CONFIDENTIAL

IHI's Development of Ammonia Combustion Technologies / Fuel Ammonia and Hydrogen Solutions

IHI

November 2021

IHI Americas Inc.

Company Profile

IHI Global Headquarters Tokyo, Japan

Founded : 1853

Capital : $1.1 billion

Employees : 29,659
(Consolidated)

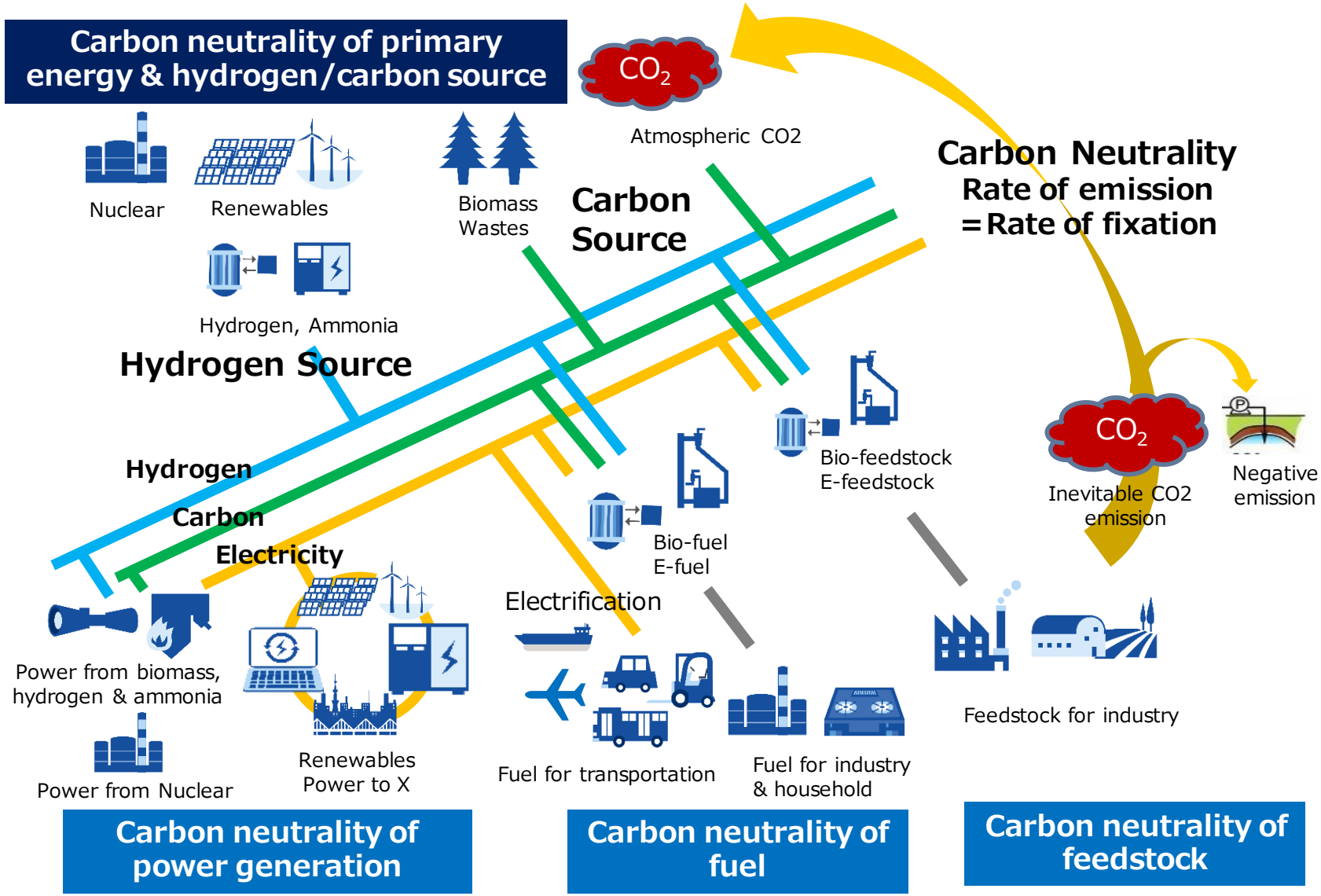
Net Sales : $13.5 billion

Global Network :

- Global headquarters : Tokyo
- Regional headquarters: New York, Singapore, Shanghai
- Overseas offices : 15
- Subsidiaries : 231 (incl. 158 overseas companies)

