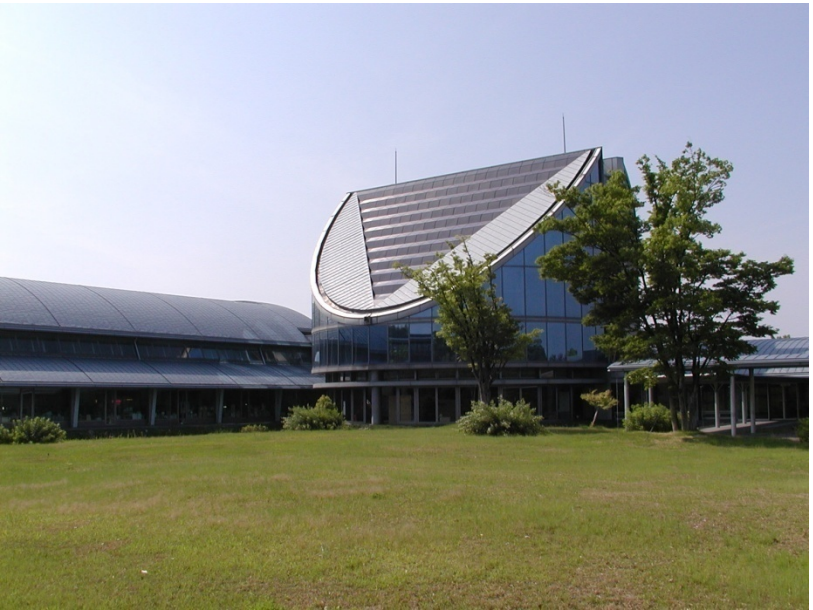
RITE
Research Institute of Innovative Technology for the Earth

Emerging hydrogen value chains for Japan

May 2, 2018



For Kawasaki Heavy Industries

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CO_2 Storage Research Group

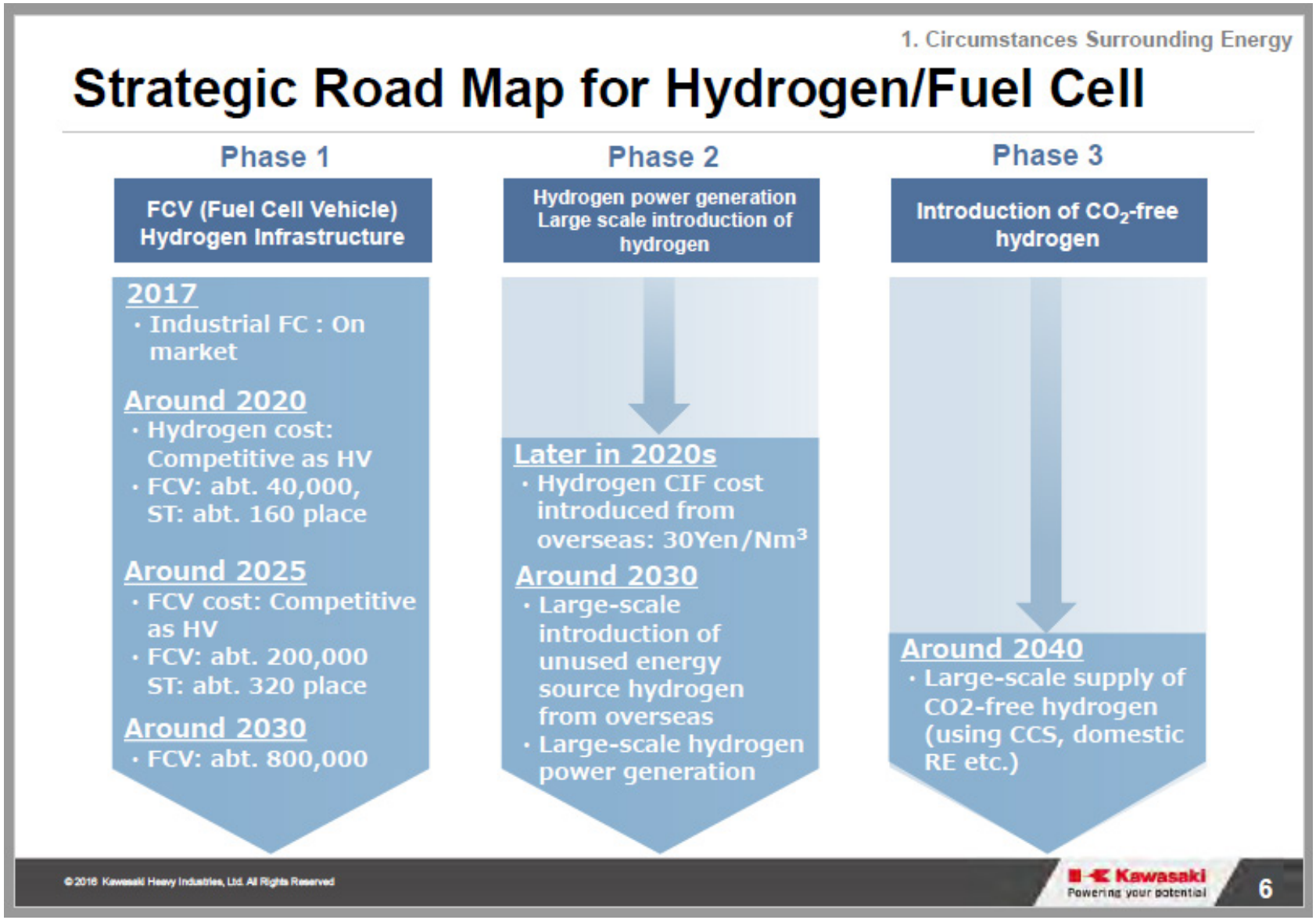
Research Institute of Innovative Technology for the Earth (RITE)

