHPS GT Line-up (50 Hz) - C/C efficiency



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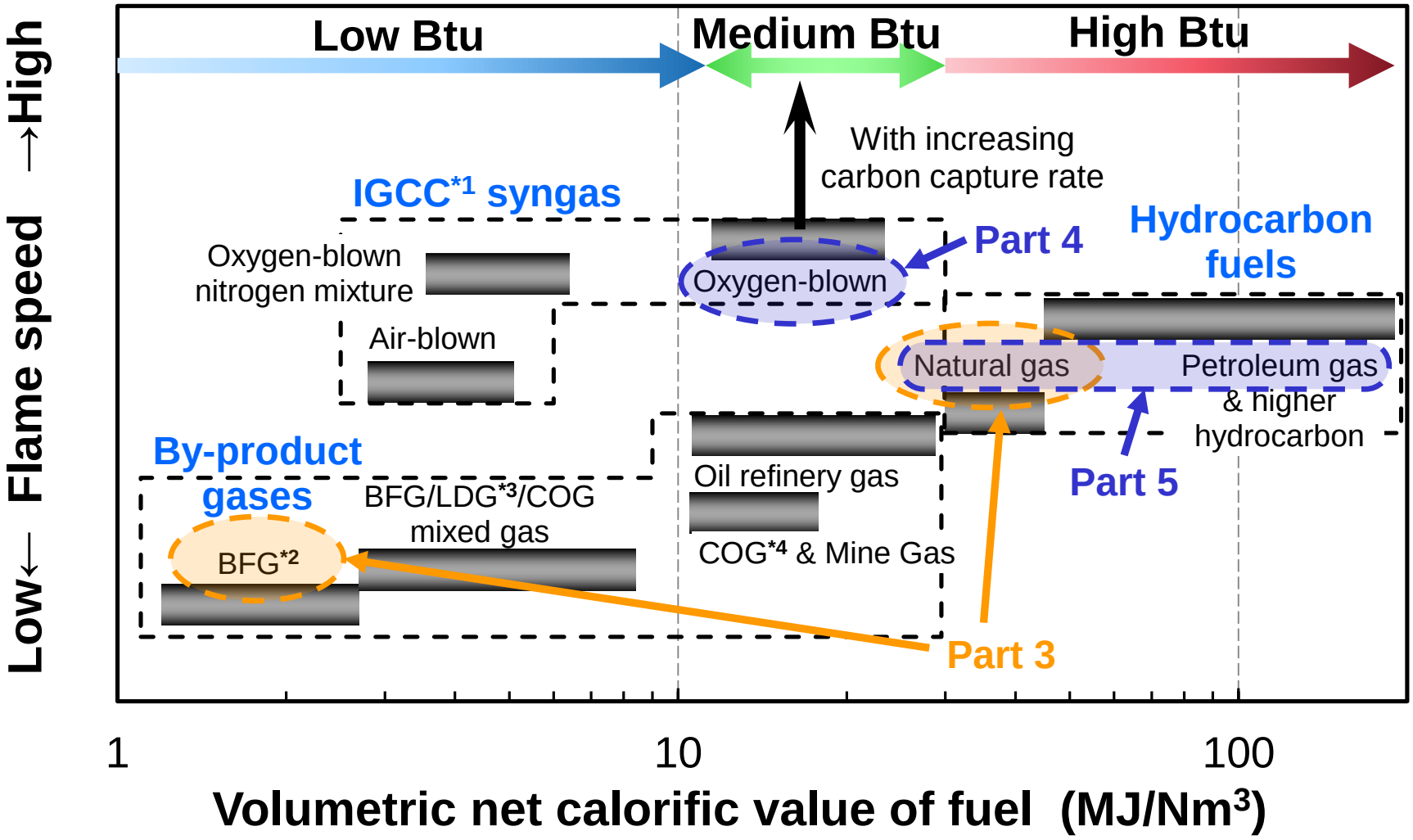
2 Addressing Fuel Flexibility



*1 IGCC: coal-based Integration Gasification Combined Cycle
*2 BFG: Blast Furnace Gas, *3 LDG: Linz-Donawitz converter Gas, *4 COG: Coke Oven Gas

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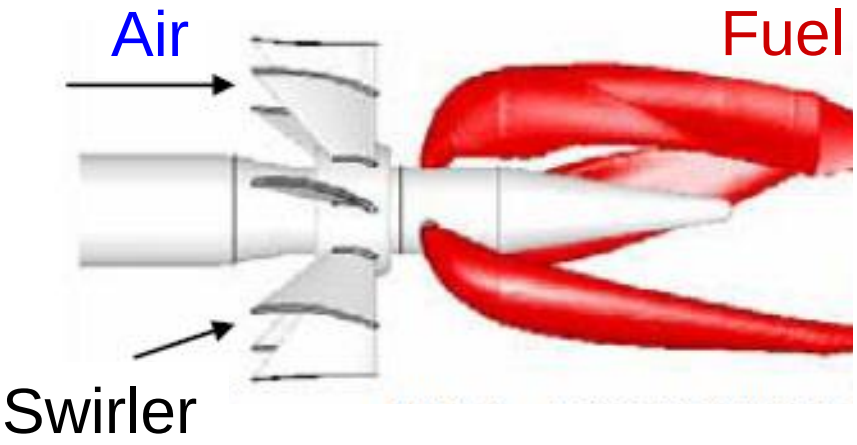
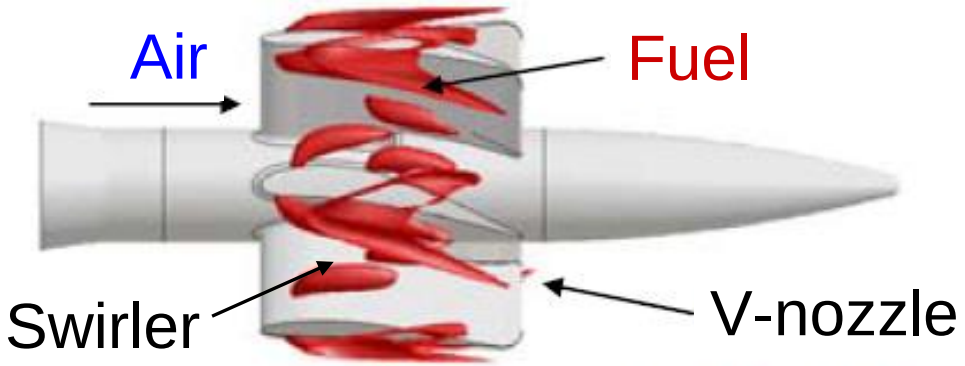
3-1 J-Series DLNC* for Natural Gas

- Combustor design concept
  1. Steam-cooled technology for cooling the combustion liner
  2. Advanced fuel nozzle “V-nozzle” for minimizing NOx by homogeneous fuel-air mixing