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

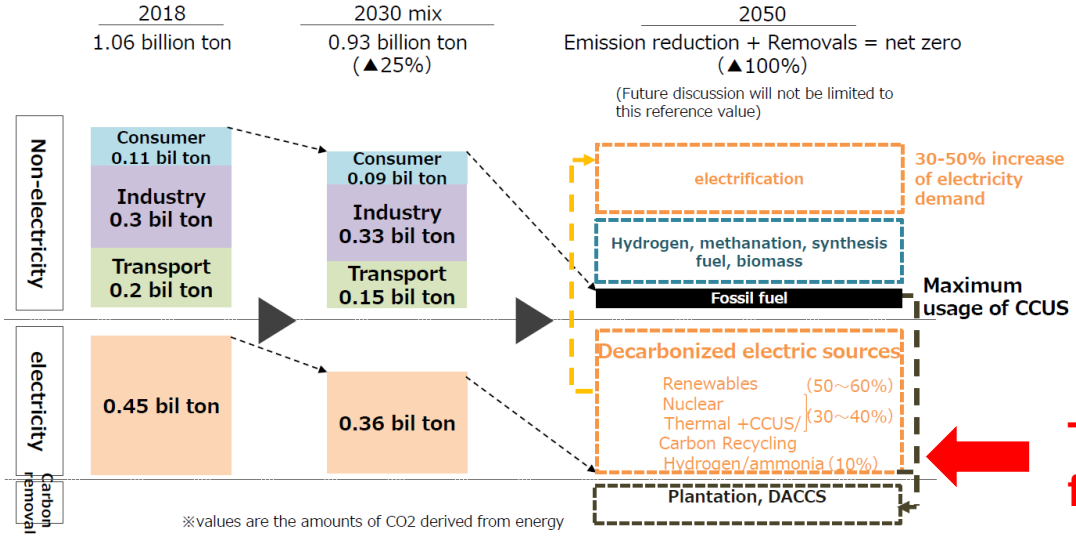
IHI Goal & Vision to Achieve Carbon Neutrality



Japan's move for Carbon Neutrality

Government Policy

October 26,2020　Policy Speech by the Prime Minister Suga
3. Realizing a green society
We hereby declare that by 2050 Japan will aim to reduce greenhouse gas emissions to net-zero, that is, to realize a carbon-neutral, decarbonized society.



Source : METI, ' Overview of Japan's Green Growth Strategy Through Achieving Carbon Neutrality in 2050'
https://www.meti.go.jp/english/press/2020/pdf/1225_001a.pdf

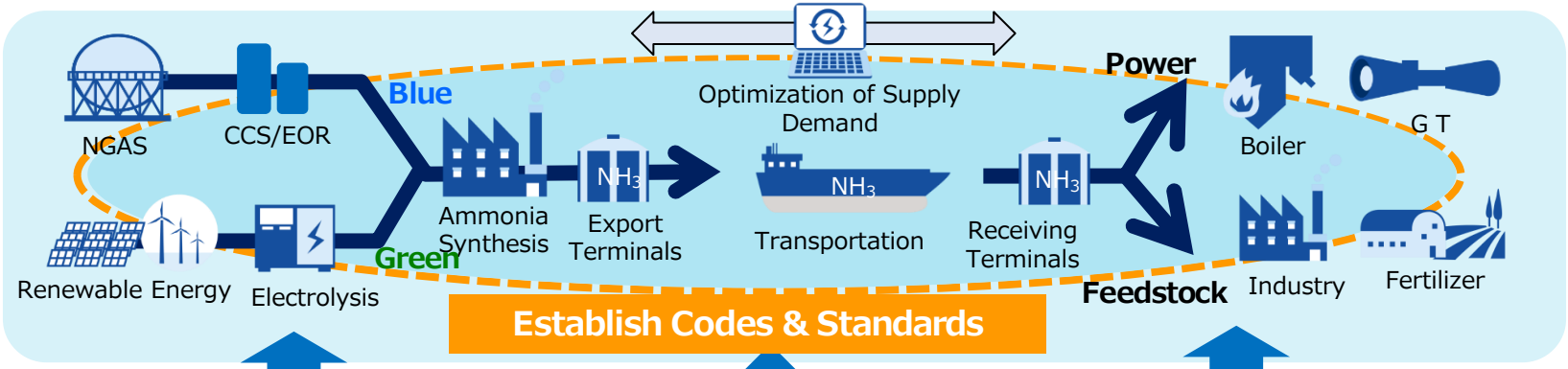
Target : 10% of electricity comes from Hydrogen / Ammonia in 2050

