IHI's Developments In Ammonia Combustion Technologies

April 2022

IHI Corporation

Accelerating Technology, Value Chain, Market Development

IHI

- Based on the Japanese Government Carbon-Neutral Policy and support, energy, power, and marine sector companies in Japan are promoting fuel ammonia utilization development to carbon neutrality.

Japan declared that by 2050 that Japan will aim to reduce greenhouse gas emissions to net-zero, that is, to realize a carbon-neutral, decarbonized society. Japan also raises emissions reduction target to 46% from 2013 by 2030

NEDO New Energy and Industrial Technology Development Organization

NEDO Green Innovation Fund (total 2 trillion JPY≒17 billion USD) to accelerate current efforts for sustainable energy, such as to structurally transform the energy and industrial sectors and innovate by investing extensively to achieve carbon neutrality by 2050. (46% carbon reduction from 2013 by 2030. This includes “Fuel ammonia supply chain development project (Total 59.8 billion JPY≒517.7MUSD)” for the following programs.

- High efficiency and lowcost ammonia production
- High ammonia cofiring ration and 100% ammonia combustion technology
- Expansion of usage and widespread of ammonia fuel

Value Chain Development Governmental Actions

METI Ministry of Economy, Trade and Industry

Public-Private Task Force to study and plan “Sustainable Energy Value Chain

MLIT Ministry of Land, Infrastructure, Transport and Tourism

Carbon Neutral Port Plan to receive sustainable energy.

Support and incentive policy for Power Sector

METI Ministry of Economy, Trade and Industry

Under planning

Promoting Fuel Ammonia Utilization Development to carbon neutrality

Power: JERA, Kansai, Hokuriku, Tohoku, Hokkaido and other

Energy: Idemits, INPEX, Tokuyama, Others

Marine: NYK, MOL, K Line

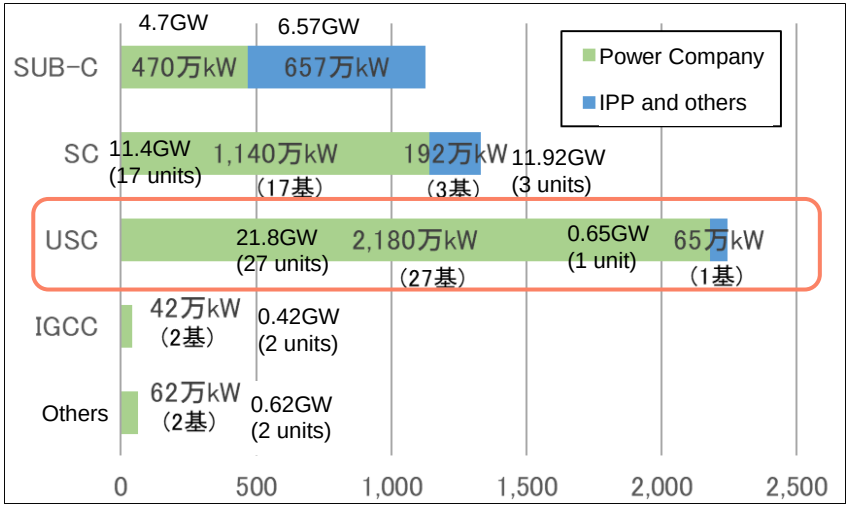
IHI **Key Technologies for Fuel Ammonia and start up Value Chain**

Fuel Ammonia Market Potential

Fuel Ammonia demand target for power sector in Japan.

- 3MTPA by 2030
- 30MTPA by 2050

Coal fired power plant in Japan



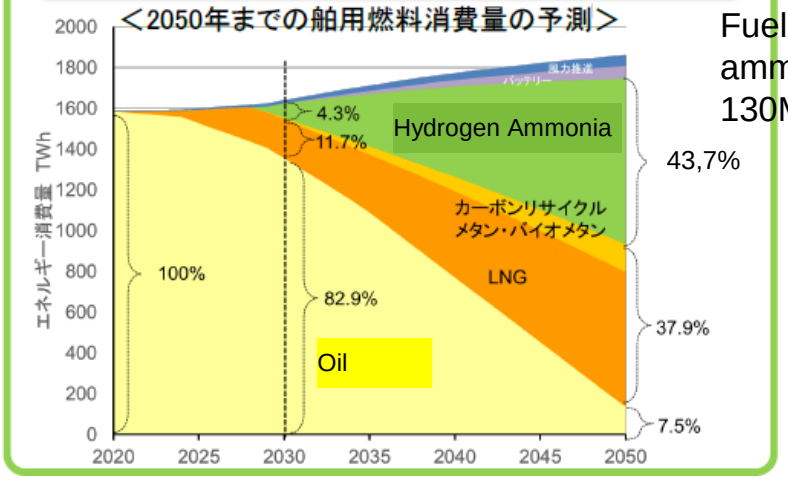
- ✓ 1000MW × 1 unit 20% ammonia co-firing =Fuel ammonia 500kTPA
- ✓ The necessary fuel ammonia for 21.8GW USC Boiler is as follows;