Hydrogen R&D and Use

Japan has a long history of R&D on hydrogen use and as a result:

- More than 200,000 units of Ene-Farm (on-site fuel cell based CHP for houses) installed since 2009,
- More than 1,800 FCVs on road as of 2016 , and
- Nearly 100 hydrogen refueling stations in service at present across Japan.

Hydrogen R&D and Use



Source: Kawasaki Heavy Industries, CSLF Technical Workshop in Tokyo, 2016

2016 CSLF Technology Workshop

CO2-Free Hydrogen Supply Chain

October 5, 2016

Kawasaki Heavy Industries, Ltd.

Kawasaki

Powering your potential

Why Hydrogen ?

Hydrogen :

- Does not emit CO2 or any hazardous materials
- Used as rocket fuel (High energy density)
- Produced from various resources (Sustainable)

Contents

1. Circumstances Surrounding Energy
2. The Concept of Hydrogen Supply Chains
3. Hydrogen Infrastructure Technology

Contents

Hydrogen Use as a National Growth Strategy

- Cabinet decision of April 2014 for “Strategic Energy Plan":
  Hydrogen use is described in detail for the first time

- The Ministry of Economy, Trade and Industry has formulated a hydrogen and fuel cell strategic road map, and specified "hydrogen production from the as-yet unused resource " and "hydrogen power generation"

Strategic Road Map for Hydrogen/Fuel Cell

Phase 1

FCV (Fuel Cell Vehicle) Hydrogen Infrastructure

2017
- Industrial FC : On market

Around 2020
- Hydrogen cost: Competitive as HV
- FCV: abt. 40,000, ST: abt. 160 place

Around 2025
- FCV cost: Competitive as HV
- FCV: abt. 200,000 ST: abt. 320 place

Around 2030
- FCV: abt. 800,000

Phase 2

Hydrogen power generation Large scale introduction of hydrogen

Later in 2020s
- Hydrogen CIF cost introduced from overseas: 30Yen/Nm^3

Around 2030
- Large-scale introduction of unused energy source hydrogen from overseas
- Large-scale hydrogen power generation