Energy mix for 2030

Renewables	36-38%
Hydrogen/Ammonia	1%
Nuclear	20-22%
LNG	20%
Coal	19%
Oil etc.	2%
GHG reduction	46%

Target : 1% of electricity (equivalent to 1GW) comes from Hydrogen / Ammonia in 2030

Total Value Chain of Hydrogen/Ammonia by IHI



Target : Reducing green ammonia cost to 30% of existing technology

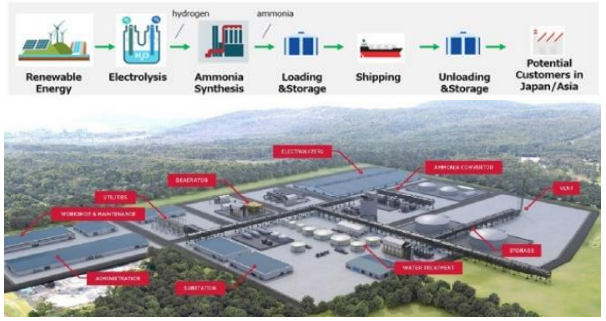
- Evaluation & execution of green ammonia project
- Promoting innovation in electrolysis technology

Target : Achieve ammonia demand of 3MTPA fuel by 2030 and 30MTPA fuel by 2050

- Development of pure ammonia combustion technology

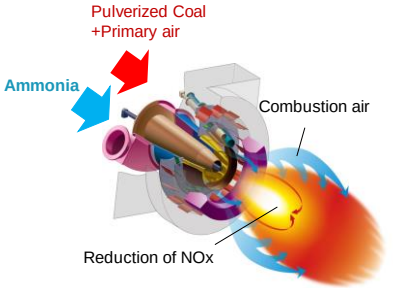
Target : Reducing time to construct ammonia infrastructure

- Large scale ammonia storage/supply system



FS on green ammonia project in TAS, Australia
(with Woodside Energy, Marubeni Corp.)

Carbon Neutral Port using large scale ammonia storage system



100% pure ammonia combustion technology

Implementation of Ammonia Fueled Power Plants

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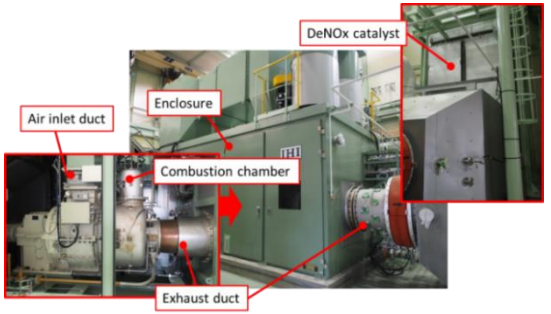
Coal fired boiler

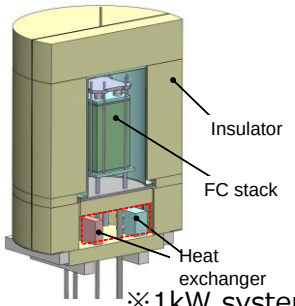
※CFT(10MWth Coal Firing Test furnace)

Gas turbine



※2MW class gas turbine(IM270)

SOFC



※1kW system

FY2014-2018

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

- Basic research of ammonia combustion mechanism
- Development of co-firing technology : stable combustion & NOx reduction
- Brief feasibility study for commercialization

FY2019-2020

NEDO

- Improvement of technology :
  - Improvement of co-firing ratio (over 50%)
  - Simplification of the system
- Feasibility study for demonstration

Target :
- Scaling up to 10kW
- Application for decentralized power

FY2021-

Target :
- Demonstration by 1,000MW commercial boiler (20% ammonia co-firing)

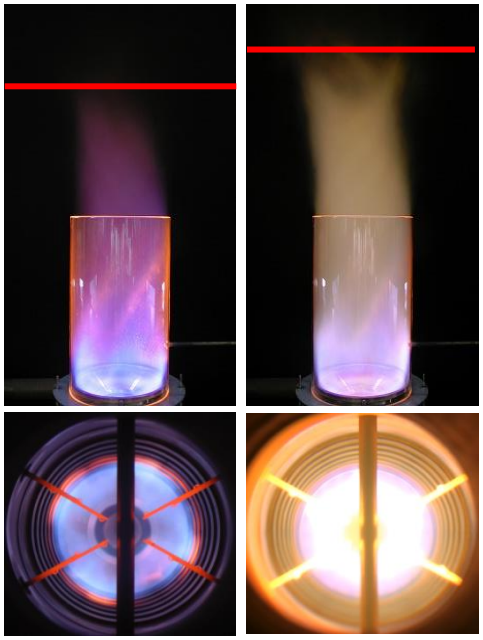
Target :
- Development of 100% ammonia fueled 2MW class GT
- Application for zero-emission combined heat and power

