Hydrogen Safety – Liquid Hydrogen (LH_2) Workshop
6th , March, 2019, Bergen,

Large Scale LH_2 Supply Chain Project & H_2 Gas Turbine Demonstration

Kawasaki Heavy Industries, Ltd.

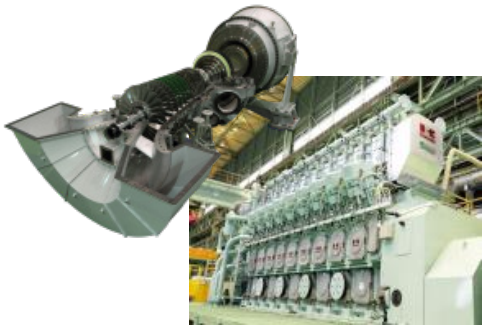
Kawasaki
Powering your potential

Products

Ships/Marine

Rolling stock

Aerospace



Gas Turbine/
Machinery

Plants/
Environment

Motorcycles and Engines

Precision Machinery

Contents

1. Low-carbon to De-carbonation Society
2. Movement Toward Hydrogen Utilization
3. Concept of Hydrogen Supply Chain
4. Hydrogen Infrastructure Technology
5. Projects on Going

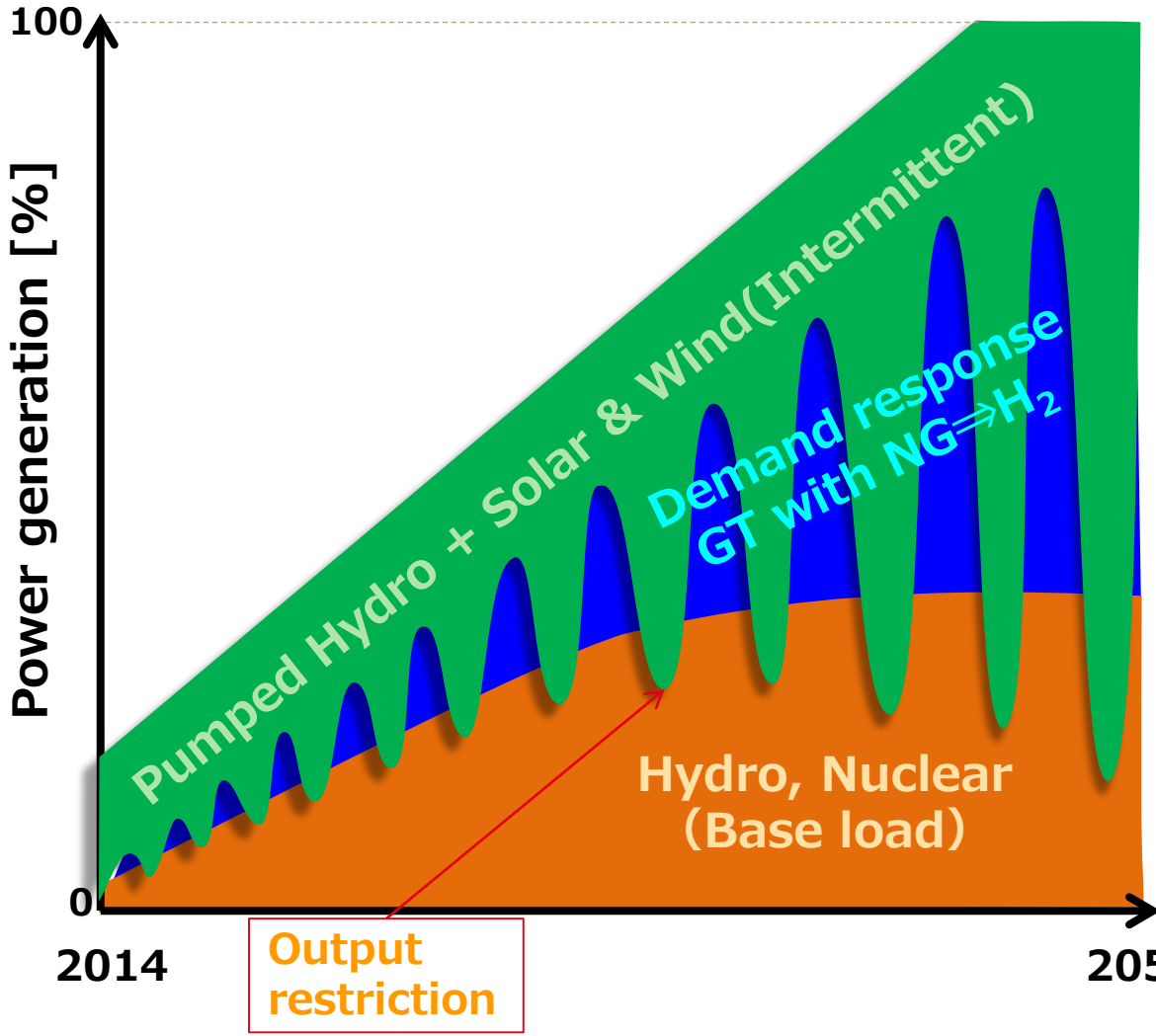
COP21 (Paris Agreement) Dec. 2015

- **Shifted from Low-carbon to de-carbonation society (Global temperature rise less than 1.5℃ at most effort, as well as 2℃ target)**
- **Became effective after 4th, Nov. 2016**
  170 nations and countries signed
  (as of 1st, Dec. 2017)
- **Target of CO_2 Reduction:**
  Japan "26% by 2030"
  Advanced Nations including Japan "80% by 2050"

Actions in Japan for COP21 (Paris Agreement)

- In order to achieve the CO_2 target at 2030, proportion of CO2 free power, i.e. nuclear and renewable energies, in the total power generation should be 44% or more
- Power retailers have to achieve the above composition ratio by law
- Creation of low-carbon power (non-fossil value) market has been opened since 18th May 2018

Solutions to Increase CO2-free Powers



Gas turbine(GT) power generation will play an important role to enhance stability of the electricity grid, by compensating intermittent power from the renewable energies.

Fuel change from natural gas(NG) to hydrogen can also regulate fluctuation of renewable energies without CO2 emission.

This will be a good combination with hydrogen production from excessive renewable power.

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Basic Hydrogen Strategy
(Ministries cooperation Common scenario)

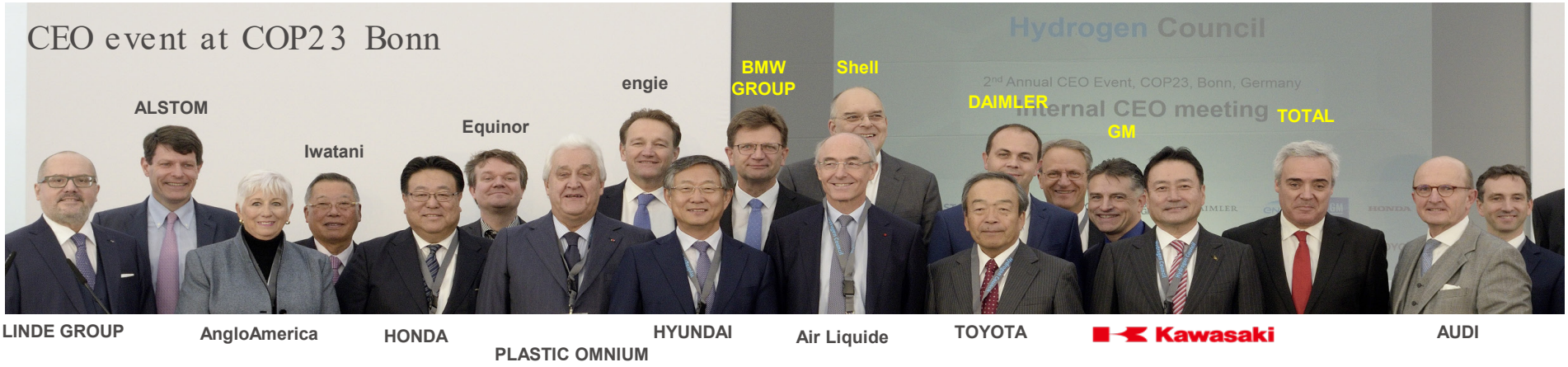
On December 26, 2017, the Ministerial Council on Renewable Energy, Hydrogen and Related Issues held its second meeting and decided on a Basic Hydrogen Strategy to accomplish a world-leading hydrogen-based society

