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Latest Developments of Liquified Hydrogen Supply Chain and Utilization Technologies

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Kawasaki Heavy Industries, Ltd.

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Kawasaki
Powering your potential

Products of Kawasaki Heavy Industries

Energy System &
Plant Engineering

Power Sports & Engine

Precision Machinery & Robot

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Introduction

- Utilization of hydrogen for decarbonization is attracting worldwide attention.
- Kawasaki is conducting demonstration tests to construct a hydrogen supply chain using liquefied hydrogen as a carrier and aims to realize a supply chain on a commercial scale in the future.
- A large-scale hydrogen supply chain will realize cost down of hydrogen, that requires large volume and long-term demands.
- Gas turbine power generation is expected as an application to stimulate a large amount of hydrogen demand, and Kawasaki is working on development and demonstration of hydrogen gas turbines necessary for this purpose.

Initiative by Global Companies

Hydrogen Council

- Comprised of 150 leading companies in the world, including energy, transportation, manufacturing, trading companies, and banks

(market capitalization is more than 10 trillion dolllers)

- Japanese companies: Toyota, Honda, Kawasaki Heavy Industries[Note], Iwatani Corporation, ENEOS, Toyota Tsusho, Mitsubishi Corporation, Mitsui & Co., Marubeni, Sumitomo Corporation, Mitsubishi Heavy Industries, NGK, SMBC, ITOCHU, Nippon Yusen, Tokyo Gas ・・・

- Global Initiative to advocate for a joint vision and long-term goals for a hydrogen-based new energy transition

  =>January 2022: Chairperson of Kawasaki Heavy industires, Ltd., Mr. Yoshinori Kanehana, has been appointed to co-Chair of the Hydrogen Council

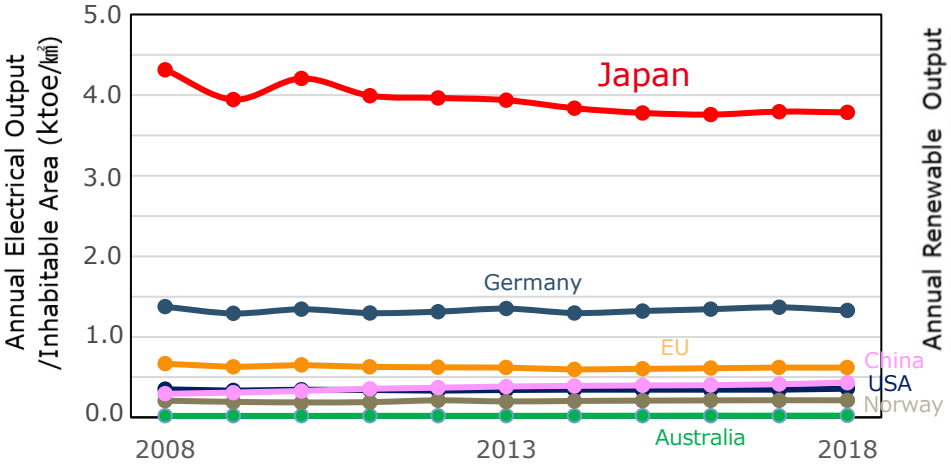
- In June 2023, the CEO meeting was held in Japan for the fiest time. (Awaji Island, Hyogo Prefecture)

Note: Japanese companies among the 13 companies established in 2017 are written in green.