Ammonia Co-firing Pulverized Coal (P.C.) Boiler

IHI

Combustion of ammonia : issues 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 for personnel protection
(4) Feasibility studies (Cost evaluation of the system)



City gas　　Ammonia co-firing

Comparison of swirl flame

Fuel	NH_3	H_2	CH_4	C_3H_8
Boiling temperature at 1 atm (˚C)	-33.4	-253	-161	-42.1
Condensation pressure at 25 ˚C (atm)	9.90	-	-	9.40
Lower heating value, LHV (MJ/kg)	18.6	120	50.0	46.4
Flammability limit (Equivalence ratio)	0.63~1.40	0.10~7.1	0.50~1.7	0.51~2.5
Adiabatic flame temperature (˚C)	1800	2110	1950	2000
Maximum laminar burning velocity (m/s)	0.07	2.91	0.37	0.43
Minimum autoignition temperature (˚C)	650	520	630	450

Source : Prof.Kobayashi, Tohoku Univ.

Ammonia Co-firing Pulverized Coal (P.C.) Boiler

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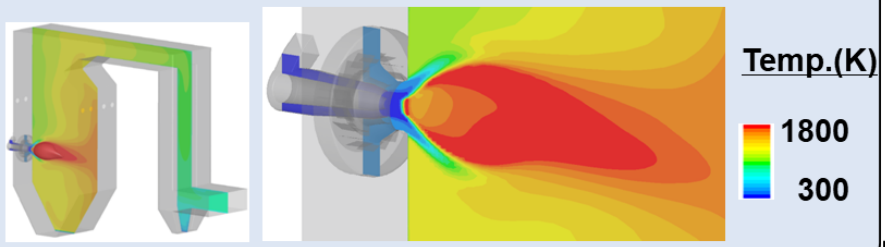
Approach to control NOx and Boiler performance

Numerical analysis and combustion test in IHI's test facilities are applied to solve technical issue.

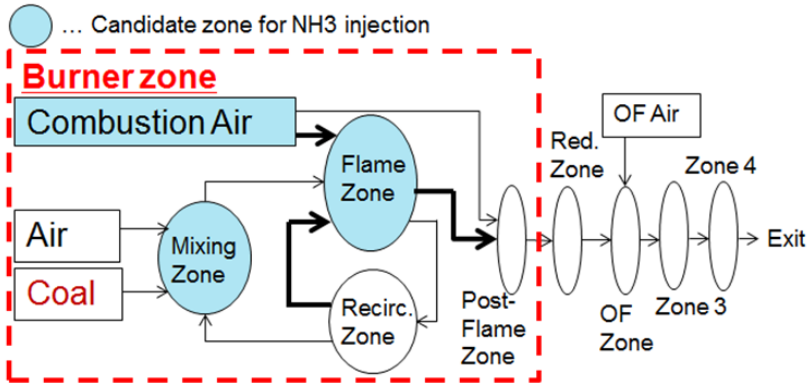
As a result of numerical analysis, the study is proceeded on the following premises,

- ✓ Ammonia is injected into the reduction zone that is created by the coal combustion.
- ✓ Ammonia is pyrolyzed into nitrogen and hydrogen in the reduction zone.

