2019 AIChE Annual Meeting in Orlando Nov. 10-15, 2019
Session: Ammonia Combustion
Date: 12th Nov. 2019
Session time: 1:45 PM - 3:40 PM
Location: Hyatt Regency Orlando, Regency Ballroom P

New Technology of the Ammonia Co-Firing with Pulverized Coal to Reduce the NOx Emission

IHI

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

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

Role of hydrogen energy on GHG reduction in Japan

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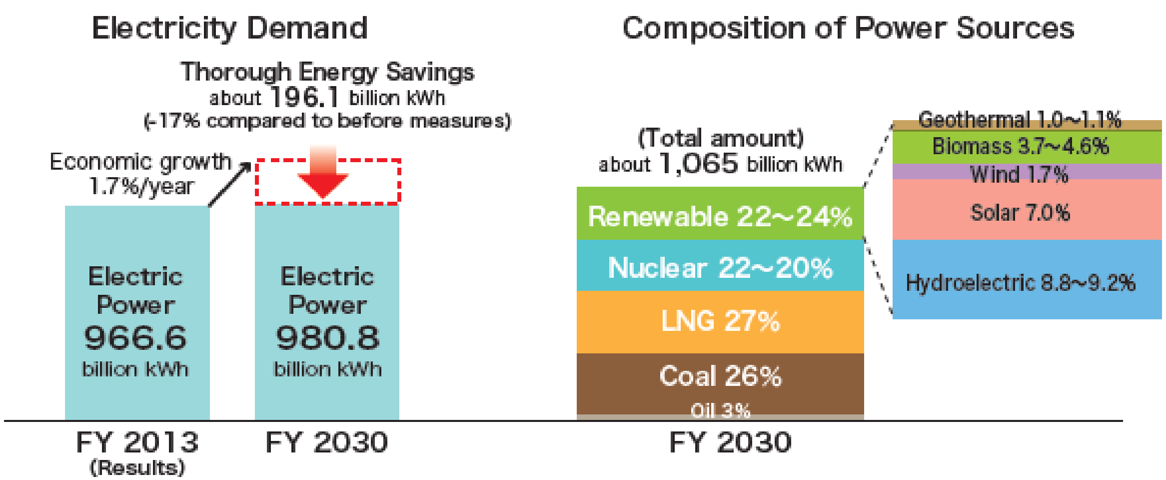
- GHG reduction targets of Japan

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.

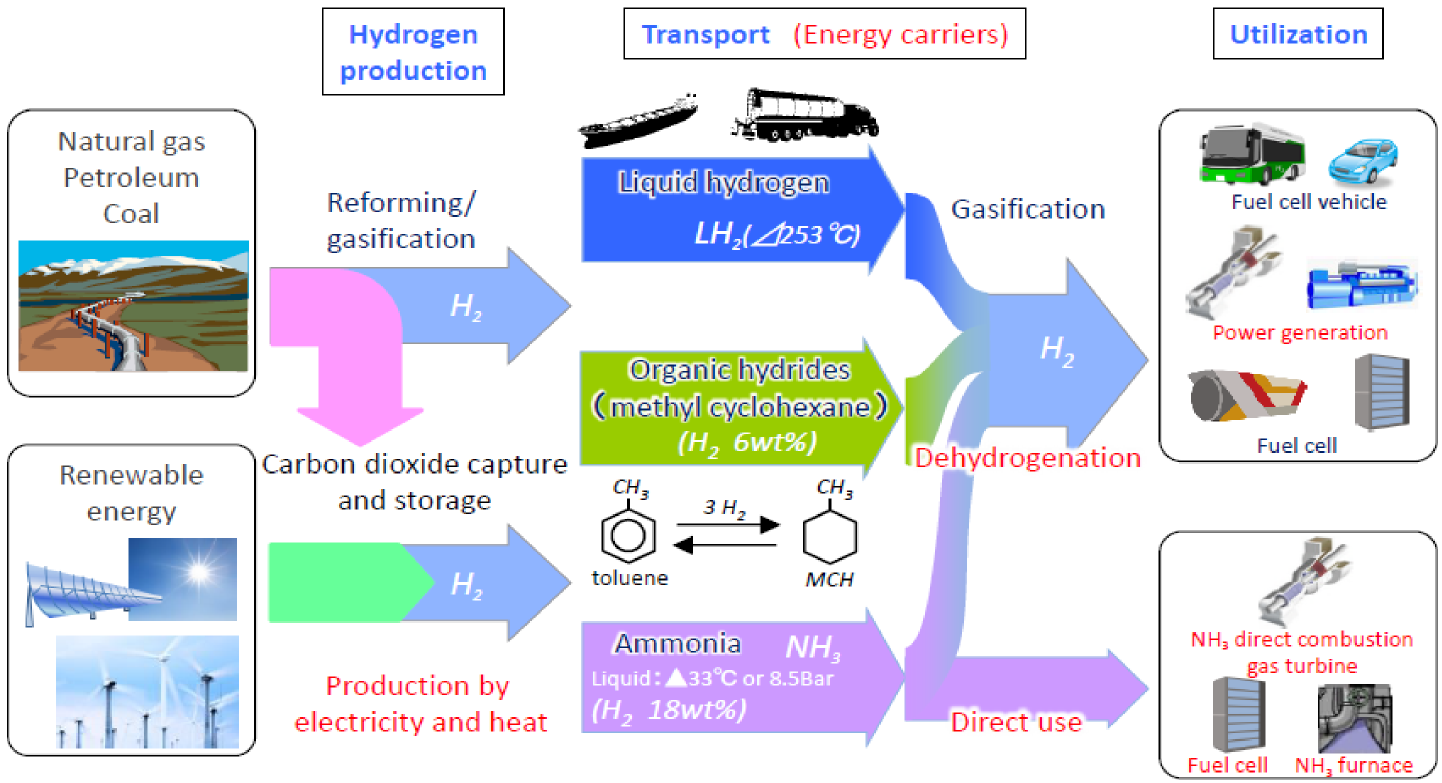
○ Energy efficiency
- Continued thorough energy efficiency
- Integrated implementation of regulation of Act on Rationalizing Energy Use and support measures