  20% Co-firing:10MTPA , 100% : 50MTPA

Fuel Ammonia potential demand for marine sector in global market

- 130MTPA by 2050

Hydrogen Ammonia Fuel Demand for ships



Fuel ammonia 130MTPA

- ✓ IMO's GHG reduction target from 2008: 50% or more

Development of ammonia combustion technology

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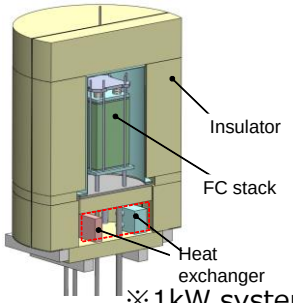
Coal fired BTG

※CFT(10MWth Coal Firing Test furnace)

2MW Gas turbine

※2MW class gas turbine(IM270)

SOFC



※1kW system

FY2014-2018 SIP

➢ **Achieved 20% co-firing** for boiler and gas turbine with acceptable NOx

FY2019-2020 NEDO

Development to expand co-firing ratio

Experimentally achieved 60% co-firing for coal burner, 70% for 2MW gas turbine

10kW～SOFC for small scale power and maritime

Current status

FY2021～ NEDO

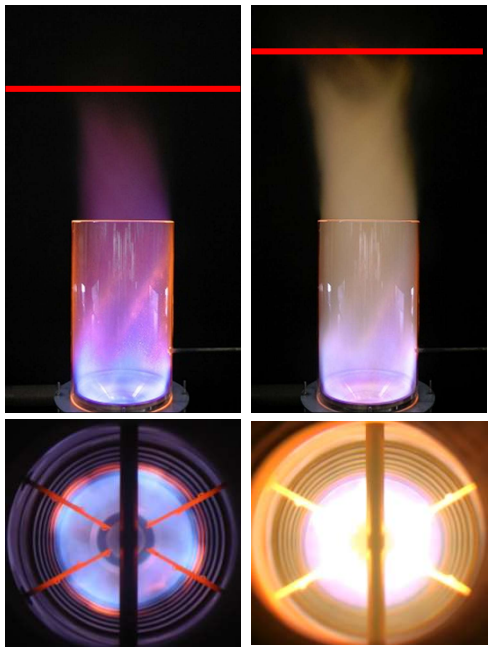
- ➢ **Demonstration for 1,000MW commercial BTG (NH_3 20%)**
- ➢ Development & demonstration over 50% co-firing technology
- ➢ Development for 2MW GT for CHP (NH_3 up to 100%)
- ➢ Study for pure ammonia fired GTCC
- ➢ Development for reciprocating engine

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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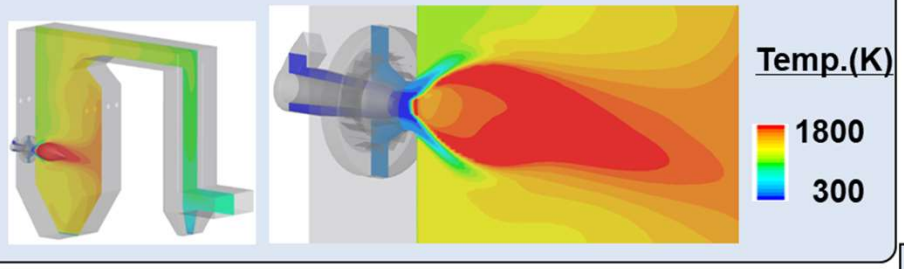
Approach to control NOx and Boiler performance