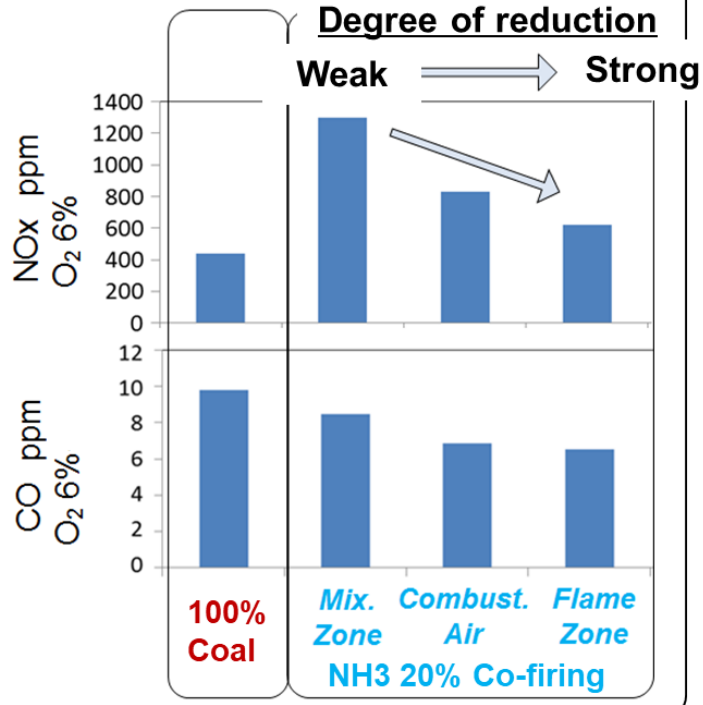
Consideration of the fluid dynamics



Consideration of the NH_3 Reaction path



NO_x reduction by the NH_3 injection method (CHEMKIN)



Ammonia Co-firing Pulverized Coal (P.C.) Boiler

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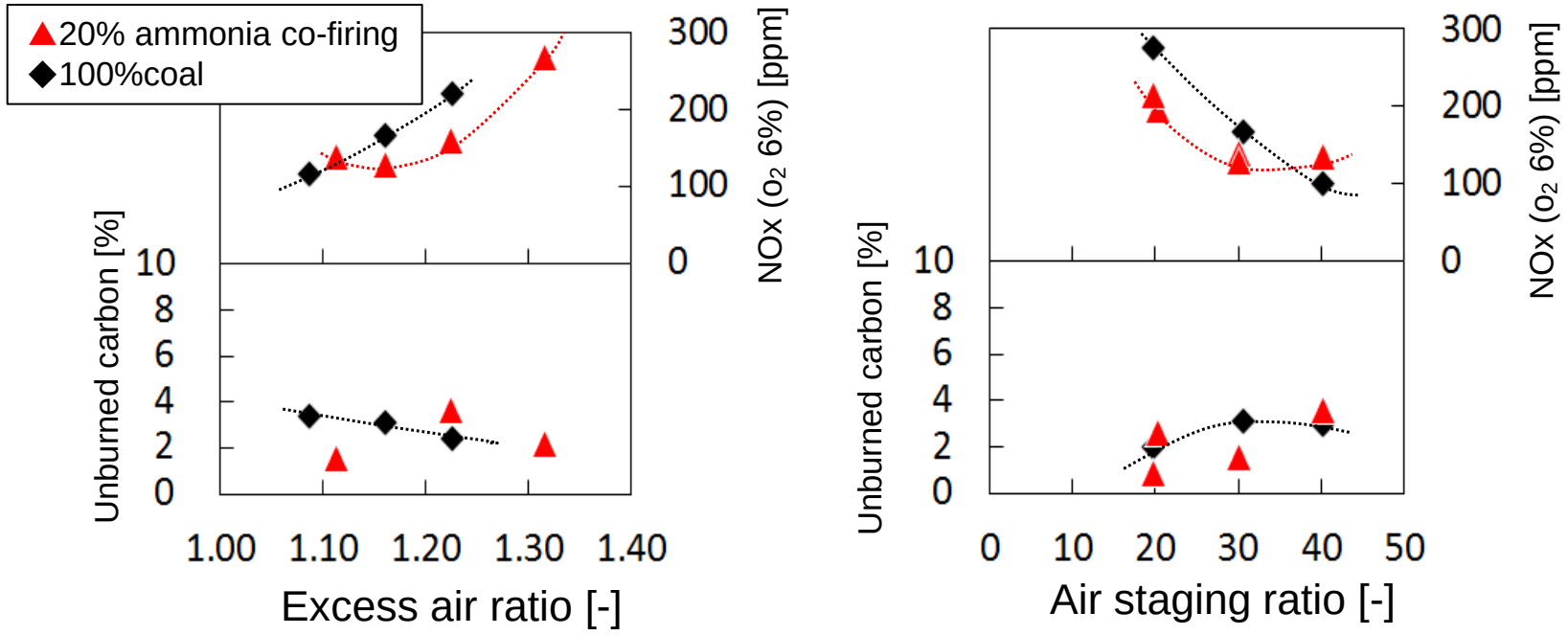
Optimization of combustion system to reduce NOx

[Experimental results: flame stability, NOx and unburned carbon]

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



Effect of ammonia co-firing on NOx and unburned carbon

Ammonia Co-firing Pulverized Coal (P.C.) Boiler

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Implementation at Existing Coal Fired Power Plant in Japan