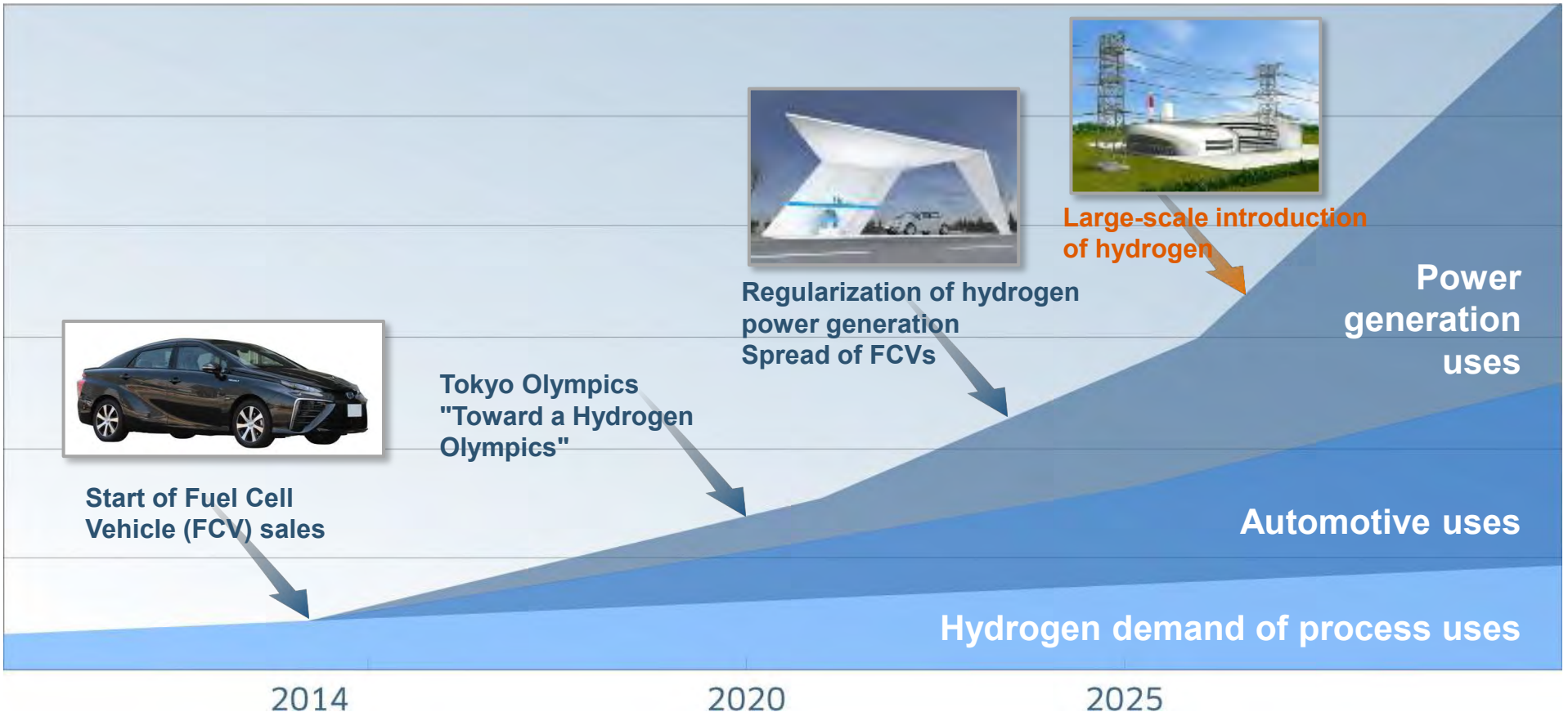
Phase 3

Introduction of CO_2-free hydrogen

Around 2040
- Large-scale supply of CO2-free hydrogen (using CCS, domestic RE etc.)

Expansion of Hydrogen Demand “From FCVs to the Power generation"

Demand progresses in the order of “Processing" ⇒ "FCV" ⇒ “Power generation"



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The Concept of CO_2-free Hydrogen Chains

Stably supplying energy while suppressing CO_2 emissions

Resourcing country (Australia)

Utilizing country (Japan)

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

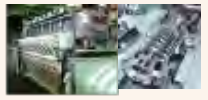
Liquefied hydrogen cargo ships

Liquefied hydrogen containers

Liquefied hydrogen storage tanks

Process uses
Semiconductor and solar battery manufacture
Oil refinement, desulfurization, etc.

Transport equipment
Hydrogen stations
Fuel cell vehicles etc.



Electrical generator
Hydrogen gas turbines
Hydrogen gas engines
Fuel cells etc.

Electrical power plants
Combined Cycle power generators etc.

Hydrogen production

Hydrogen transport/storage

Hydrogen use

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)

What is brown coal?

- It is young coal, plentiful, and occurs widely around the world
- Water content is high at 50-60%
- Since it naturally ignites easily when dried,
  it is not suitable for transport,
  and it can only be used for on-site power generation

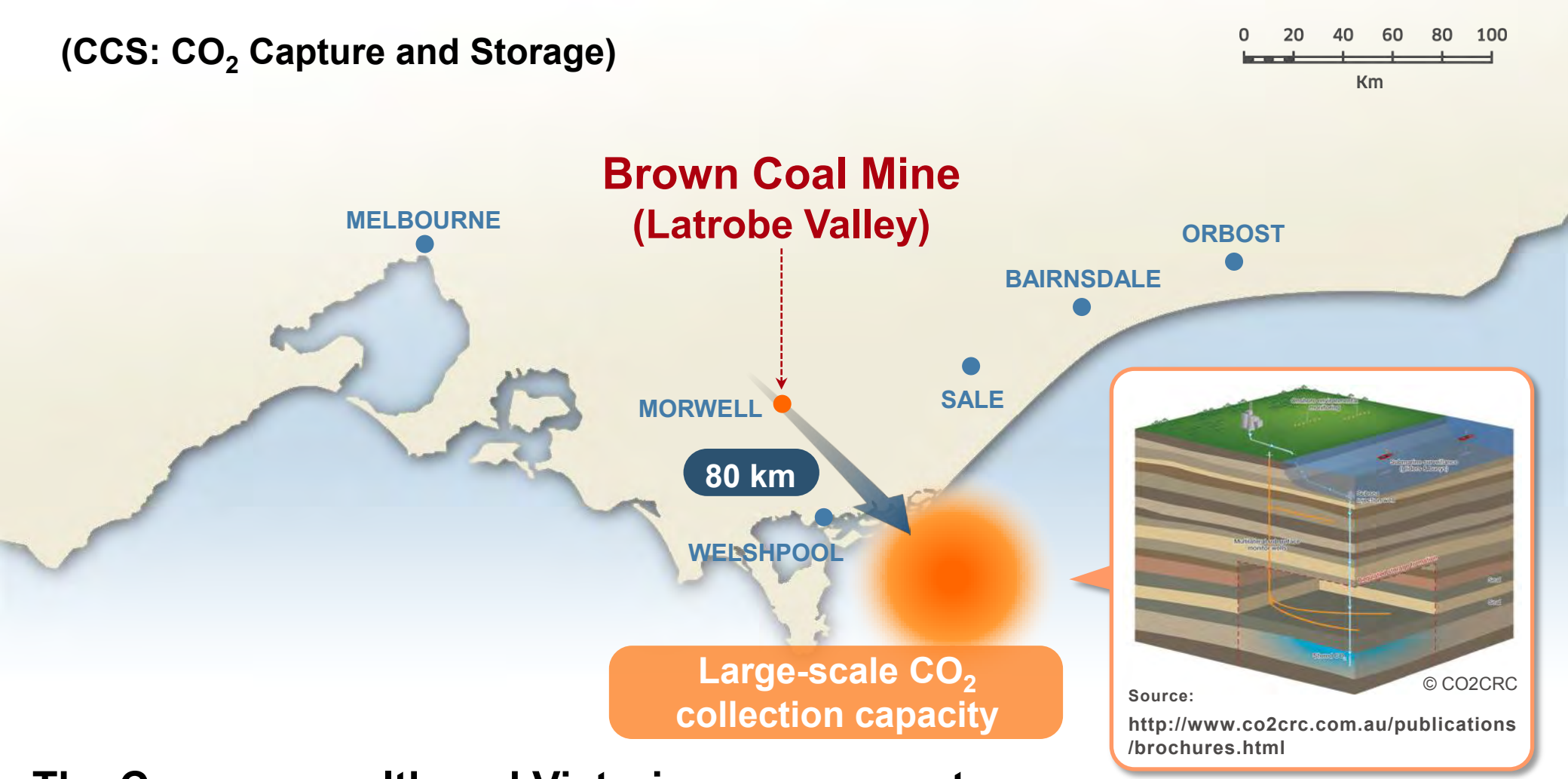
- Because it cannot be transported, overseas transaction is impossible and "unused resource" = “reasonable" and "easy rights acquisition" only for mining rights
- Among the many hydrogen production methods, hydrogen production from brown coal is one of the most economical methods