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

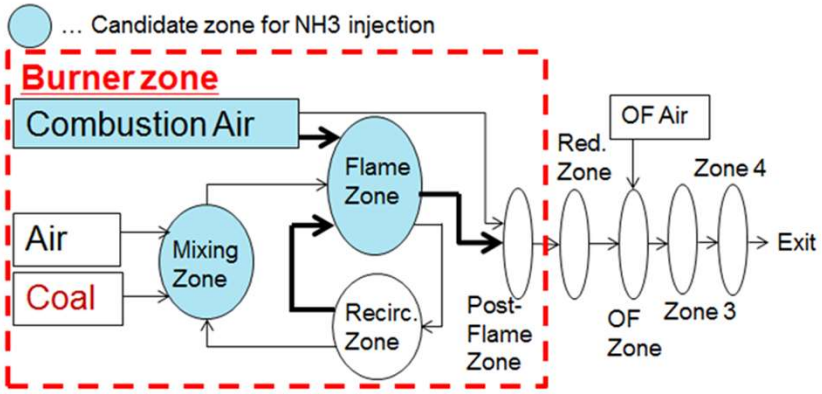
As a result of numerical analysis, the study is proceeded on the following premises,

- ✓ 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.

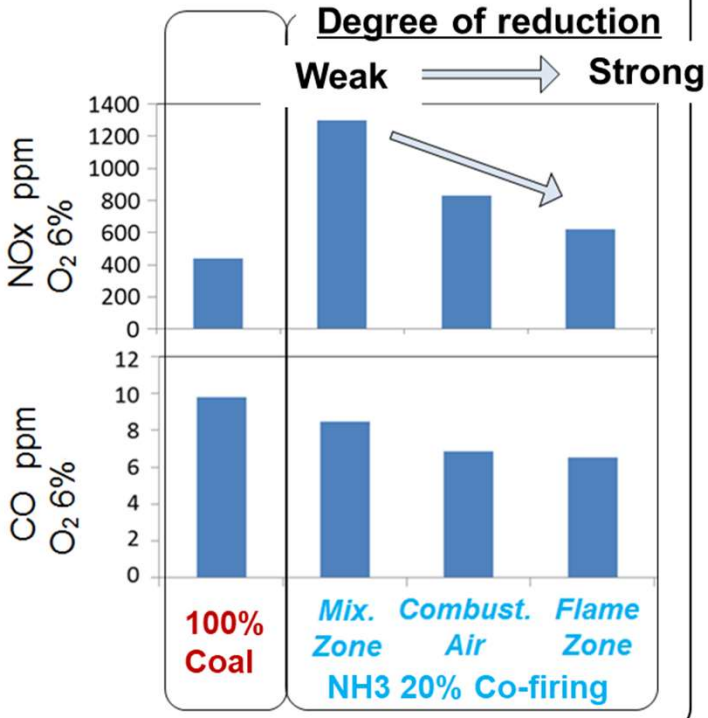
Consideration of the fluid dynamics



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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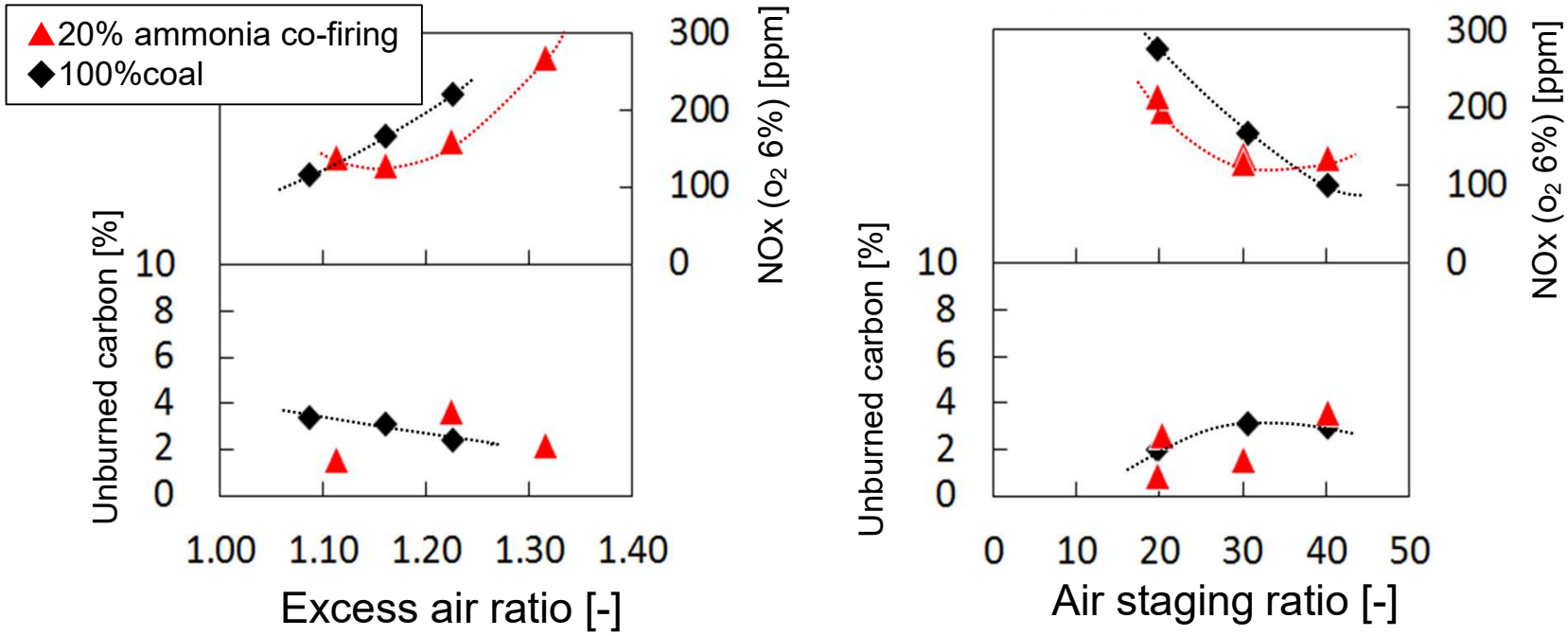
Optimization of combustion system to reduce NOx

[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

