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NH3 Energy Implementation Conference

Technologies to use carbon free ammonia in power plant

IHI

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戦略的イノベーション創造プログラム
Cross-ministerial Strategic Innovation Promotion Program

国立研究開発法人 科学技術振興機構
Japan Science and Technology Agency

IHI Corporation

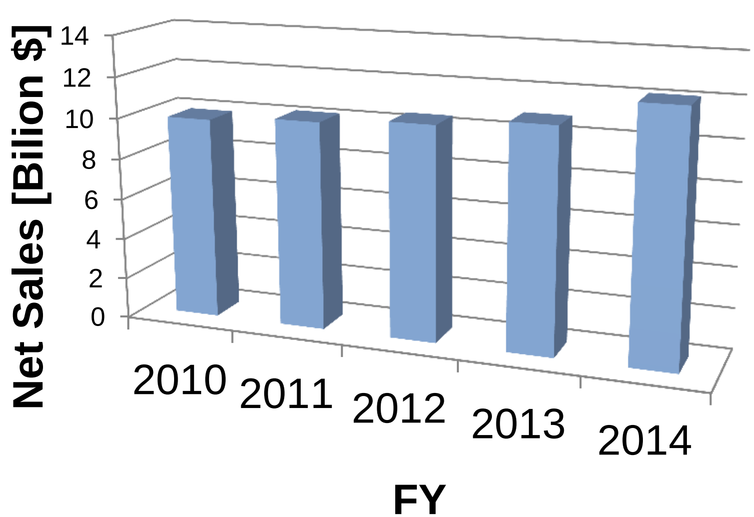
IHI Profile

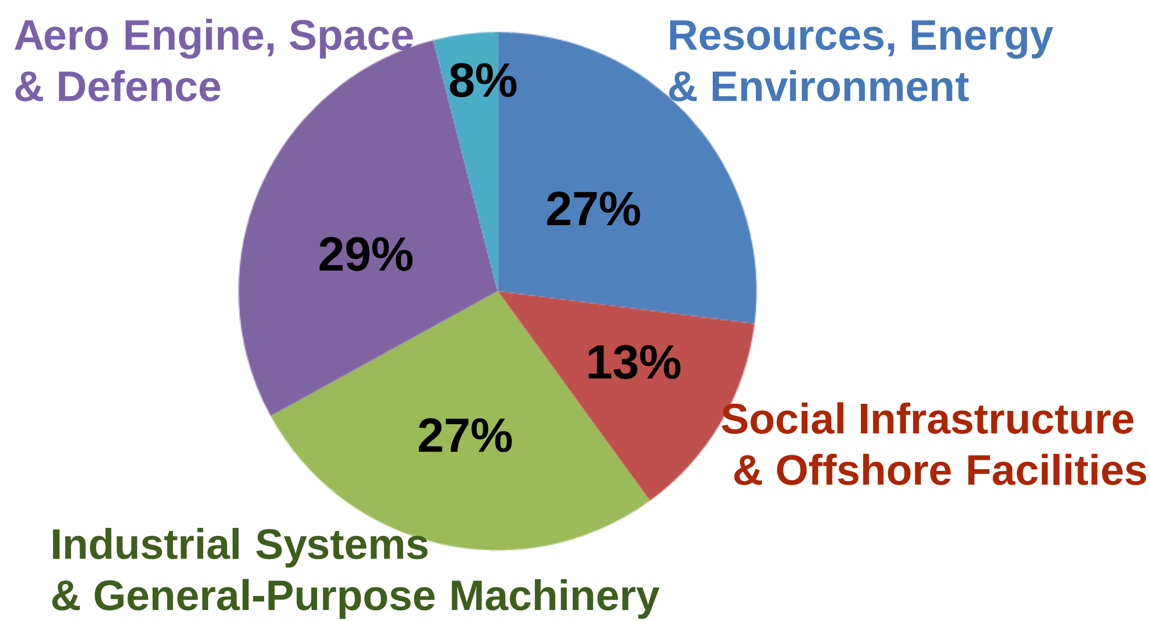
IHI Headquarters, Toyosu, Tokyo

Founded in : 1853
Capital : JPY 107.1 billion (around $892.5 million)
Total Employees : 28,533
Consolidated Net Sales : JPY 1,456 billion (around $12.13 billion)
Affiliated Companies : Domestic 82
Overseas 170

(Information correct as of March 31, 2015)

Further info: www.ihi.co.jp/en





Net Sales by Business Segment

Business Area of the IHI Group

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Resources, Energy & Environment Business Area

Minimizing Environmental Impact

- Boilers
- Power system plants
- Large power systems
- Power systems for land and marine use
- Process plants
- Pharmaceutical plants
- Environmental response systems
- Nuclear energy
- Asian base EPC

Large-scale tower type boiler

Industrial Systems & General-Purpose Machinery Business Area

Transforming the World's Industrial Infrastructure

- Rotating machinery
- Turbochargers for vehicles
- Heat treatment and surface engineering
- Agricultural machinery and small power systems
- Transport machinery
- Parking
- Logistics and machinery

Turbochargers for vehicles

Social Infrastructure & Offshore Facilities Business Area

Underpinning the Essentials of Modern Living

- Bridges and Watergates
- Shield systems
- Concrete construction materials
- Transport systems
- Urban development
- F-LNG

Osman Gazi Bridge across Izmit Bay

Aero Engine, Space & Defense Business Area

Opening New Horizons

- Aircraft engines
- Defense equipment and systems
- Rocket systems and space exploration

GEnx turbofan engine

Role of hydrogen energy on GHG reduction in Japan

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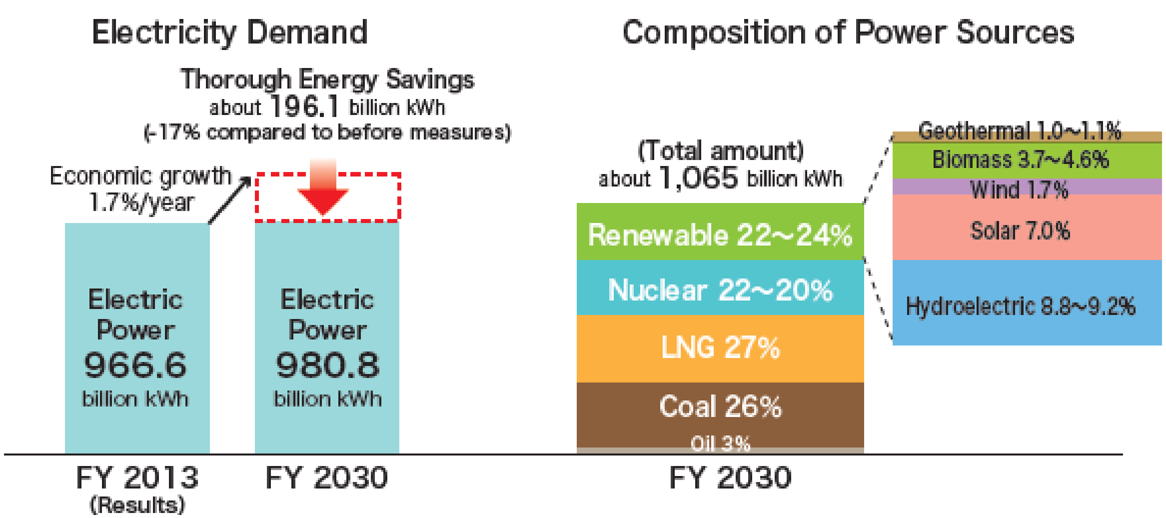
- GHG reduction targets of Japan

mid-term : 26% by 2030FY (compared to 2013FY)
long term : 80% by 2050FY

- On July 3, 2018, the Cabinet approved the new 5th Strategic Energy Plan. Promotion of hydrogen energy is one of the measures to achieve mid-term target.



Ideal composition of power sources in 2030FY
Source : Japan's ENERGY (2017 EDITION)

Towards 2030
~ To reduce emission of greenhouse gases by 26% ~

~ To achieve energy mix target ~
– Currently halfway to the target
– Deliberate promotion
– Realistic initiatives
– Intensify and enhance measures

<Primary measures>

○ **Renewable energy**
- Lay foundations to use as major power source
- Cost reduction, overcome system constraints, secure flexibility of thermal power

○ **Nuclear power**
- Lower dependency on nuclear power generation to the extent possible
- Restart of nuclear power plants and continuous improvement of safety

○ **Fossil fuels**
- Promote independent development of fossil fuels upstream, etc.
- Effective use of high-efficiency thermal power generation
- Enhance response to disaster risks, etc.