From HP. of Prime Minister's Office

- Hydrogen is an option as important as renewable energies (R.E.)
- Mass production from low cost sources: utilizing brown coal and foreign R.E. (Develop international liquefied hydrogen supply chain)
- Promotion of furl cell vehicles and hydrogen refueling stations
- Commercialization of hydrogen power generation and mass consumption of hydrogen (hydrogen consumption 10 mill. t/year, Power generation capacity 30GW)
- Leading to growth strategy to leveraged Tokyo Olympic Paralympic Games

Initiative by Global Companies

Hydrogen Council



- **Composed of 53 leading companies from energy, transportation, manufacturing industry and trading sectors: 33 steering members and 20 associate members.**
- **A global initiative advocates long term target to move to hydrogen utilizing new energy economy**
- **With understanding of importance of hydrogen on energy transition, Hydrogen Council aims to create effective action plan with Governments and other stakeholders**

Hydrogen Introduction Vision 2050

Hydrogen Council & McKinsey

- Hydrogen market, 2.5 trillion dollars, creates 30 million employment allover the world
- Responsible for 18% of energy and 20% of CO_2 reduction
- CO_2 reduction of 6 billion t/year （50 billion t/year as of 2010 including feed stock)
- Hydrogen power generation of 1,500TWh/year （recent 10 years Japan : about 1,000TWh/year, the world : about 22,000TWh/year）
- Excessive renewable energy of 500TWh/year will be stored and utilized

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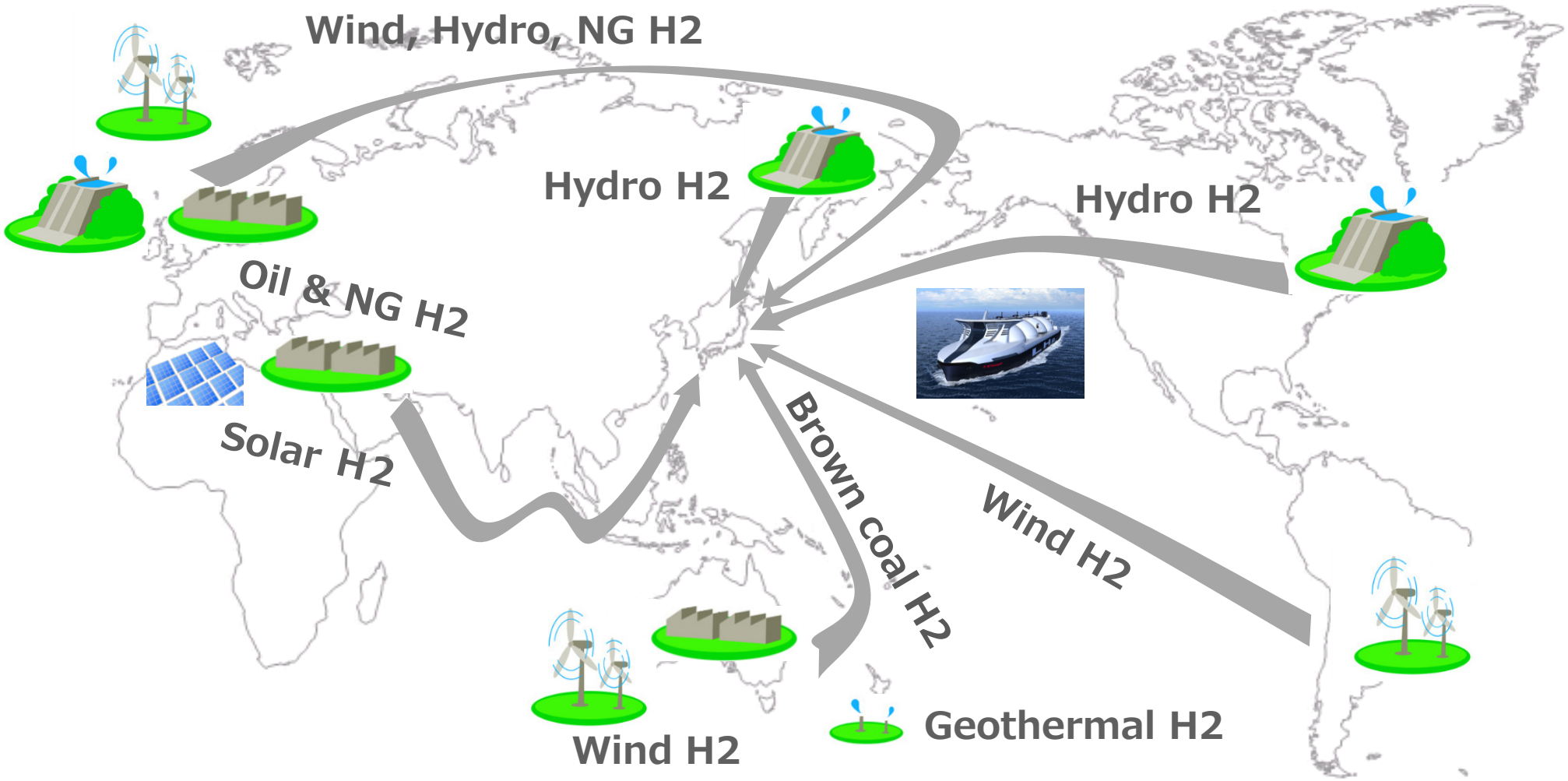
Expected CO_2-free H2 Supply chain



Concept of CO_2-free Hydrogen Chains

Stable energy supply while suppressing CO_2 emissions

Resourcing country (Australia)

Production of hydrogen at low costs from **unused resources (brown coal)** and/or abundant recyclable energy

Affordable renewable energy

Liquefaction/ loading

Brown coal

CCS (CO_2 capture/storage)

CO_2-free hydrogen

Hydrogen production

Hydrogen transport/storage

Liquefied hydrogen cargo ships

Liquefied hydrogen containers

Liquefied hydrogen storage tanks

Hydrogen transport/storage

Utilizing country (Japan)

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

Transport equipment
Hydrogen stations
Fuel cell vehicles etc.