○ Promotion of hydrogen/power storage/distributed energy

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

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

Applying ammonia co-firing to coal fired power plant

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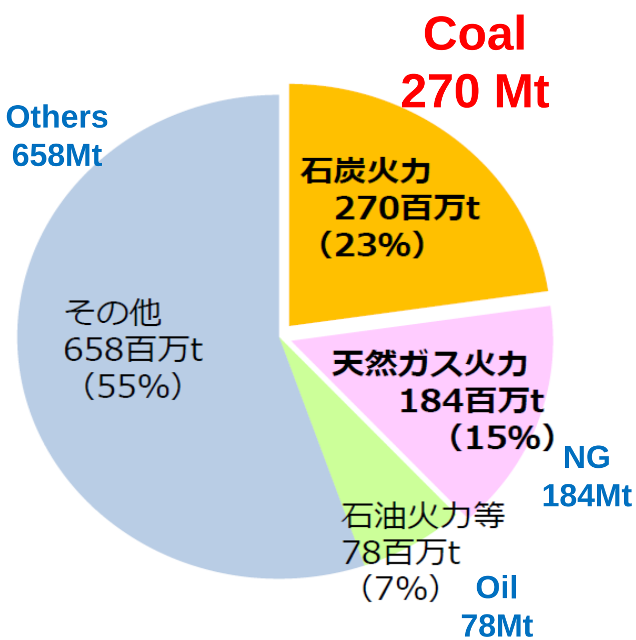
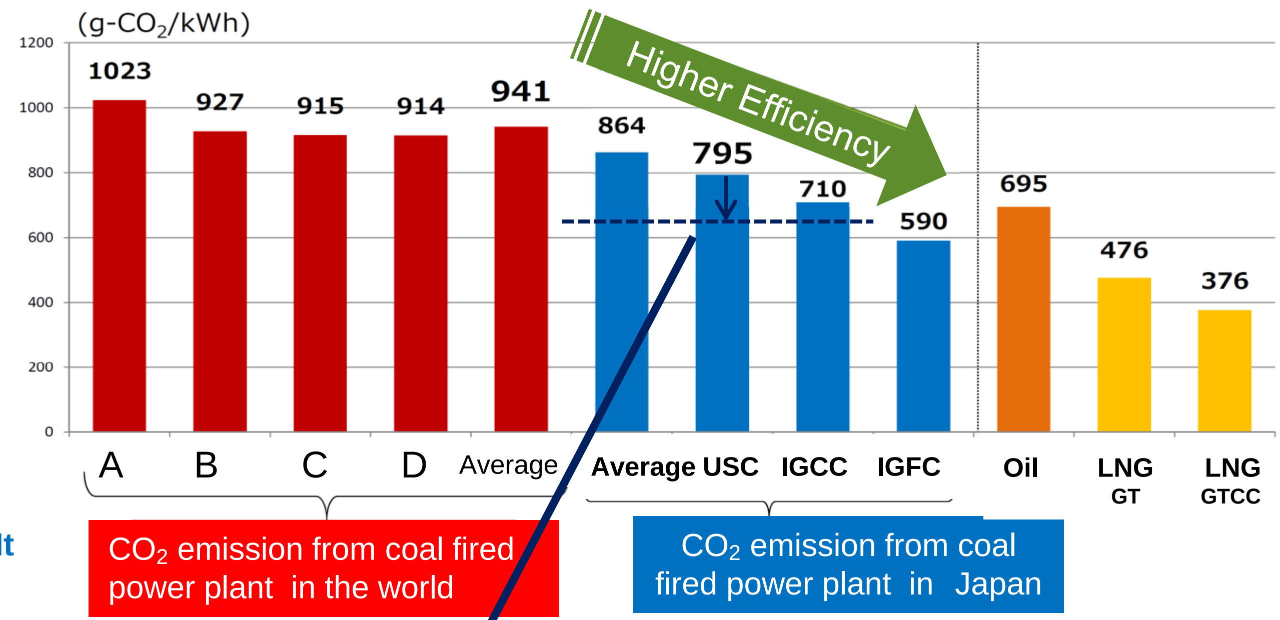
- CO_2 emission from coal fired power plant = 23% of total emission in Japan.
- **Green ammonia co-firing can directly reduce CO_2 emission.**

  Applying 20%(LHV) ammonia co-firing to USC boiler

  USC : 795g-CO_2/kWh ⇒ USC with ammonia 20% co-firing : **636g-CO_2/kWh**



CO_2 emission in Japan
(2015)



CO_2 emission factor of power plant

Ammonia co-firing can directly reduce CO_2
Applying to USC : 795×80%=636g-CO_2/kWh

Source : Agency for Natural Resources and Energy
https://www.enecho.meti.go.jp/about/special/johoteikyo/sekainosekitankaryoku.html

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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.

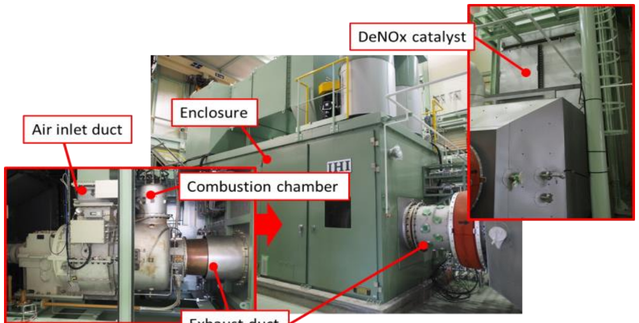
SIP 戦略的イノベーション創造プログラム Cross-ministerial Strategic Innovation Promotion Program

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

Coal fired boiler

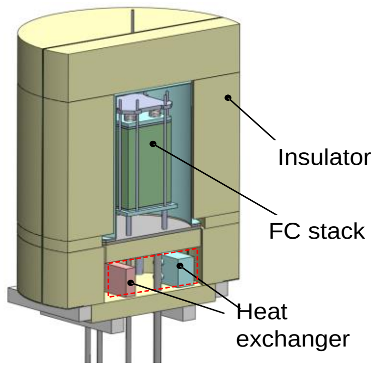
※CFT(Coal Firing Test Furnace)

