Toward the Realization of a Hydrogen Society

- Trustworthy Solutions for the Future

カワる、
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Changing forward

June 2021

Kawasaki Heavy Industries, Ltd.

Kawasaki
Powering your potential

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1. Wants of the Next Society

National Greenhouse Gas Targets

- At the 2021 Climate Change Summit, the leaders of major emitters announced ambitious targets for the reduction of greenhouse gas emissions by 2030. In addition, a target of virtually zero emissions by 2050 to 2060 was announced.
- The International Energy Agency reports that 50% of the world's final energy consumption is thermal energy. Hydrogen fuel is indispensable for the decarbonization of heat.

Year	Japan	EU	China	India	U.S.A.	
					President Trump	President Biden
2020					breakaway from Paris Agreement	return to Paris Agreement
2030	46% reduction compared to 2013	at least 55% reduction compared to 1990	decrease emissions	33 ~ 35% decrease in GDP compared to 2005		50 ~ 52% reduction compared to 2005
2040						
2050	Net zero	Net zero				Net zero
2060			Net zero			

Hydrogen Strategies

- Each country has made progress in various areas such as the use of hydrogen in industrial fields, the introduction of hydrogen power generation, and the investigation of CO2-free hydrogen chain for the import of hydrogen.

Year	Japan	Germany	EU	France	China
~2020	• Mar 2019: formulation of the hydrogen and fuel cell strategy roadmap • Dec 2020: formulation of the green growth strategy with the carbon neutrality in 2050	• Jun 2020: formulation of the national hydrogen strategy	• Jul 2020: announcement of hydrogen strategy	• Sep 2020: update of hydrogen strategy	• Apr 2020: announcement of subsidies to the formulation of FCV industry supply chain
2030	• Establishment of 3 million ton per year commercial-scale supply chain • Hydrogen supply cost: 30 JPY/Nm3 • Commercialization of hydrogen from renewal energy sources around 2032 • Commercialization of hydrogen power generation around 2030, target cost: 17 JPY/kWh	• Hydrogen production capability target: 5 GW	• Electrolytic hydrogen production capacity target: 40 GW by 2030	• Electrolysis equipment installation target: 6.5 GW by 2030, produce 0.6 million tons of green hydrogen per year	
2040		• Increase to 10 GW			
2050	• Hydrogen power generation cost target: 20 JPY/Nm3 (*less than gas-fired)				

2 . Kawasaki's Solutions for Carbon Neutrality

From Kawasaki "Group Vision 2030" (1/3)

■ 3 Keywords to Achieve Group Vision

Frontier

Pioneering the technology frontier with our challenger "DNA"

Since our founding, we have always identified ourselves as challengers. Throughout a history studded with the world's first and Japan's first achievements in many sectors, including shipbuilding, rolling stock, and aerospace, we have been leveraging our cutting-edge technologies and fostering a "DNA" characterized by the spirit of pioneering the frontier that draws on our unique perspective. Based on that unique prospective, we will continue to respond to the frontier of the new era' s social challenges to create a hopeful future.

To Realize Hydrogen Society:

Establishment of a CO2-free Hydrogen Chain

From Kawasaki "Group Vision 2030" (2/3)

■ 3 Keywords to Achieve Group Vision

New Values

Providing innovative solutions for the problems faced by the world

Currently, the world is facing a variety of problems, including environmental deterioration, energy challenges, expanding populations, graying societies, natural disasters, and pandemics.
We are committed to providing new and high-add value solutions to a wide range of customers and communities, by focusing on the reliable technologies that we have been building and the knowledge that we have been assimilating in order to provide innovative solutions and rapidly accommodate social change.

To Realize Hydrogen Society:

Development/Popularization of Hydrogen Gas Turbine

From Kawasaki "Group Vision 2030" (3/3)

■ 3 Keywords to Achieve Group Vision

Cross Over

Becoming a creative challenger that continues to grow by breaking barriers

To provide innovative solutions focused on social challenges, we will continue to be an open-minded, free-thinking, and creative team that goes beyond the boundaries of internal and external organizations and of product/service categories, thereby leveraging our rich diversity. Moreover, we will continue to grow as an organization and as individuals by expanding our potential and boldly taking up challenges in unfamiliar domains and learning from the experience.

To Realize Hydrogen Society:

Establishment of Global/Local Alliance

Frontier

Establishment of a CO2-free Hydrogen Chain

Concept of CO2-free Hydrogen Chain

- Kawasaki will take on the challenge of creating a CO2-free hydrogen chain before the rest of the world does.

Resource Country (Australia)

Produce low cost hydrogen from fossil fuels combined with CCS* or abundant renewable energy

Low Cost Renewable Energy

Liquefaction/ Loading

Fossil Fuel

CCS

PRODUCE

TRANSPORT/ STORE

Liquefied Hydrogen Carrier

Liquefied Hydrogen Trailer

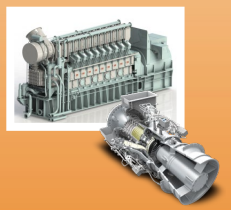
Country of Use (Japan)

Process Use

Semiconductor, Solar battery, Oil refining, Desulfurizing etc.

Transport Equipment

H2 station, Fuel cell vehicles, etc.



Distributed Power Plants

Hydrogen Gas Turbines / Gas Engines, Fuel cells, etc.

Electricity Plants

CCPP, etc.