Australian brown coal

There is a brown coal layer to the horizon
One layer is up to 250 meters below the surface
There are also layers further down (Here, there is brown coal equivalent to Japanese total energy generation for 240 years)

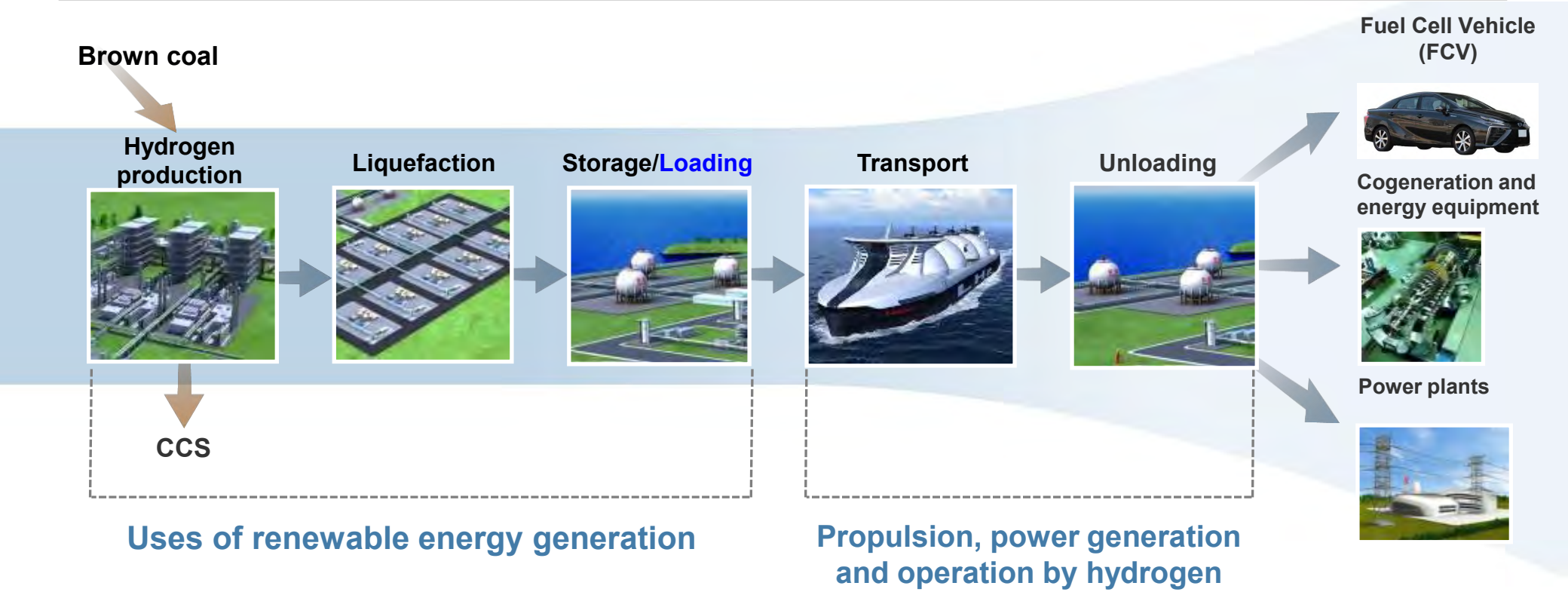
CCS/CO_2 Storage Sites

(CCS: CO_2 Capture and Storage)