Gas turbine



※IM270 Gas turbine

SOFC



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

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

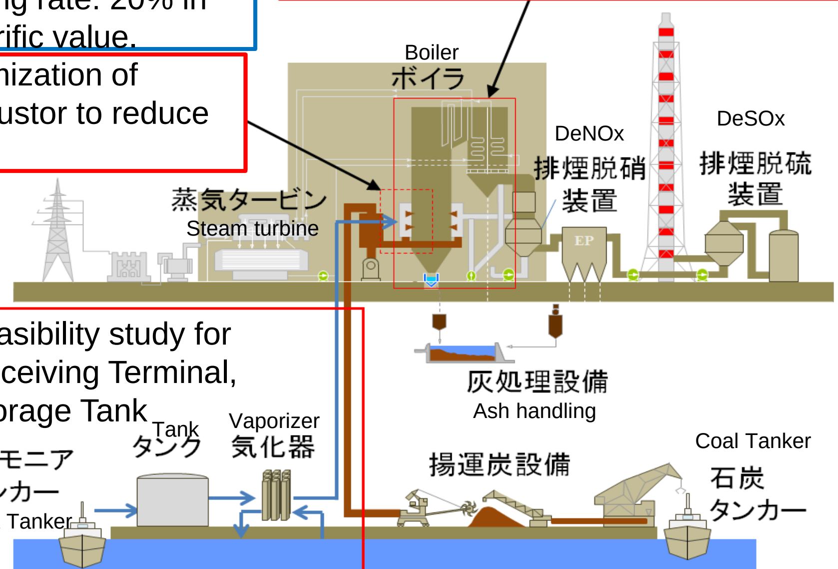
⇒ 2017FY : Co-firing test using $10MW_{thermal}$ test furnace
2018FY : Trial design to introduce ammonia co-firing system for existing coal fired power plant (1000MW)

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

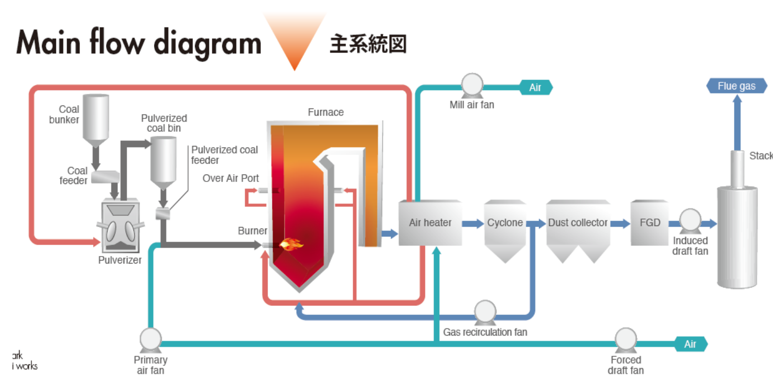
1.Optimization of combustor to reduce NOx

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

4. Feasibility study for Receiving Terminal, Storage Tank



Tasks



Combustion test facility

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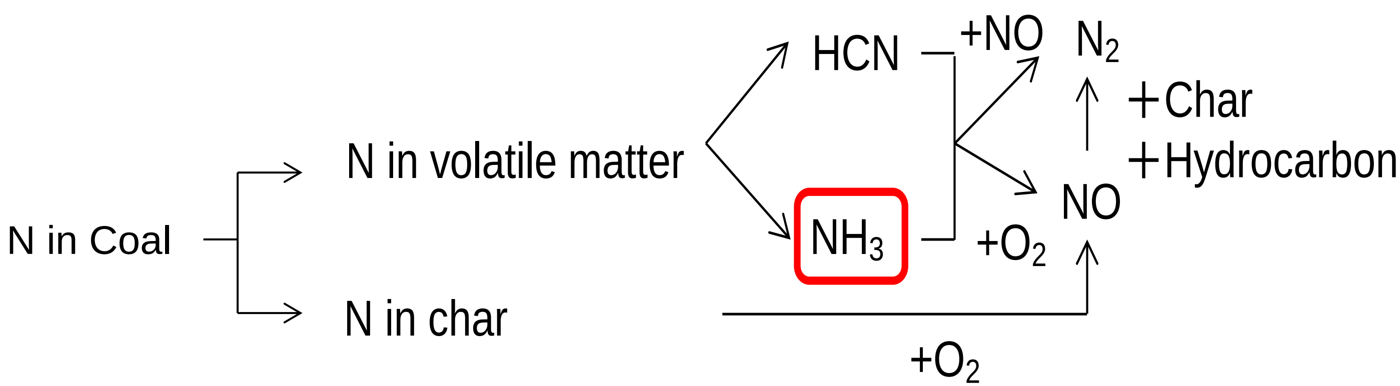
NO_x formation in coal combustion



NO_x formation in ammonia combustion

Ammonia oxidation	$NH_3 + (5/4) O_2 \rightarrow NO + (3/2) H_2O$
NO reduction by ammonia	$NH_3 + NO + (1/4) O_2 \rightarrow N_2 + (3/2) H_2O$
Ammonia decomposition	$2 NH_3 \rightarrow N_2 + 3 H_2$

Approach to control NOx and boiler performance

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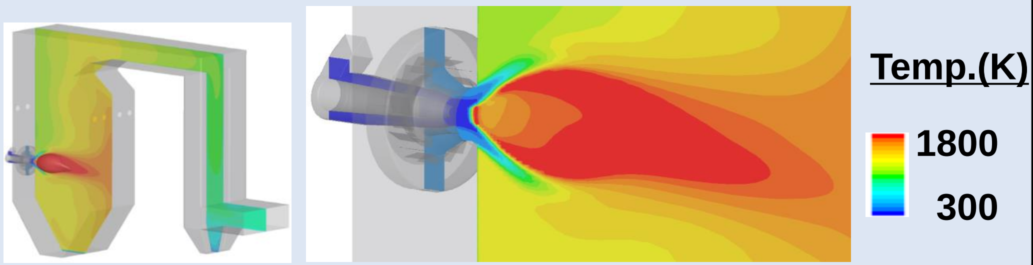
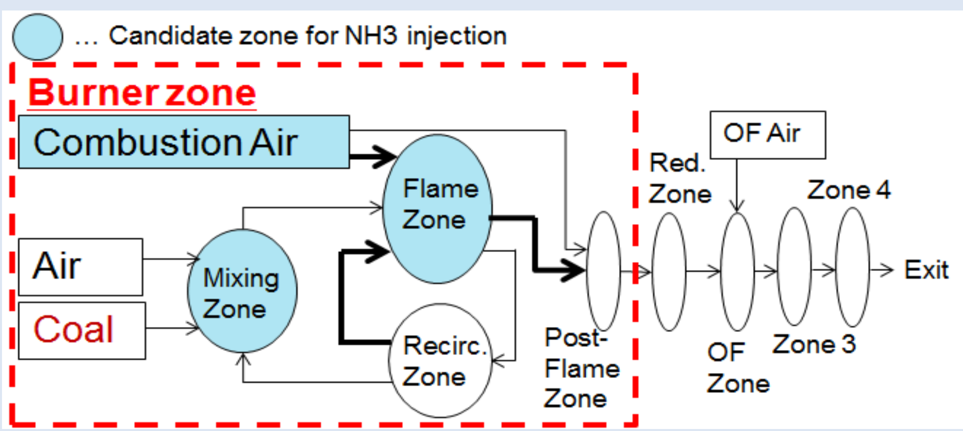
- Technical Issue and approaching method:
  - NO_x reduction by experimental and numerical analysis
  - Boiler performance (amount of the steam generation) by numerical analysis