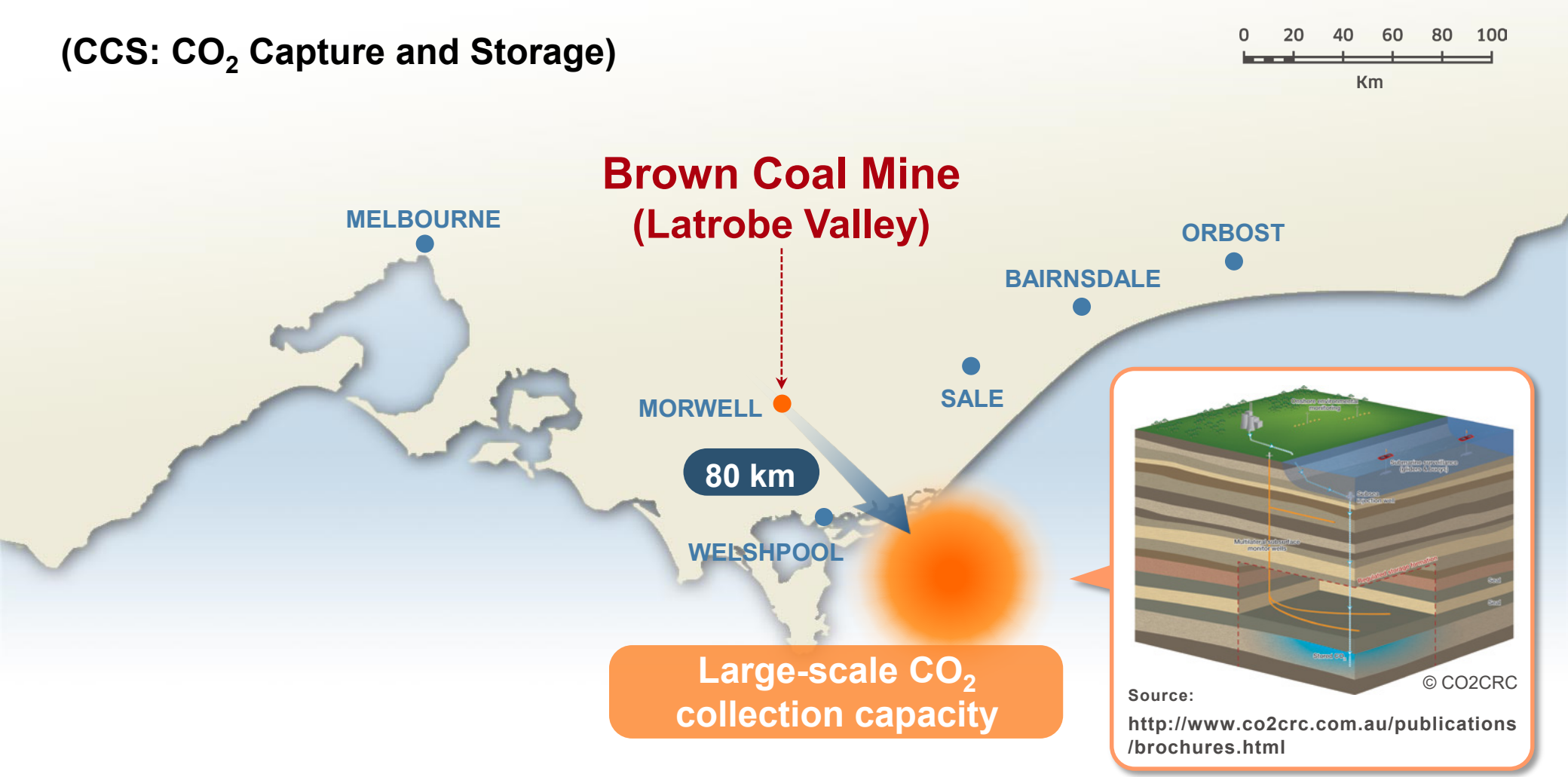
Distributed power plants
Hydrogen gas turbines
Hydrogen gas engines
Fuel cells etc.

Electrical power plants
Combined Cycle power generators etc.

Hydrogen use

CCS/CO_2 Storage Sites

(CCS: CO_2 Capture and Storage)



The Commonwealth and Victorian governments are promoting the "CarbonNet" CCS Project

Liquefied Hydrogen
~ Large-scale Transport Methods for Hydrogen ~

Characteristics of liquefied hydrogen

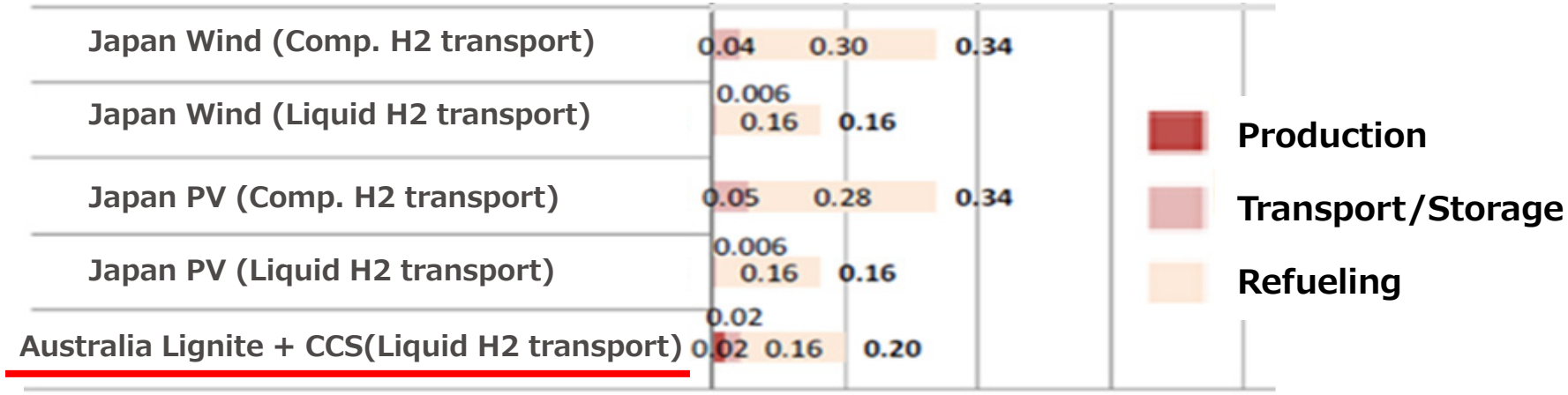
- Extremely low temperature (-253 degrees C)
- 1/800 the volume of hydrogen gas
- Transport medium of proven practical use in industry and as rocket fuel
- High purity = no need for refinement (can be supplied to fuel cells by evaporation alone)

Largest liquefied hydrogen tanks in Japan
(Tanegashima Rocket Base)

LNG ship
(large-scale energy transport)

LCA by Mizuho Information & Research Institute

Well-to-Tank CO_2 emission per 1Nm^3-Hydrogen [kg-CO_2e/Nm^3-H_2]



Ref: https://www.mizuho-ir.co.jp/publication/report/2016/pdf/wttghg1612.pdf

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Hydrogen Infrastructure Technologies

Production

Brown coal hydrogen production
Drying, pulverizing, and other lignite processing technology

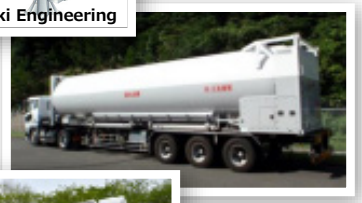
Hydrogen liquefier
Plant/turbine technology

Transport • Storage

Liquefied hydrogen cargo ships
LNG ship technology

Loading system
Ultra-low temperature sealing system technology

Liquefied hydrogen tanks
Ultra-low temperature technology

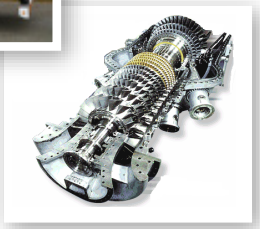


Liquefied hydrogen container
Ultra-low temperature technology

Compressed hydrogen trailer
Composite material-related technology

Use

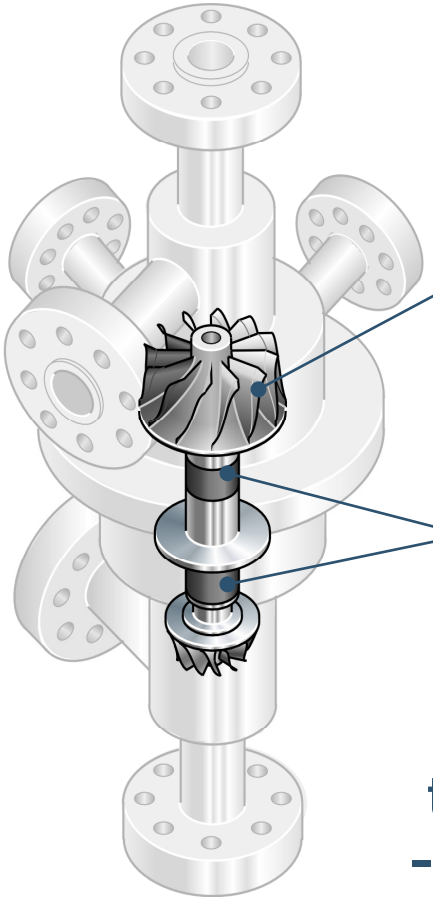
Hydrogen gas turbines
Stable, clean combustion technology



Hydrogen Liquefier

Hydrogen production ▶ Transport/Storage ▶ Hydrogen use

Realization of a hydrogen liquefier by means of unique key hardware and expansion turbines