Conventional fuel nozzle

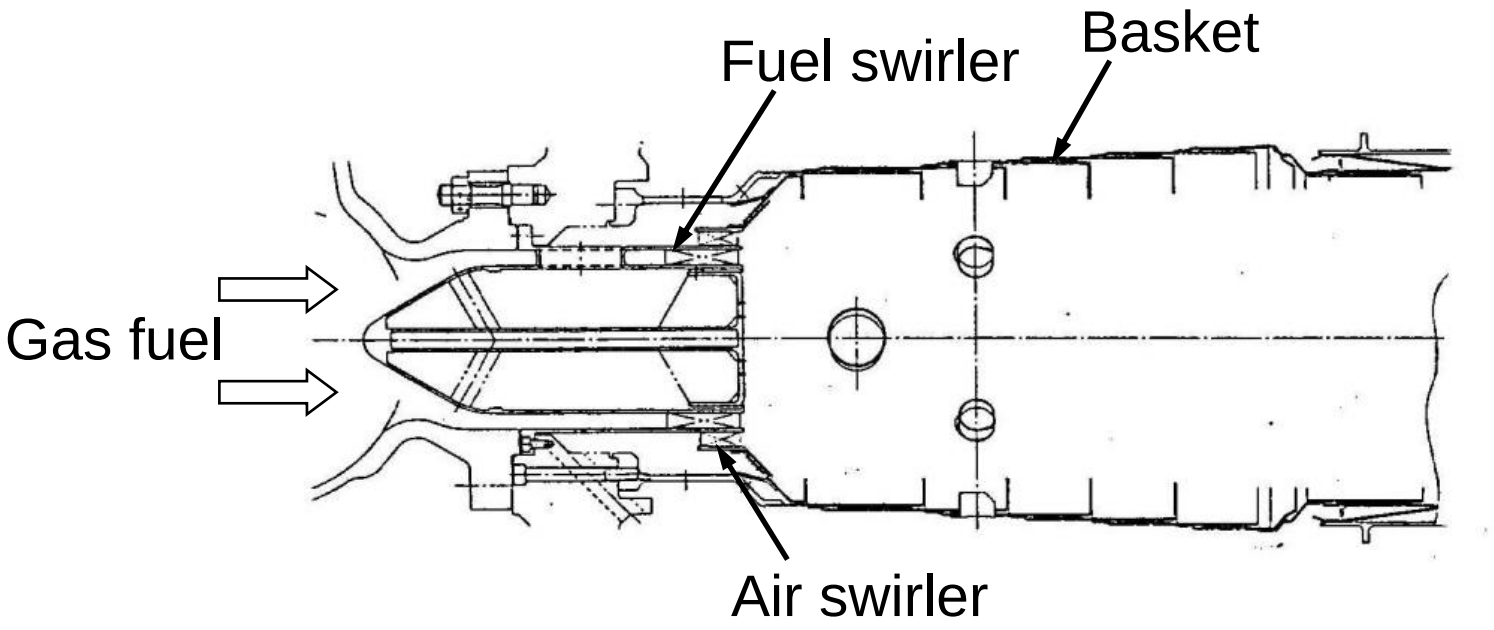


Advanced fuel nozzle

*DLNC: Dry Low NOx Combustor

3-2 Diffusion-Flame Combustor for Low Btu Fuels

- Technical hurdles with low Btu fuels (BFG)
  - Limited stable range, low flame speed, large amounts of fuel & air
    → Ensuring flame stability is required
- Design concept for BFG-fueled diffusion-flame combustor
  1. Basket with increased diameter for ensuring flame stability
  2. Fuel swirler for decreasing excessive nozzle pressure loss



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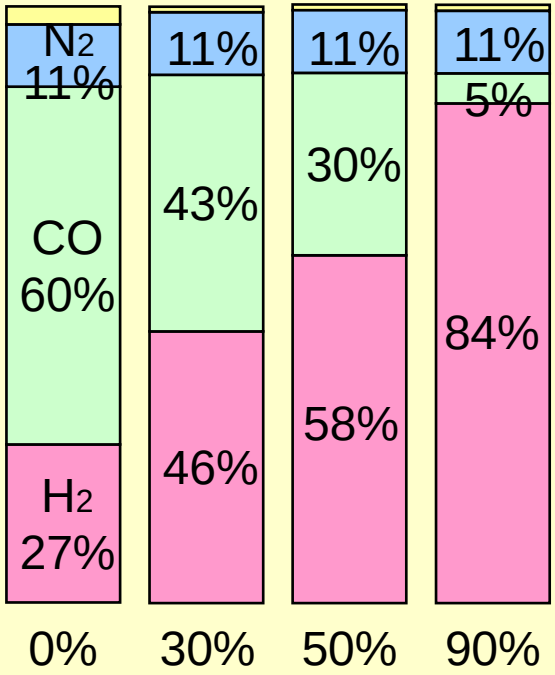
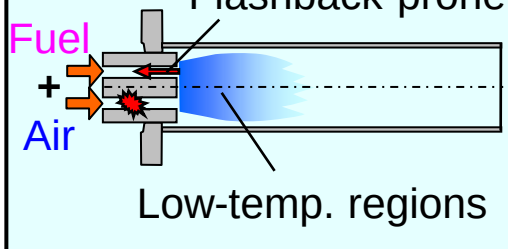
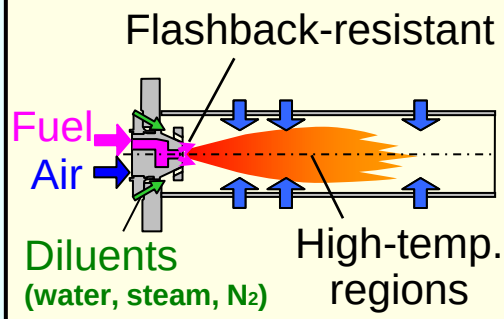
4-1 Application to IGCC Syngas Fuels

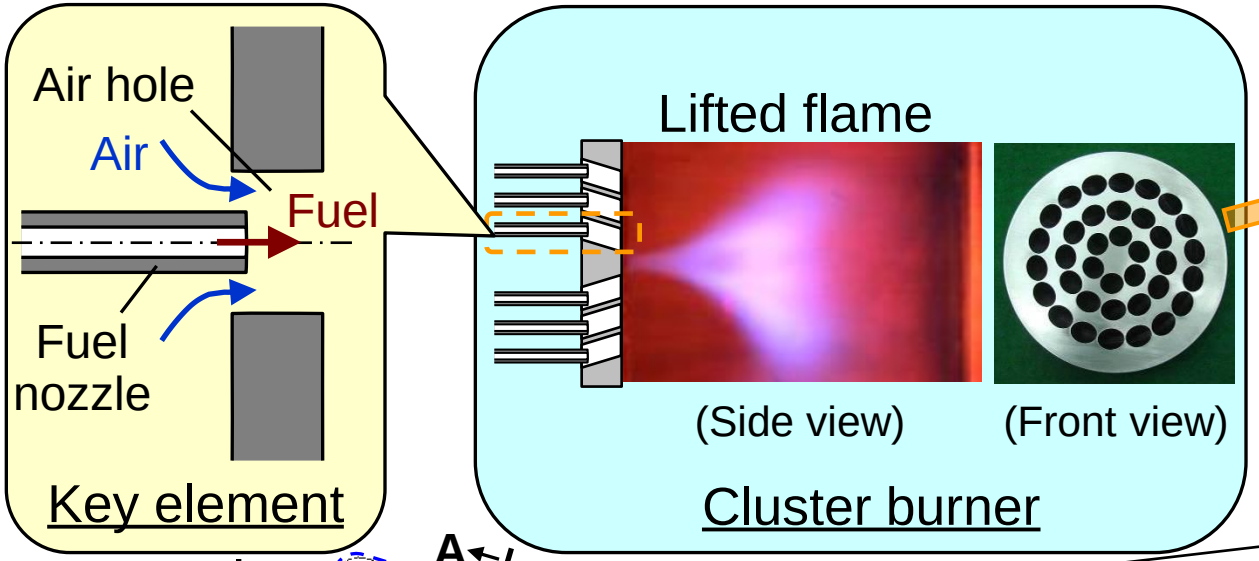
- Feature: H_2-rich syngas fuels in O_2-blown IGCC with CCS*
- Hurdle: Conventional combustors are incapable of achieving highly efficient and low-emissions power generation for H_2-rich fuels.
- Solution: Advanced combustion technologies for “dry” (diluent-free) low-NOx for high efficiencies and low emissions