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

CO_2-free Hydrogen Commercial Chain Feasibility Study

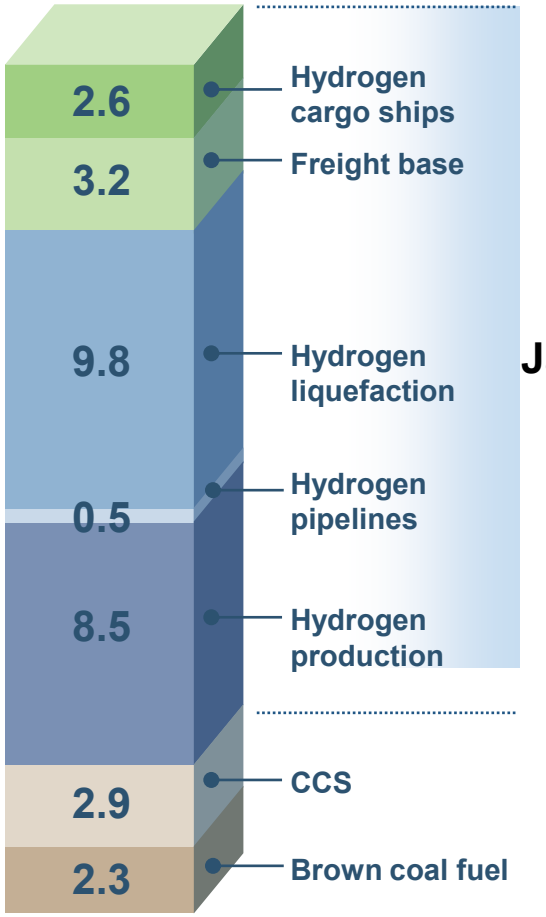


- Hydrogen source: Australian brown coal
- Byproduct CO_2 processing: On-site storage ⇒ CO_2 free
- Amount of hydrogen production (use): 770 t/day,
  Equivalent to fuel for 3 million FCVs or
  1 GW of thermal power generation

Commercial Chain FS Results

Hydrogen cost (CIF)

29.8 yen/Nm^3



Japanese technologies and products

[Scale]