Ultra-fast rotation

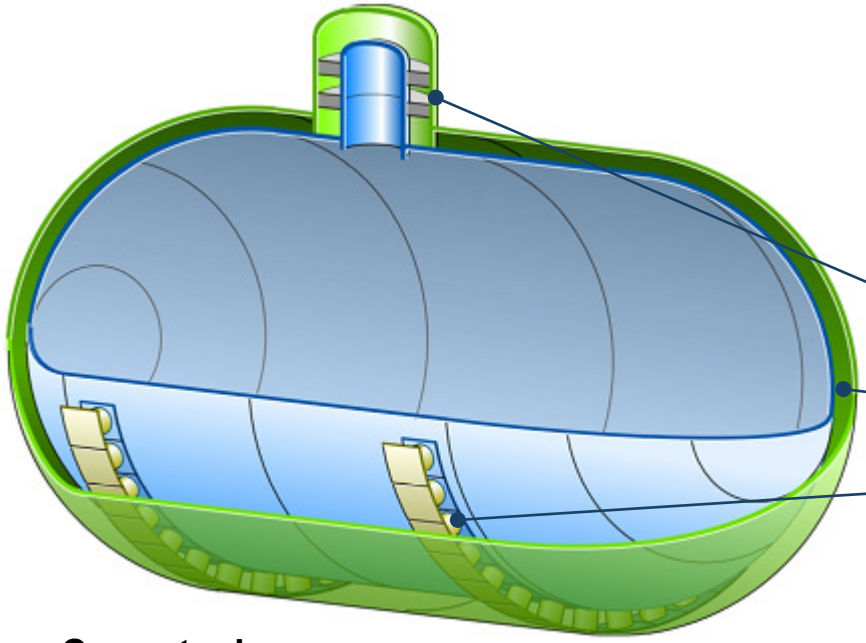
Hydrogen gas bearings

Liquefaction temperature: -253 degrees C

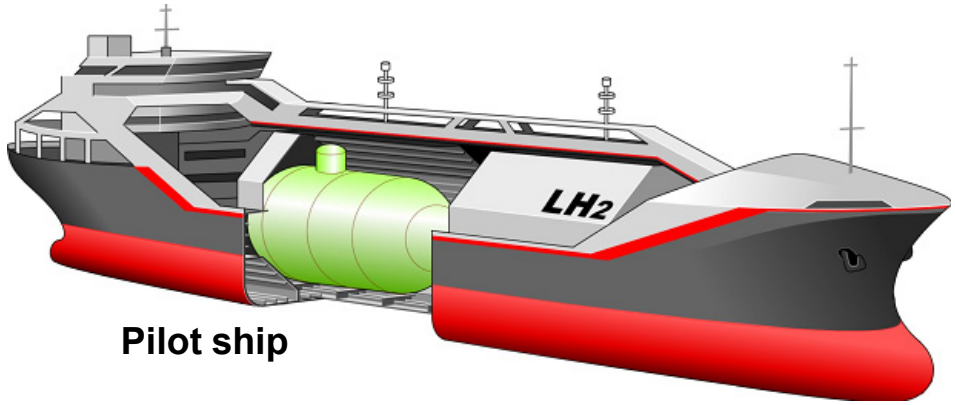
Liquefied Hydrogen Cargo Ship

Hydrogen production ▶ **Transport/Storage** ▶ Hydrogen use

World‘s first liquefied hydrogen cargo ship toward realization



Cargo tank



Pilot ship

- Special dome structure for maintaining vacuum
- Stainless steel vacuum thermal insulation double hull
- High thermal insulation supporting structure

December 2013
Basic certification obtained from Nippon Kaiji Kyokai

Guideline to complement IGC code is being proposed to IMO by both Japan and Australia

*IGC code: International regulations relating to the structure and equipment of vessels for transporting bulk shipments of liquefied gas
IMO: International Maritime Organization

Approval of Safety Requirements

- Interim recommendations were discussed on safety requirements for offshore carriage of liquefied hydrogen in bulk proposed by Japan.
- IMO MSC(Maritime Safety Committee, Parent Committee of CCC3) was held from 21th to 25th Nov. , 2016 and approved the recommendations.
- Thus, IMO officially acknowledge the demonstration of liquefied hydrogen transportation between Japan and Australia.

IMO: International Maritime Organization

Cryogenic Storage

Liquefied hydrogen storage tanks

Liquefied hydrogen storage tank specifications	
Models	Spherical double-hull tank
Storage capacity	540 m^3
Design pressure	0.686 MPa + Vacuum
Design temperature	-253°C
Thermal insulation method	Vacuum pearlite thermal insulation

Land Transport of Liquefied Hydrogen

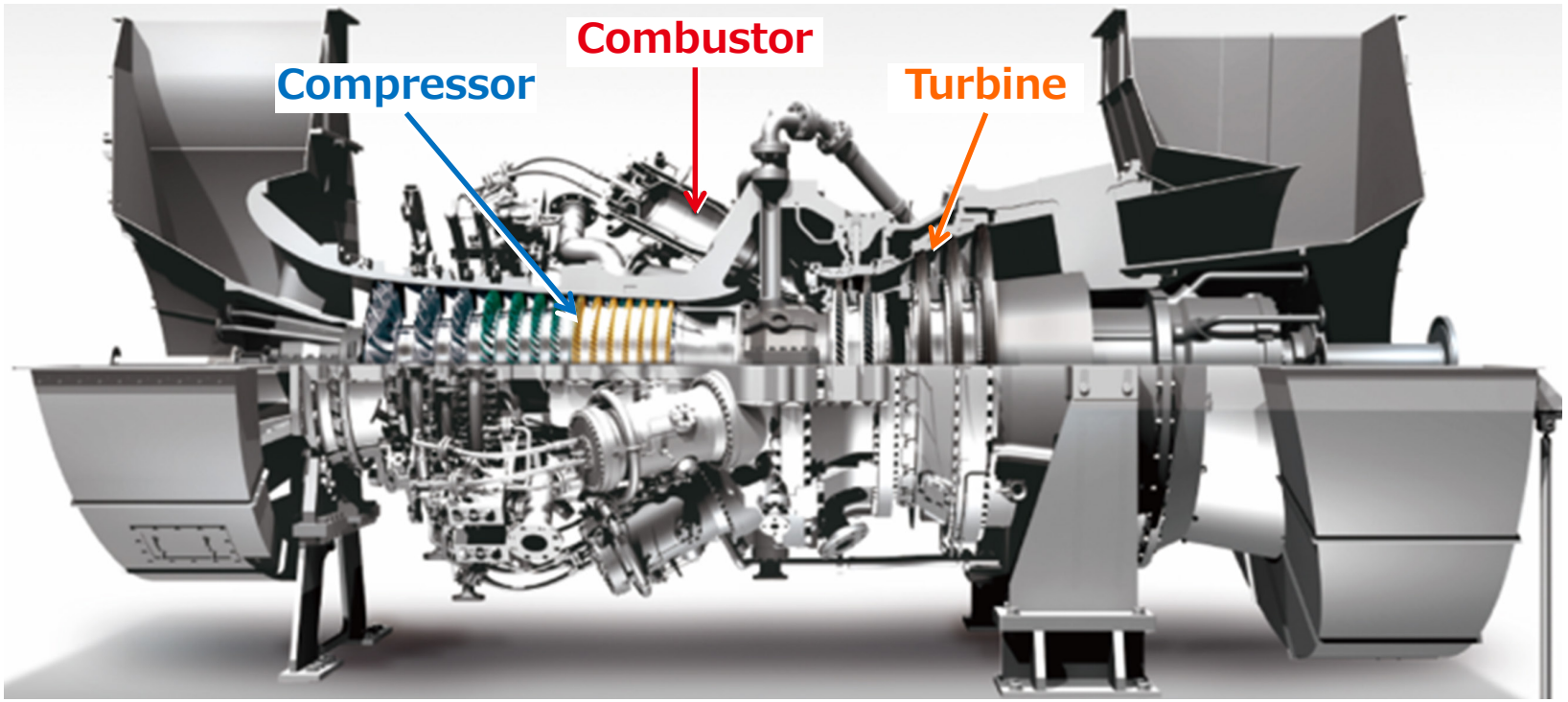
Liquefied hydrogen transport container

Liquid hydrogen transport container specifications	
Models	ISO 40 ft container
Internal volume	45.6 m^3
Unladen weight	22.3 ton
Hydrogen load capacity	2.8 ton
Thermal insulation method	Vacuum lamination thermal insulation
Accessories	Pressure evaporator

Hydrogen Gas Turbine

Application to hydrogen by exchanging combustor only, no modification of compressor and turbine