JERA and IHI to Start a Demonstration Project Related to Ammonia Co-firing at a Large-Scale Commercial Coal-Fired Power Plant

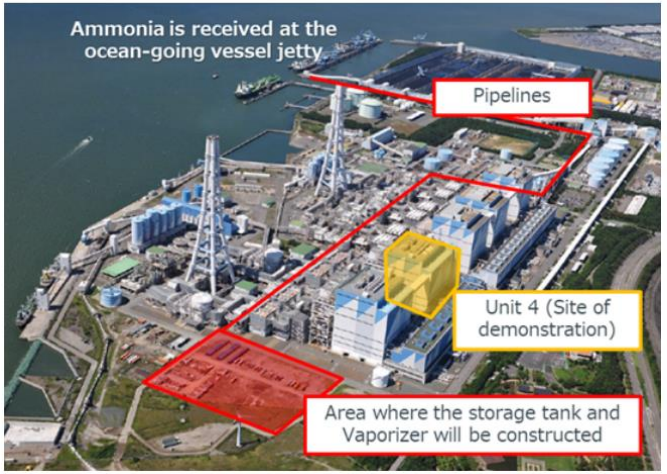
-May 24, 2021- press

TOKYO – 24 May 2021 – JERA Co., Inc. ("JERA") and IHI Corporation ("IHI") have received notice of acceptance of their joint grant application to conduct a demonstration project under the New Energy and Industrial Technology Development Organization's "Development of Technologies for Carbon Recycling and Next-Generation Thermal Power Generation / Research, Development and Demonstration of Technologies for Ammonia Co-Firing Thermal Power Generation" program.

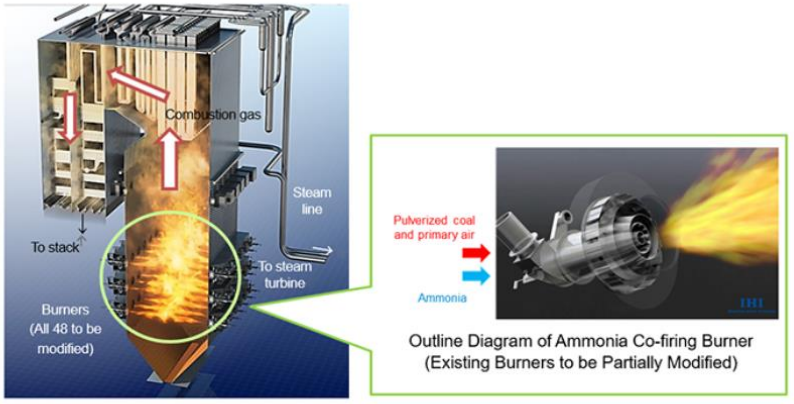
Ammonia enables efficient, low-cost transport and storage of hydrogen. In addition to this role as an energy carrier, it can also be used directly as a fuel in thermal power generation. As a fuel that does not emit carbon dioxide when burned, ammonia is expected to offer great advantages in reducing greenhouse gas emissions.

Looking to reduce future environmental impact, the demonstration project aims to establish ammonia co-firing technology by co-firing coal and ammonia at a large-scale commercial coal-fired power plant and evaluating both boiler heat absorption and environmental impact characteristics such as exhaust gases. The project will run for approximately 4 years from June 2021 to March 2025.

Reference 1: Hekinan Thermal Power Station (Hekinan City, Aichi Prefecture), where the demonstration project will be conducted



Reference 2: Outline of Boiler and Modified Burners



https://www.ihi.co.jp/en/all_news/2021/resources_energy_environment/1197406_3360.html

Roadmap for Fuel Ammonia Implementation

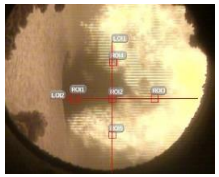
IHI

~FY2030
Goal: Development of 100% pure ammonia combustion technology
Purpose: Power plants without CO_2 emissions

FY2021 ~
20% ammonia co-firing demonstration by JERA's 1,000MW commercial unit

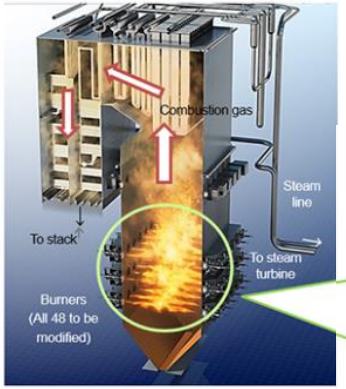
Commercial operation (after construction of ammonia terminal)