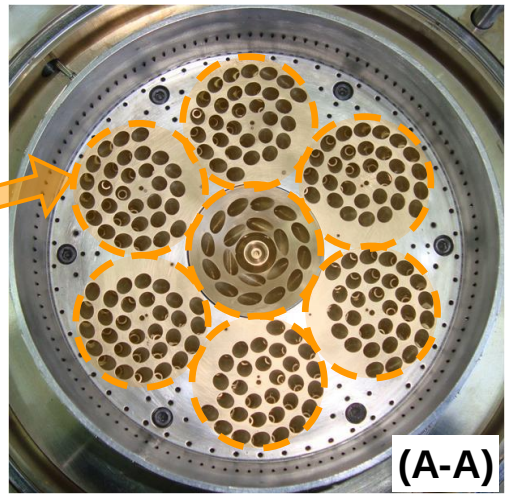


	Premixed combustor	Diffusion-flame combustor
Type		
Merit	**Low NOx**	**Flashback-resistant**
Demerit	**Flashback-prone**	**Efficiency decrease**
IGCC experience	**No**	**Yes**

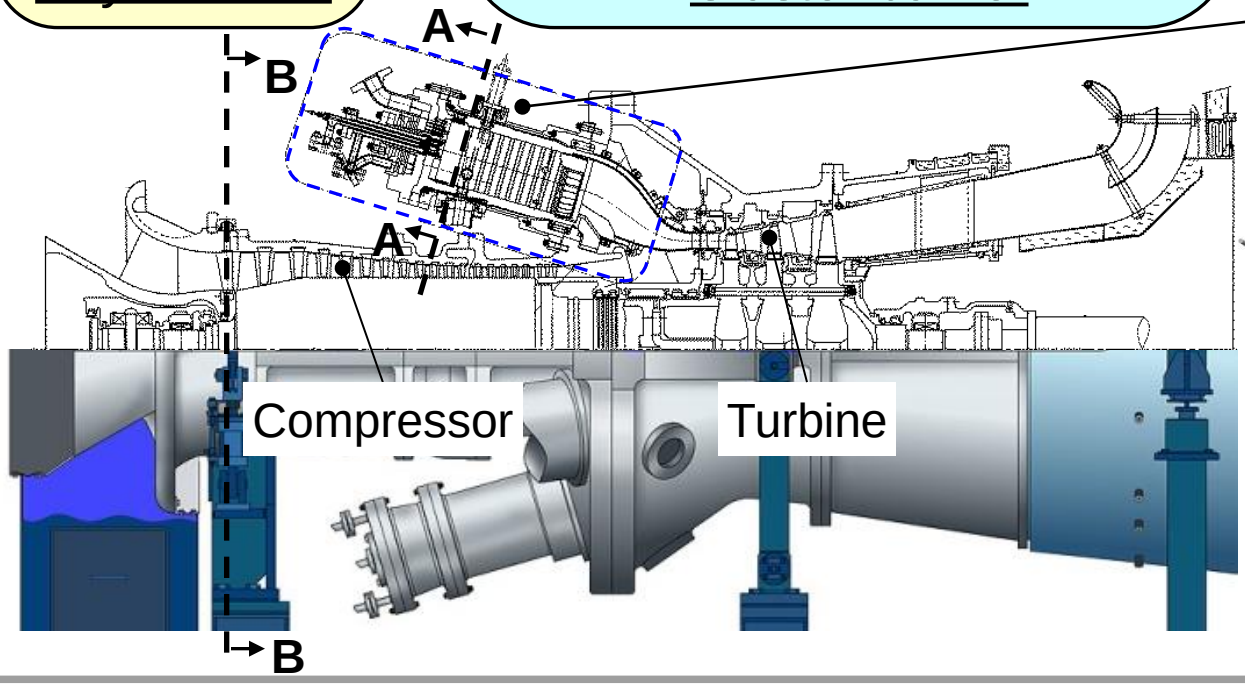
***CCS: Carbon Capture & Storage**

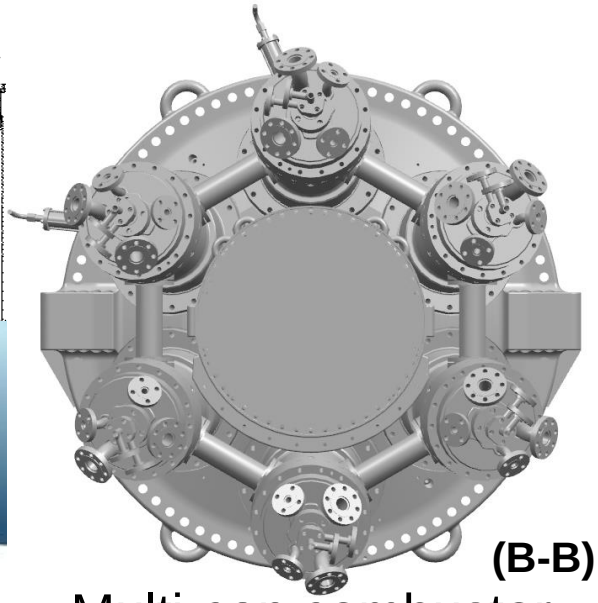
4-2 Multi-Cluster Combustor





Multi-cluster combustor

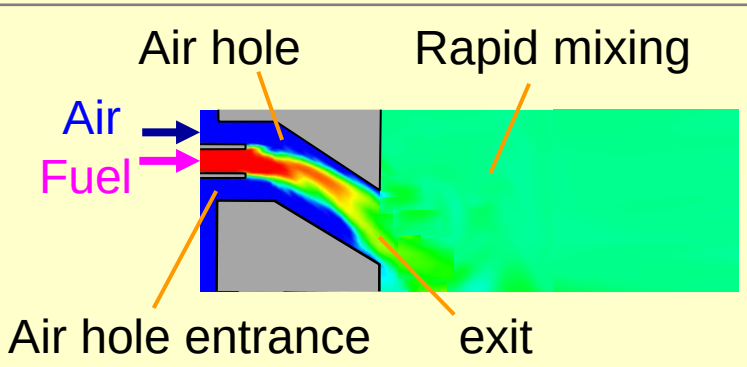
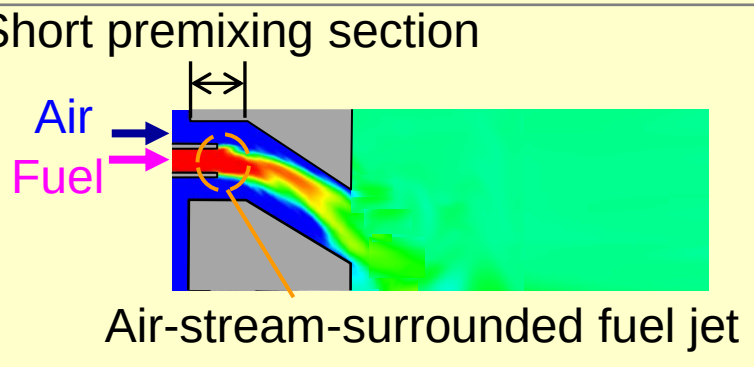
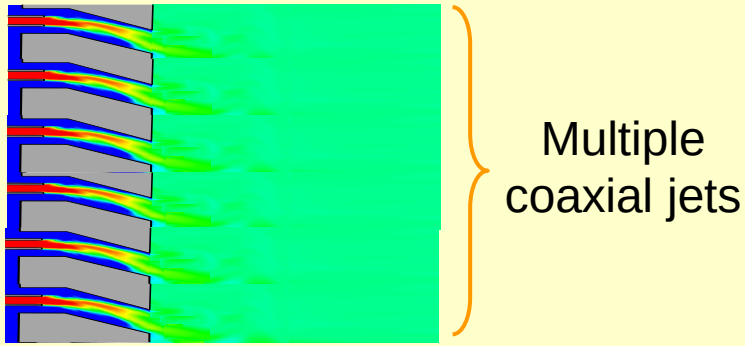
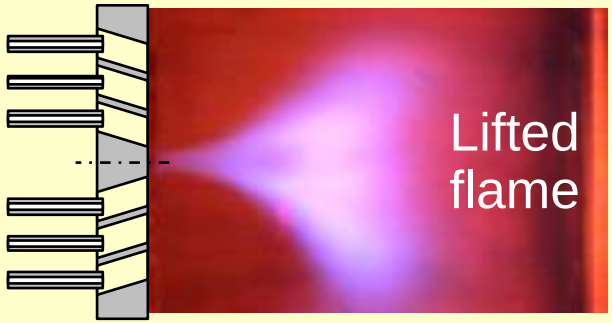