Issue: stable combustion and suppression of NOx



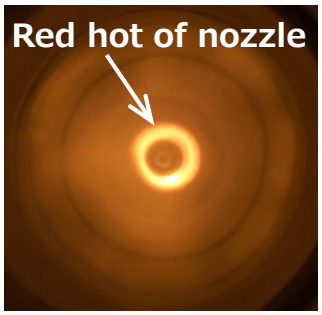
Hydrogen Combustion Issues

- Higher combustion temperature than that of natural gas (hot spot in the combustion chamber)

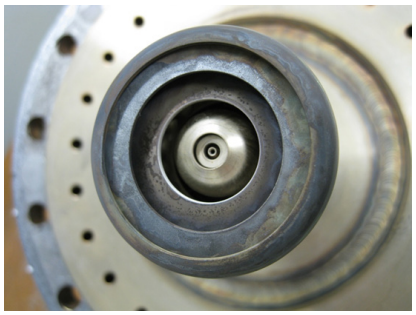
  ⇨ Higher NOx emission

- Higher flame propagation velocity than that of natural gas
- Shorter flame quenching distance

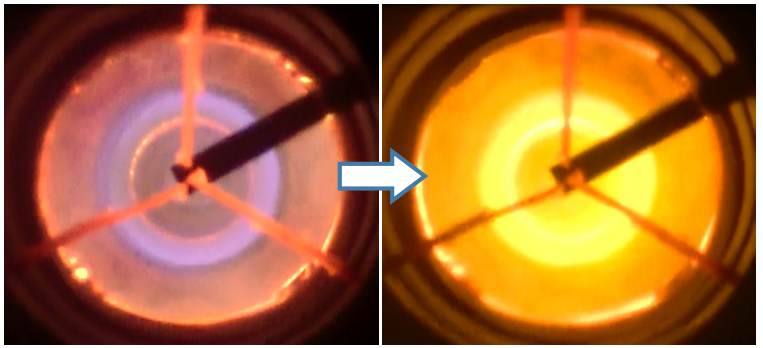
  ⇨ Structural burnout, flash back



Hydrogen fueled



The nozzle after test

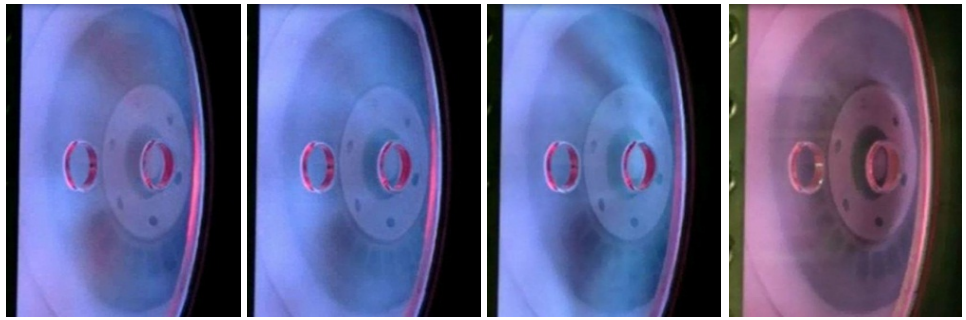


Flash back with pre-mixed combustion

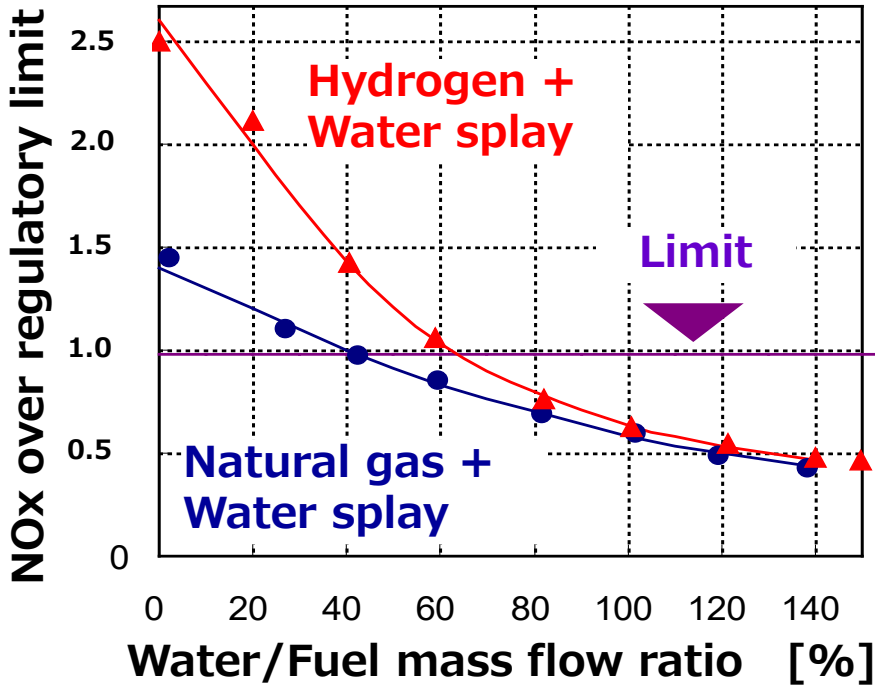
Fuel Flexible Low NOx Combustion

Flame behavior (Visualization test)

Pure natural gas → Pure hydrogen



Natural gas	100%	60%	20%	0%
Hydrogen	0%	40%	80%	100%



NOx suppressed less than the limit with water injection

Supported by NEDO

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Progress of Hydrogen Project

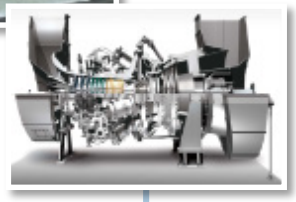
2014 | 2020 | 2030

Technologies in Kawasaki Heavy Industries

LNG technology

Liquefied hydrogen technology

"Strategic Energy Plan"



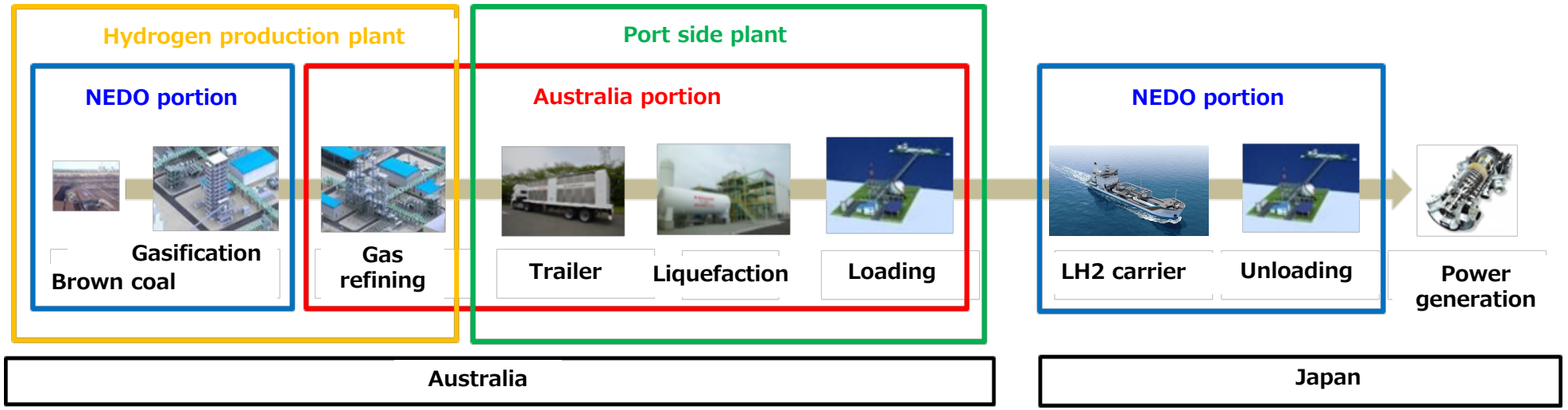
2018 Kobe
Hydrogen Gas Turbine
Co-generation