3 million FCVs

FCV

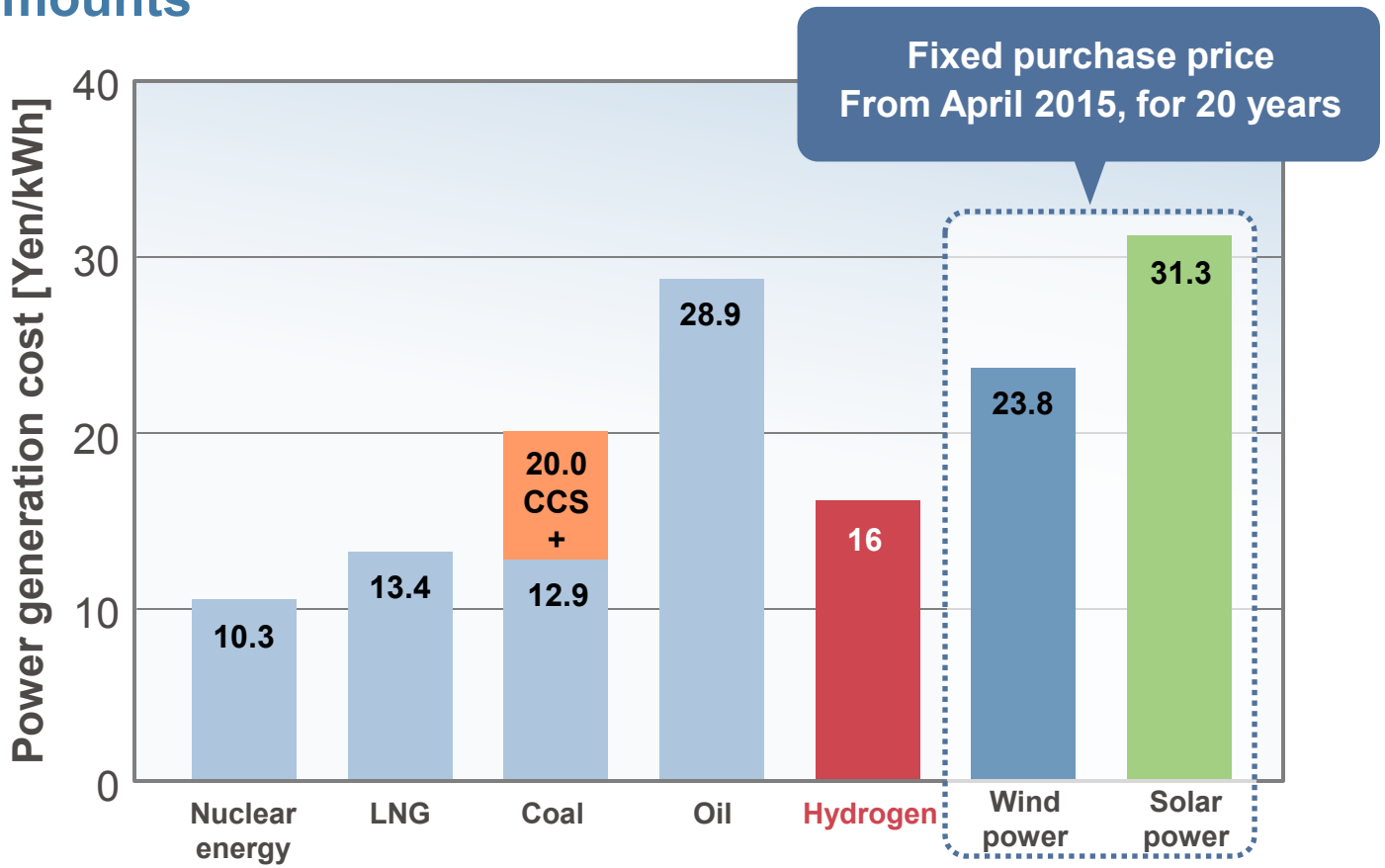
or

Equivalent to one 1 GW hydrogen power plant

Hydrogen power plant

Power Generation Cost Comparison

Although more expensive than fossil fuel generation, among CO_2-free energies, it is cheaper and more stable than renewable energy and usable in large amounts



Reference: "Power Generation Cost Work Group Verification Report 2030 Model Plant, May 2015"

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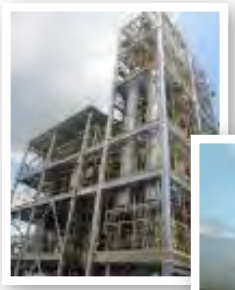
Hydrogen Infrastructure Technology Development

Production

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



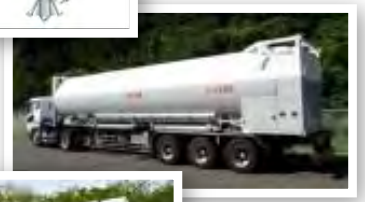
Today's introduction

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

Liquefied Hydrogen 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

Overland Transport of High Pressure Hydrogen

Compressed hydrogen transport trailer with high-pressure composite container (first in Japan)
Transports enough hydrogen for 52 FCVs

2012 NEDO collaborative research project
Cooperation:
The Research Association of Hydrogen Supply/Utilization Technology (HySUT)
JX Nippon Oil & Energy

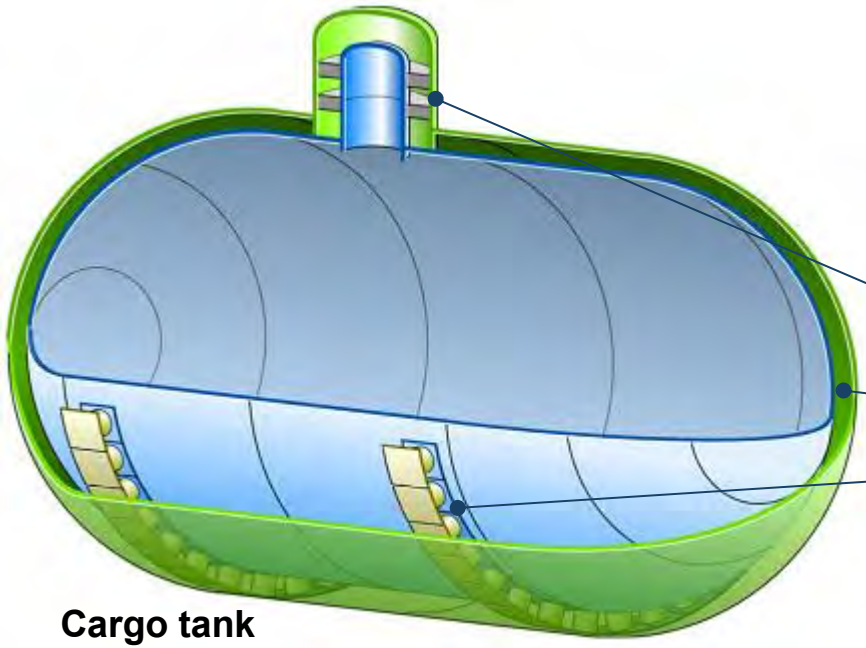
Compressed hydrogen transport trailer specifications	
Total length*	10,260 mm
Total width	2,500 mm
Total height	3,500 mm
Weight*	19,310 kg
Number of containers loaded	24
Hydrogen load capacity	260 kg