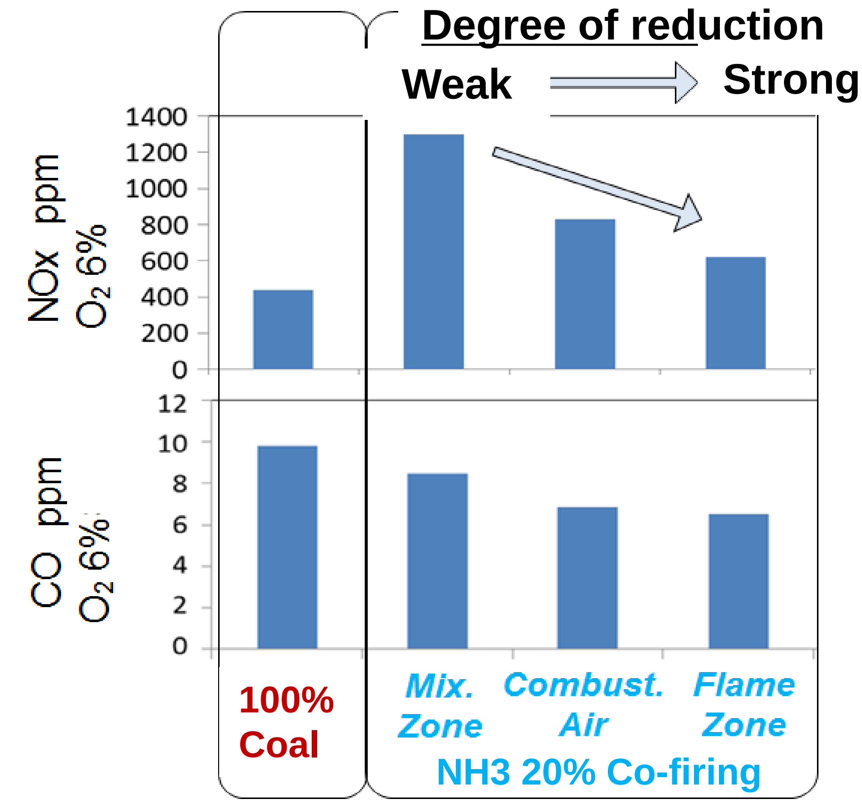
Consideration of the fluid dynamics



Consideration of the NH_3 Reaction path



NO_x reduction by the NH_3 injection method (CHEMKIN)



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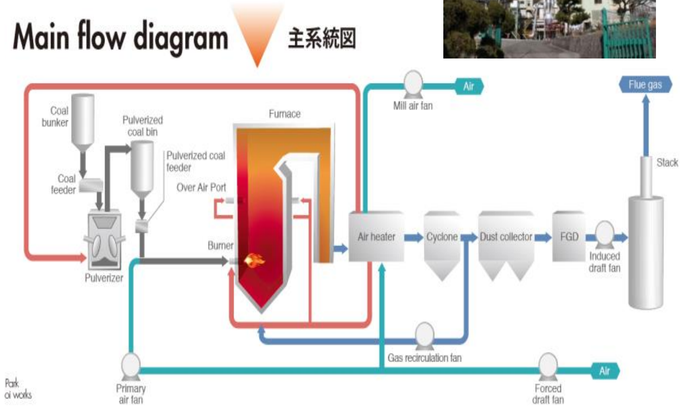
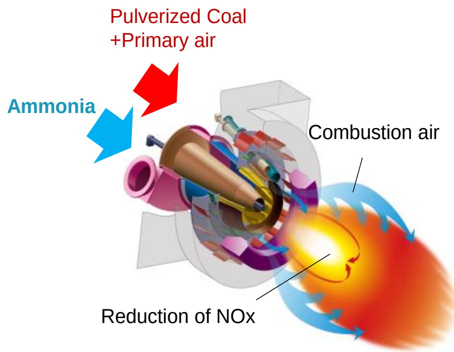
Test facility



Burner for coal combustion co-firing with ammonia



Measurement items

・Exhaust gas
（CO、CO2、NO、N2O）
・Unburned carbon
・Heat flux
・Flame shape
etc.