Tokyo Olympics & Paralympics

Pilot demonstration

Commercial chain

Pilot Demonstration Structure



- **NEDO portion: consisting of gasification in Australia, H2 carrier and unloading terminal in Japan supported by NEDO, performed by HySTRA**
- **Australia portion: consisting of gas refining and loading terminal in Australia supported by Australian Governments**
- **Hydrogen Production Plant: consisting of gasification and gas refining in Latrobe Valley**
- **Port side plant: consisting of trailer, liquefaction and loading terminal in Hastings**

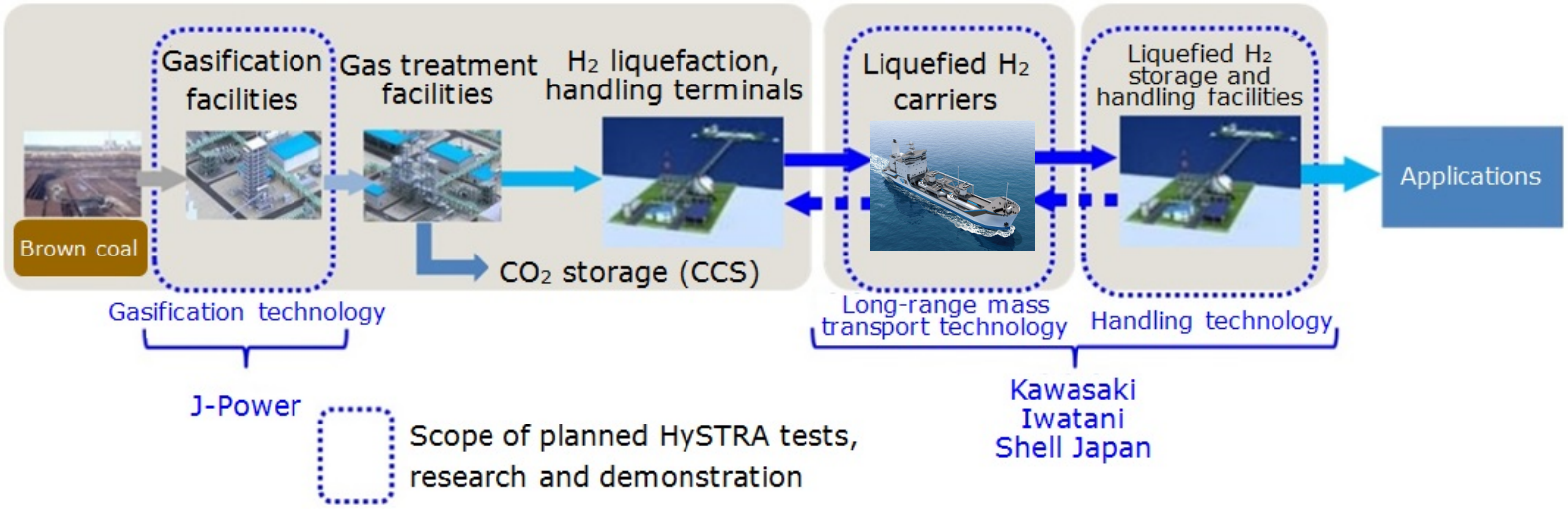
Technical Research Association

Name of TRA: CO2-free Hydrogen Energy Supply-chain Technical Research Association (Abbreviation: HySTRA)

Established date: February in 2016

Member: KHI, Iwatani Corporation, Shell Japan, J-Power

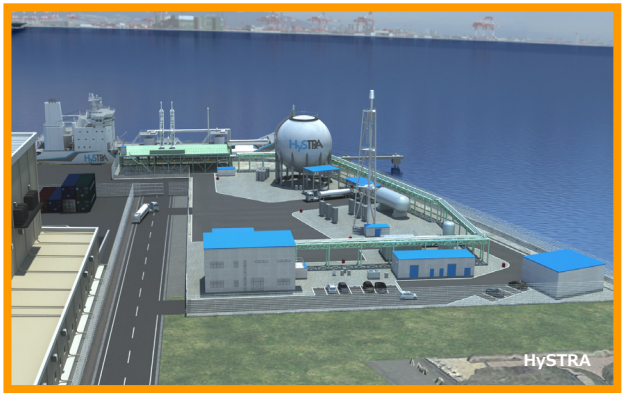
President: Eiichi Harada(Executive Officer, KHI)

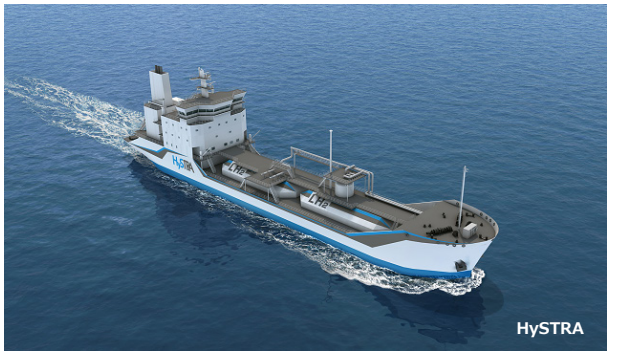


Pilot Demonstration

- Entrance to commerce
- Brown coal gasification technology
- On-shore base for liquefied hydrogen technology for loading/unloading between ships
- Marine transport technology for large volumes of liquefied hydrogen
- Technology demonstration of feasibility in fiscal 2020 when the Tokyo Olympics is held

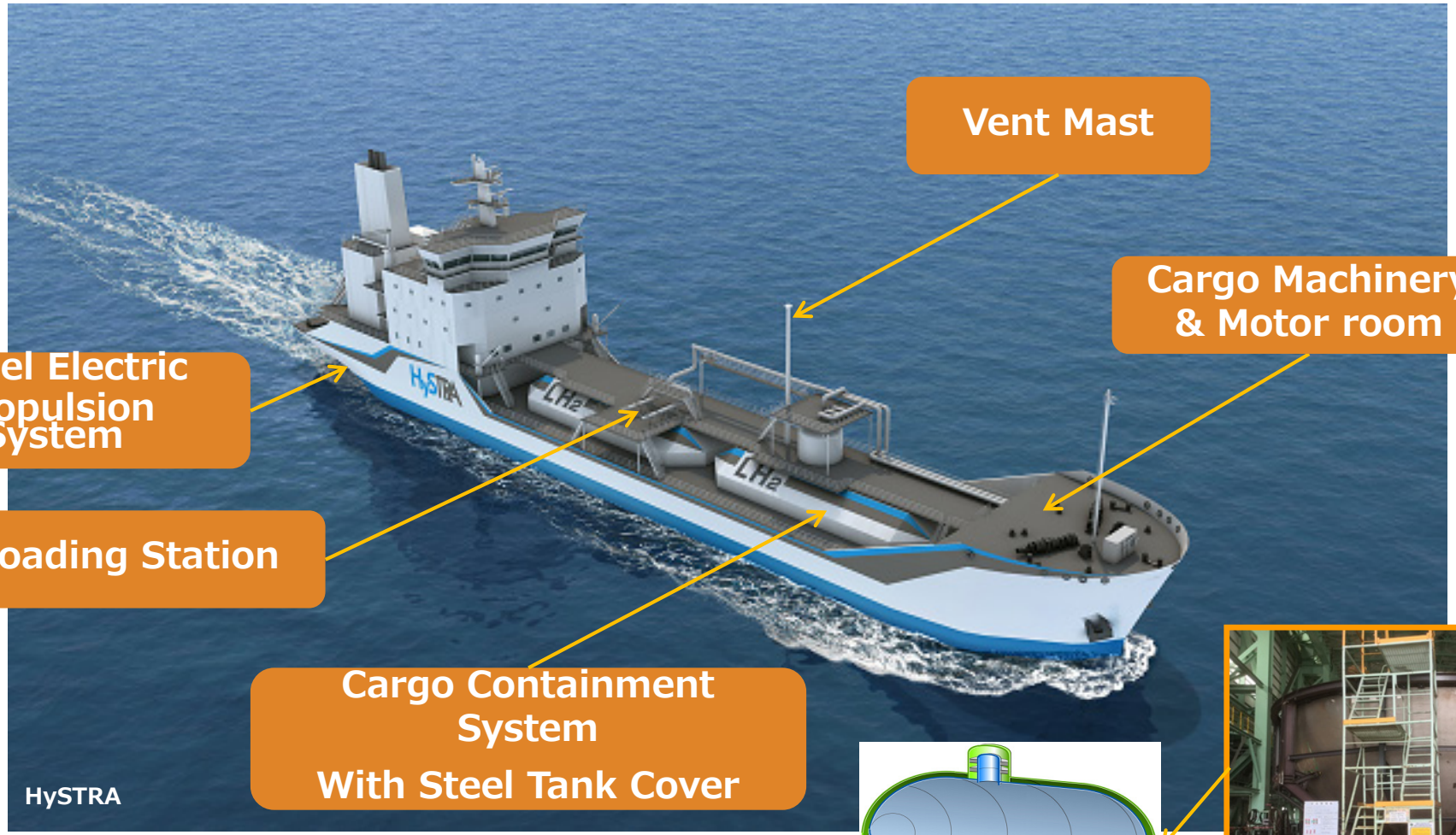
Supported by NEDO (New Energy and Industrial Technology Development Organization)