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

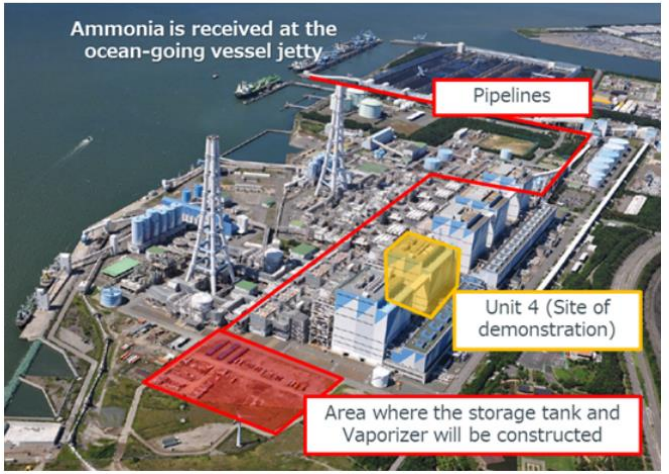
-May 24, 2021- press

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.

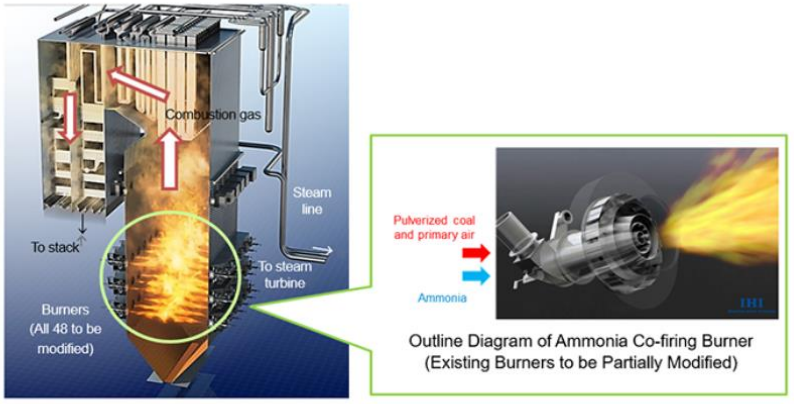
Ammonia enables efficient, low-cost transport and storage of hydrogen. In addition to this role as an energy carrier, it can also be used directly as a fuel in thermal power generation. As a fuel that does not emit carbon dioxide when burned, ammonia is expected to offer great advantages in reducing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