USE

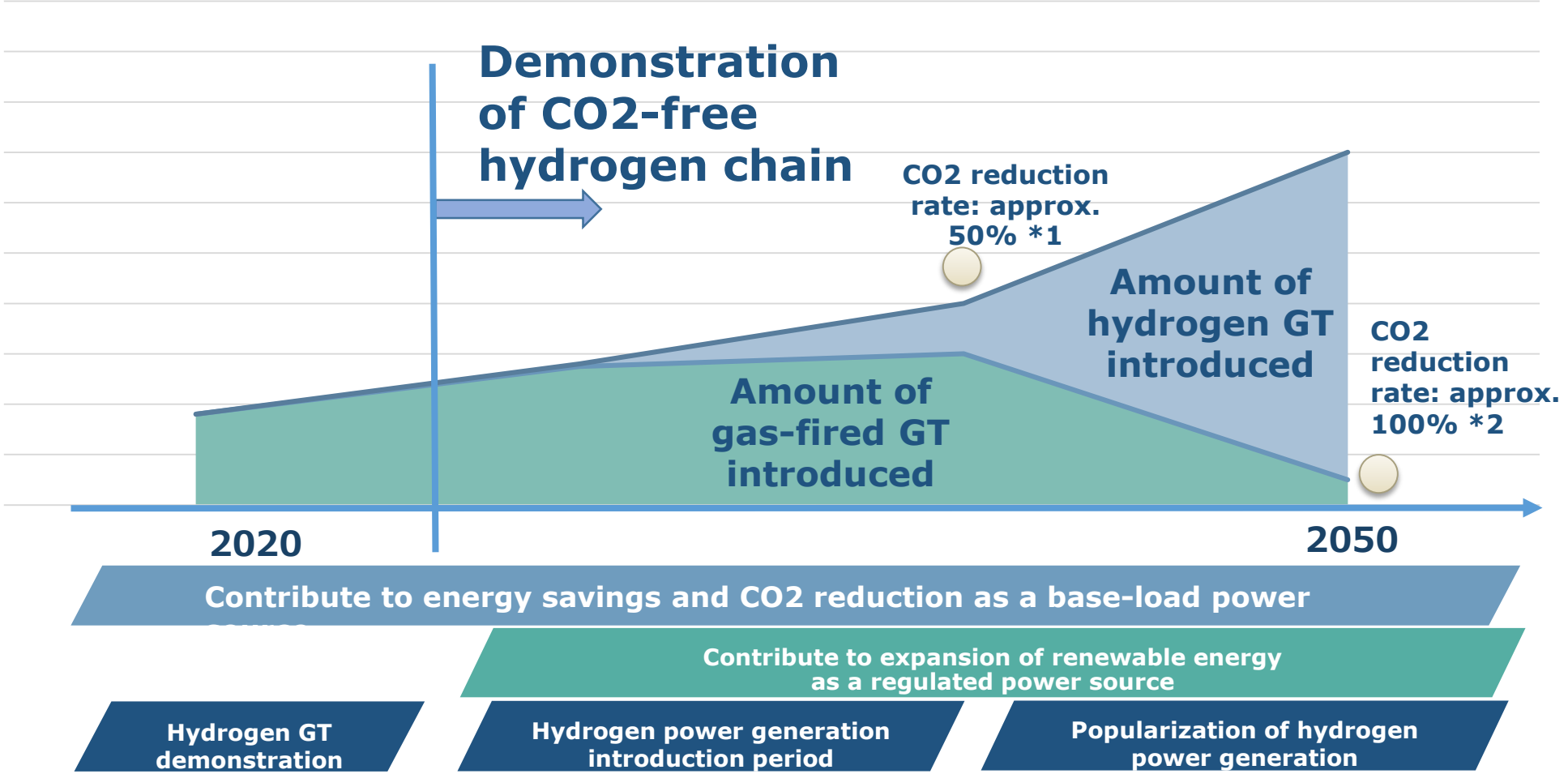
CO2 Free Hydrogen

CO2 Free Hydrogen

*CCS: Carbon Dioxide Capture and Storage

Image of CO2 Reduction Rate and Gas Turbine Installation

- Contribution to CO2 reduction through fuel conversion from natural gas to hydrogen gas turbine and introduction of hydrogen gas turbine.