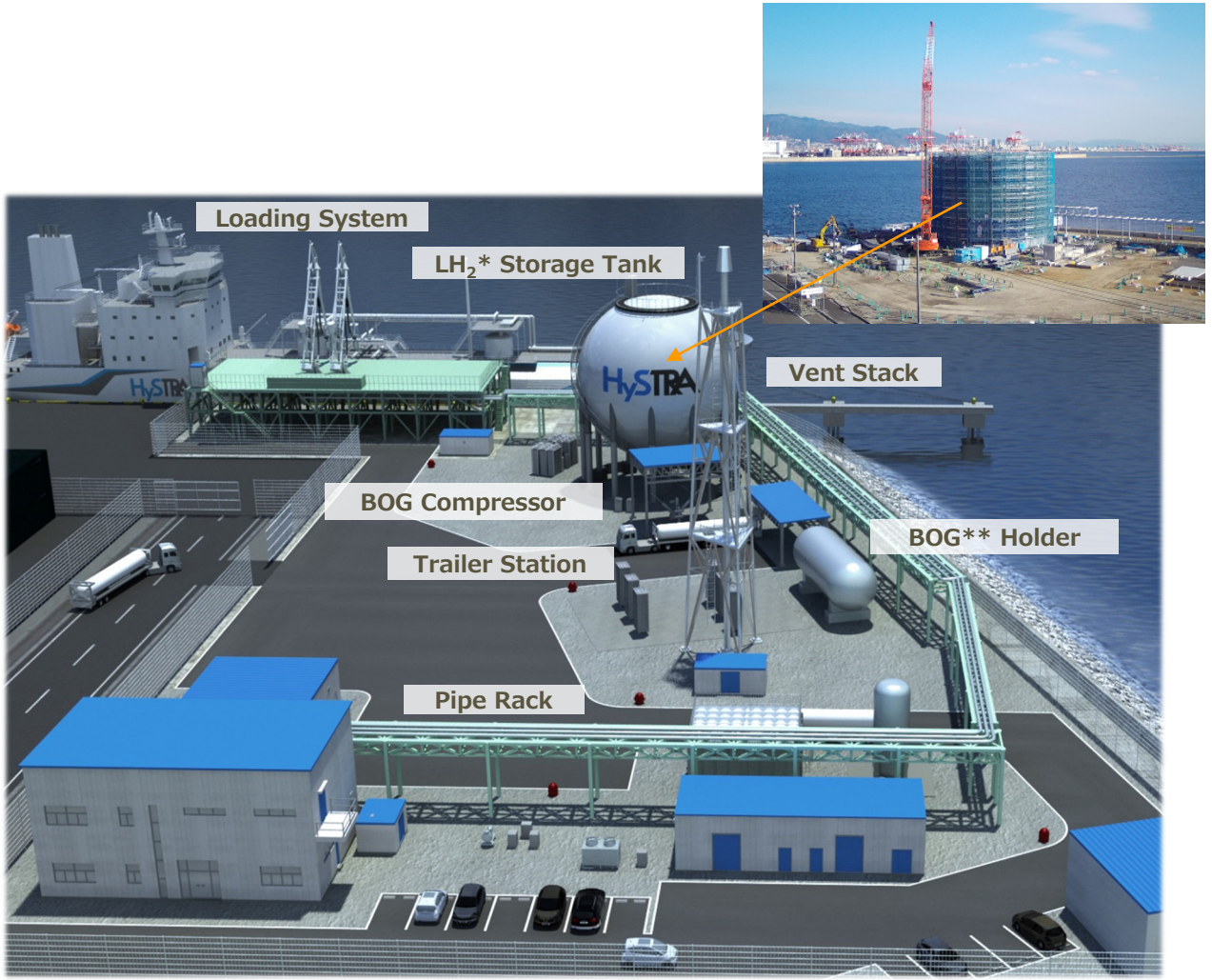


Liquefied Hydrogen Cargo Ships

Hydrogen production ▶ Transport/Storage ▶ Hydrogen use



Pilot Demonstration (LH_2 Terminal)



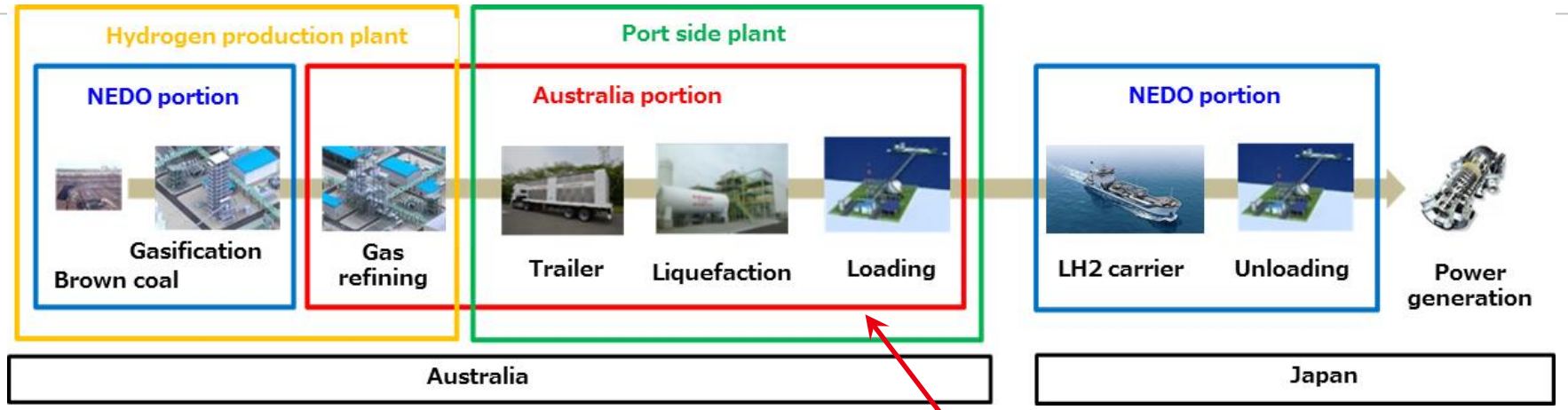
*LH_2 : Liquefied Hydrogen

**BOG : Boil Off GAs

Computer Graphic of Liquefied Hydrogen Terminal in Kobe Air Port Island

Pilot Demonstration (LH_2 Terminal)

Australian Portion Launched



- Australian portion subsidization was announced in Latrobe Valley on 12, April
- Prim minister Turnbull and ministers attended the event
- METI and NEDO attended from Japan
- Kawasaki Heavy Industries, J-POWER, Iwatani Corp, Marubeni and AGL attended from the private sector