○ **Energy efficiency**
- Continued thorough energy efficiency
- Integrated implementation of regulation of Act on Rationalizing Energy Use and support measures

○ **Promotion of hydrogen/power storage/distributed energy**

Measures to reduce 26% GHG by 2030FY
Source : The 5th Strategic Energy Plan

Basic Hydrogen Strategy

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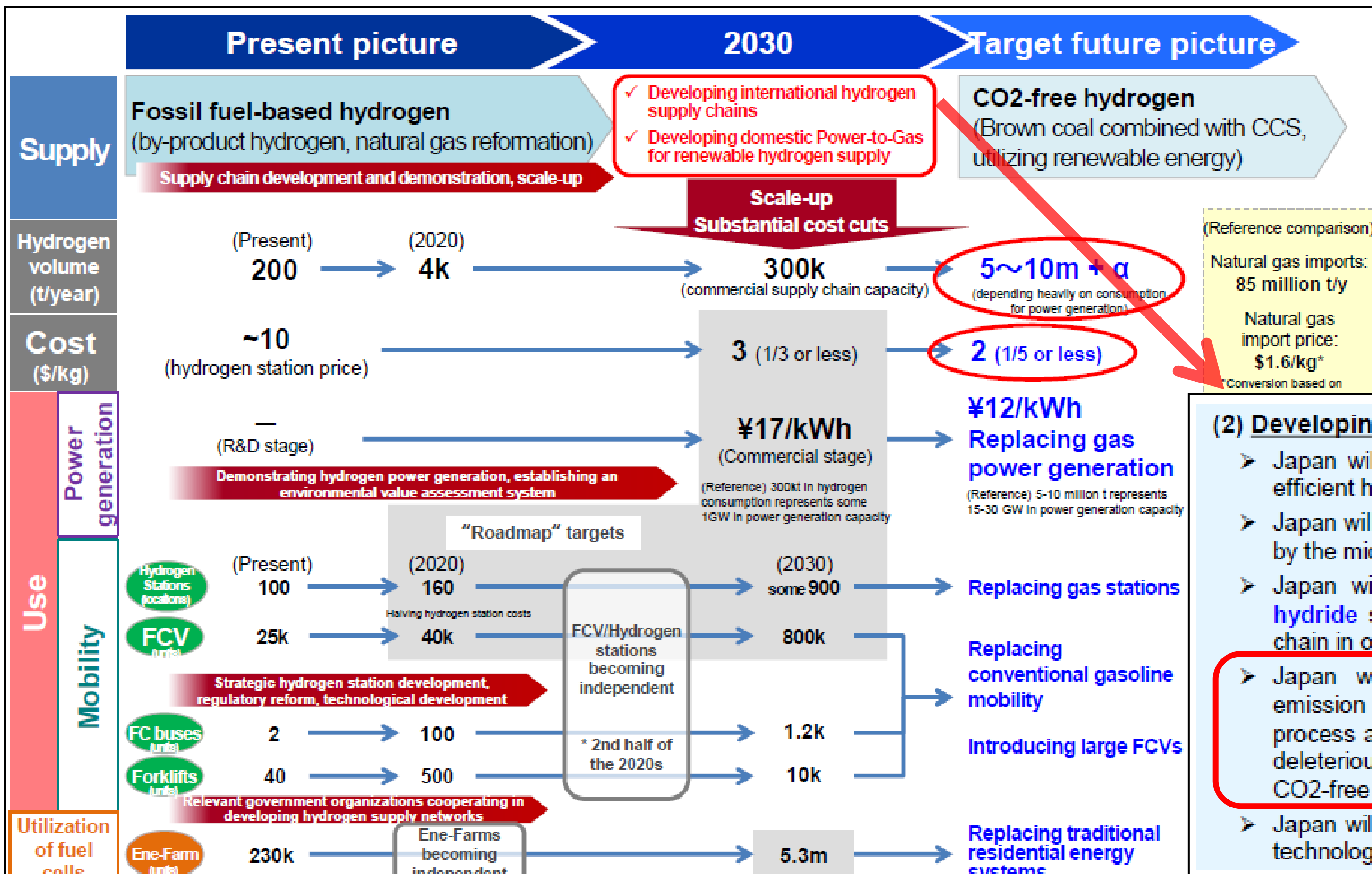
- ‘Basic Hydrogen Strategy’ was determined by METI on December 25th, 2017.
- In order to develop international hydrogen supply chains, 4 types of energy carrier is considered in the strategy.
  Ammonia is considered to be one of the energy carriers.



(2) Developing international hydrogen supply chains

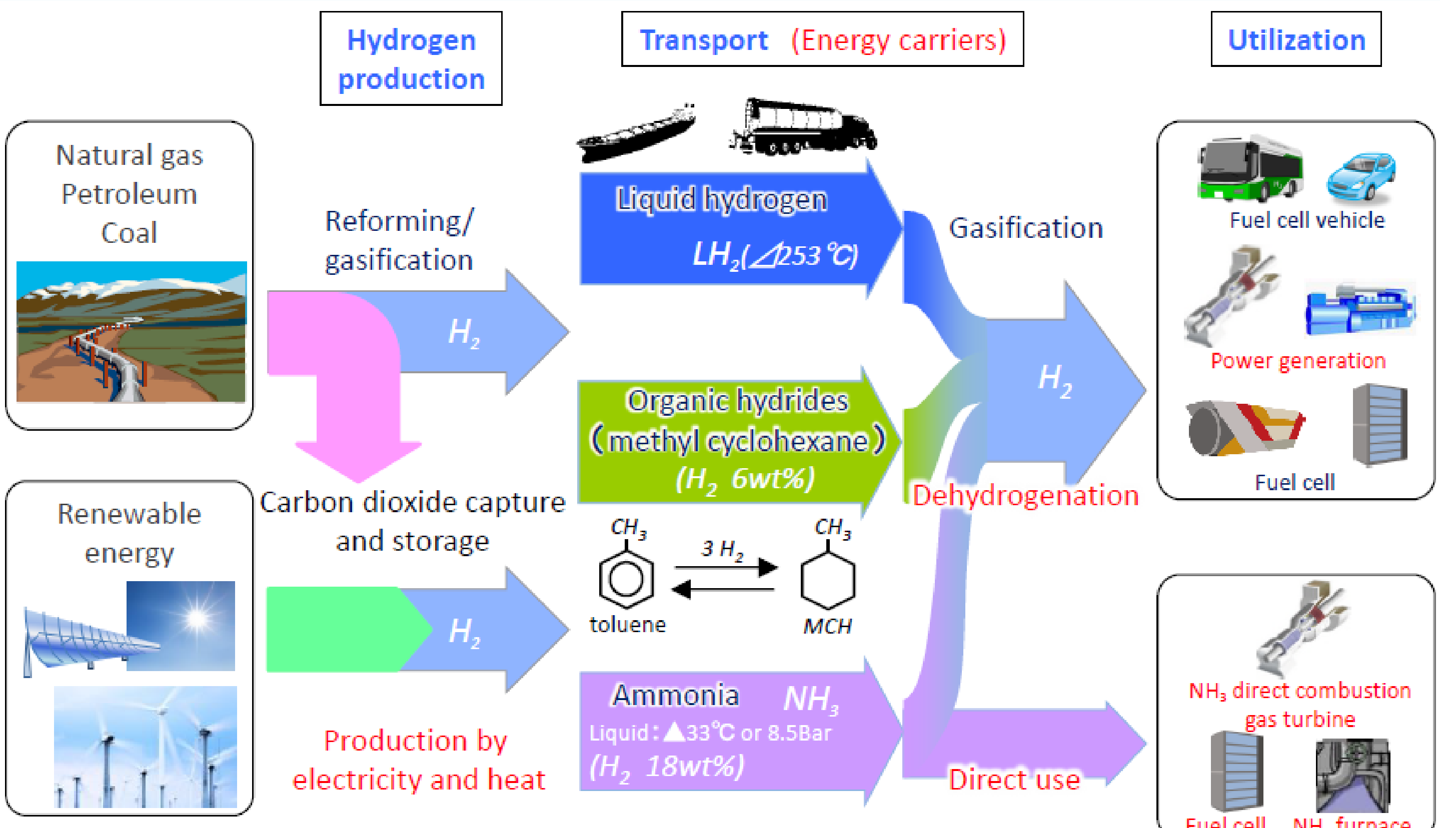
- Japan will develop energy carrier technologies to enable efficient hydrogen transportation and storage.
- Japan will demonstrate a liquefied hydrogen supply chain by the mid-2020s for commercialization around 2030.
- Japan will establish basic technologies for an organic hydride supply chain by FY2020 and commercialize the chain in or after 2025.
- Japan will resolve such challenges as reducing the emission of nitrogen oxide in the direct combustion process and ensuring safety in handling of flammable and deleterious substances in a bid to introduce the use of CO2-free ammonia by the mid-2020s.
- Japan will consider how best to disseminate methanation technology that employs CO2-free hydrogen.