Multi-can combustor

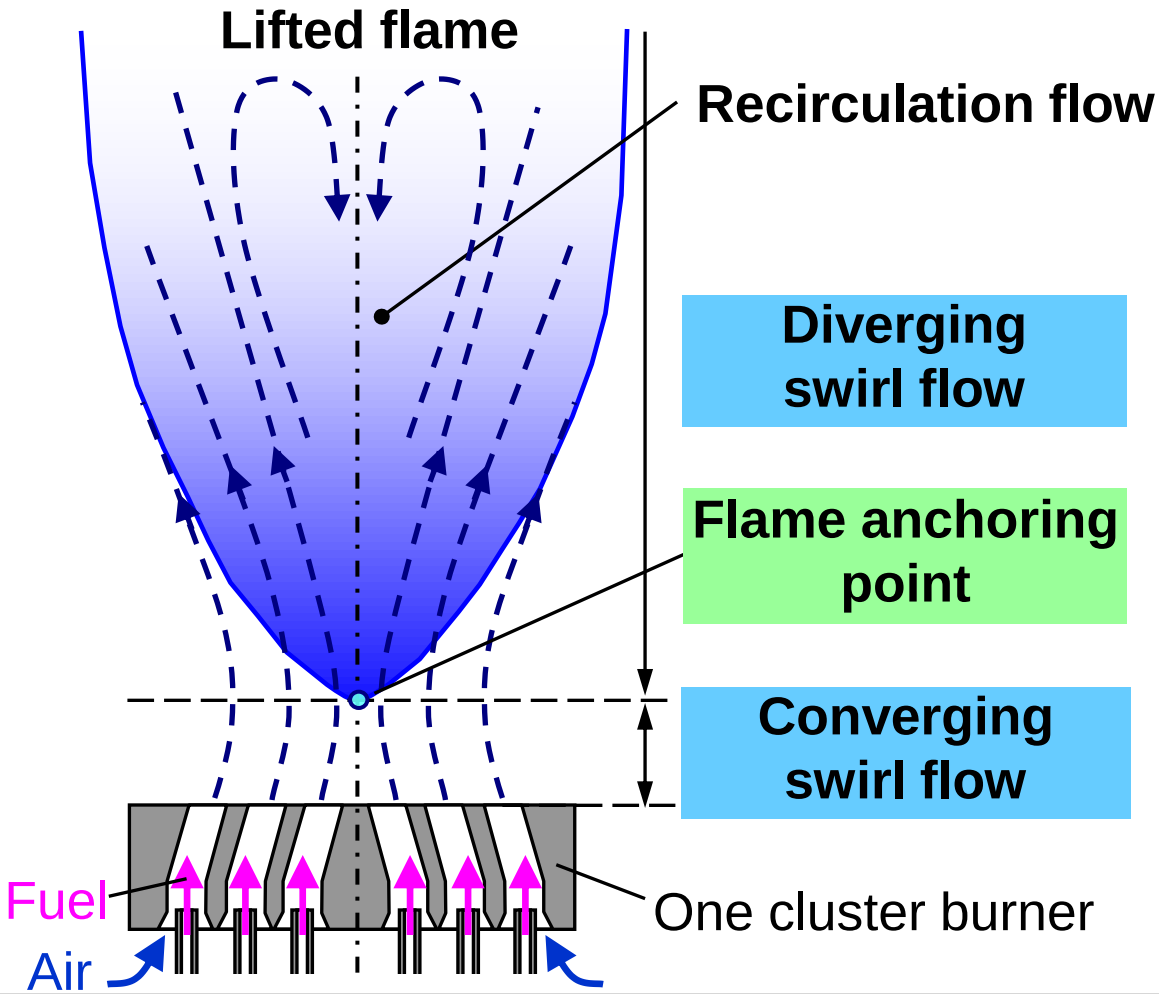
4-3 Concept of Cluster Burner

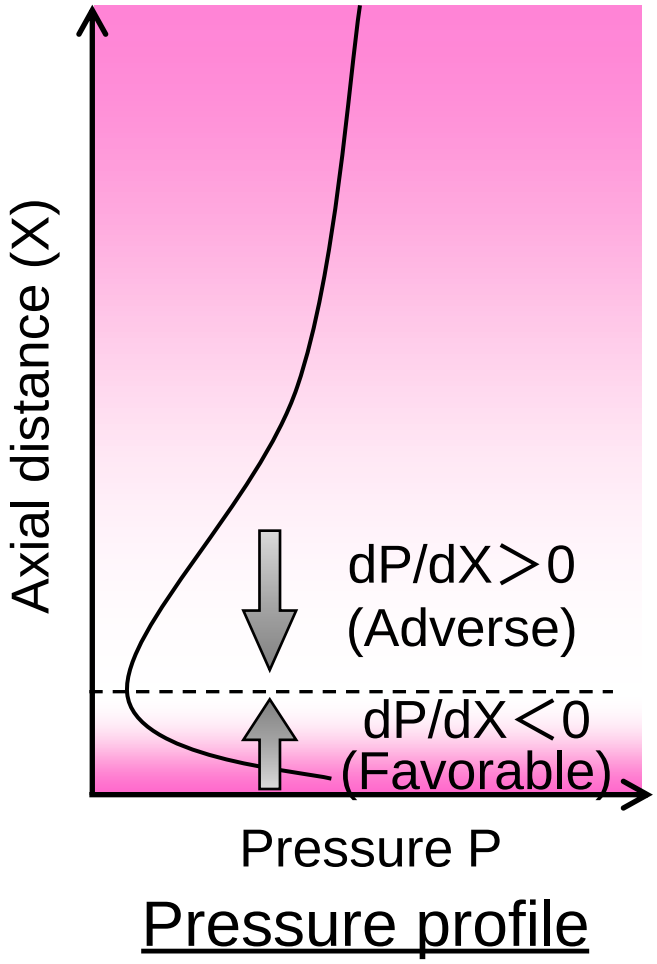
● Integration of two key tech.: Low-NOx & Flashback-resistant

	1. Low-NOx	2. Flashback-resistant
Single air hole	Rapid mixing 	Short premixing section Air-stream-surrounded fuel jet 
Multi-air hole	Fuel dispersion 	Flame lifting 

4-4 Operating Principle of Flame Lifting

- The cluster burner can lift the flame for flashback-resistant combustion by producing converging and diverging swirl flows.