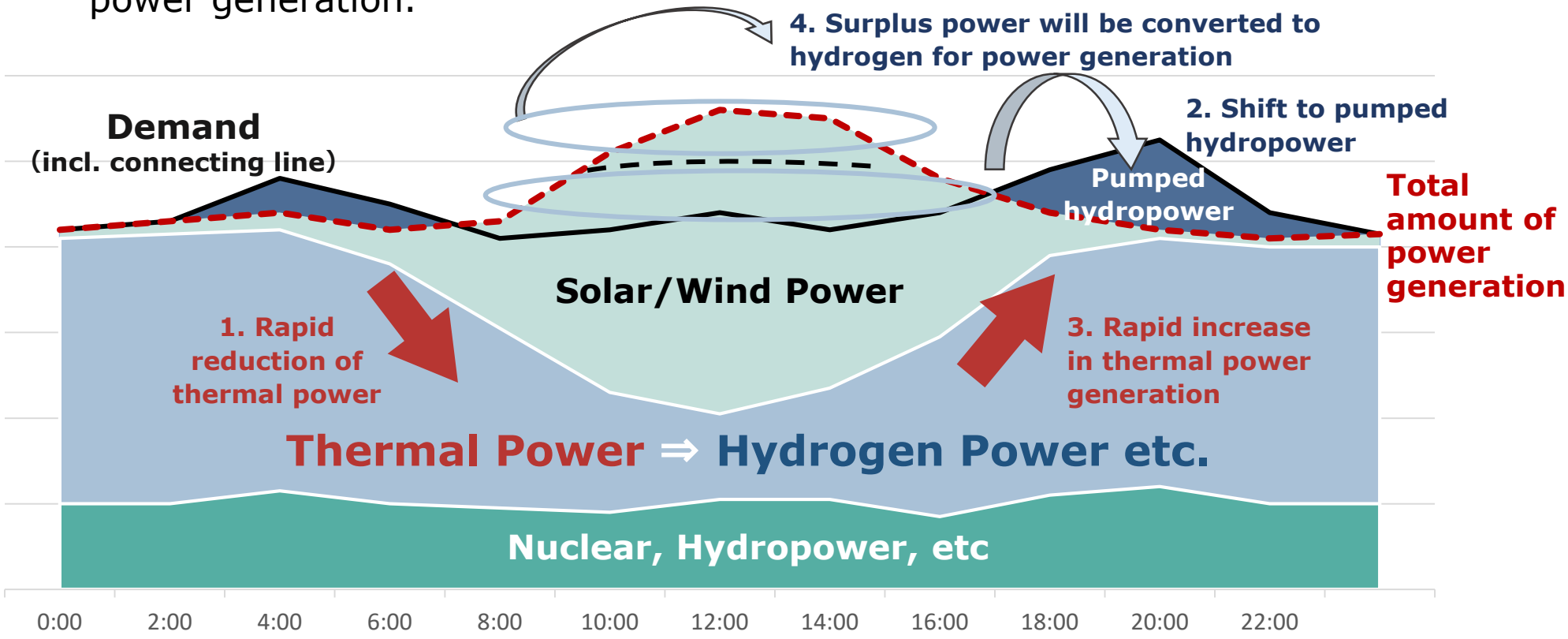
*1 Source: CO2 reduction rate of fuel conversion from heavy oil to city gas based on the calculation and report manual of greenhouse gas emissions (2012), enforcement regulations of the Law Concerning the Rational Use of Energy (2012), interim report of the meeting scenario subcommittee of the Global Environment Committee of the Central Environment Council (2001)
*2 CO2 reduction rate in gas fired GT with CCU/S and hydrogen power generation

New Values

Role of the Hydrogen Gas Turbine

Role of Thermal Power Generation in the Era of Mass Introduction of Renewable Energy

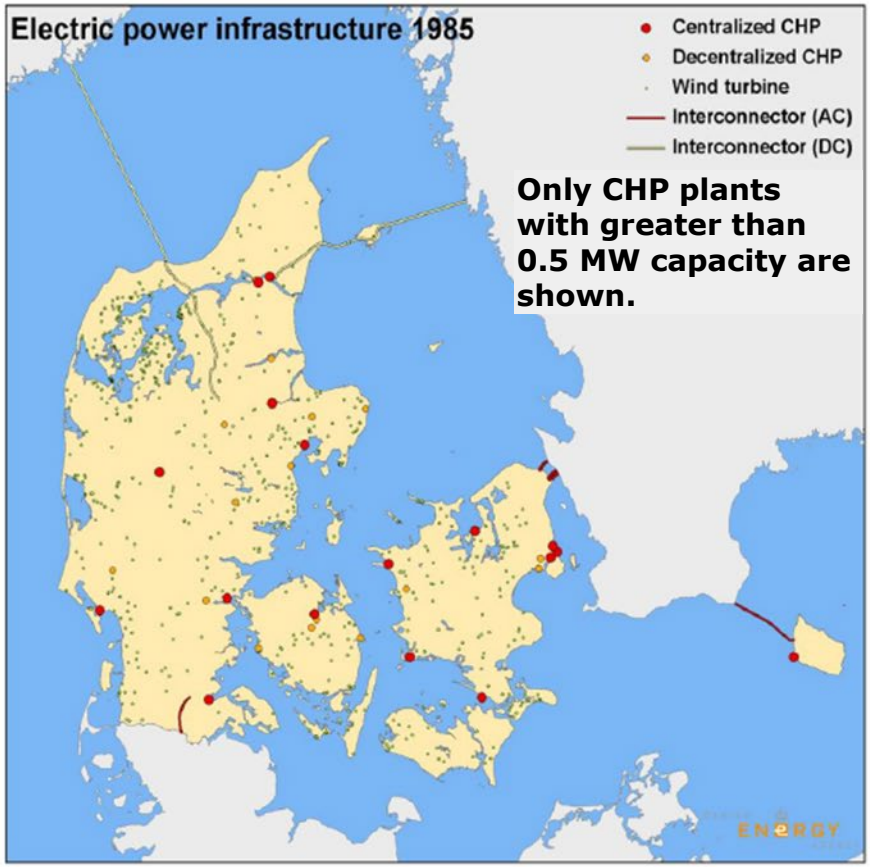
- Thermal power generation can contribute to the expanded introduction of variable renewable energy, such as solar and wind power, as they can adjust the balance between power supply and demand.
- Thermal power plants will be replaced by CO2-free hydrogen power plants, and surplus power from renewable energy sources will be converted to hydrogen for power generation.