Scenario for Basic Hydrogen Strategy

Source : Basic Hydrogen Strategy by METI

Advantages of ammonia as an energy carrier

(1) Highest hydrogen content per unit volume
(2) Easy to liquify (-33℃ at 1bar, similar to LPG)
(3) Infrastructures for production and transportation are already existing
(4) Can be used directly as a fuel for power plant



Energy carriers considered in 'SIP Energy Carriers' project

Problems to overcome

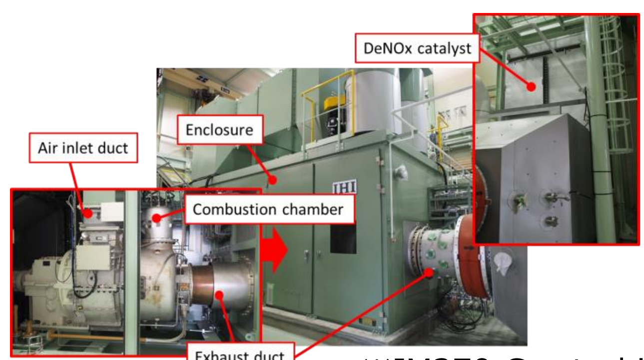
(1) Optimized combustor design for stable flame and reduction of fuel-NOx to use ammonia in thermal power plant.
(2) Evaluation of performance of power plant
(3) Safety measures
(4) Feasibility studies

IHI has joined Cross-ministerial Strategic Innovation Promotion Program (SIP) for the development of Ammonia Direct Combustion technology for gas turbine and coal fired boiler and also Ammonia Fuel Cell.

Coal fired boiler

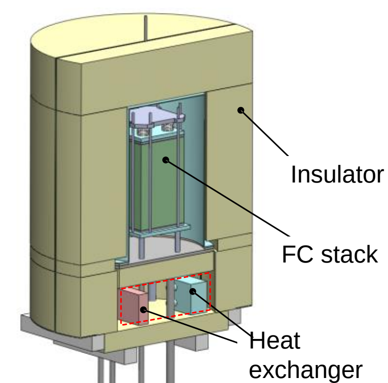
※CFT(Coal Firing Test Furnace)

Gas turbine

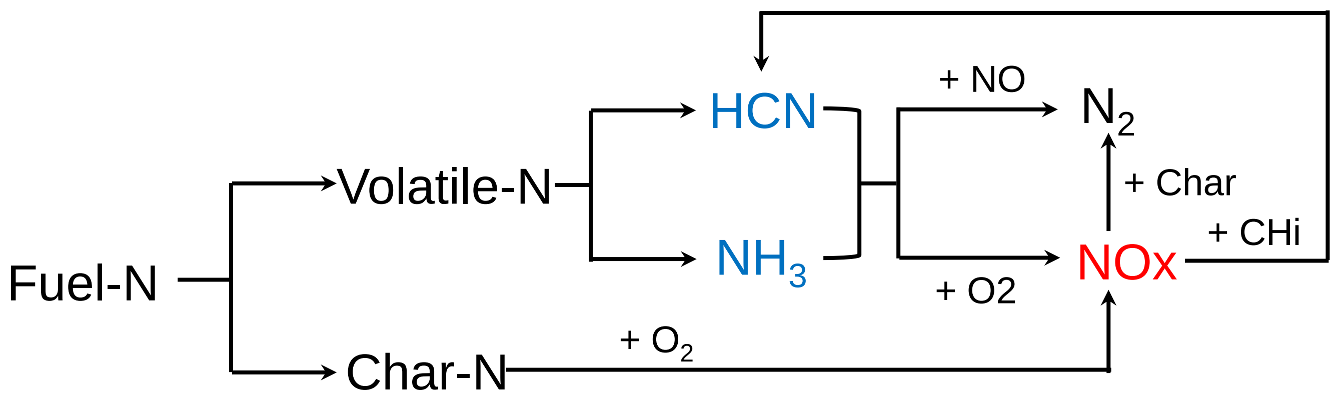


※IM270 Gas turbine

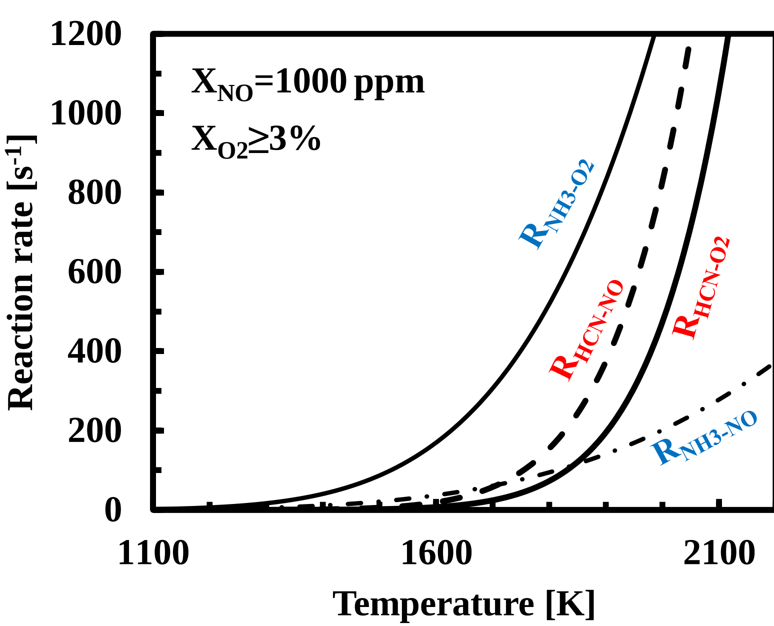
SOFC



Target power plant of 'SIP Energy Carriers' project in IHI



NO$_X$ formation in coal combustion



Calculated by most widely used **De Soete's expression**

Reactions of intermediate N species

$HCN + O_2 \rightarrow NO + \dots$

$NH_3 + O_2 \rightarrow NO + \dots$

$HCN + NO \rightarrow N_2 + \dots$

$NH_3 + NO \rightarrow N_2 + \dots$

From De Soete's expression

High-temp.: $R_{NH3\text{-}O2} \gg R_{HCN\text{-}O2}, R_{HCN\text{-}NO}, R_{NH3\text{-}NO}$

Increasing $[NH_3]/[HCN]$ facilitates more NOx formed

Contradict with some literature:

Increasing $[NH_3]/[HCN]$ facilitates more N_2 formed

Some studies showed $R_{HCN\text{-}O2}$ is too low

Ammonia co-firing pulverized coal (P.C.) boiler

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Task : Optimization of the combustion system for the NOx reduction.
Feasibility study to introduce ammonia into the existing power plant

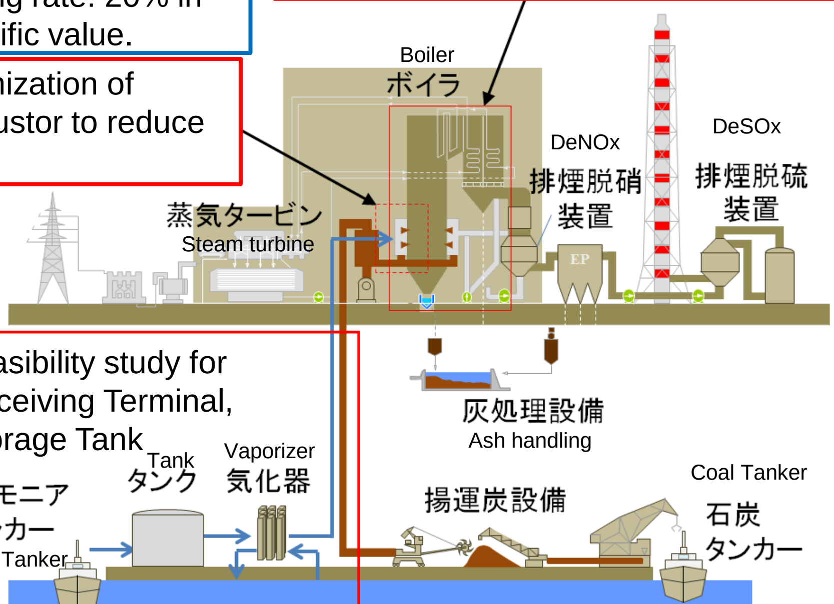
⇒ 2017FY : Co-firing test using 10MW$_{thermal}$ test furnace
2018FY : Trial design to introduce ammonia co-firing system for existing coal fired power plant (1000MW)

Study condition :
Model plant
Output :1000MWe
Co-firing rate: 20% in calorific value.