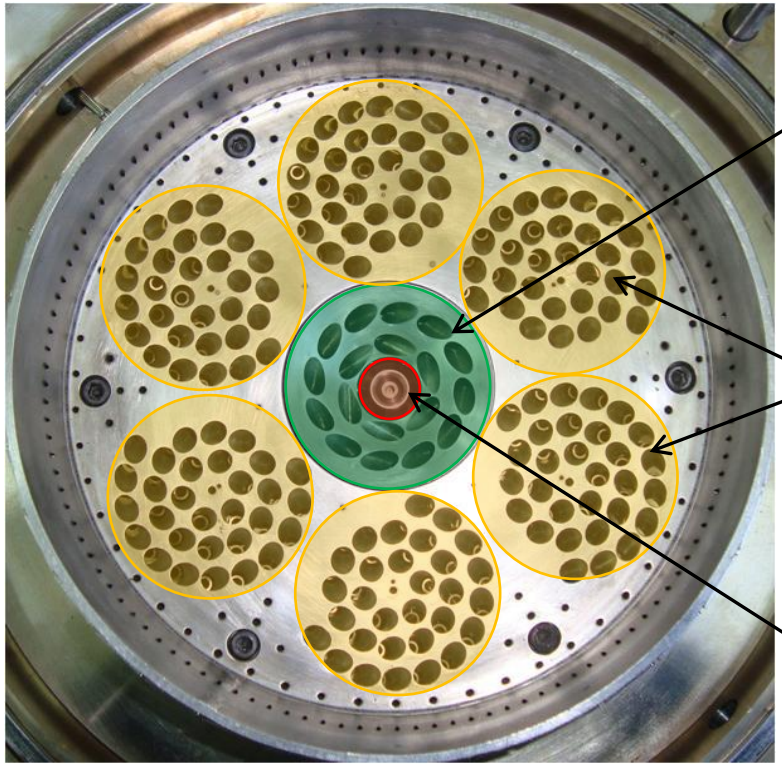




Pressure profile

4-5 Functions of Each Burner

- The multi-cluster combustor assigns specific functions to each burner for stable flame-holding and low-NOx.



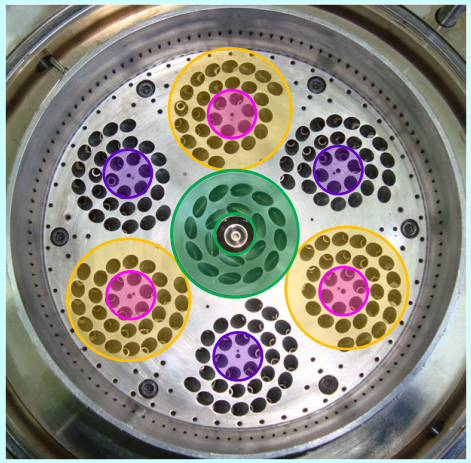
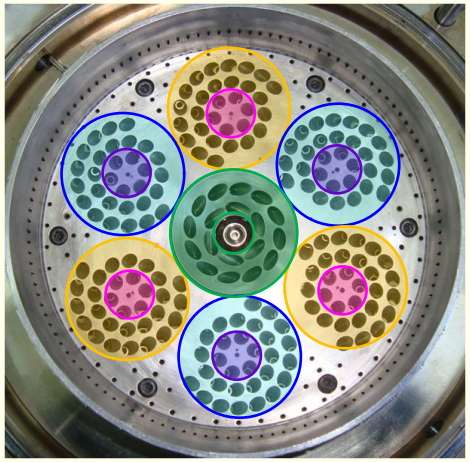
Pilot burner (center: 1) → **Flame-holding**

Main burners (surrounding: 6) → **Low-NOx**

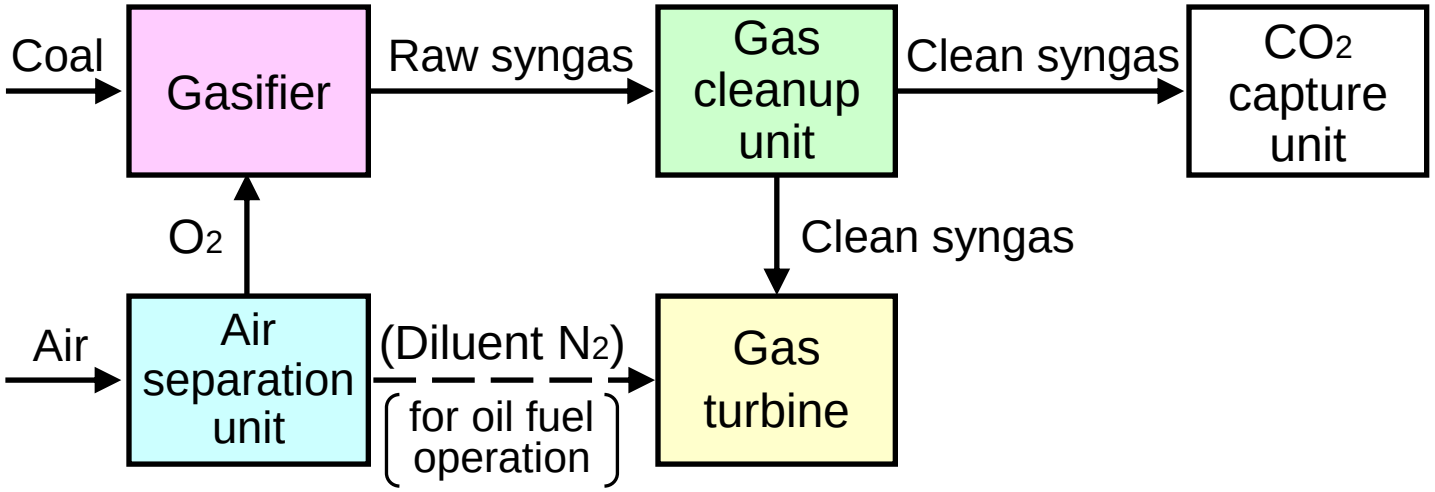
Oil spray nozzle (center: 1) → **Gas turbine startup**

4-6 Fuel Staging & Fuel Supplying System

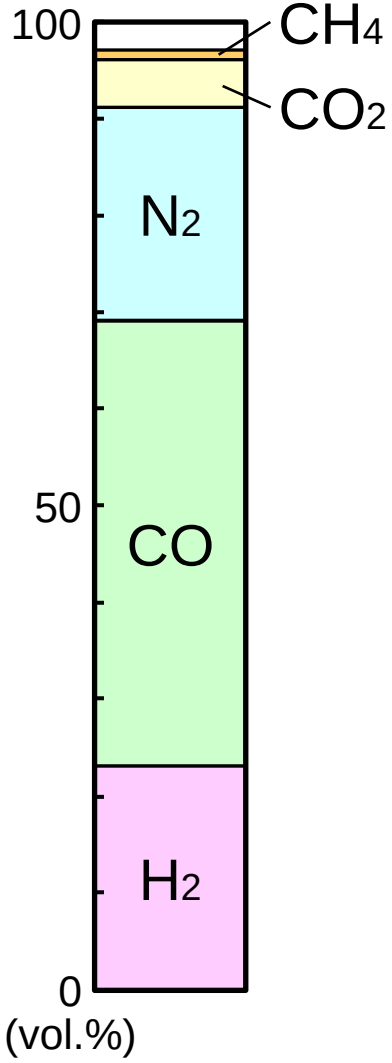
- The combustor can achieve low emissions & high operability over the operating range by switching combustion modes.
- The fuel supplying system consists of one oil fuel circuit and five gas fuel circuits for high operability.