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

Experimental results: flame stability, NOx

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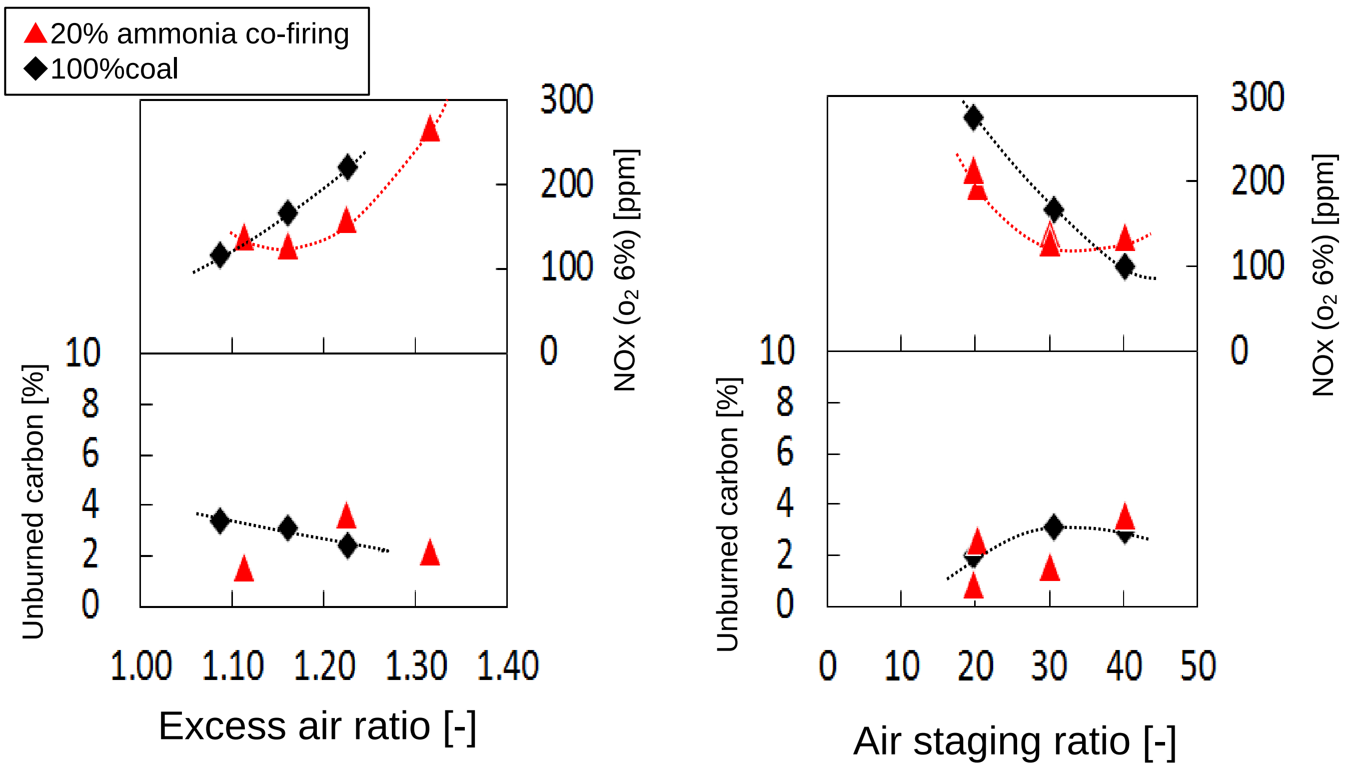
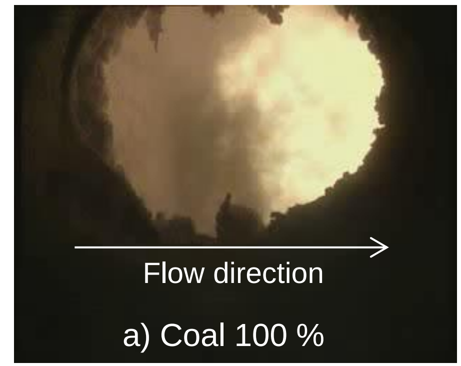
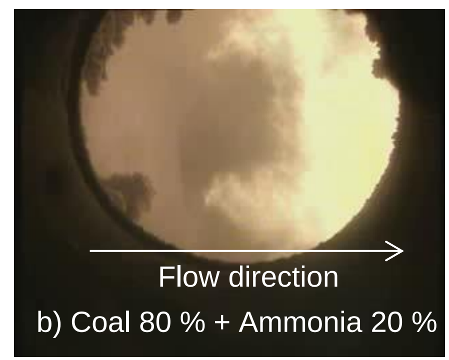
- Stable flame can be achieved by controlling swirl of the secondary air.
- NOx concentration in 20% ammonia co-firing condition is same or under that of 100% coal firing condition.
- NH_3, N_2O in exhaust gas is under detection limit.







<u>Effect of ammonia co-firing on NOx and unburned carbon</u>

Ref. SIP report 2018

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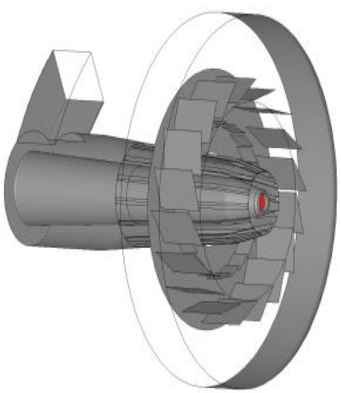
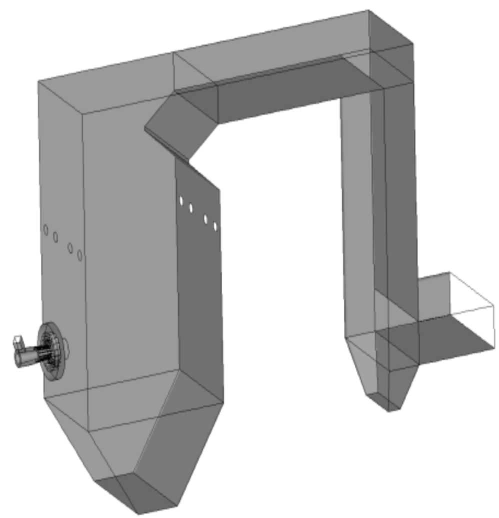
Conditions for the Numerical evaluation

	Coal firing	NH_3 co-firing
Co-firing ratio of NH_3 (LHV, %)	0	20.5
Heat input from fuel (MW)	9.5	9.5
Overall excess air ratio	1.22	1.22
Staging air ratio (%)	30.8	30.9



Burner



Furnace

Tool

Software: Fluent 15.0

Dimension: 3D

Turbulent model: k-ε

Chemistry: Eddy Dissipation Concept

Radiation: DO

Mesh: around 2 million

Ref. 35th Annual International Pittsburgh coal conference, China, 2018, Oct. 15-18

Reactions considered in the numerical evaluation

Devolatilization (HCN,NH_3 formation)
Volatile combustion
Char oxidation/gasification (Char NO_x formation)

NH3 related reactions

$NH_3 + O_2 \rightarrow NO + H_2O + H_2$
$NH_3 + NO \rightarrow N_2 + H_2O + H_2$
$NH_3 \rightarrow 1.5N_2 + 0.5H_2$

HCN related reactions

$HCN + O_2 \rightarrow NO + 0.5H_2 + CO$
$HCN + NO \rightarrow N_2 + 0.5H_2 + CO$

Thermal NOx formation

$O_2 \rightarrow O + O$
$O + H_2O \leftrightarrow 2OH$
$O + N_2 \leftrightarrow N + NO$
$N + O_2 \leftrightarrow O + NO$
$N + OH \leftrightarrow H + NO$

NOx reduction by char

$C + NO \rightarrow 0.5N_2 + CO$

Volatile matter combustion

Volatile $\rightarrow$ tar + $C_mH_n + H_2 + CO + CO_2 + H_2O$
tar + $O_2 \rightarrow CO + H_2$
$C_mH_n + (m/2)O_2 \rightarrow mCO + (n/2)H_2$
$C_mH_n + mH_2O \rightarrow mCO + (n/2+m)H_2$
$H_2 + 0.5O_2 \leftrightarrow H_2O$
$CO + H_2O \leftrightarrow CO_2 + H_2$
$CO + 0.5O_2 \rightarrow CO_2$