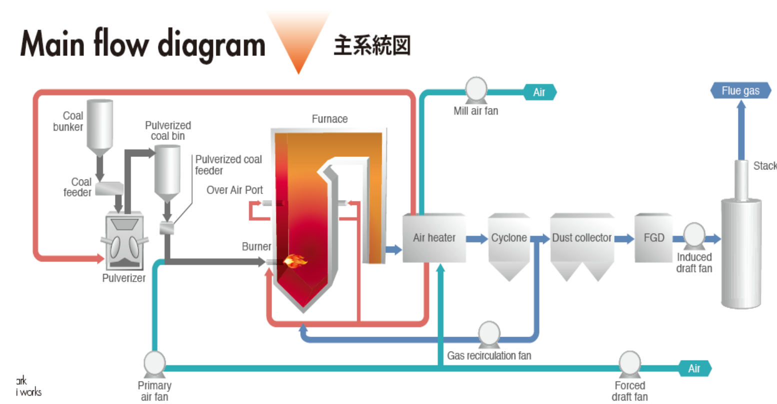
1.Optimization of combustor to reduce NOx

2. Evaluation of boiler performance by CFD
3. Feasibility study for boiler

4. Feasibility study for Receiving Terminal, Storage Tank



Tasks



Combustion test facility

Approach to control NOx and boiler performance

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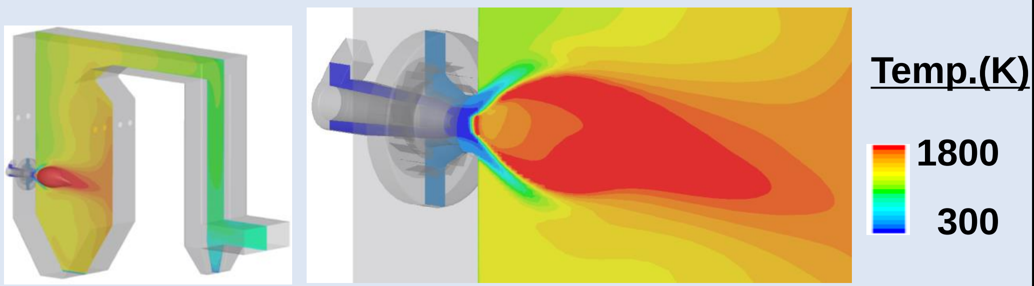
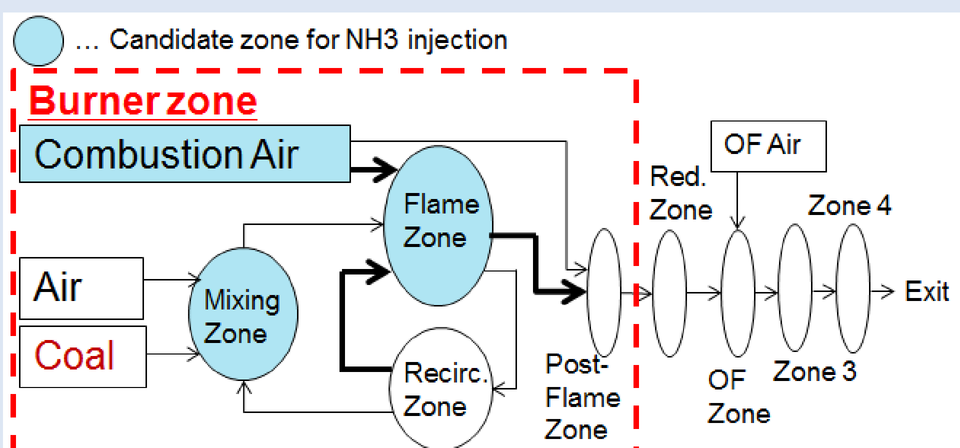
➢ Technical Issue and approaching method:
- NO_x reduction by experimental and numerical analysis
- Boiler performance (amount of the steam generation) by numerical analysis

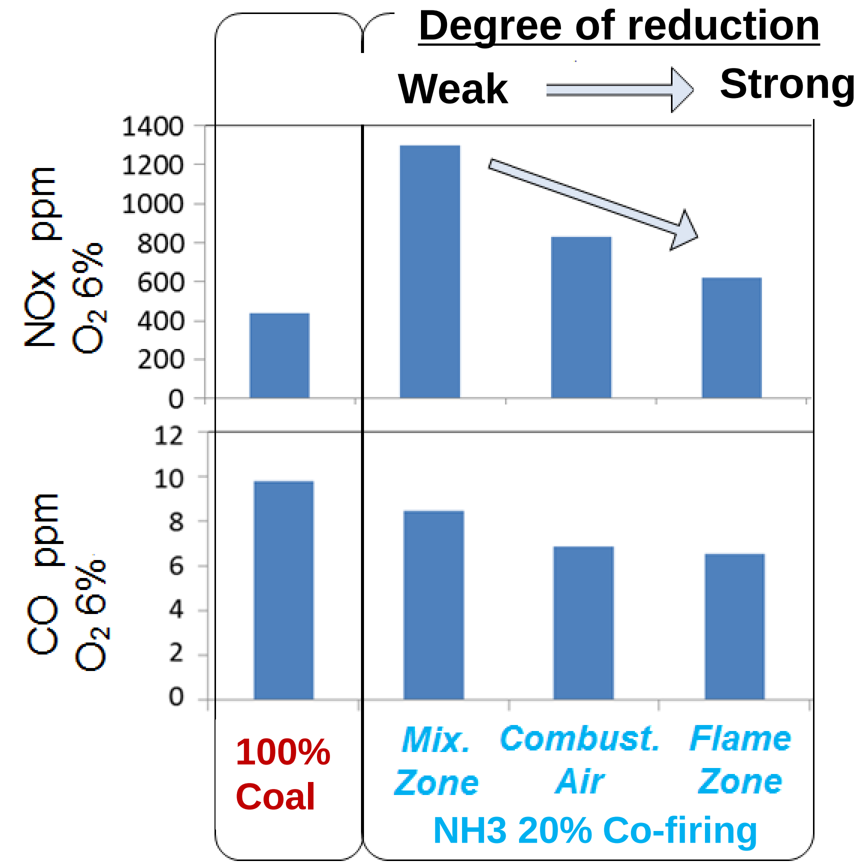
Consideration of the fluid dynamics



Consideration of the NH_3 Reaction path



NO_x reduction by the NH_3 injection method (CHEMKIN)



Coal Firing Test Furnace (CFT)

Fuel feeding rate	Coal 1.0-1.6 ton/hour Ammonia 0.4 ton/hour
Burner type	IHI-Dual Flow burner,
Target	NO below 200 ppm (@ O_2 6% conversion, NH_3 20% co-firing)

Ammonia feeding facility

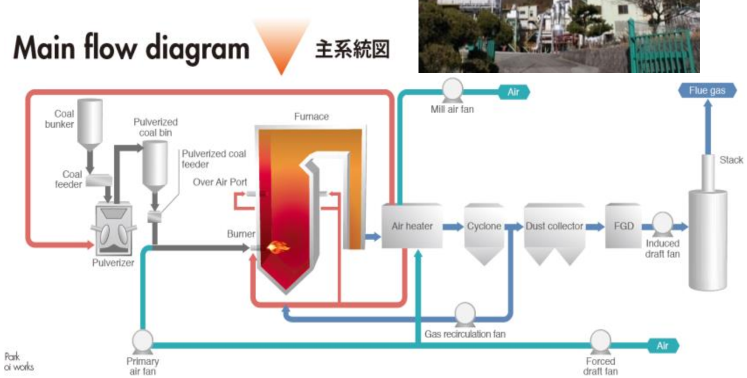
Overview

Ammonia tank

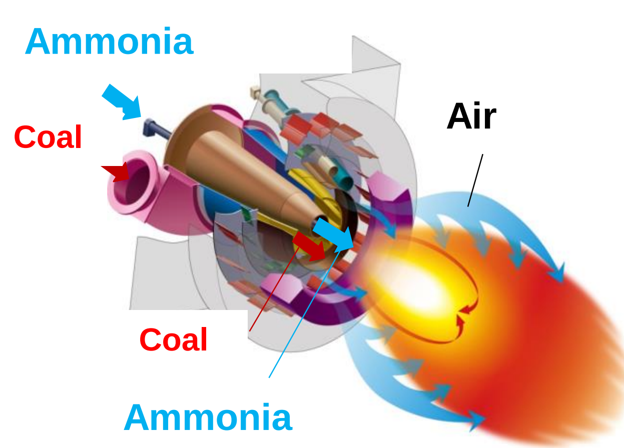
Control box

Evaporator

CFT



Burner for ammonia co-firing



Measurement items

- Exhaust gas
  (CO、CO_2、NO、N_2O)
- Unburned carbon
- Heat flux
- Flame shape

etc.