Expand ammonia co-firing technology to coal fired power plants overseas



FY2019~2020
Feasibility Study for 20% co-firing demonstration (NEDO)

FY2010~2018
Base technology for ammonia co-firing (SIP:2014~)



Boiler

Outline Diagram of Ammonia Co-firing Burner (Existing Burners to be Partially Modified)

Demonstration using commercial 2MW class GT

IHI

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

2MW class ammonia fueled gas turbine (IM270)

Ammonia supply unit

Co-development of Ammonia Fuel Roadmap

GE Gas Power

IHI
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Roadmap of Fuel Ammonia Social Implementation

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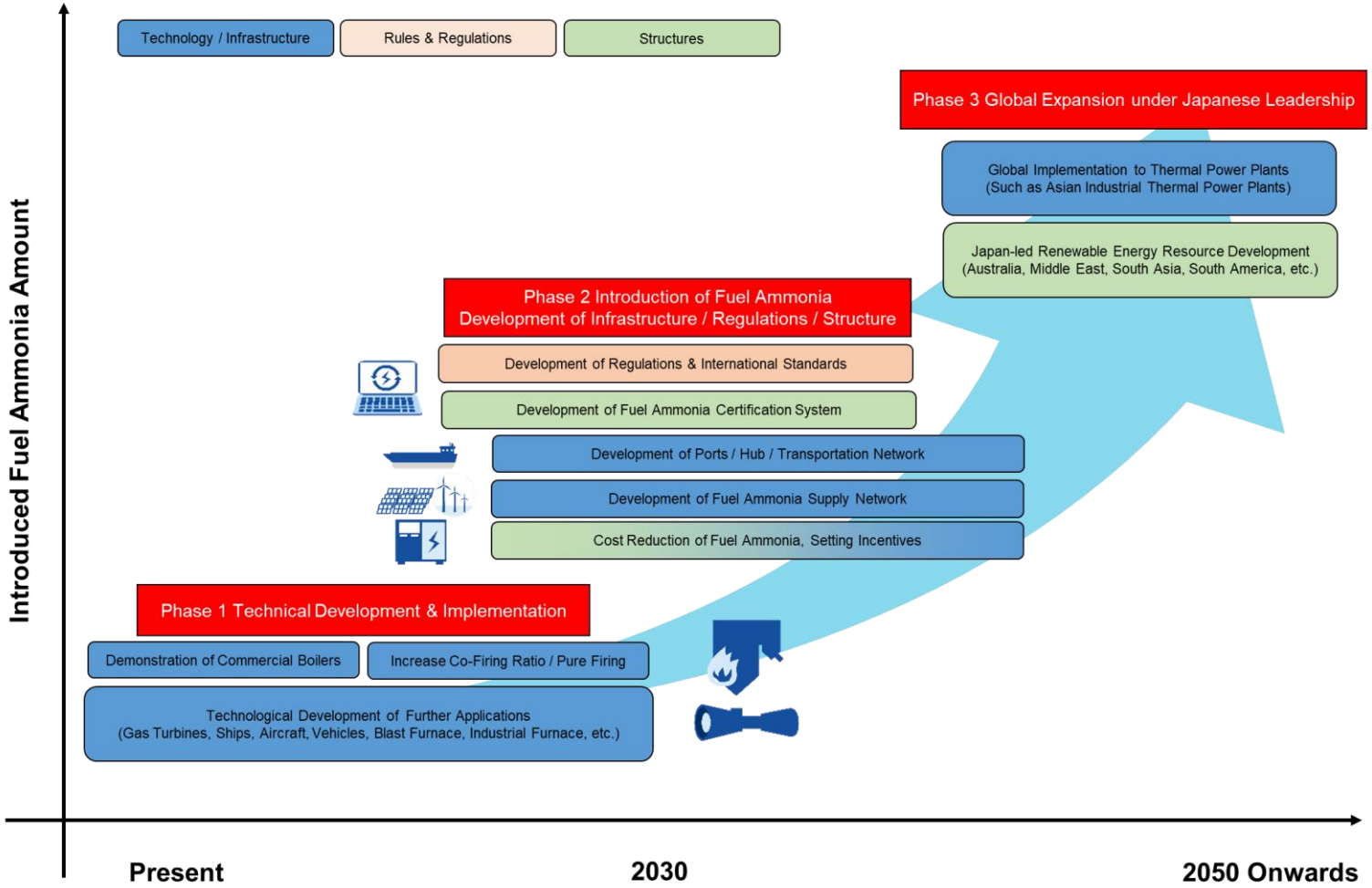
IHI involvement in CFAA and its development of Social Implementation of Fuel Ammonia