Char combusiton

C (char) + $0.5O_2 \rightarrow CO$
$C + H_2O \rightarrow CO + H_2$
$C + CO_2 \rightarrow 2CO$

Results of the numerical evaluation

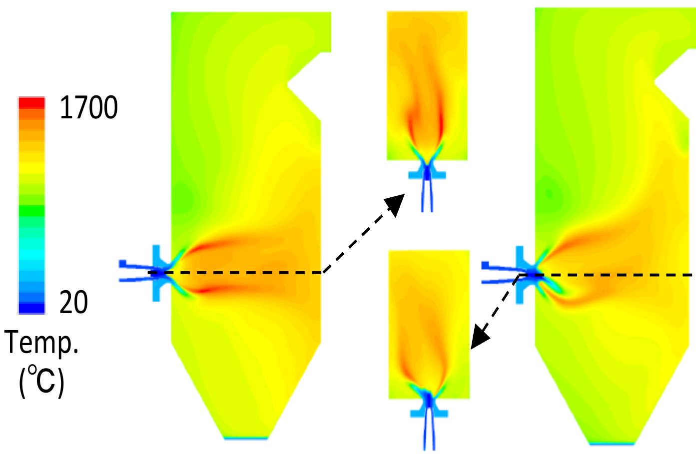
	Coal firing		NH_3 co-firing	
	Exp.	Num.	Exp.	Num.
Heat absorption (MW)	-	7.4	-	7.3
Gas temp. at exit (℃)	1045.0	1051.0	1033.0	1043.0
H_2O at exit (vol.%, wet)	-	6.1	-	11.2
CO_2 at exit (vol.%, 6%O_2)	13.0	13.6	11.0	10.9
CO at exit (ppm, 6%O_2)	21.0	1.9	21.0	0.4
NO at exit (ppm, 6%O_2)	222	214	160	263
Unburned carbon (wt.%)	2.4	2.5	3.7	3.4

Ref. 35th Annual International Pittsburgh coal conference, China, 2018, Oct. 15-18

Numerical results

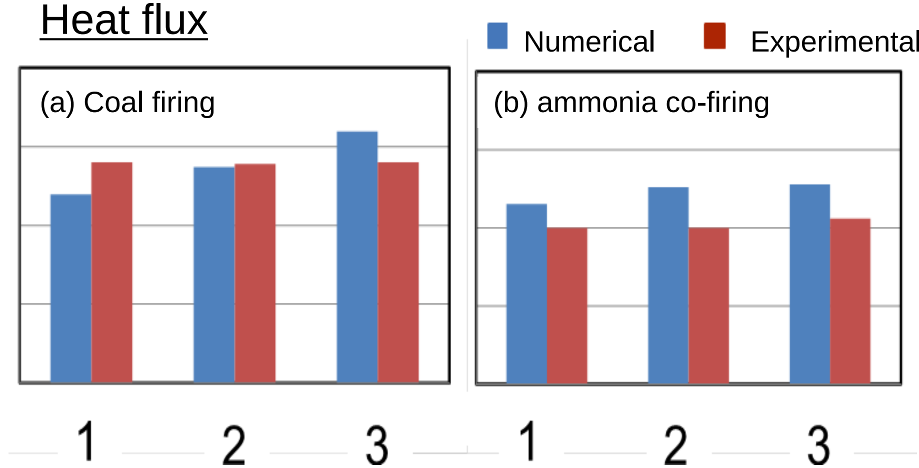
Local heat flux is reduced in ammonia co-firing.
This trend is adequately simulated in the CFD.