45 MPa class composite container specifications	
Total length	3,025 mm
Diameter	436 mm
Weight	220 kg
Pressure	45 MPa
Internal volume	300 L
Container type	Type 3

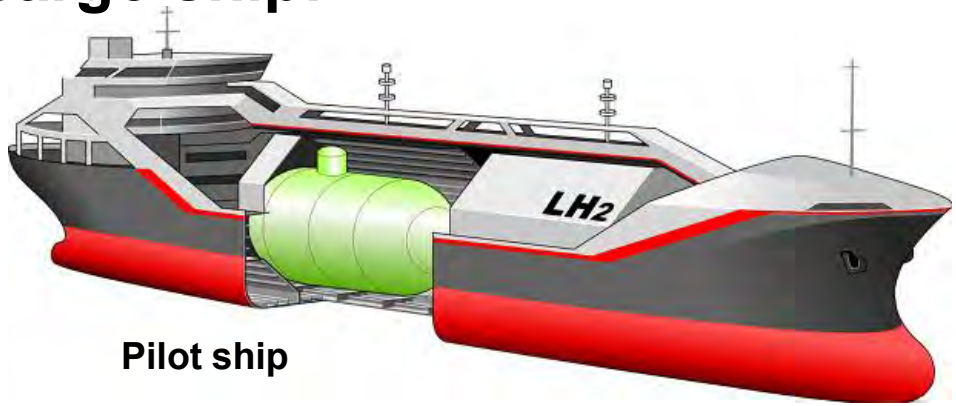
*Minus tractor

Liquefied Hydrogen Cargo Ships

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

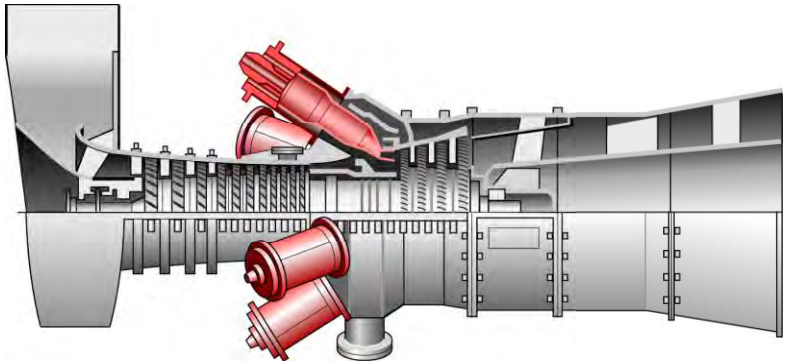
→

September 2016
Interim recommendations on safety requirements were approved at IMO CCC3 held in London

*IGC code: International regulations relating to the structure and equipment of vessels for transporting bulk shipments of liquefied gas
IMO: International Maritime Organization CCS3：the 3rd Carriage of Cargoes and Containers

Hydrogen Gas Turbine Power Generation

Development of hydrogen gas turbines



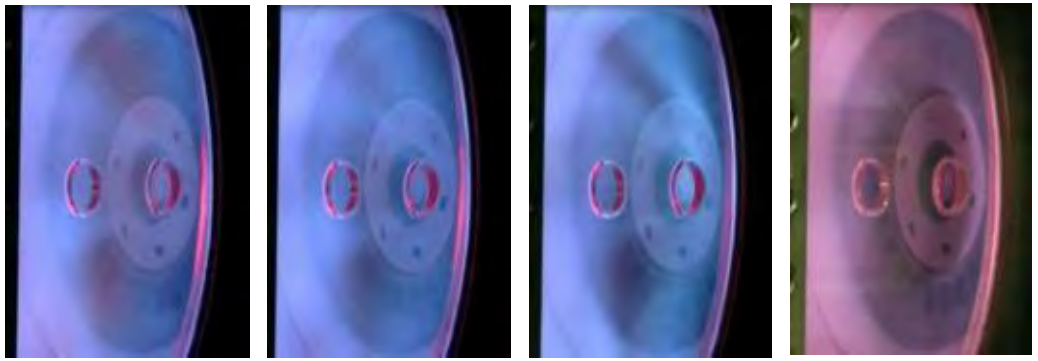
Combustion chamber is key hardware

Hydrogen burner

- Independently developed hydrogen burner that suppresses NO_x creation and realizes stable combustion
- Freely switchable between natural gas and hydrogen density

Natural gas

100% 60% 20% 0%



0% 40% 80% 100%

Hydrogen

Development of Hydrogen Project

2014

2020

Tokyo Olympics

2030

Technologies also in the possession of this company

LNG technology

Liquefied hydrogen technology

"Strategic Energy Plan"