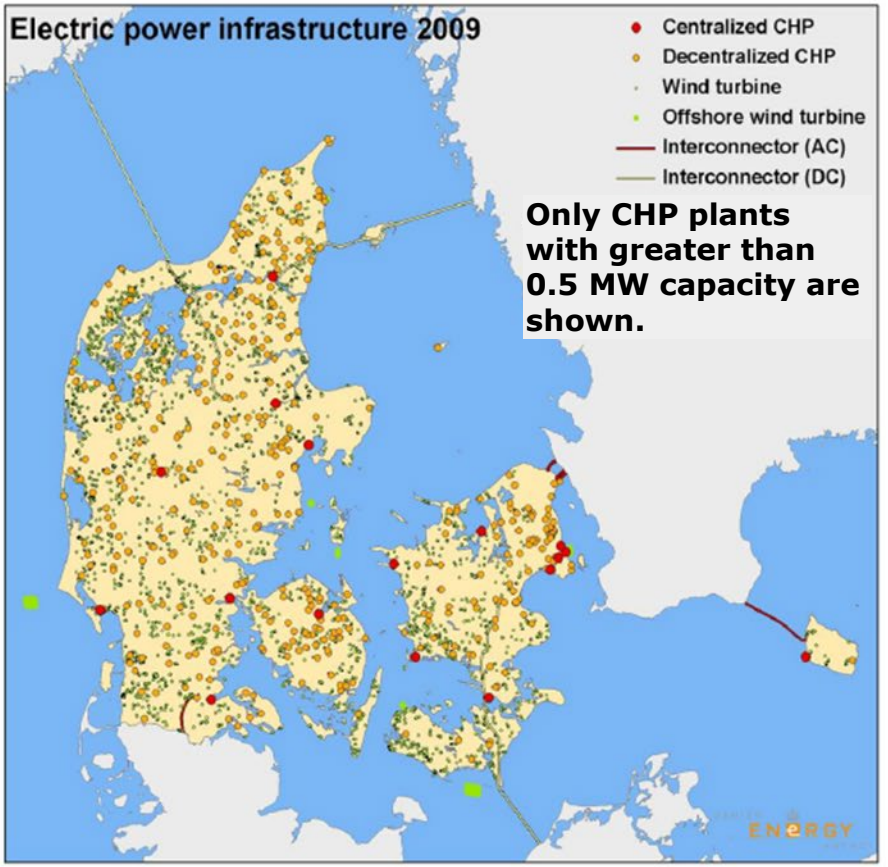


Example of Transition of Electric Power Infrastructure due to the Advancements in Renewable Energy: Denmark

- Denmark introduced a large amount of variable renewable energy*, and distributed power generation is also widespread throughout the country.
- Cogeneration systems that can utilize waste heat and are excellent for energy savings are the mainstream of distributed power generation.

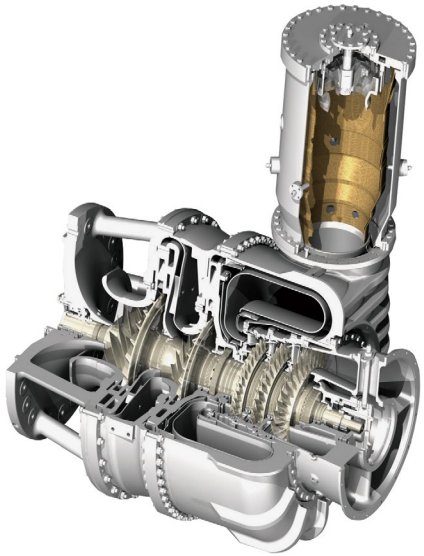
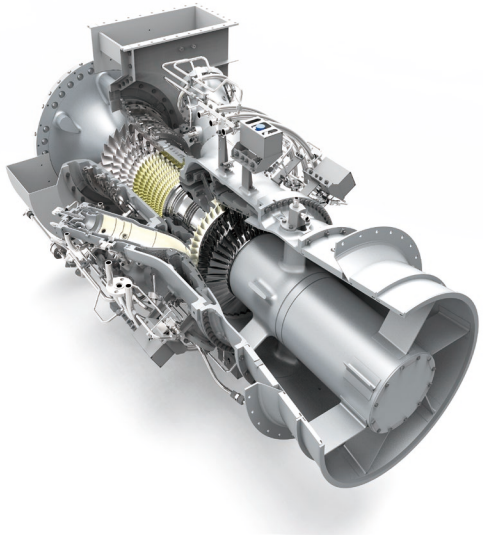
*The share of renewable energy in total energy supply increased from approx. 7% in 1990 to approx. 22% in 2010





Features of Kawasaki Gas Turbine: Product Lineup

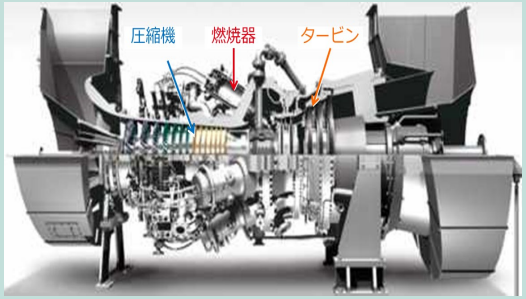
- Kawasaki Gas Turbine is suitable for distributed cogeneration.

	DLE combustion capable of hydrogen co-firing and exclusive firing (under demonstration)	Hydrogen co-firing (to be commercialized)	Capable of hydrogen co-firing	L30A hydrogen co-firing (to be commercialized)	
G T series	M1	M5	M7	L	
GT model	M1A-17	M5A	M7A-03	L20A	L30A
output	1.7 MW	5 MW	8 MW	18 MW	30 MW
structural diagram of each models					

Advantages of Hydrogen Gas Turbines

- Hydrogen gas turbines have multiple environmental and economic benefits. Transition to hydrogen combustion is possible by remodeling the combustor.