	Ignition Acceleration	Gas turbine load →	
Fuel	Oil	Syngas	
Mode	**Oil mode**	**Partial mode**	**Final mode**
Operating burners			

4-7 IGCC Pilot Plant “EAGLE”



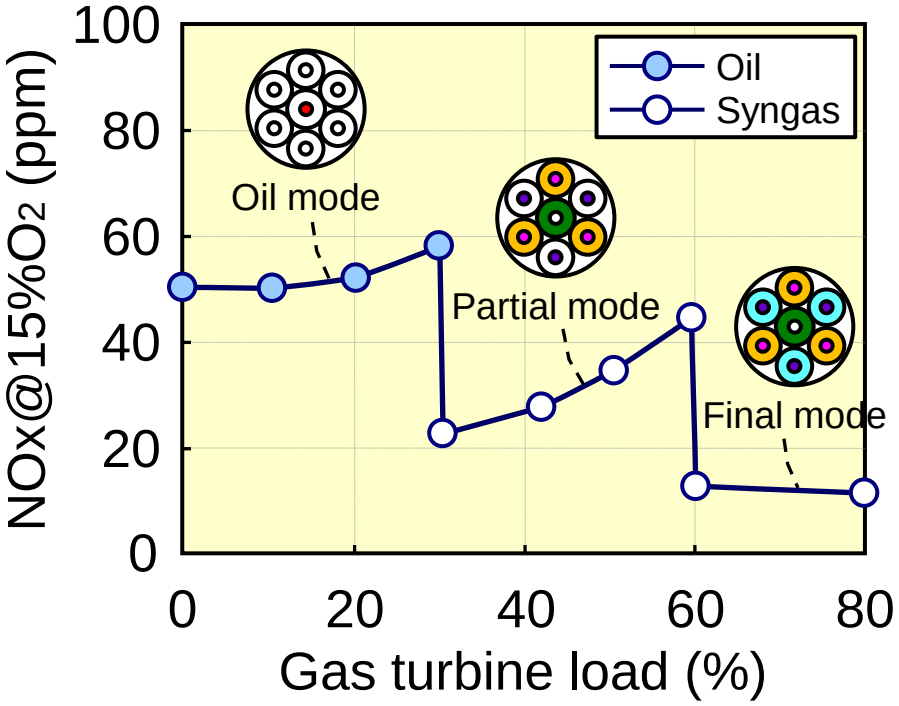
IGCC pilot plant “EAGLE” (J-POWER)



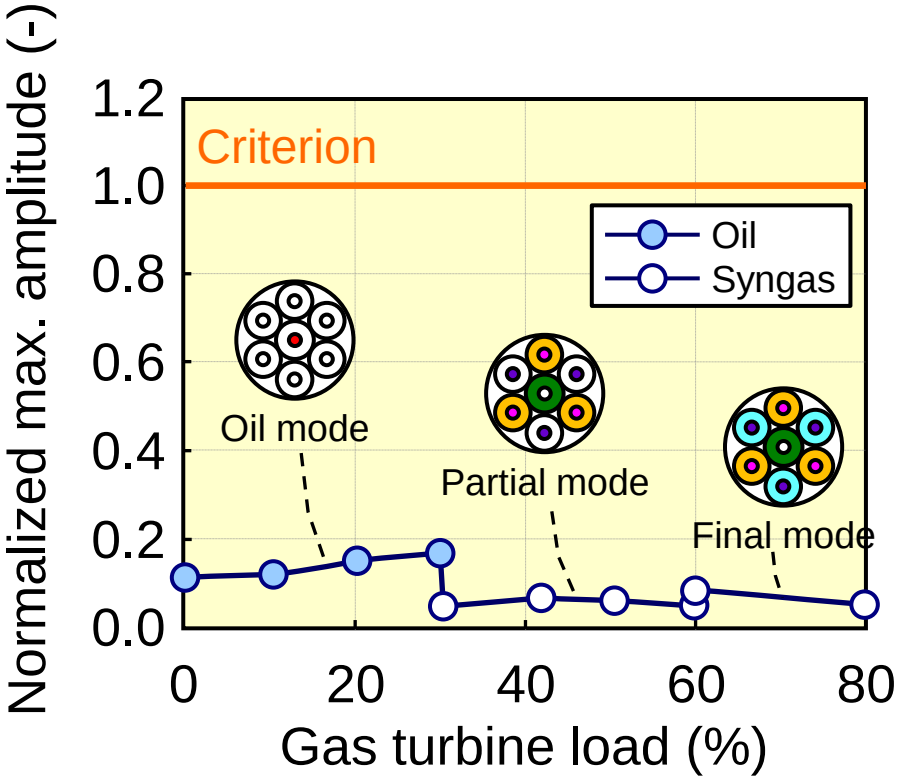
Syngas mix

4-8 Plant Test Results

- The multi-cluster combustor achieved dry low NOx combustion of H_2-rich syngas fuel in the IGCC pilot plant
- The combustor achieved stable operation during part load with the pressure fluctuation amplitudes well below the criterion.



NOx emissions



Pressure fluctuations

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5-1 Application to Natural Gas/Petroleum Gas

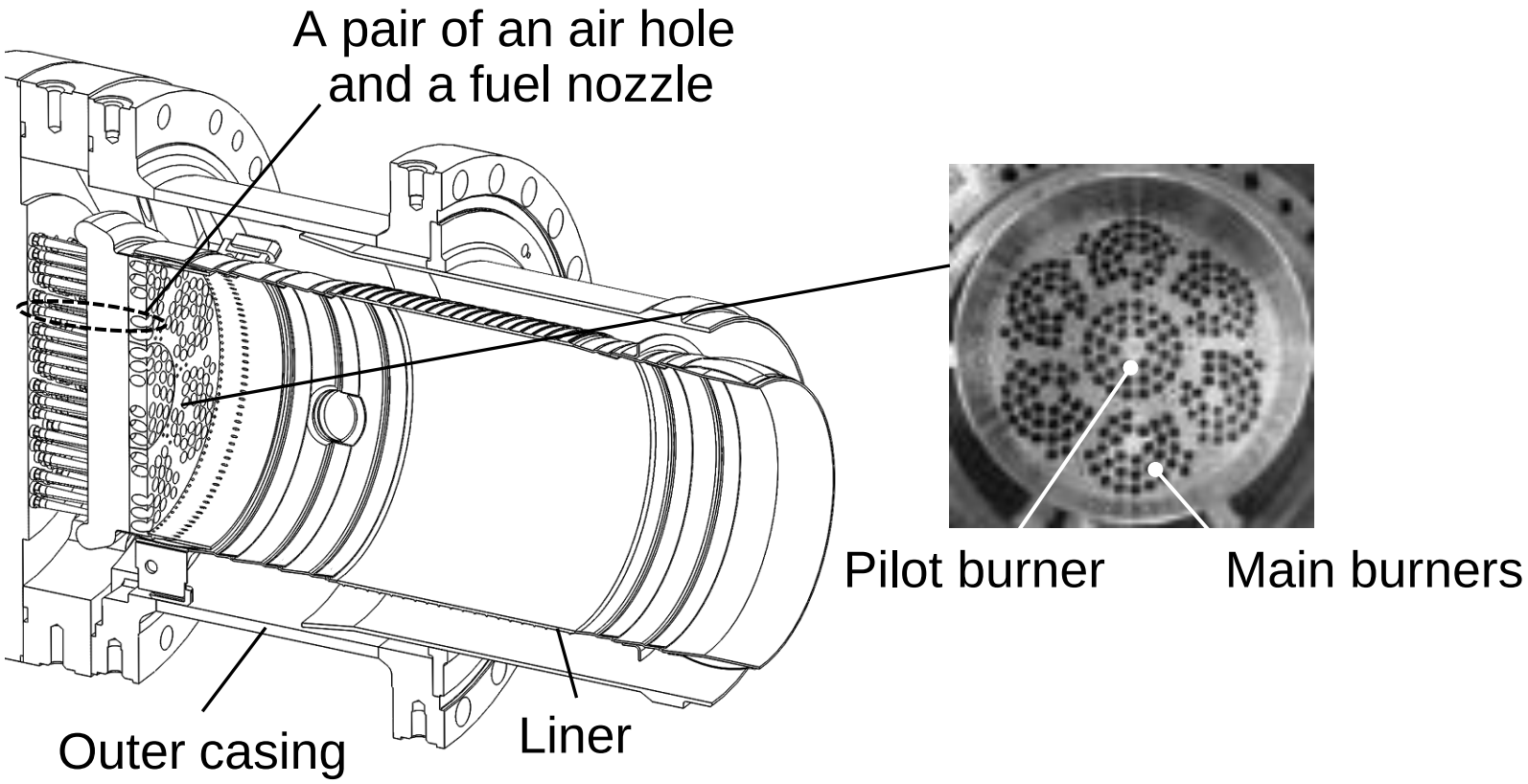
- Motivation: The increasing petroleum gas (LPG) production with shale gas/oil increases the demand for LPG as a GT fuel.
- Purpose: Application of dual fuels of natural gas/petroleum gas