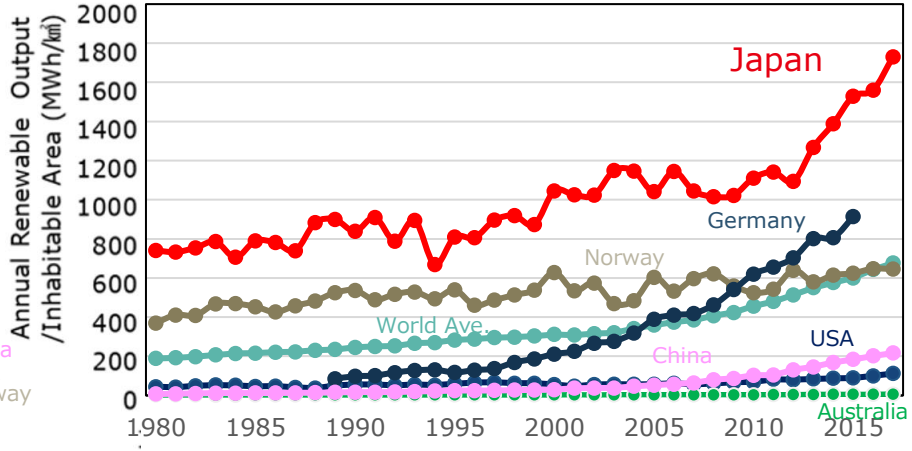
High energy demand density of Japan

- The energy consumption density of Japan is top level in the world
- Japan's renewable energy power generation density is the top, more than twice the world average.

➡ Within the limited land area of Japan, it is necessary to expand renewable energy and use it in combination with various clean energies.



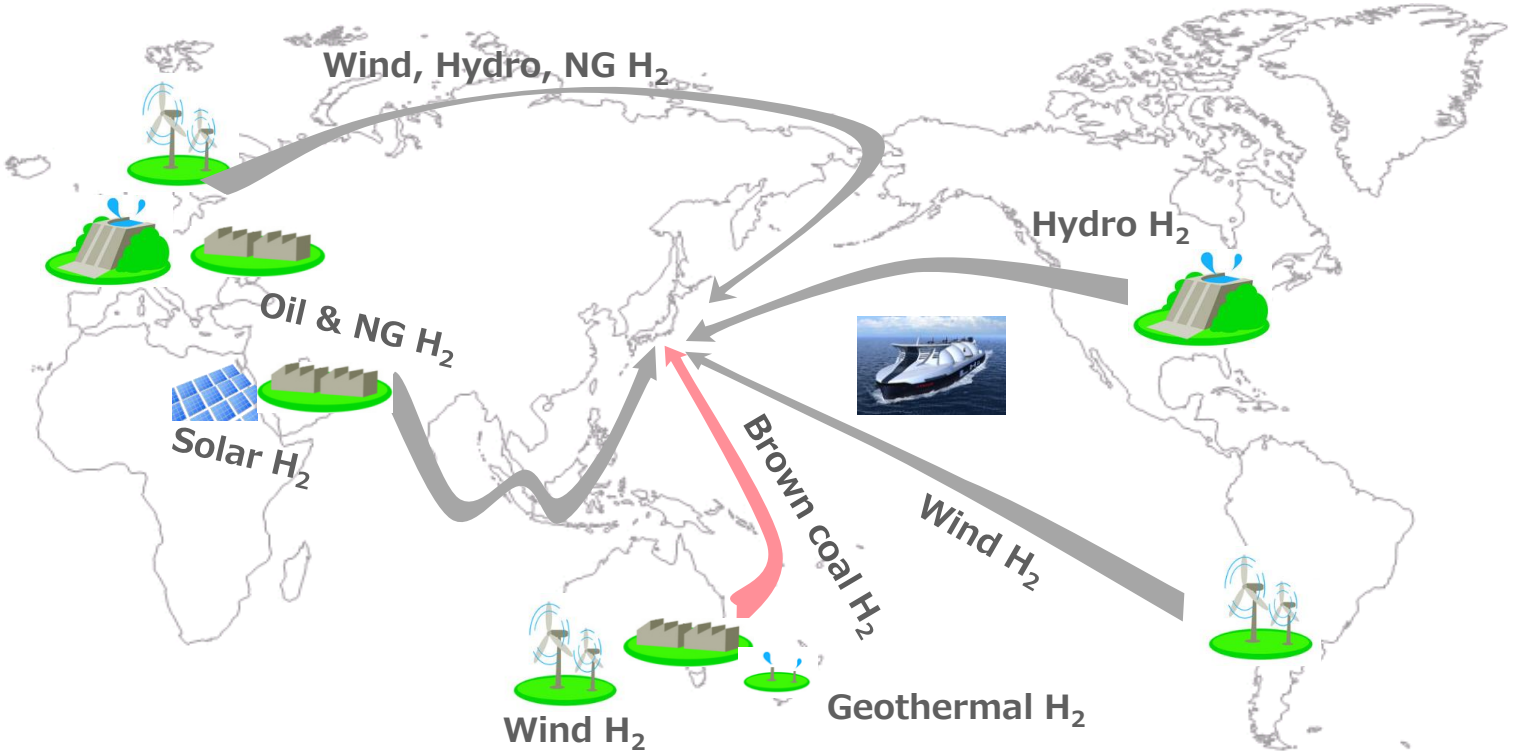
Country primary energy consumption density