Reduction of investment costs

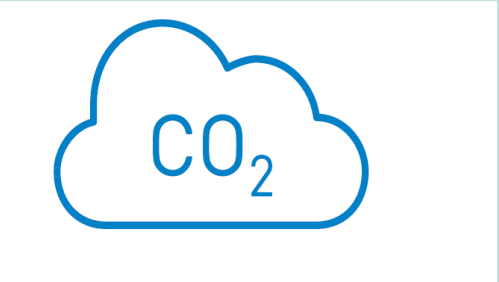


Hydrogen combustion can be achieved by replacing the combustor of the existing natural gas turbine.

Mixed combustion

Mixed combustion of city gas and hydrogen achieves fuel flexibility and stable operation. Flexible transition from low-carbon to decarbonized society.

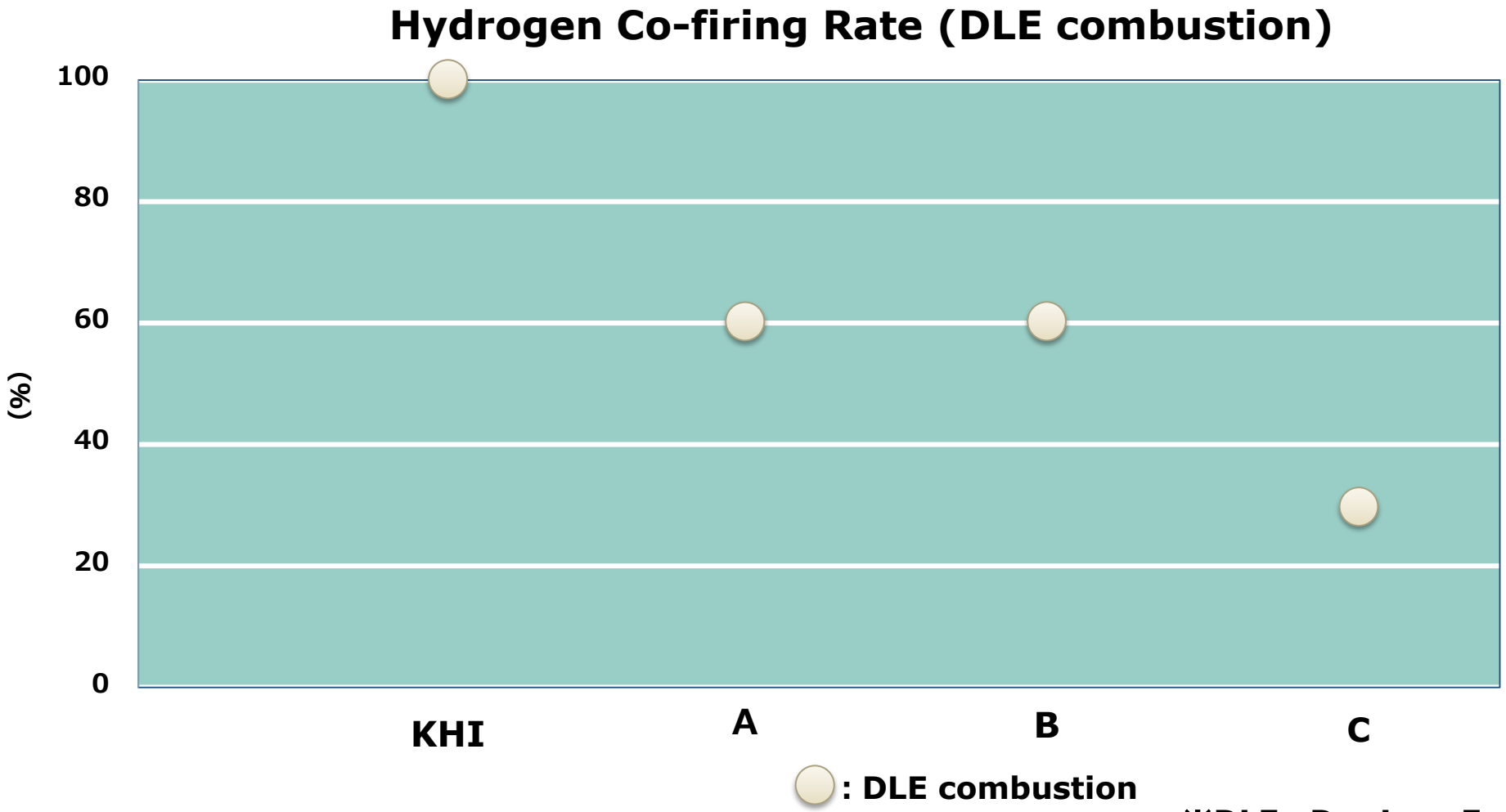
Reduction of CO2 emission



By using hydrogen as fuel, CO2 emissions from gas turbines can be reduced through high energy efficiency.

Comparison of Hydrogen Co-firing Rate (*DLE combustion) with other companies

- Kawasaki demonstrated 100% hydrogen DLE combustion in a 1 MW class GT for the first time in the world.