Results ：Stability, NOx and unburned carbon

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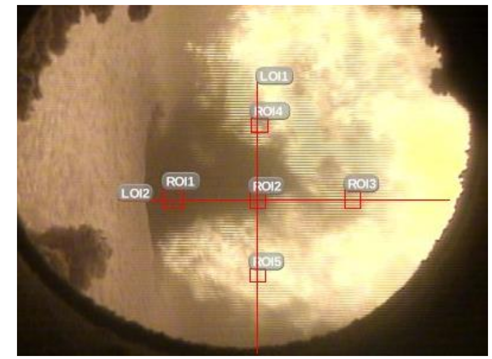
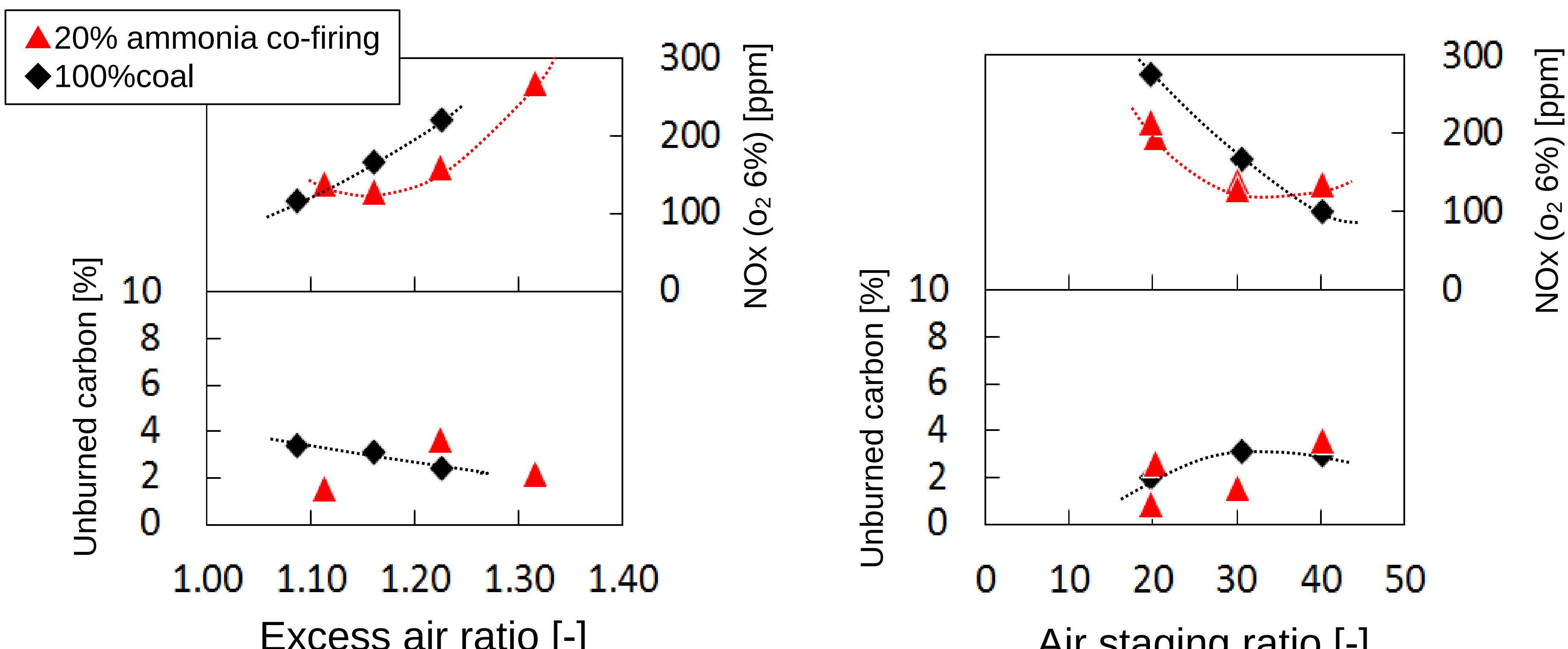
- Stable flame can be achieved by controlling swirl of the secondary air.
- NOx concentration in 20% ammonia co-firing condition is same or under that of 100% coal firing condition.
- NH_3, N_2O concentration in exhaust gas is under detection limit.



Flame at the outlet of burner
20% ammonia co-firing



Effect of ammonia co-firing on NOx and unburned carbon

Ammonia co-firing gas turbine

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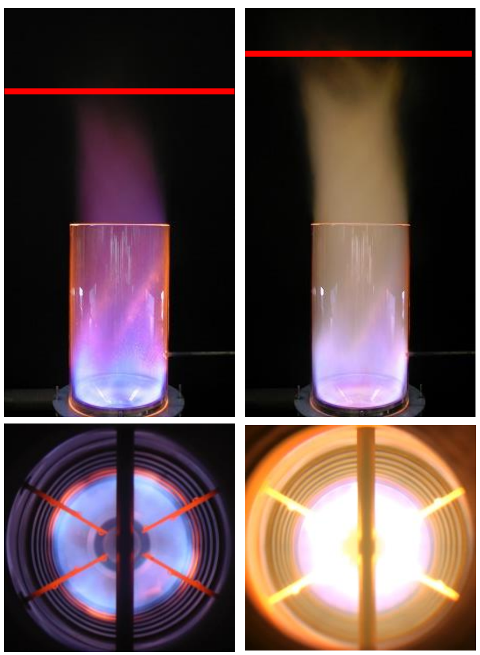
Task : Optimization of combustor design to reduce NOx
Demonstration using 2MW scale commercial gas turbine

⇒ 2015-2017FY : Optimization of combustor design
2018FY : Demonstration using commercial 2MW class GT (IM270)



City gas   Ammonia co-firing

Comparison of swirl flame

Feature of NH_3 combustion (compared with CH_4)

- ✓ Lower flame speed (approx. 1/5)
- ✓ Lower heating value (approx. 1/2)
- ✓ Lower flame temperature(approx. 200℃)
- ✓ Emission of fuel-NOx

Problems to be solved

- ✓ Burner design to achieve stable flame
- ✓ Reduction of fuel-NOx
- ✓ Reduction of unburned NH_3
- ✓ Stable supply of vaporized NH_3
- ✓ Control method for stable operation

Demonstration using commercial 2MW class GT

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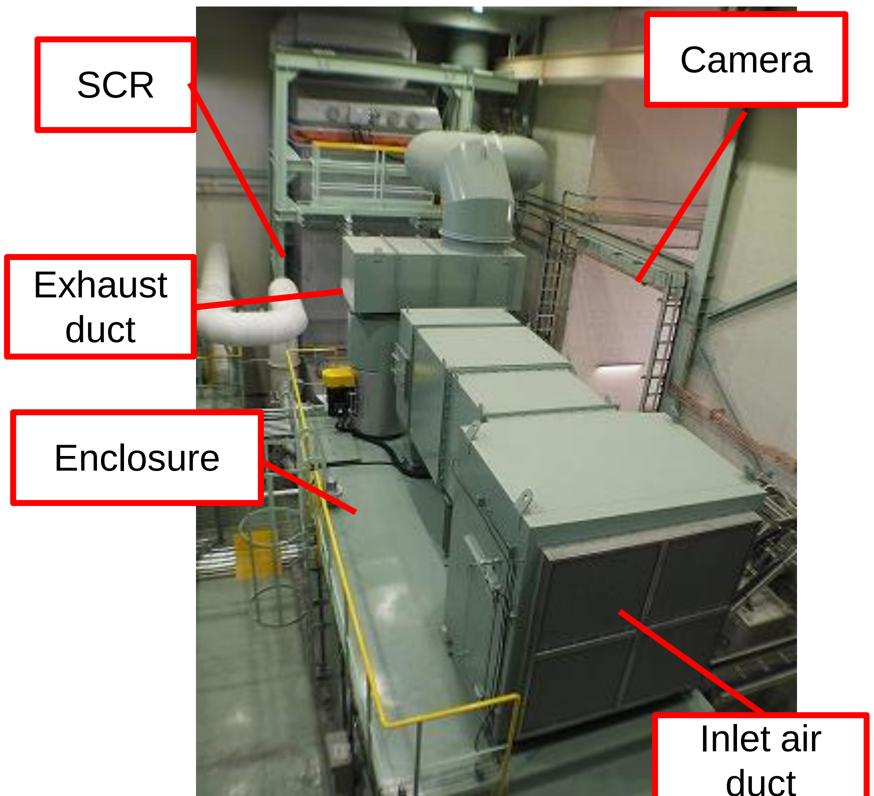
- IM270 gas turbine with ammonia supply unit is installed for the demonstration.
- Only combustor is modified to achieve stable combustion and low NOx emission.