Country Renewable Energy Density

(US Energy Information Administration, & BP Statistical Review of World Energy (2019))

Energy and Economic Securities



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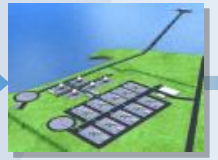
Concept of a CO_2-free Liquefied Hydrogen Chain

Producing country (Australia, ・・・)

Production of hydrogen at low costs from unused resources and/or abundant renewable energy

Affordable renewable energy



Liquefaction/ loading

Fossil fuel: Natural gas coal .....

CCS (CO_2 capture/storage)

CO_2-free hydrogen

Liquefied hydrogen carrier

Liquefied hydrogen containers

Liquefied hydrogen storage tanks

Utilizing country (Japan)

Process uses
Semiconductor and photovoltaic cell manufacture
Oil refinement, desulfurization, etc.

Transport
Hydrogen stations
Fuel cell vehicles etc.

Distributed power plants

Hydrogen gas turbines
Hydrogen gas engines
Fuel cells etc.

Electrical power plants

Combined Cycle power generators etc.

Production(Transitional)

transport / storage

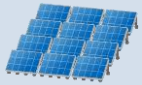
utilization

Concept of a CO_2-free Liquefied Hydrogen Chain

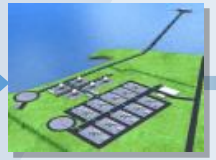
Producing country (Australia, ・・・)

Utilizing country (Japan)

Production of hydrogen at low costs from unused resources and/or abundant renewable energy



Clean hydrogen



Liquefaction/ loading

CO_2-free hydrogen

Liquefied hydrogen carrier

Liquefied hydrogen containers

Liquefied hydrogen storage tanks

Process uses
Semiconductor and photovoltaic cell manufacture
Oil refinement, desulfurization, etc.

Transport
Hydrogen stations
Fuel cell vehicles etc.

Distributed power plants

Hydrogen gas turbines
Hydrogen gas engines
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Electrical power plants

Combined Cycle power generators etc.

Production(Goal)