Properties		Unit	Natural gas	Petroleum gas
Constituents	CH_4	vol%	90.6	–
	C_2H_6	vol%	5.1	0.7
	C_3H_8	vol%	2.8	98.9
	C_4H_{10}	vol%	1.4	0.4
Density		kg/Nm^3	0.80	1.96
Net calorific value		MJ/Nm^3	40.0	91.1
Stoichi. flame temp.*1		°C	1937	1994
Minimum ignition temp.		°C	537	466
Normalized flame speed		-	1.0	1.1
Dew point *2		°C	-96	78

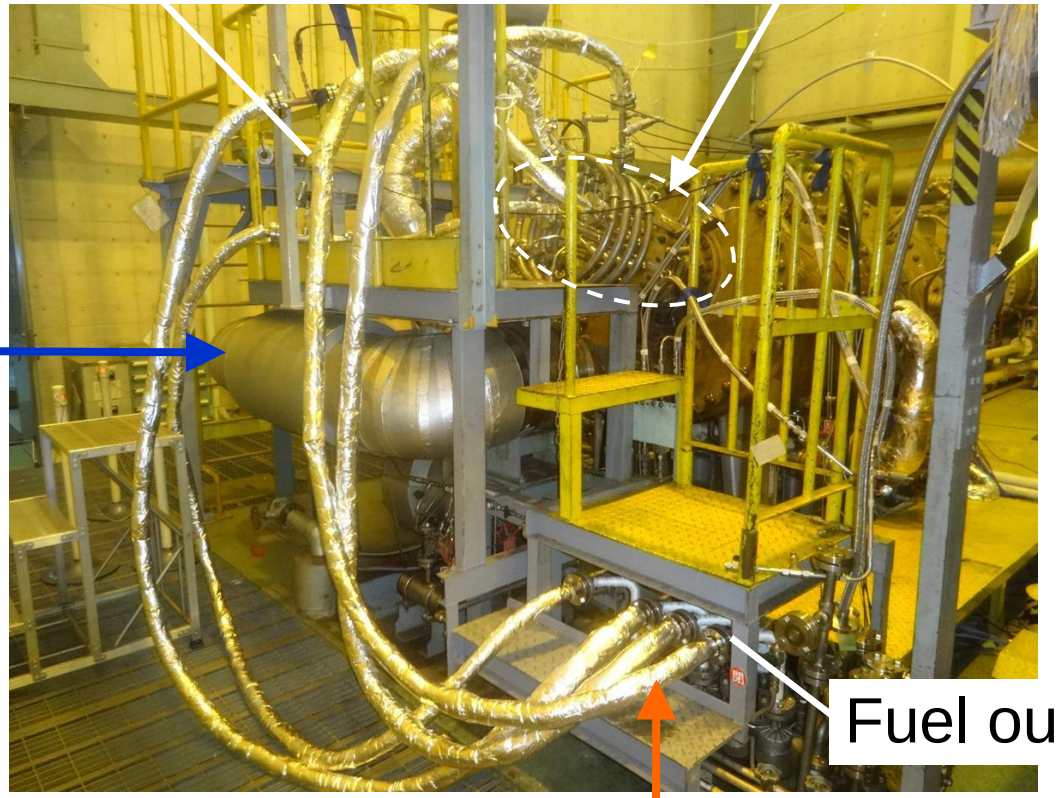
***1 at atmospheric press. & room temp.**
***2 at 3.0 MPa(A)**

5-2 Multi-Cluster Combustor for Dual Gas Fuels

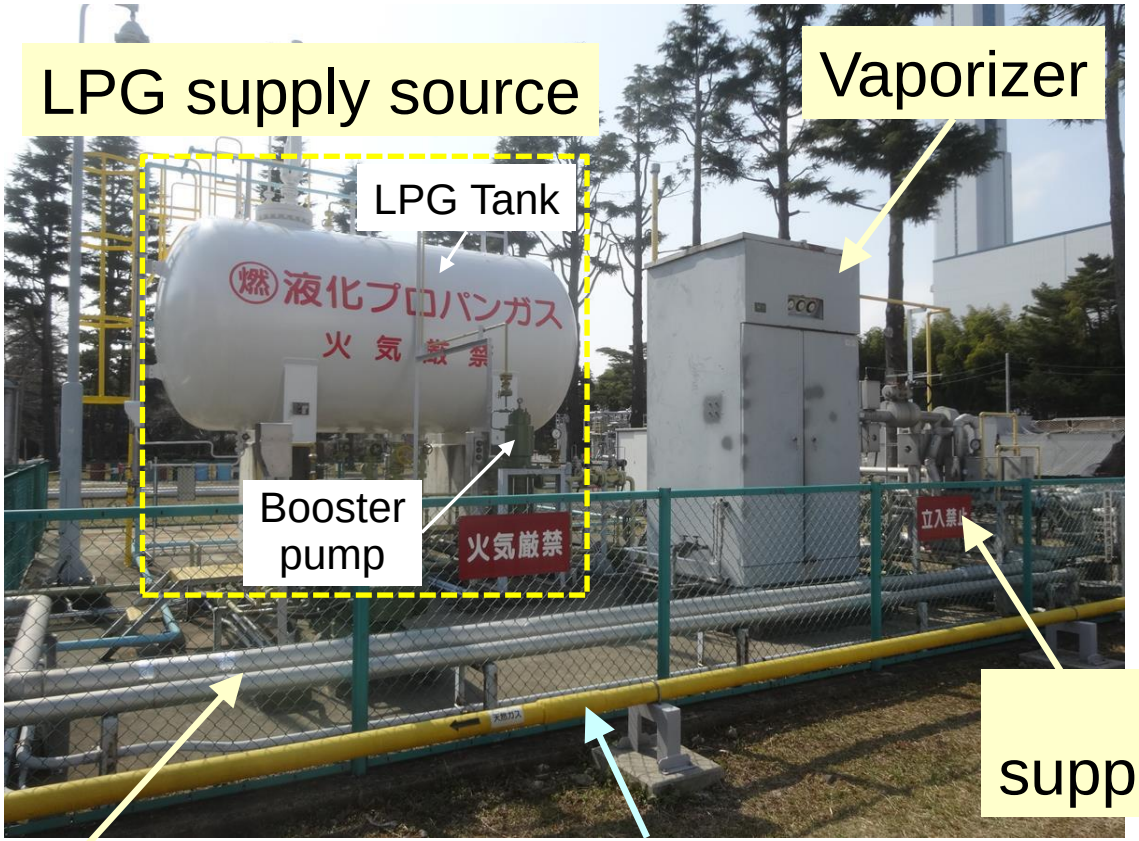
- Application to dual gaseous fuels of natural gas/petroleum gas
- The combustor is equipped with a pilot burner at the center and six main burners around the pilot for burning gaseous fuels.