IM270 Gas Turbine

Ammonia supply unit

Results : Combustion efficiency and NOx emission

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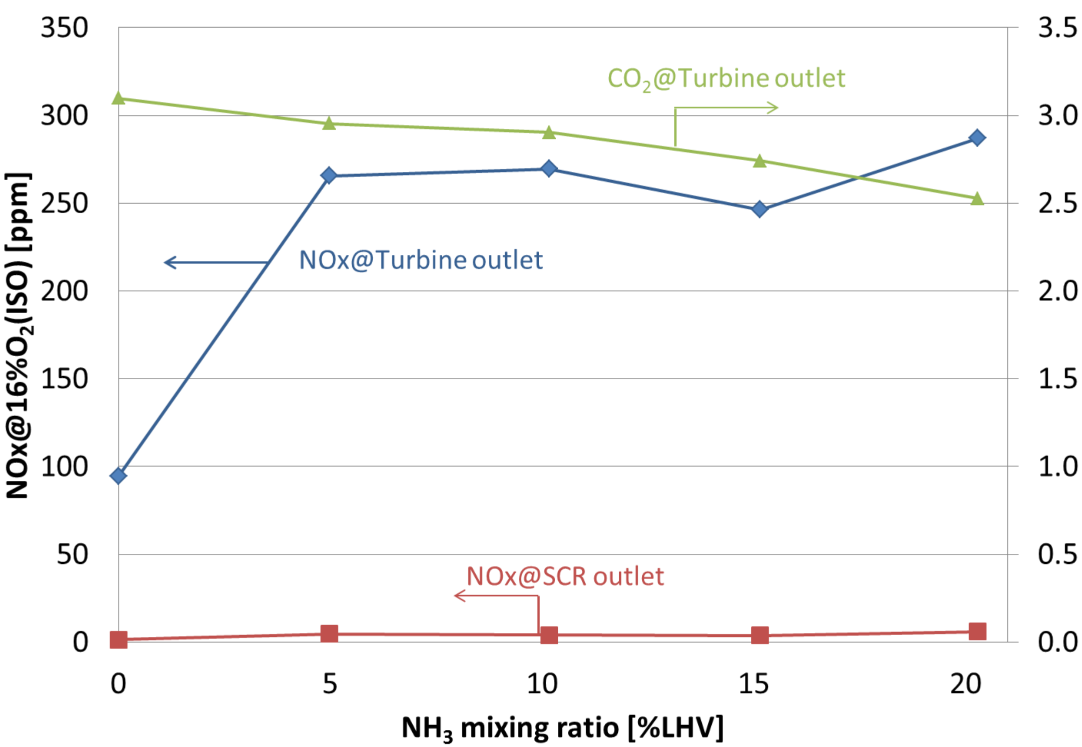
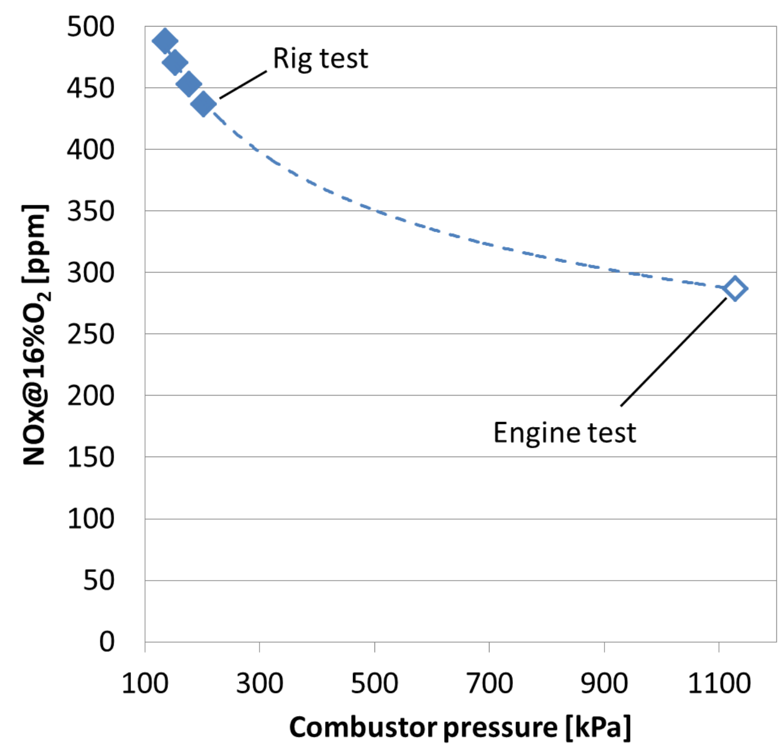
- Stable operation of gas turbine is achieved.
- Combustion efficiency is approximately 99.87% (considering heating value of NOx)
- NOx can be controlled below regulation limit using de-NOx catalyst with the improvement of combustor.



Effect of co-firing ratio on NOx emission

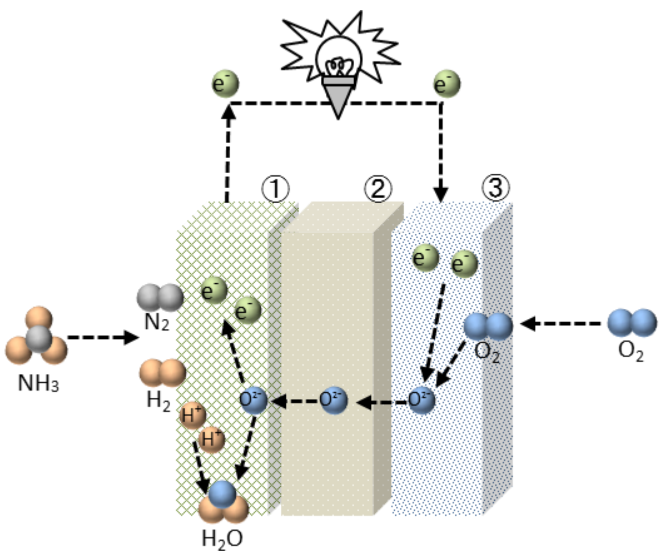


Effect of pressure on NOx emission

Ammonia fueled SOFC

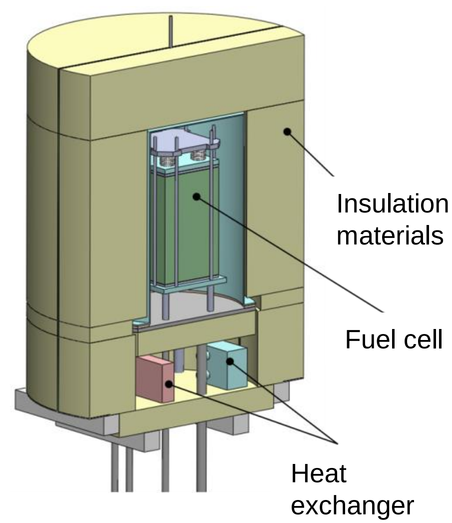
Task : Evaluation of SOFC stack performance using 100% ammonia.
Optimized design of SOFC system including stack and other components.
Demonstration test using 1kW-class SOFC integrated system.