Temperature profile

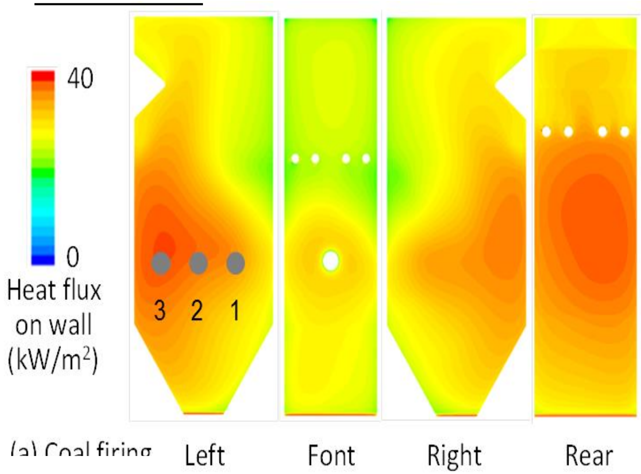


(a) Coal firing (b) NH_3 co-firing

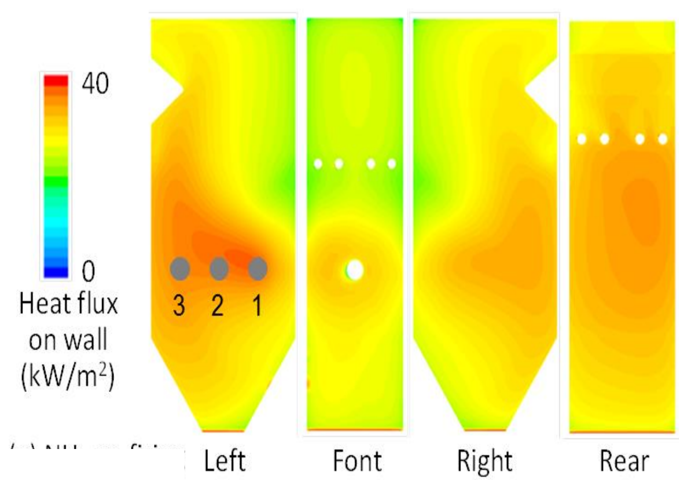
Heat flux



Heat flux



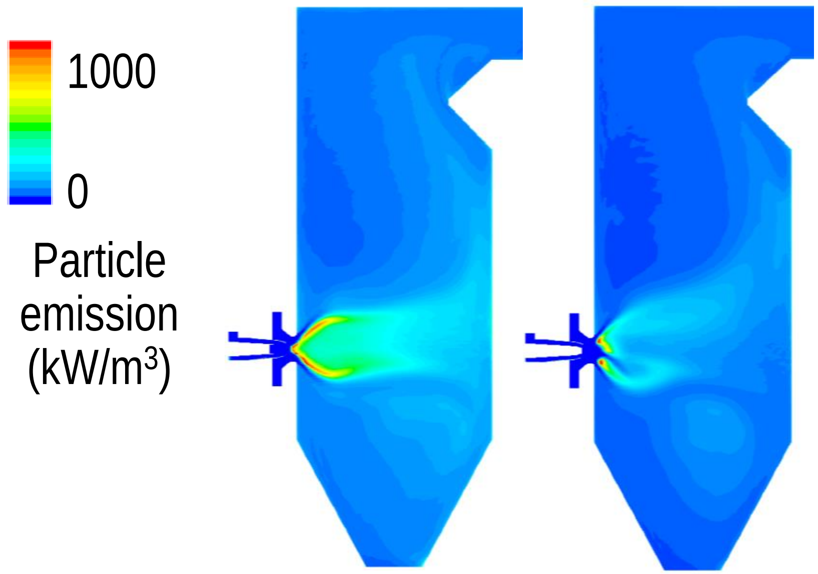
Coal firing

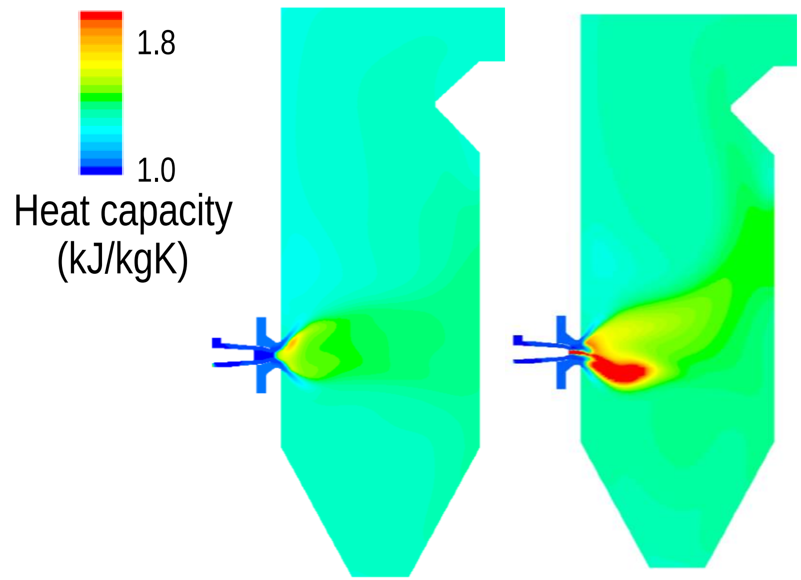


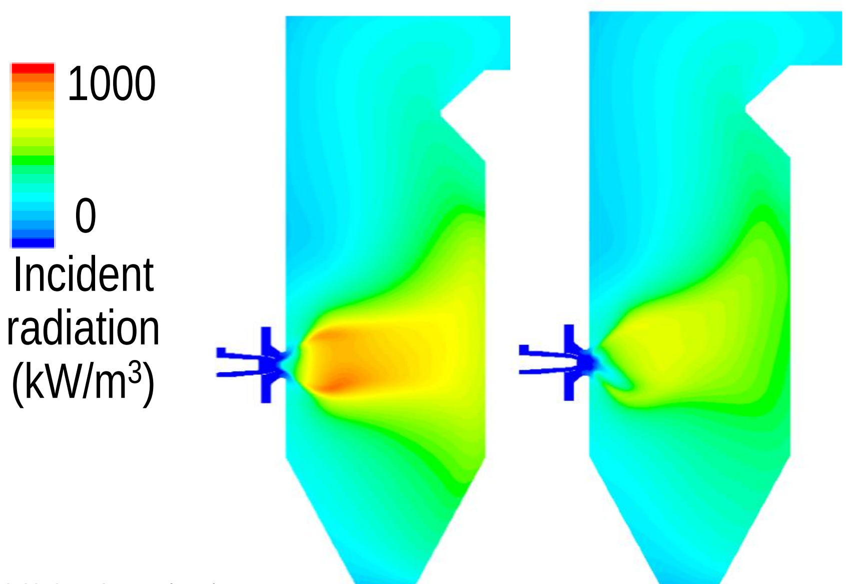
Ammonia co-firing

Ref. 35th Annual International Pittsburgh coal conference, China, 2018, Oct. 15-18

