International workshop on Renewable Energy and Hydrogen Export

Hydrogen Supply Chain with Long Distance Transport

24th, March, 2015

Kawasaki Heavy Industries, Ltd.
Corporate Technology Division

Kawasaki
Powering your potential

Products

Aerospace (Boeing 787)

Motorcycles

Gas turbine power generation

Transportation
Energy・Environment

Refuse incincration

Rolling stock
(Shinkansen)

Ships (LNG carrier)

Energy plant
(Coal-fired power generation plant)

Products for Hydrogen

Fertilizer Plant
(Hydrogen production)

H-II rocket fuel
hydrogen storage tank

Liquefied hydrogen
storage tank

Liquefied hydrogen container

High pressure hydrogen gas trailer

Contents

1. Circumstances of energy resources
2. Movement to hydrogen utilization
3. Concepts of hydrogen supply chain
4. Technologies for hydrogen infrastructure
5. Progress of the project

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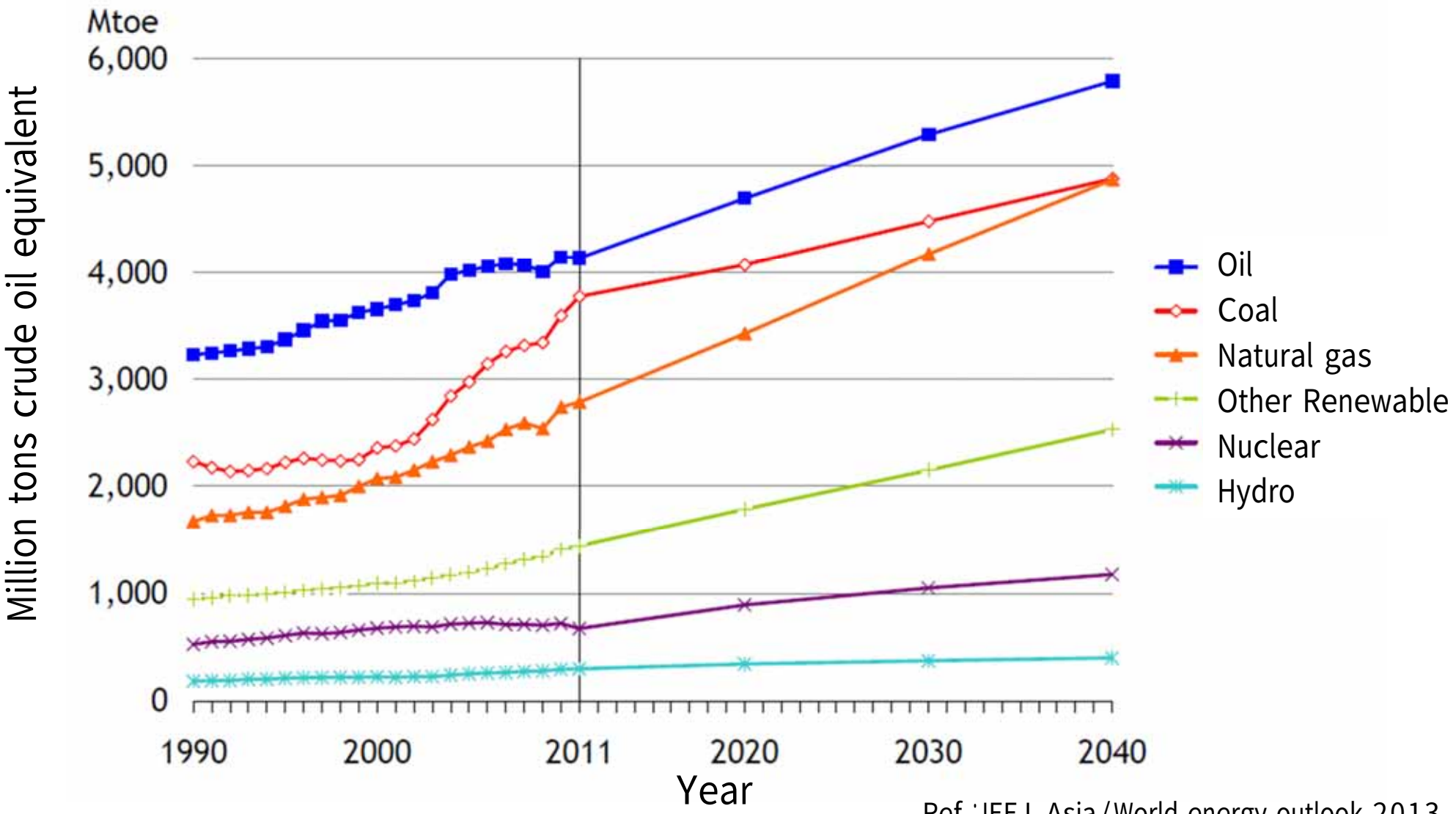
The World Energy Consumption