⇒ 2017-2018 : Demonstration test by 1kW-class integrated SOFC system

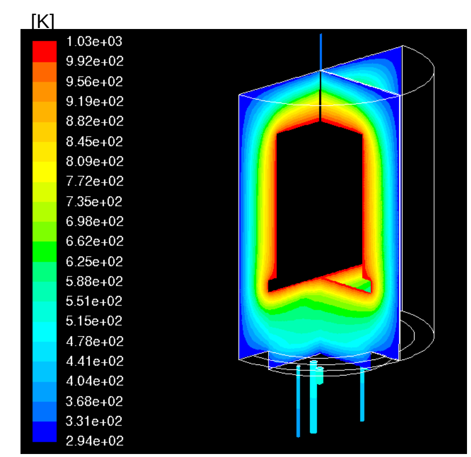


①Fuel electrode (Anode)
②Ceramic membrane (Electrolytes)
③Air electrode (Cathode)

Mechanism of ammonia fueled SOFC



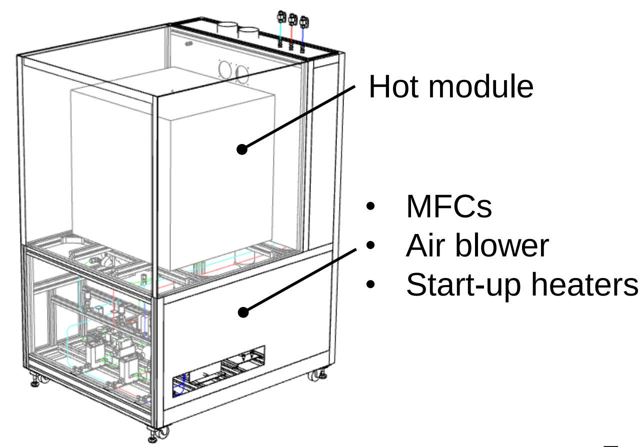
Structure of hot module

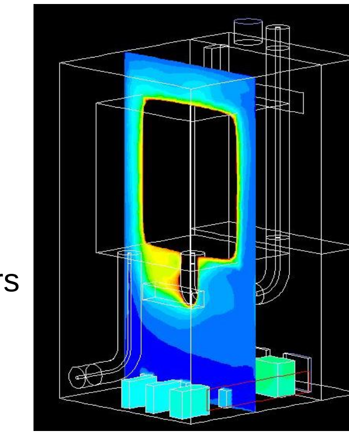


Numerical simulation of temperature distribution in hot module

Development of SOFC hot module

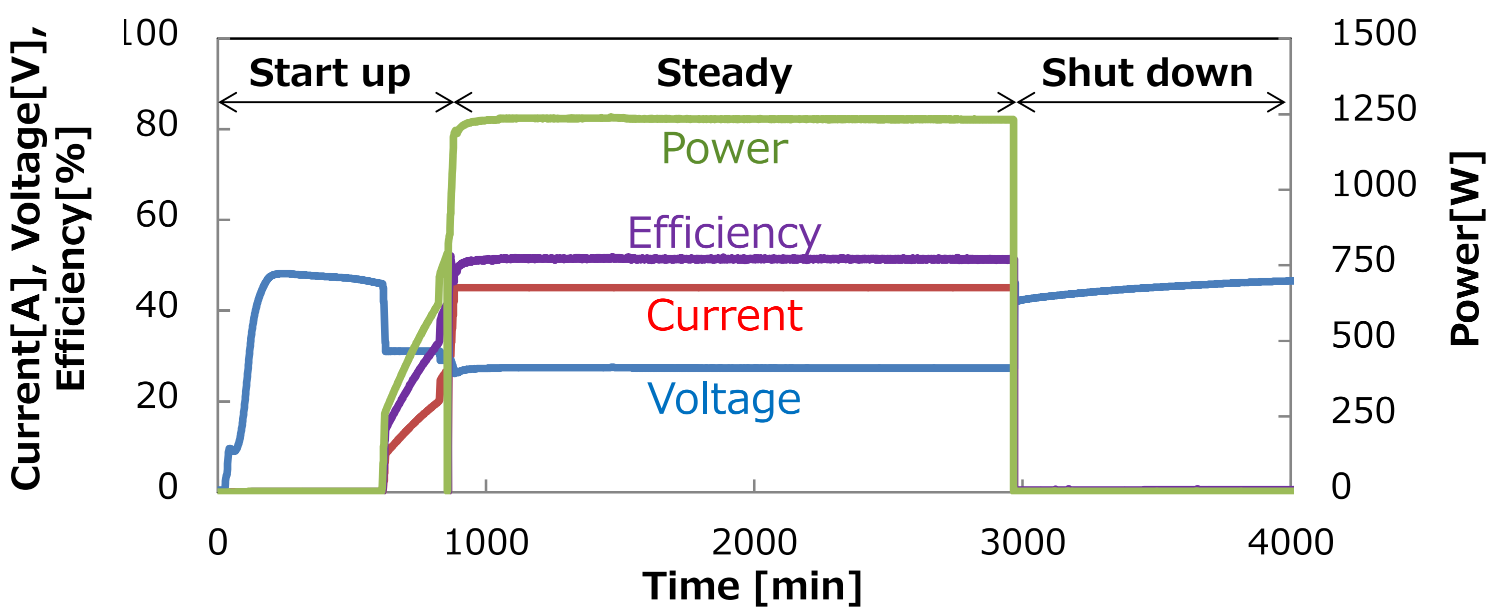
- High efficiency (56% DC) and thermal independent operation is achieved by the optimized thermal design.
- Stable operation is achieved by air flow control.
- 1000 hours continuous run is on-going.





Temperature distribution in the system

Thermal design of SOFC system



Operation of SOFC system

Conclusion

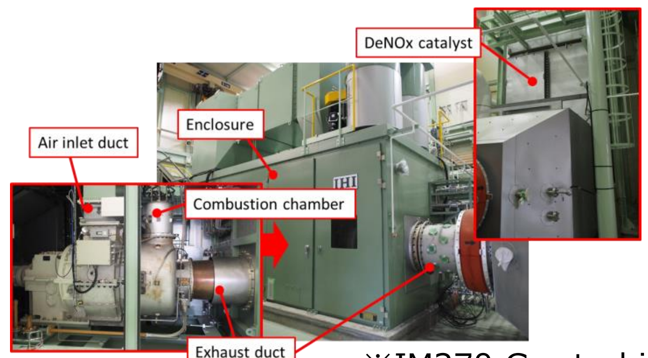
In order to use carbon free ammonia as a fuel for power plant, technologies to use ammonia directly as a fuel in coal fired boiler, gas turbine and SOFC are developed.

Coal fired boiler

※CFT(Coal Firing Test Furnace)

- 20% co-firing test of ammonia with pulverized coal is succeeded using 10MWth test furnace.
- NOx emission can be controlled at the same level as 100% coal firing condition.

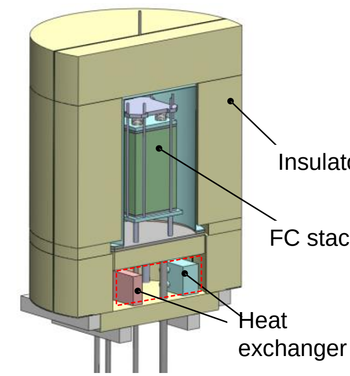
Gas turbine



※IM270 Gas turbine

- 20% co-firing test of ammonia with city gas is succeeded using 2MW commercial gas turbine.
- NOx can be controlled below regulation limit using de-NOx catalyst with the improvement of combustor

SOFC



- Test using 100% ammonia as a fuel is succeeded using 1kW hot module.
- High efficiency and thermal independent operation are achieved

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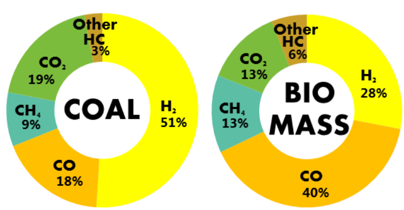
Ammonia Synthesis: Twin IHI Gasifier (TIGAR®)