※DLE : Dry Low Emission

Road Map of Hydrogen Gas Turbine Development

	2020	2021	2022	2023	2024	2025	~	2030
Hydrogen Growth Strategy in Japan	Current (2017) : cost :100 JPY/Nm3 volume: 200 t/y	Demonstration of actual hydrogen power generation facilities						Goal cost : 30 JPY/Nm3 volume : 3 mil t/y
		Source: Ministry of Economy, Trade and Industry "Green Growth Strategy for Carbon Neutrality in 2050 (December 2020)"					Promotion of introduction of hydrogen power generation	
Hydrogen co-firing (DLE combustor)	PUC50D PUC80D	Hydrogen 30% Co-firing						
	PUC180D PUC300D	Hydrogen 30% Co-firing						
Hydrogen 100% (Diffusion combustor)	PUC50D PUC80D			Diffusion/Hydrogen 0~100%				
	PUC180D PUC300D	Diffusion/Hydrogen 0~100%						
Hydrogen 100% (MMX combustor)	PUC50D PUC80D						Micromix combustion/Hydrogen 100%	
	PUC180D PUC300D	Micromix Combustor (micro-DLE combustion)		Micromix combustion/Hydrogen 100%				

PUC 17, world's first hydrogen cogeneration system (completion: 2018)

Cross Over

Global & Local Alliance

Technology Development Issues (Examples)

- Challenging issues of hydrogen mass transport and hydrogen gas turbines in the construction of a CO2-free hydrogen chain

Liquefied hydrogen for mass transport
Challenges in transport at cryogenic

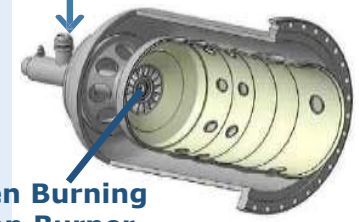
Liquefied Hydrogen Storage Tank

Liquefied Hydrogen Loading Arm

Liquefied Hydrogen Carrier

Achieving stable combustion and low NOx simultaneously
Challenges in achieving high efficiency

Hydrogen/City Gas

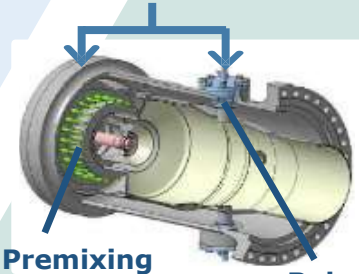


Hydrogen Burning Diffusion Burner

Diffusion Combustor

Developed Product

Hydrogen/City-Gas



Lean Premixing Burner

DLE Combustor

Reheating Burner

Hydrogen

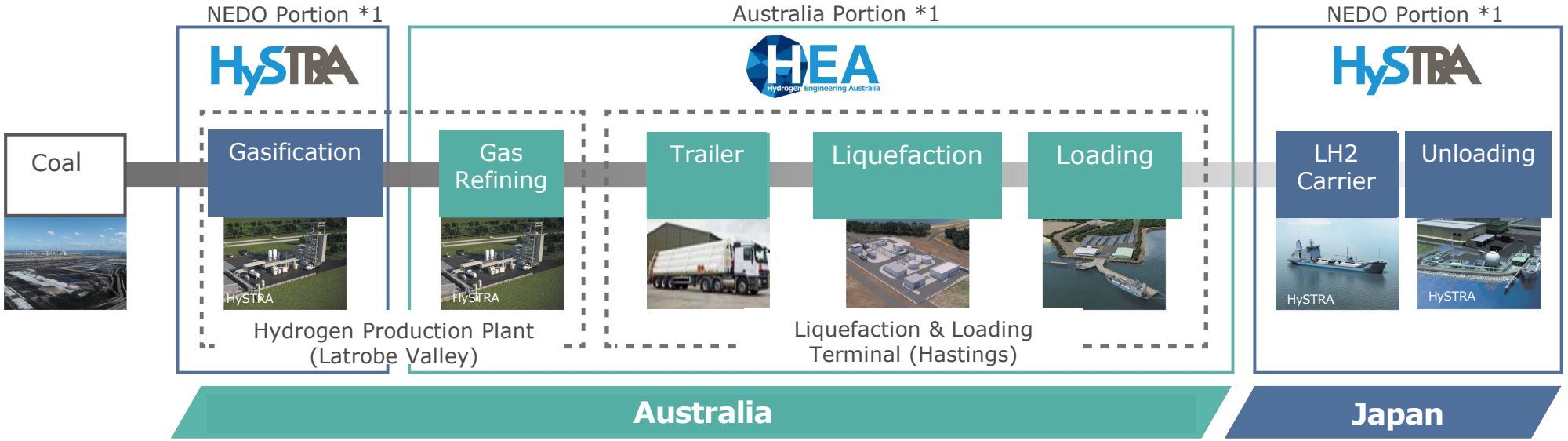
Micromix Burner

Micromix Combustor

Development of DLE combustor: high efficiency without water injection

Japan-Australia Hydrogen Supply Chain Pilot Demonstration

- Government agencies and private companies in Japan and Australia began cooperating in 2015 to demonstrate hydrogen supply chain. Kawasaki has completed construction of a hydrogen liquefaction/loading plant in Australia, the LH2 carrier, and a hydrogen unloading plant in Kobe, Japan. Demonstration will continue until 2022.