transport / storage

utilization

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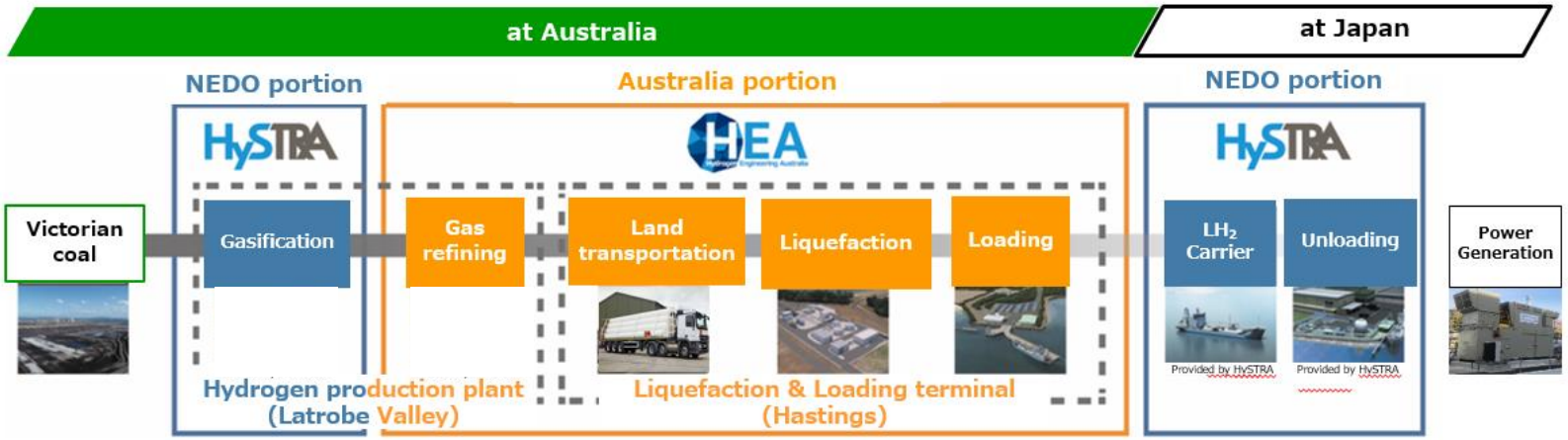
Hydrogen Energy Supply Chain Pilot Project

Kawasaki is working with a number of partners on a pilot project supported by the governments of Japan and Australia.



HySTRA

CO2-free Hydrogen Energy Supply-chain Technology Research Association

Iwatani, Kawasaki, Shell Japan, J-Power, Marubeni, ENEOS, KLINE As of 2023 March

Supported by NEDO

*NEDO : New Energy and Industrial Technology Development Organization

HEA Hydrogen Engineering Australia

Hydrogen Engineering Australia

Kawasaki, J-Power, J-Power group, Iwatani, Marubeni, Sumitomo, AGL

As of 2023 March

Status of the Pilot Demonstration Project

Land Transportation and Liquefaction(Australia)

Maritime Transportation

Unloading and Storage

The world's first international liquified hydrogen supply chain had been demonstrated

- **The world's first demonstration of hydrogen transport and cargo handling by liquefied hydrogen carrier**

First voyage from Japan to Australia 2021/12/24

"Suiso Frontier" Australia arrival ceremony 2022/1/21

Japan-Australia Pilot Project Completed (2022/4/9)

At the ceremony to complete the demonstration of the Japan-Australia hydrogen supply chain

Prime Minister Kishida attended the meeting.

Contents

Scaling up of Hydrogen Transportation and Utilization

Production

Hydrogen production and liquefaction

Transportation

Liquefied hydrogen carrier

Storage

Liquefied hydrogen tank

Utilization

Hydrogen power generation and mobility

Technical Demonstration

2020

Scale-up

Commercial Demonstration

Transportation Volume **28,000t/y** (provisional value)

2025

Project Fee 2.3 bill. $

Commercialization

Transportation Volume **225,000t/y**

2030

Supported by Green Innovation Fund

Cost reduction by scaling-up facilities

Transport

@HySTRA

Suiso Frontier: 1,250m³

Storage

Storage Tank at Hy touch Kobe: 2,500m³

128 times

20 times

Transport

Large-scale Carrier : 160,000m³

Storage

Large-scale Storage Tank: 50,000m³

Further Development for Hydrogen Demand Activation

Liquefied Hydrogen
Supply Chain

Energy Solution & Marine Engineering Company

Hydrogen Valves
For FCV

Precision Machinery & Robot Company

Fuel Cell Vehicles

Rolling Stock Company

Kawasaki Heavy Industries, Ltd.