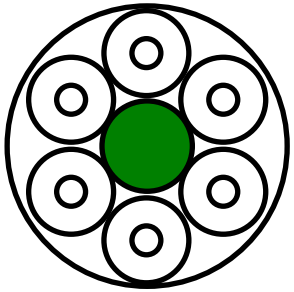
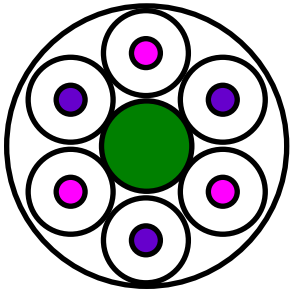
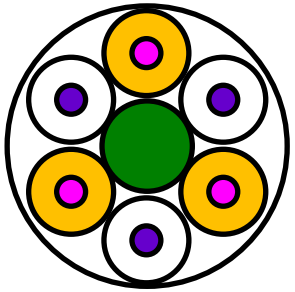
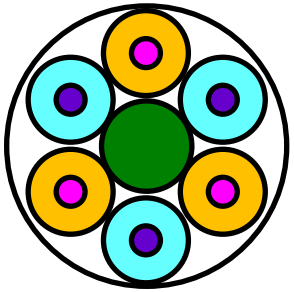
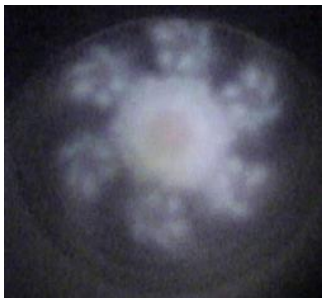
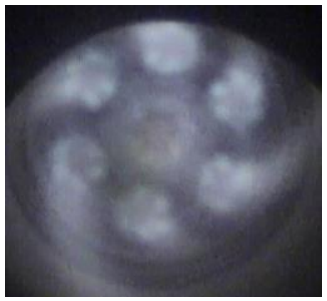
5-3 Single-Can Combustor Test Stand



5-4 LPG Supplying Facilities



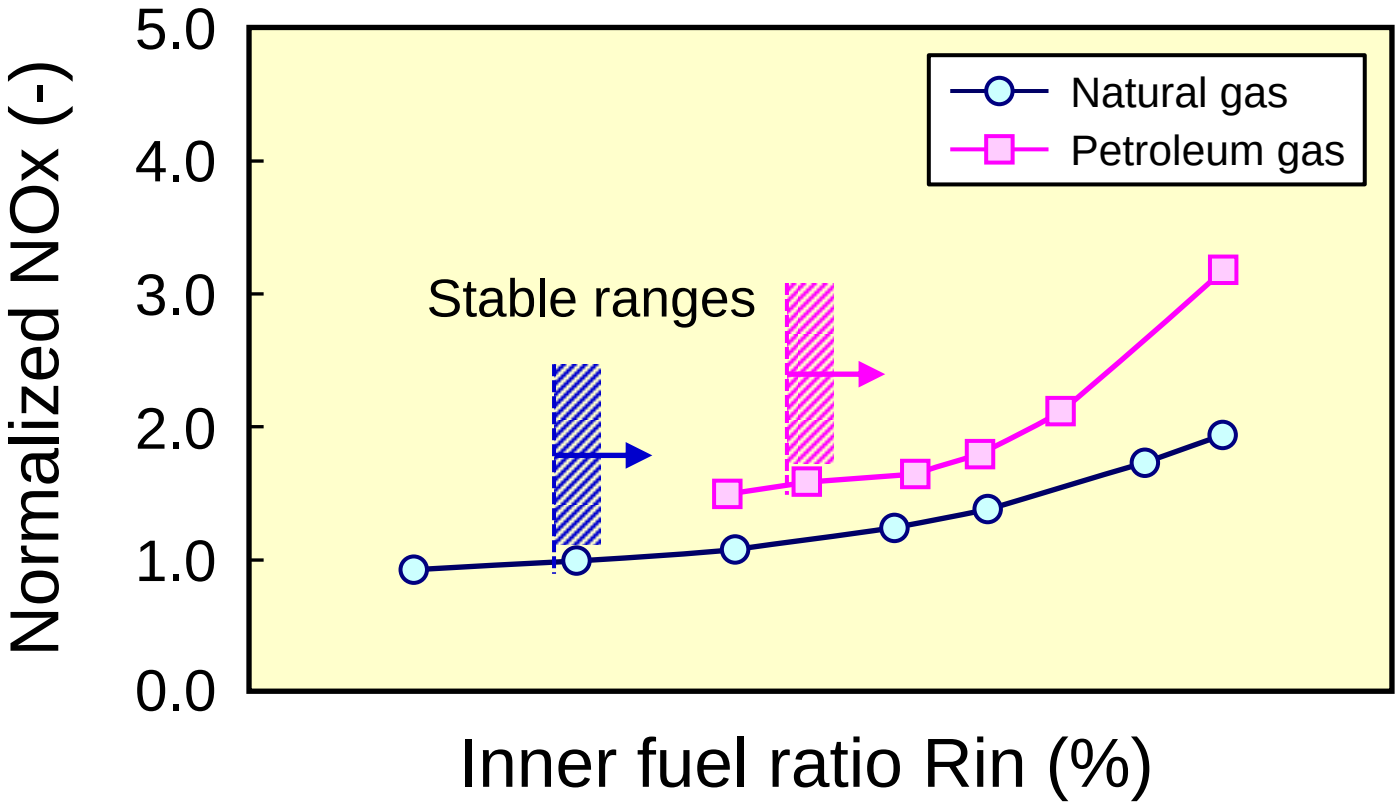
5-5 Flames in Fuel Staging

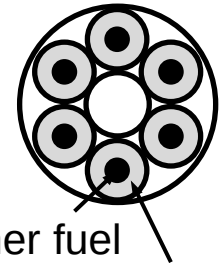
	Gas turbine load →			
Mode	**Pilot**	**Partial A**	**Partial B**	**Final**
Operating burners*				
Natural gas flames				
Petroleum gas flames				

***Colored regions indicate operating burners**

5-6 NOx Performance

- The results indicated that the combustor has the capability to achieve dry low NOx & flashback-resistant combustion of the dual gaseous fuels.





Inner fuel ratio

$$Rin = \frac{Gin}{Gin + Gout}$$

NOx emissions at base load

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6-1 Summary

- Development of multi-cluster combustors as an advanced dry low NOx & flashback-resistant combustion technology for fuel flexibility

1. IGCC syngas fuel

The pilot plant tests demonstrated the feasibility of achieving the dry low NOx & flashback-resistant combustion of the IGCC syngas fuel.

2. Dual gaseous fuels of natural gas/petroleum gas

The single-can test results showed that the combustor possesses the capability to achieve dry low NOx & flashback-resistant combustion of the dual gaseous fuels.

6-2 Next Steps

- O_2-blown IGCC demonstration test of the Osaki CoolGen Corporation
  - Based on the experiences in the pilot plant test, a multi-cluster combustor was developed & installed in the demonstration plant.
  - The demonstration test will start in March 2017.

- Application of multi-cluster combustors to gas turbines with large capacities.

Acknowledgements

The authors sincerely thank …

- New Energy and Industrial Technology Development Organization (NEDO) of Japan for sponsoring the IGCC project
- J-POWER for supporting the IGCC pilot plant test
- Osaki CoolGen Corporation for providing valuable guidance and support

Thank you so much for your attention!

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POWER SYSTEMS