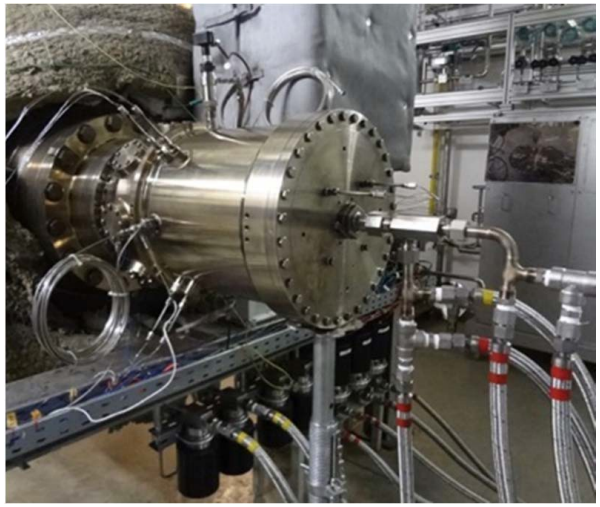
【 Government of Australia】
Australian Federal Government
Victorian State Government
【Hydrogen Engineering Australia(HEA)】
Kawasaki Sumitomo Corp. Iwatani J-POWER Marubeni AGL J-POWER Group

【 Government of Japan】
Ministry of Economy, Trade and Industry NEDO
【CO2-free Hydrogen Energy Supply-chain Technology Research Association (HySTRA) 】
Kawasaki Iwatani J-POWER Shell Marubeni ENEOS "K"LINE

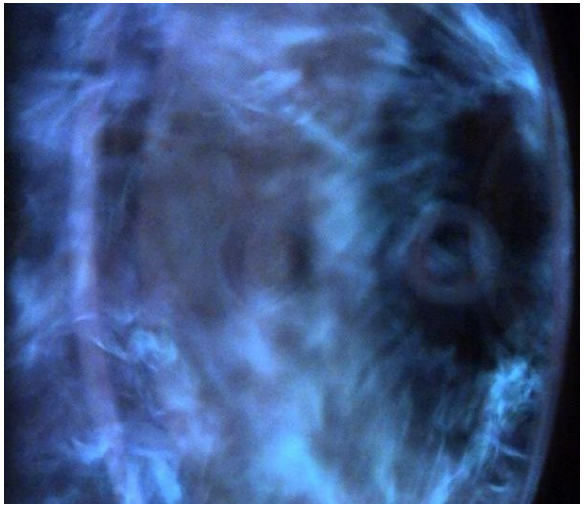
***1 From 2015 to FY 2022 NEDO Grant Program for Technological Development for Industry with Issues "Demonstration Project for Construction of Large-scale Marine Transport of Hydrogen Derived from Unused Brown Coal and Supply Chain"**

Evaluation and Study of Next Generation Hydrogen Combustor (DLE Combustor, Hydrogen 100%)

- Developed next-generation combustor by collaborating with Aachen University of Technology
- NOx level of 40 ppm* achieved under actual gas turbine operating conditions and under 50% to 100% rated load operating conditions
- Combustor was held for 2 hours under the condition corresponding to the rating of 100%; no fire damage to the combustor after the test
- The operation was carried out in the hydrogen gas turbine cogeneration demonstration facility in Port Island, Kobe, in fiscal 2020.



Hydrogen 100% DLE Combustor test in Aachen University of Technology)



Hydrogen Combustion

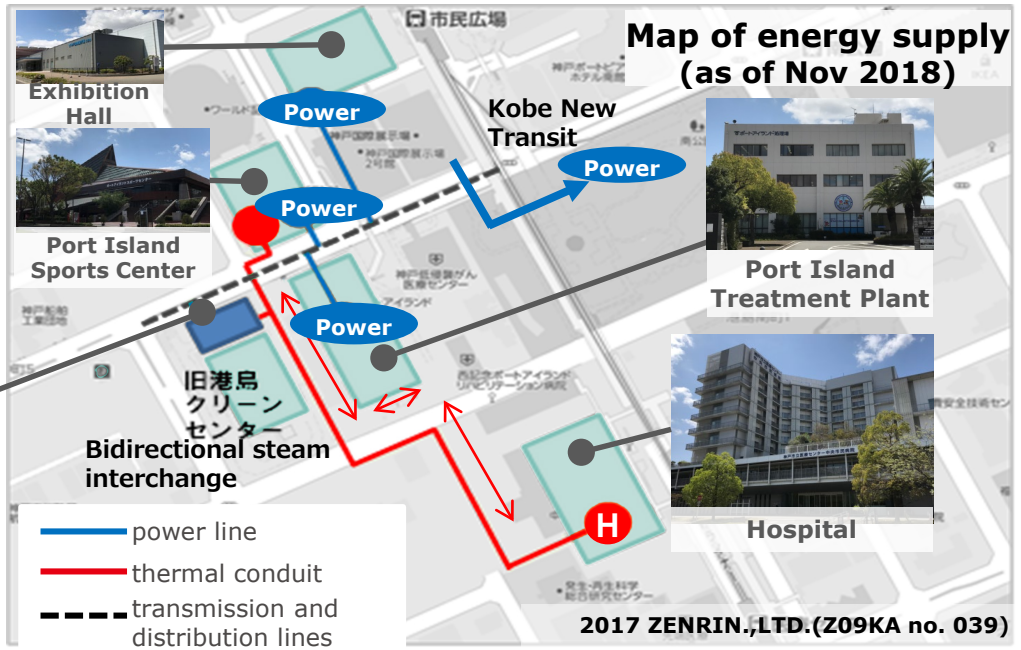
Combustor interior after 2h test
*Residual oxygen 16% equivalent