Demonstration using commercial 2MW class GT

- 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

Technology Roadmap

IHI

Ammonia co-firing ratio

Scale

FY2011～2014
Basic research on ammonia co-firing

FY2019～2020
Research on improvement of co-firing ratio

～FY2027
Development of 100% ammonia fired 2MW gas turbine

Development of liquid ammonia direct combustion technology

GT

Combustor scaling up

～FY2030
Develop technology for 100% ammonia fired BTG,GTCC

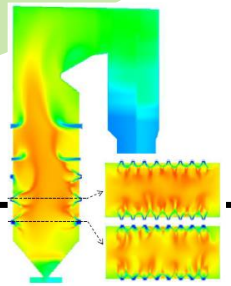
Development of pure ammonia burner

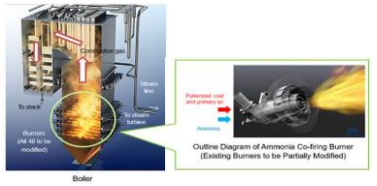
～FY2028
More than 50% ammonia co-firing demonstration

～FY2024
20% ammonia co-firing demonstration using 1,000MW commercial BTG

BTG

Scaling up & evaluation of boiler performance





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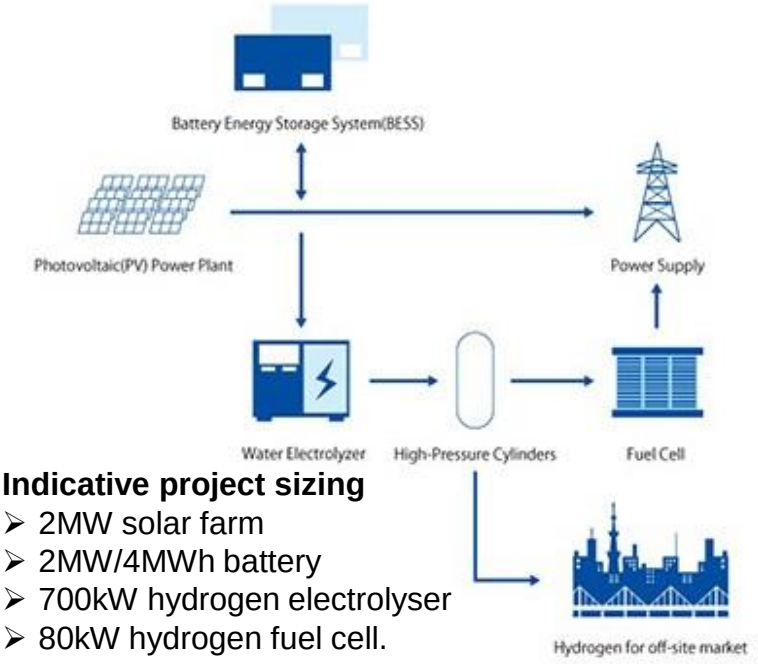
Realize your dreams

IHI Involvement in Green Hydrogen Production

Kogan Hydrogen Demonstration Project(HDP)

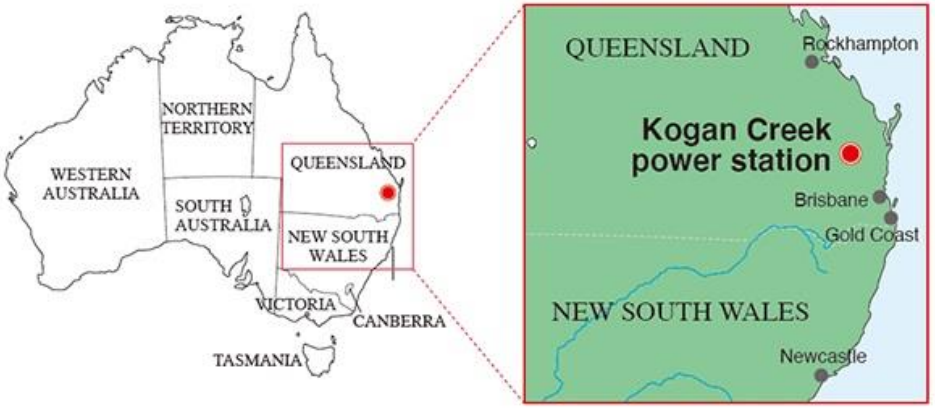
January 2021, IHI started a feasibility study on “Kogan Hydrogen Demonstration Project (Kogan HDP)” which will produce and sell carbon free hydrogen from Solar PV Power located next to Kogan PS site with CS Energy, a Queensland-owned and based energy company.