Hydrogen Vehicles

Motorcycle & Engine Company

Aerospace Systems Company

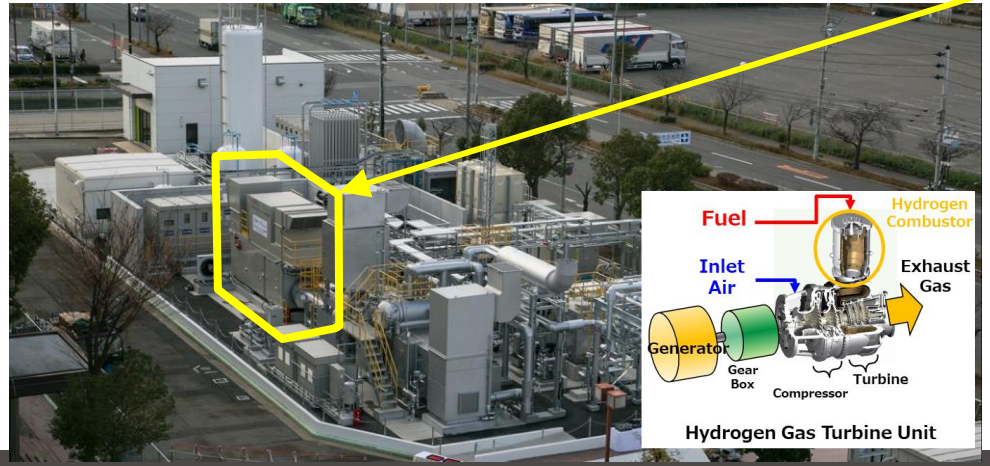
Hydrogen Aircraft Engines

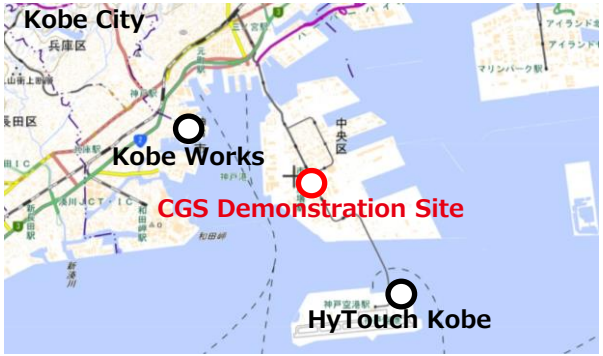
Hydrogen Power Generation

Hydrogen Co-generation Demonstration in the city

- Co-generation system (CGS) with 1 MW class hydrogen gas turbine has been installed in city area (Kobe Port Island)
- Demonstrating power and heat derived from hydrogen to community
- Partners: Obayashi, Kawasaki, Kobe City, KEPCO, Iwatani, Kenes, Osaka University

[NEDO grant project]





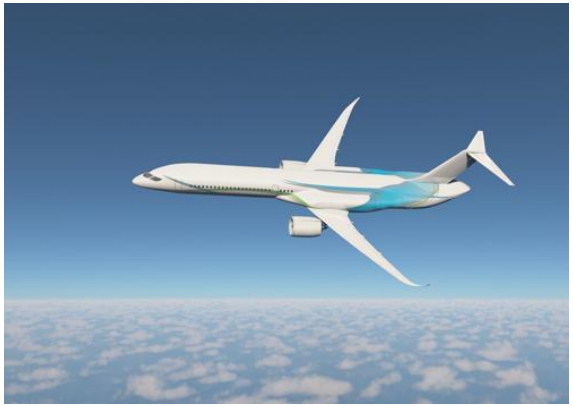
Expanding Hydrogen Fuel to Marine/Aerospace Divisions

In-House capability to safely and cleanly combust H2 proven due to successful hydrogen combustion test
Leading the world in combustion technology, developing Internal Combustion Engines for other mobility
The related market will grow to several trillion yen by 2050.