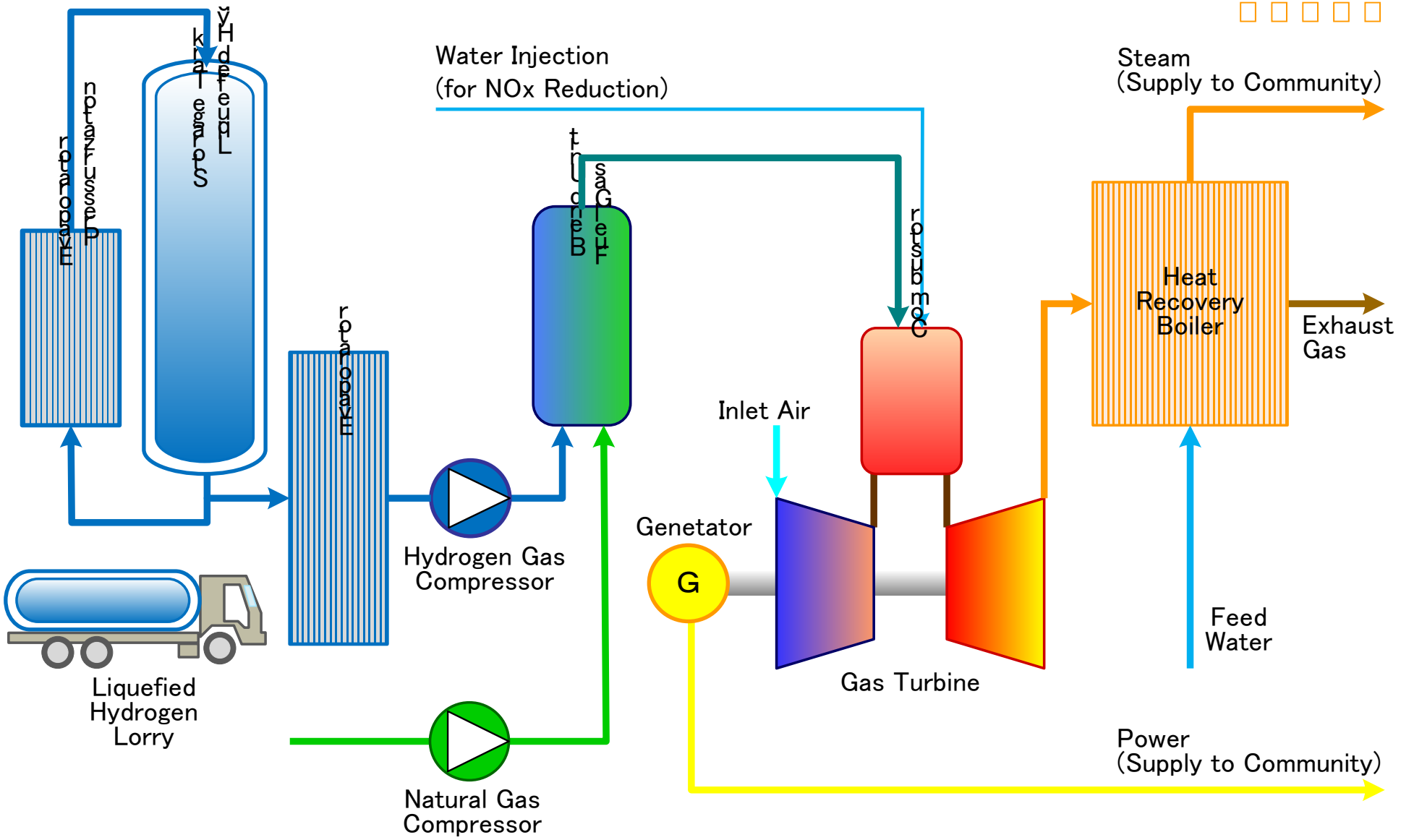
Hydrogen Power Station in Kobe

Power and heat management system using hydrogen and natural gas as a fuel.

Power Generation: 1 MW class
Partners: Obayashi (Leader), Kawasaki, Kobe City, KEPCO, Iwatani, Kenes, Osaka University(~FY2018)
Period: FY2016~FY2019

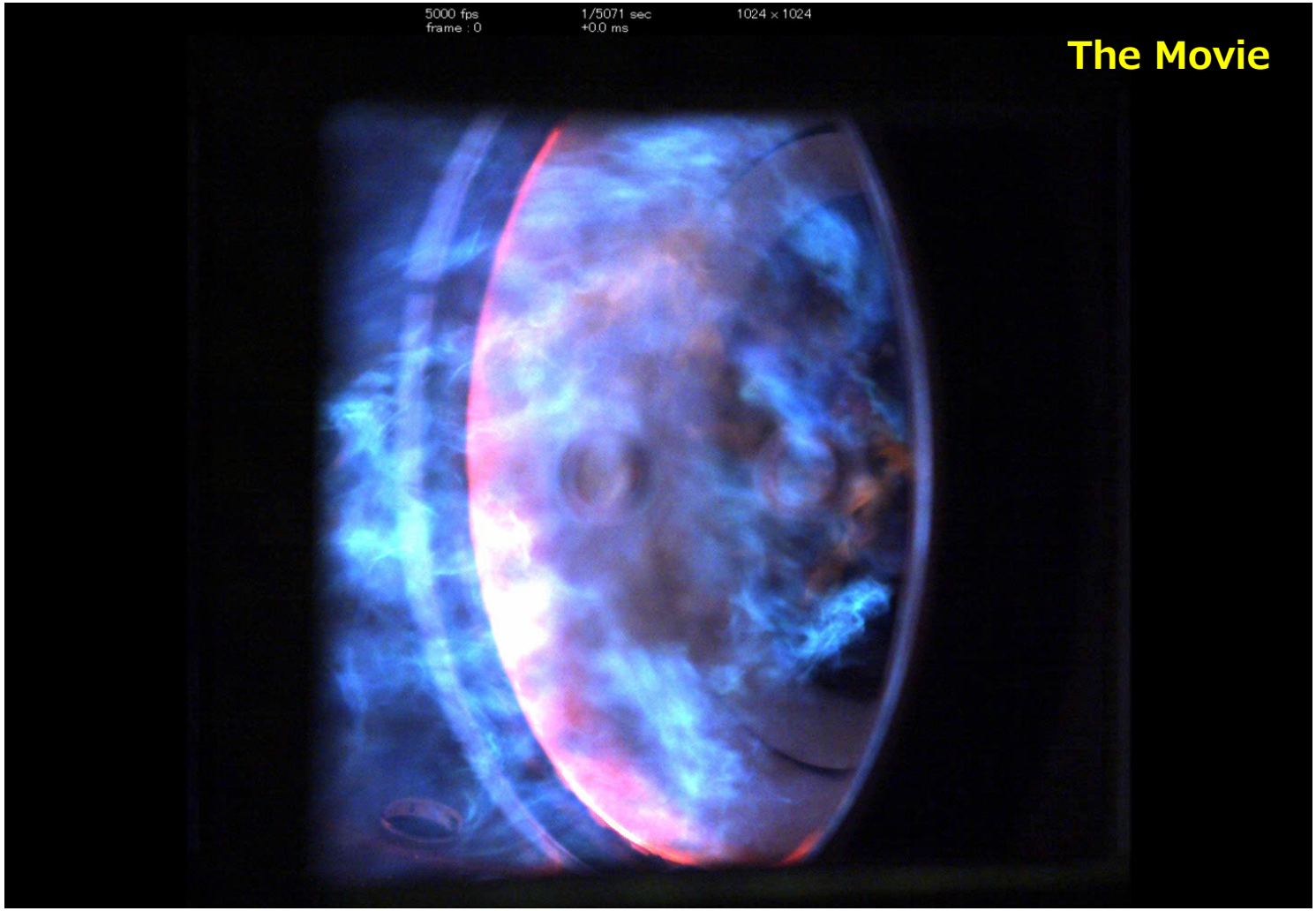
Supported by NEDO

Hydrogen Gas Turbine CGS System Flow Diagram



Flexible Fuel Nozzle with Water Injection

Flexible for Hydrogen, Natural Gas and Mixed Fuel Gas



Role and Effect of CO_2-free Hydrogen Chains

1 Stable Supply

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

→ Contribute to hydrogen economy deployment and energy security

2 Environmental

- No CO_2 emissions when used (only water is emitted)

→ "Ultimate clean energy"

3 Improvement of Industrial Competitiveness

- Wide use of hydrogen brings Industrial growth → Broad spectrum of jobs and employments
- Hydrogen production started from fossil fuel gradually shifted to the renewables → Way of the sustainable development goals

Thank you for listening

Kawasaki, working as one for the good of the planet

“Global Kawasaki”

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