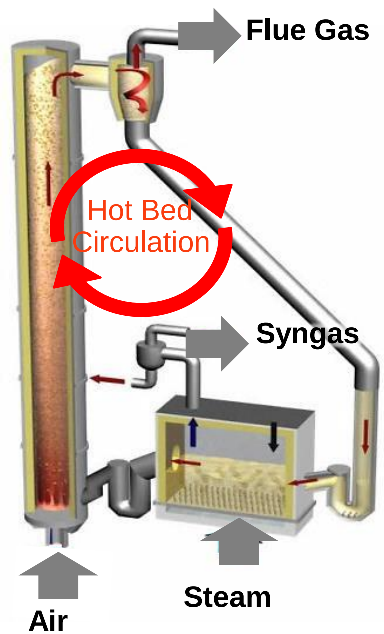
IHI

TIGAR is ready to commercialize

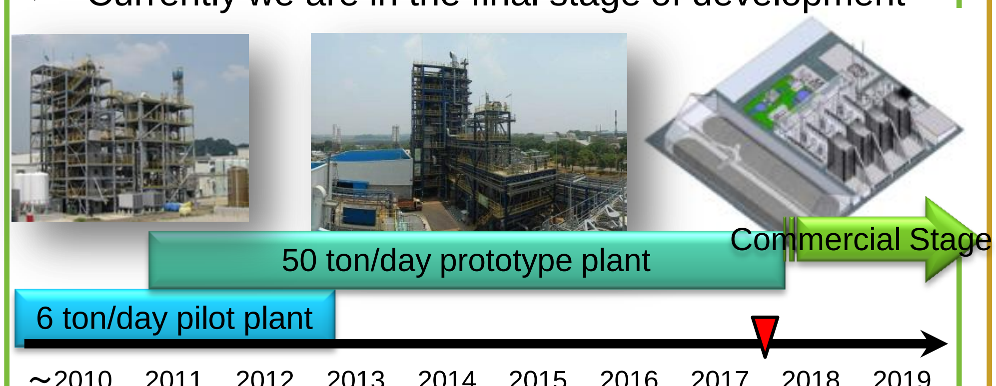
◆What is TIGAR?

- ✓ TIGAR is a gasifier suitable for low rank feedstock like lignite and biomass.
- ✓ TIGAR has been developed based on the fluidized bed technologies of which we have extensive experience and knowledge.
- ✓ Using steam as gasifying agent, H_2 rich syngas can be obtained.



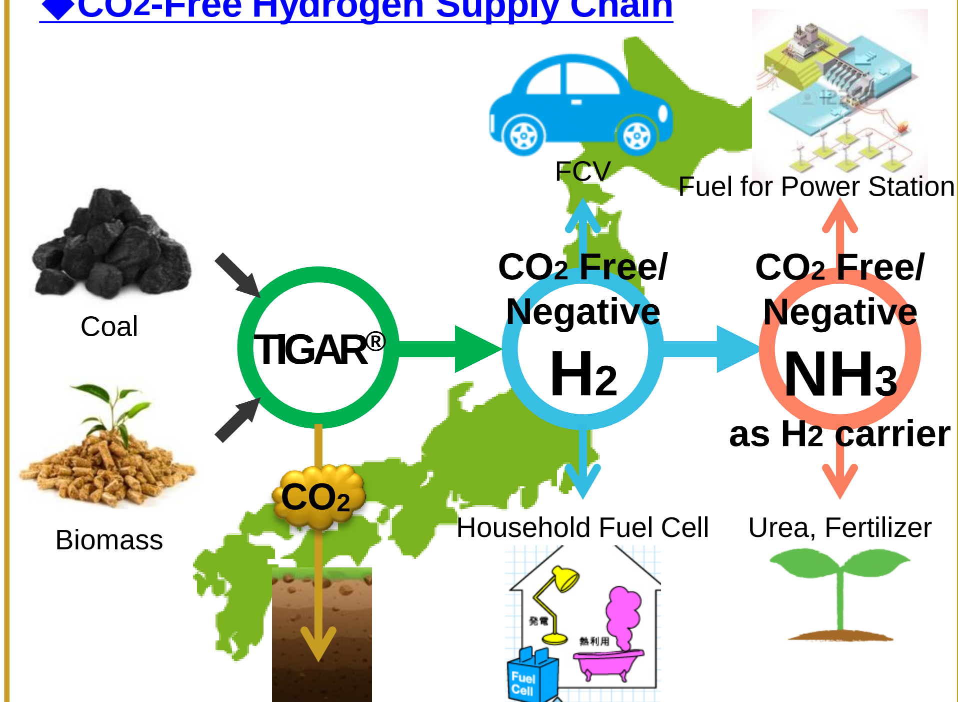


- ✓ Currently we are in the final stage of development



TIGAR leads to Hydrogen Society in Japan

◆CO2-Free Hydrogen Supply Chain



◆Business Model Example

	Business Model A	Business Model B
Feedstock	Biomass	Lignite with CCS
TIGAR Capacity	200 ton/day as feedstock	1000 ton/day as feedstock
Product	CO2-free-H2 5,000 ton/year as H2	CO2-free-NH3 200,000 ton/year as NH3
End use	FCV, Fuel Cell	Power plant, Urea

TIGAR is being developed with the support of METI and NEDO

IHI's Carbon free energy network using ammonia

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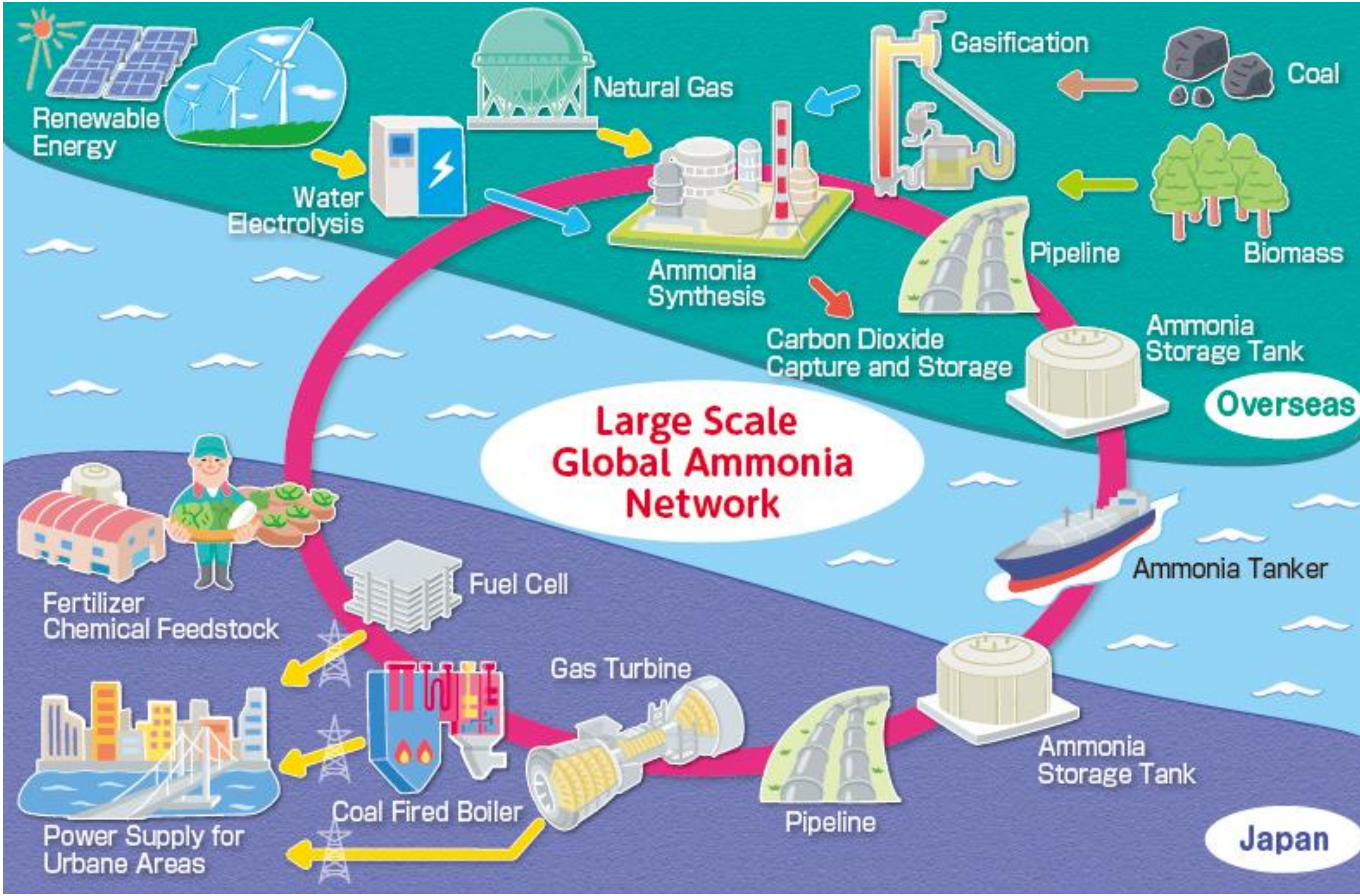

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Realize your dreams