Kogan HDP will have a Solar PV array, Battery Energy Storage System, Electrolyser and Fuel Cell to produce and sell carbon free hydrogen from Solar Power and also sell surplus power to the market through the grid. Design of the HDP system, verification of hydrogen market, and etc. will be performed for business feasibility evaluation during FS. Demonstration Plant construction and operation are also under planning after FS



Indicative project sizing

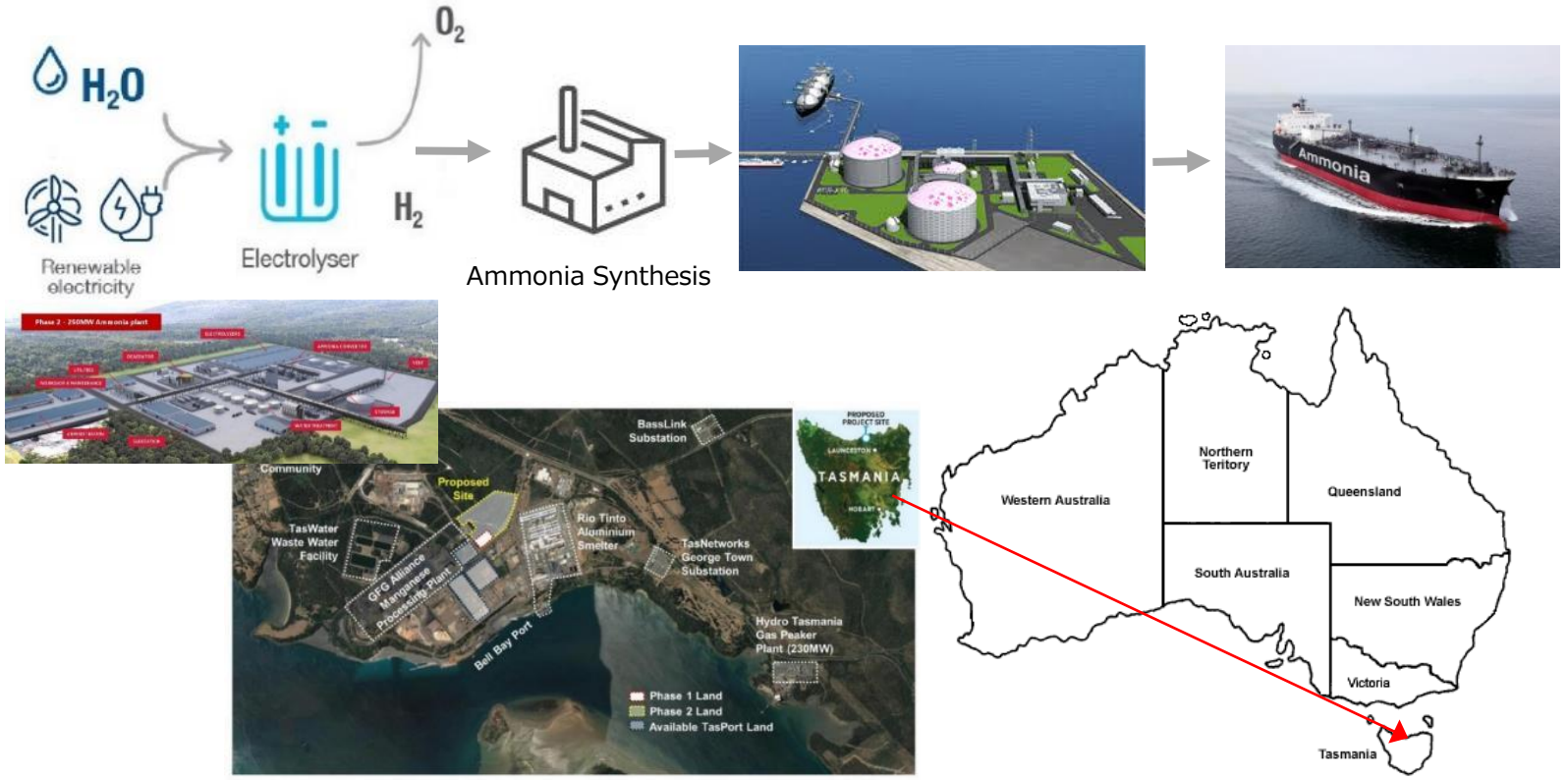
- 2MW solar farm
- 2MW/4MWh battery
- 700kW hydrogen electrolyser
- 80kW hydrogen fuel cell.