Numerical results



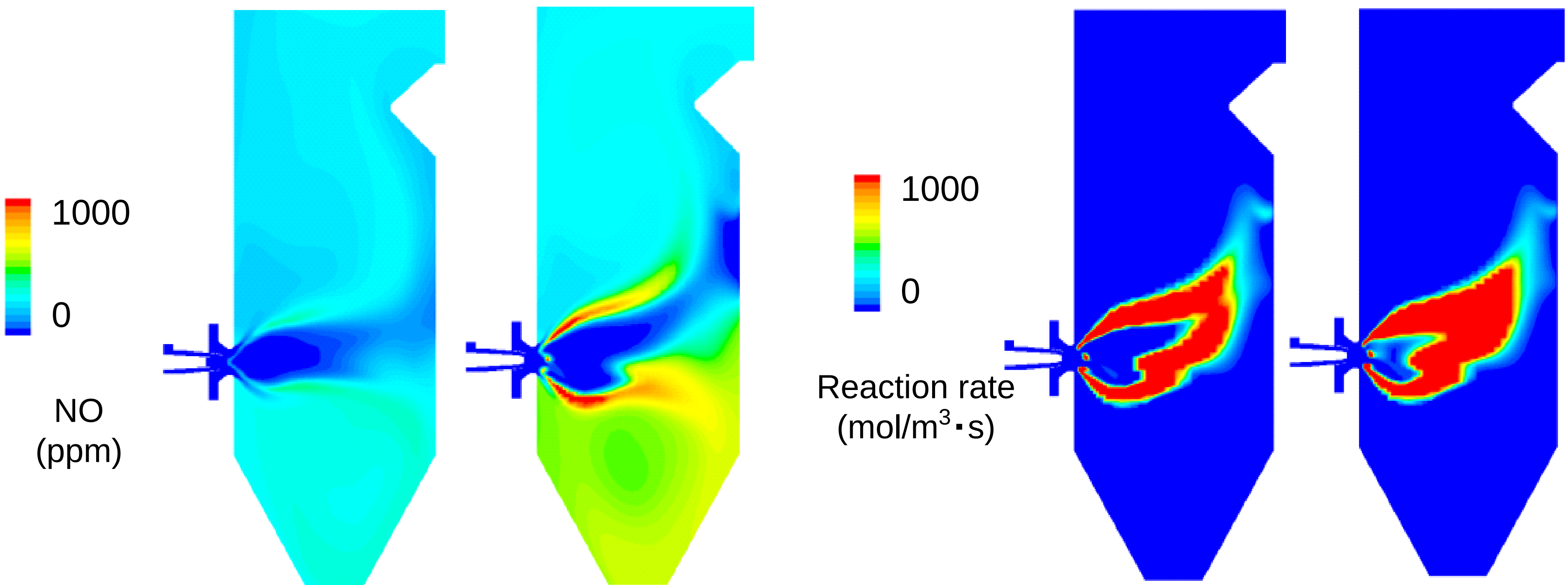




Reduction of the heat flux on the furnace wall in the ammonia co-firing is induced by the thermal properties related to the heat transfer.

Ref. 35th Annual International Pittsburgh coal conference, China, 2018, Oct. 15-18

Numerical results



(a) Coal firing

(b) Ammonia co-firing

Ammonia oxidation

NO reduction by ammonia

Ref. 35th Annual International Pittsburgh coal conference, China, 2018, Oct. 15-18

Conclusion

- In this study, injection method of ammonia into the pulverized coal fired boiler was investigated.
- Ammonia is injected into the reduction zone that is created by the coal combustion and the thermal cracking of the ammonia is promoted.
- In some test cases, it was experimentally observed that NO concentration in the ammonia co-firing is lower than that in the coal firing.
- By the numerical study, the reason for it could be seen that some part of the injected ammonia contribute to the denitrification.
- According to this study, it can be mentioned that ammonia can be used as the fuel for the coal fired power plant.

Acknowledgements ：This work is supported by the Council for Science Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP) , “Energy Carrier” (Funding agency：Japan Science and Technology Agency)

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NEDO New Energy and Industrial Technology Development Organization

(1)Development of ammonia co-firing technology optimized for multi burner in pulverized coal boiler

IHI, CRIEPI(Central Research Institute of Electric Power Industry), Osaka Univ.

(2)Development of direct combustion technology of liquefied ammonia for gas turbine

IHI, Tohoku Univ., AIST(National Institute of Advanced Industrial Science and Technology)

- Establishment & improvement of the technology
- Feasibility study for demonstration

IHI's Carbon free energy network using ammonia

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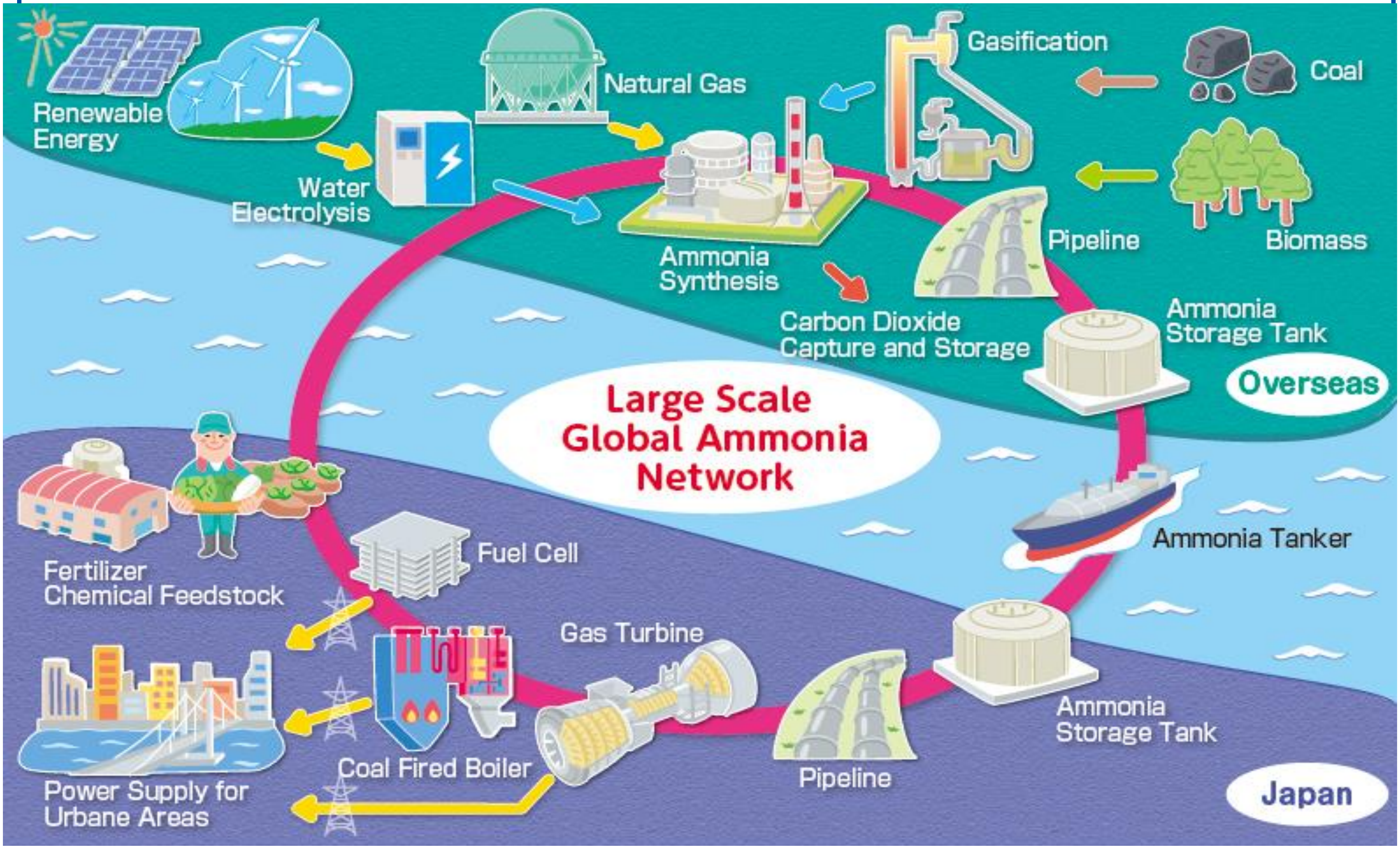

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