Pilot demonstration

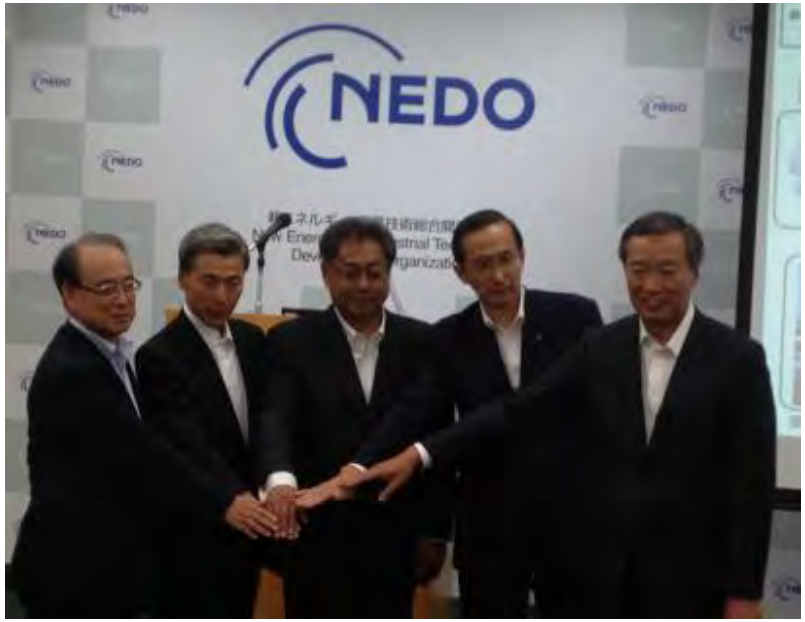
Commercial chain

Pilot Demonstration

- 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

Selection of NEDO Projects

- Select NEDO's promotion services relating to hydrogen supply chain and hydrogen cogeneration demonstration
- Hydrogen supply chain: Kawasaki Heavy Industries, Ltd. (organizer), Iwatani Corporation, J-Power
- Implement press conference hosted by NEDO



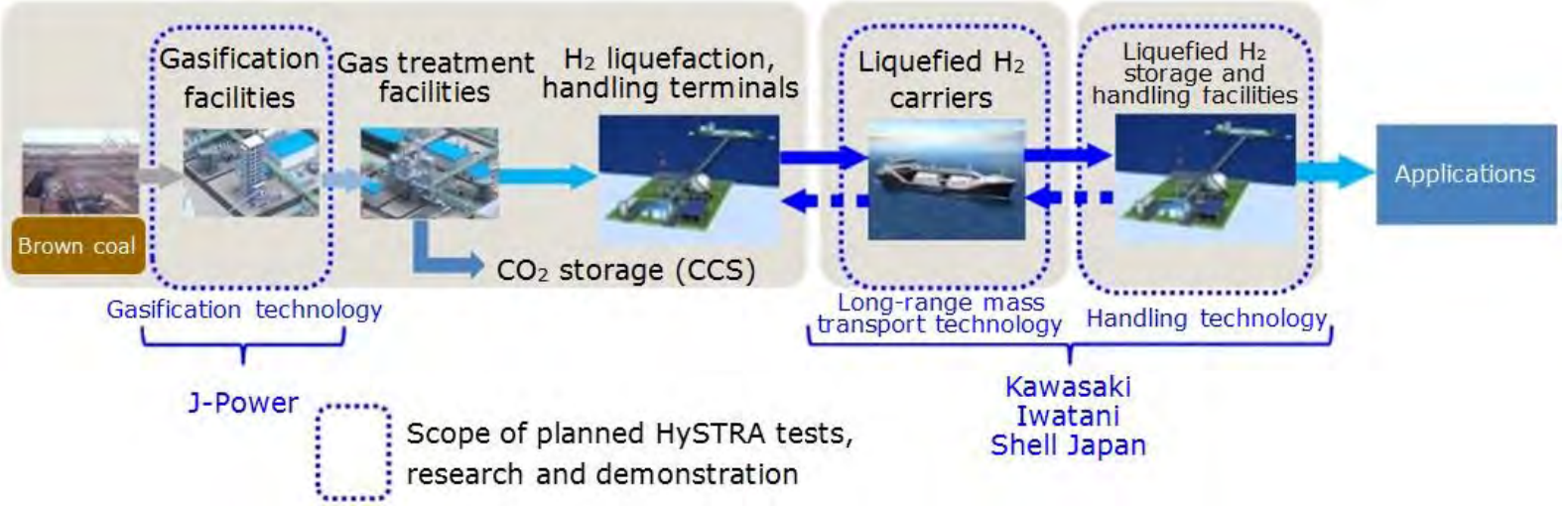
Established Technical Research Association

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)



The Significance and Utility of CO_2-free Hydrogen Chains

1 Stability of supply

- Brown coal: World-wide distribution, enormous reserves
  Currently has no price, acquisition of independent rights is easy

→ Contribution to energy security (240 years worth in Australia alone)

2 Environmental

- No CO_2 emissions during use (only water is emitted)

→ "Ultimate clean energy"

3 Improvement of industrial competitiveness

- Energy security for Japanese technology and products → Suppression of national resource outflow
- Related industries will grow due to spread of hydrogen → Contribution to growth strategies Development toward infrastructure export

Thank you for listening

Kawasaki, working as one for the good of the planet

“Global Kawasaki”

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