IHI, as Board Member and Technology Leader of Japanese Clean Fuel Ammonia Association (CFAA), is developing a roadmap to implement ammonia as fuel along with Japanese government



F/S for Green Ammonia Export in Australia

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Woodside, IHI and Marubeni to Study Hydrogen Exports as Green Ammonia from Tasmania

-May 20, 2021- Press Release

Woodside Energy Ltd.
IHI Corporation
Marubeni Corporation

Woodside Energy Ltd., IHI Corporation and Marubeni Corporation have signed a Heads of Agreement to investigate the production and export of green ammonia produced from renewable hydro power in the Australian state of Tasmania.

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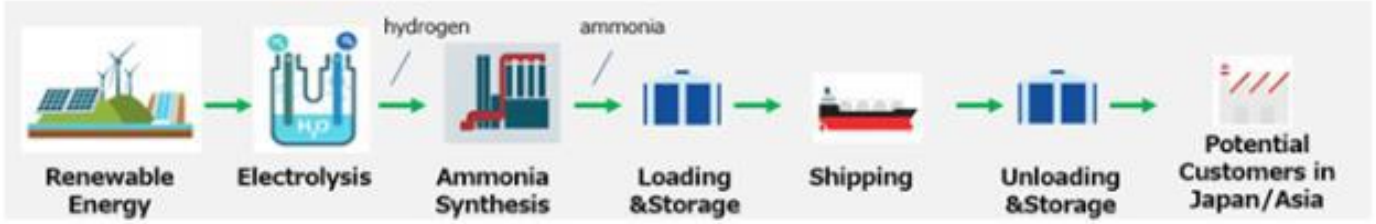
  - Industrial Systems and

<Green Ammonia Supply Chain>



Development of Large Ammonia Receiving Terminal

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Home / News / 2021FY / Resources, Energy and the Environment / IHI Starts Developing Large Ammonia Receiving Terminal to Help Establish Large Ammonia Supply Chain

IHI Starts Developing Large Ammonia Receiving Terminal to Help Establish Large Ammonia Supply Chain

-October 05, 2021- Press Release

IHI Corporation announced today that it has begun developing a large ammonia receiving terminal (see note 1) to bolster its ammonia receiving and storage technologies and establish an infrastructure to swiftly, efficiently, and economically handle large volumes of imported ammonia (see note 2).

Establishing an ammonia supply chain is vital to ensure the widespread adoption of this compound as a fuel. IHI embarked on this initiative in view of limited current uses of ammonia and an inadequate receiving and storage infrastructure. The company looks to lift capacity at its receiving facility to that of a liquefied natural gas (LNG) receiving terminal. IHI aims to complete development in around 2025.

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Computer-generated image of large ammonia receiving terminal

Co-development of Ammonia Fueled Marine Engine

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Joint R&D Starts for Practical Application of Ammonia-fueled Tugboat - World's First Effort to Achieve Zero Emissions from Ships Using Ammonia Fuel -

-September 03, 2020- Press Release

NYK Line
IHI Power Systems Co., Ltd.
Nippon Kaiji Kyokai (ClassNK)

On August 18, NYK, IHI Power Systems Co., Ltd., and Nippon Kaiji Kyokai (ClassNK) signed a joint research and development agreement to put the world's first ammonia-fueled tugboat into practical use.

- News
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- 2020FY
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  - Resources, Energy and the Environment
  - Social Infrastructure and Offshore Facilities

NYK Line	•Research and design of hull and fuel supply system •Verification of operation method based on experience of Sakigake
IHI Power Systems Co., Ltd.	**•Research and design of engine and exhaust gas after treatment devices**
Nippon Kaiji Kyokai (ClassNK)	•Safety assessment of ammonia-fueled tugboat

IHI Carbon Capture & Utilization Technology

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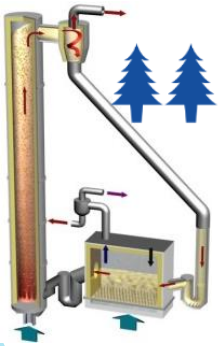
Oxyfuel combustion

Chemical adsorption

CO_2 Capture

CCU Technology

Electrolysis



Gasification

Compact reactor for SMR

Hydrogen, syngas production

Conversion to valuable resources
Methanation, Olefin production

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