<Site location>
The neighboring area of Kogan Creek Coal Fired PS (1 x 750MW)
240km West of Brisbane, QLD

IHI Involvement in Green Ammonia Production

20th May 2021,IHI Corporation, Woodside Energy Ltd. 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. Green ammonia production would be start from a small-scale and plant could eventually be scaled up to 250 MW Class Electrolysis plant with ammonia synthesis for export.



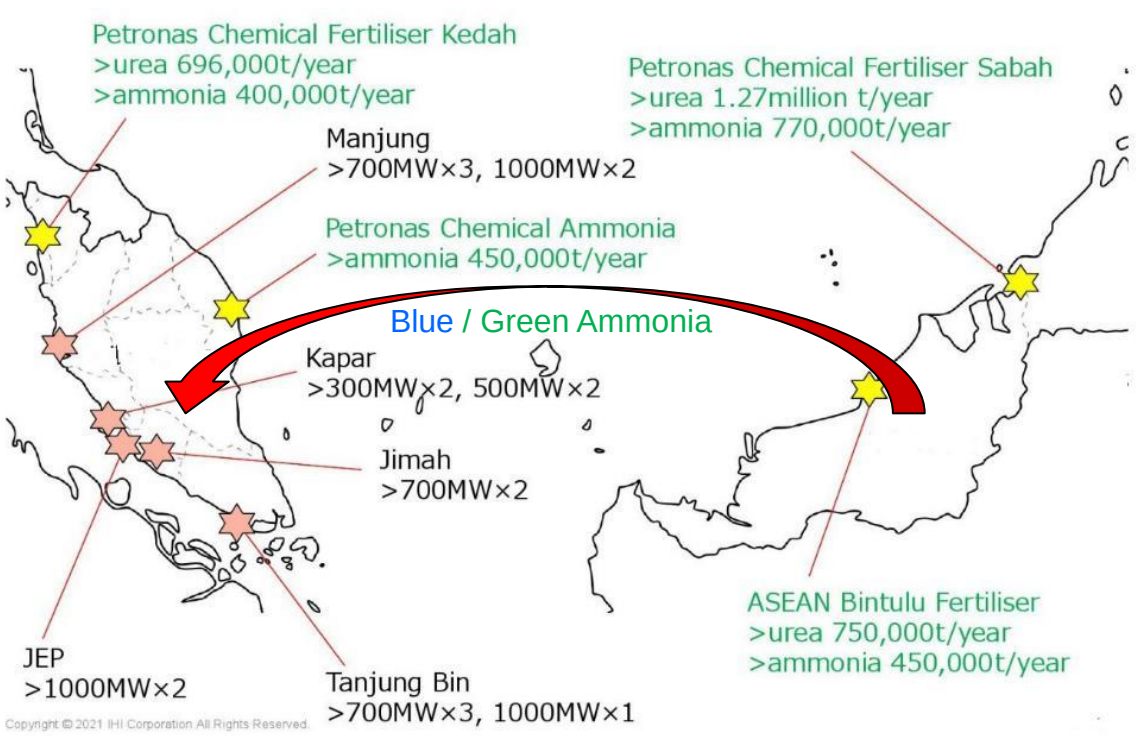
Project Site：Bell Bay Advanced Manufacturing Zone, 40km North of Launceston, TASMANIA

IHI Involvement in Blue/Green Ammonia Production

Feasibility Study on Ammonia Fuel to decarbonize Power Sector in Peninsular Malaysia

- METI grant to investigation / Exports of High-Quality Energy Infrastructure to Overseas
- Joint FS between IHI(IPSM) / TNB / Petronas
- FS on Ammonia Co-Firing at TNB/Janamanjung #1 (700MW)
- FS on Ammonia Supply Chain in Malaysia

Ammonia production (Sabah, Sarawak)⇒Transportation⇒ Fuel Ammonia Utilization (Peninsula Malaysia)



TNB's Coal Fired PS and Petronas's Ammonia Plant