Development of H2-fueled marine propulsion system※1

Complete development of product Line-up with various applications by 2026

※1 NEDO Green Innovation Fund「Development of hydrogen propulsion system for marine use」(Subsidy approx. 22 billion JPY)
(Selected in a consortium with Yanmar Power Technology and Japan Engine Corporation)



Core Technology Development for H2 airplanes※2

R&D work in progress to prepare for commercial scale usage of H2 airplanes by 2035

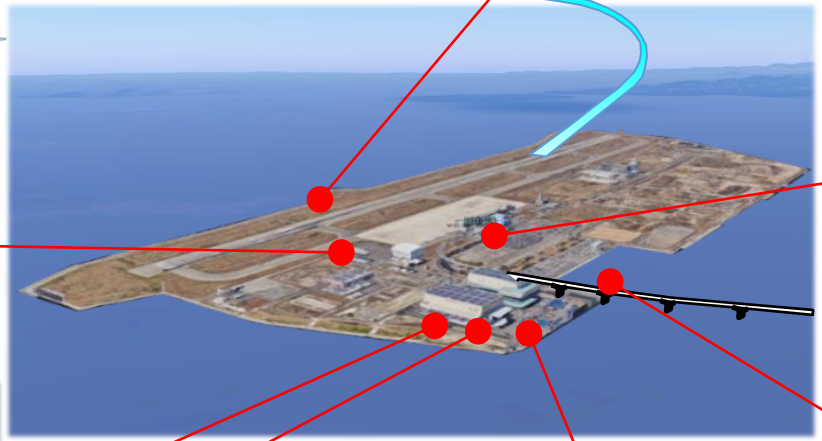
※2 NEDO Green Innovation Fund “Core Technological Development for H2 Airplanes”(Subsidy approx.18 billion JPY)

MoU with Airbus to explore H2 use in Airport areas

LH_2 Airport infrastructure joint study

Hydrogen Aircraft

LH_2 fuel refueling



LH_2 Tanker Truck

Fuel Cell Bus

Large LH_2 Carrier

LH_2 Tank

Loading Arm System

Hydrogen power generation & Heat supply

Fuel Cell Train

LH_2: Liquified Hydrogen

Initiatives for small hydrogen engines

Obtained approval for establishment of Hydrogen Small mobility Engine Technology（HySE）(Press release on 2023 May 17th)

Started research activities to develop and expand the use of small hydrogen engines to realize a decarbonized society

■Overview of HySE
【Name】HySE: Hydrogen Small mobility & Engine technology
【Location】 Yaesu Central Tower, 2-2-1 Yaesu, Chuo-ku, Tokyo
【Chairman】Kenji Komatsu, Executive Officer of Yamaha Motor Co., Ltd.
【Union members】Kawasaki Motors, Suzuki, Hoda, Yamaha Motor, KHI, Toyota
【Establishment date】 2023 May 17th

From left) Yamaha Motor President Hidaka, Kawasaki Motors President Ito, Suzuki President Suzuki, Honda Tsukamoto, General Manager of Development and Production, Motorcycle Power Products (May 17, Chiyoda-ku, Tokyo) (From the electronic version of the Nihon Keizai News)

Started development of hydrogen engine based on supercharged engine※1
※1 : Kawasaki Motors HP “CSR” presentation (Japanese)

Demonstration run of research off-road four-wheel vehicle equipped with motorcycle hydrogen fuel direct injection engine※2
※2 : KHI HP Press release 2022, Sep.3rd

Hydrogen Trade in 2050 reported by Hydrogen Council ad McKinsey

Trade flows in 2050 from study by Hydrogen Council in October 2022

- **Europe : mainly piped**
- **Other : mainly shipped**

Wide spread of hydrogen economy and economic growth

Global Hydrogen Flows: Hydrogen trade as a key enabler for efficient decarbonization, Published in October 2022 by the Hydrogen Council. This report was authored by the Hydrogen Council in collaboration with McKinsey & Company

Summary

1 Stable Supply

- Hydrogen from fossil fuel linked with CCS will realize vast and affordable energy supply

→ **Contribute energy security**

2 Environmental

- No CO_2 emissions when used

→ **“Carbon Neutrality"**

3 Economy

- Decarbonization brings Industrial growth

→ **Creating job opportunity**

- Hydrogen production started from fossil fuel shifted to the renewables in the future

→ **Sustainability**

4 Clean Hydrogen implementation in Japan

- Start from 3 million ton/year in 2030
  12 million ton/year in 2040
  20 million ton/year in 2050

Kawasaki

Powering your potential