Results of this research were obtained through below:
・FY 2014 – 15: SIP (Strategic Innovation Creation Program) "Energy Career" (Managed by JST)
・Fiscal 2016 – 18: NEDO's Hydrogen R & D Initiative Business and Large-scale Hydrogen R & D "Research and development of hydrogen gas turbine combustion technology"

World's First 100% Hydrogen Regional Combined Heat and Power Supply (Port Island, Kobe)

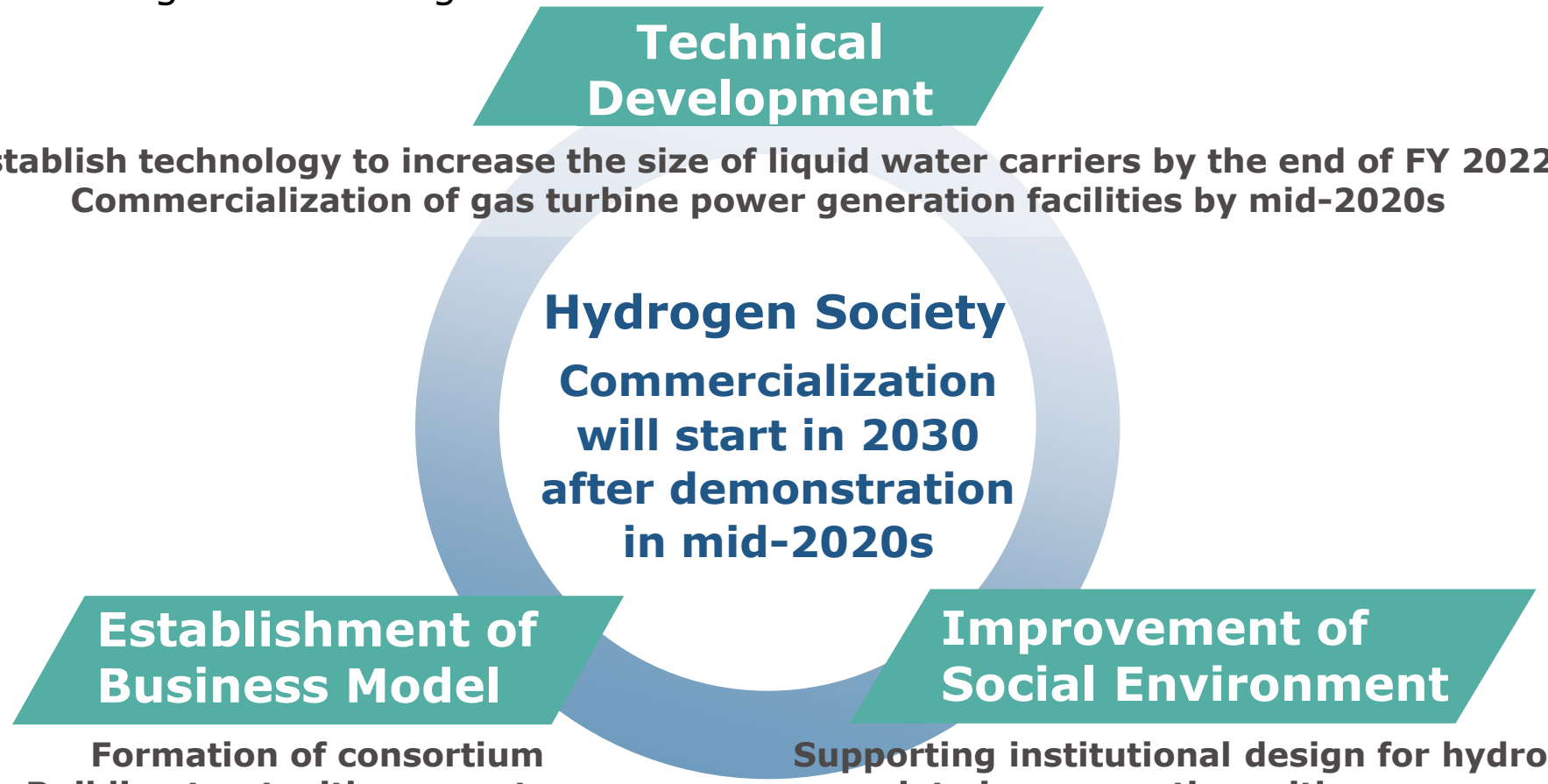
- Technology development and demonstration of a system to use “Power", "Hydrogen" and “Heat" efficiently at the regional level were carried out using a 1 MW class gas turbine power generation facility fueled by hydrogen and natural gas.
- FY 2017 & 2018: Demonstration tests of hydrogen gas turbine equipped with diffusion combustors that can handle 100% natural gas / 100% hydrogen / mixture of natural gas and hydrogen (0 ~ 100%). NOx amount conformed to meet the air pollution control law regulation value of 70 ppm or less (16% O2 equivalent).
- FY 2019 & 2020: Development and demonstration of hydrogen gas turbine using DLE combustor, that can enable 100% hydrogen. NOx amount was 70 ppm or less (16% O2 equivalent), which is the same as that of a diffusion combustor.
- Business Structure: Kawasaki Heavy Industries, Obayashi Corporation, Kobe city, Kansai Electric Power, Iwatani Corporation, Kenes, Osaka University, Kansai University

Hydrogen Gas Turbine Energy Center



Toward the Realization of a Hydrogen Society

- With a target for commercial launch in 2030, technology development, commercialization system construction, and social environment improvement has begun in an integrated manner.



Kawasaki, working as one for the good of the planet

“Global kawasaki”

Kawasaki

Powering your potential