Ref.：IEEJ, Asia/World energy outlook 2013

Domestic Energy Demand

・Simulation of hydrogen supply

Conditions

・Available supplies of CO_2-free-hydrogen at 25～45 Japanese yen/Nm^3 (CIF: cost insurance and freight)

・Restriction on CO_2 by 2020 : -15%, by 2050 : -80% (As compared to 1990)

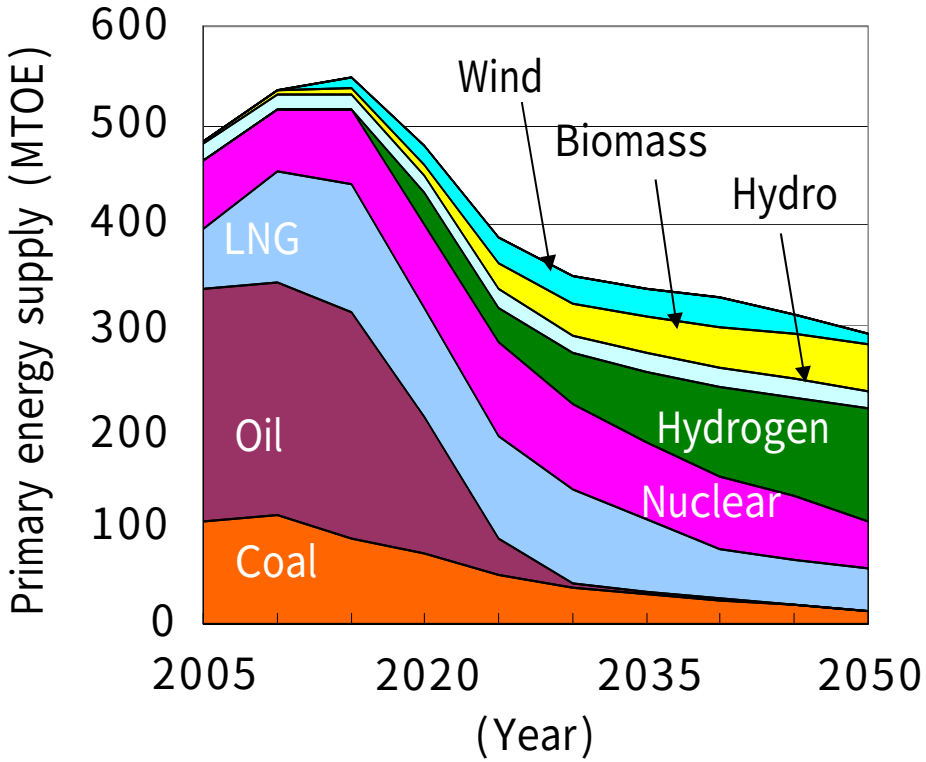
・Difficult to combine with CCS domestically

→ Search for the lowest economic burden on citizens caused by energy supply and CO_2 emission reduction

＊This simulation has been done using the simulator 'GRAPE' by The Institute of Applied Energy.

Future Hydrogen Supply

Prediction of hydrogen supply (primary energy supply)



- In 2020, introduction of hydrogen (hydrogen cost: CIF25 yen/Nm^3)
- Switching to CO_2-free fuels is necessary by 2050
- In 2050, hydrogen demand is more than 20% even if hydrogen costs 45 yen/Nm^3

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Japanese Government Energy Policy

In April 2014, the Japanese Government released the “Strategic Energy Plan”. Hydrogen is expected to play a central role in the future energy system:

- Dissemination of residential use stationary fuel cell
- Introduction and dissemination of Fuel Cell Vehicles (FCV)
- Introduction of hydrogen power generation
- Introduction and dissemination of a large scale production, transportation and storage of hydrogen (derived from unutilized brown coal and other sources)
- Draw up the “Strategic Roadmap for Hydrogen and Fuel Cell”

Strategic Road Map for Hydrogen and Fuel Cell

Expansion of hydrogen use
Phase 1

2015
Release FCV onto the market

2020
Achieving a reduction of hydrogen price to a level equal to or lower than that of fuels for hybrid vehicles

2025
Achieving a reduction of FCV prices to the level of hybrid vehicles

Hydrogen power generation / Large scale hydrogen supply system
Phase 2

Mid 2020s
Introduction of hydrogen from overseas

Around 2030
Production, transportation and storage of hydrogen derived from unutilized energy resources imported from overseas

Zero-carbon emission hydrogen supply system
Phase 3

Around 2040
Zero-carbon emission hydrogen with a CCS process or others

Demand Growth "FCV to Olympic/Paralympics"

"Process gas"⇒"FCV"⇒"Power generation"

Vast demand for hydrogen

Diffusion of power generation and FCV

TOKYO●2020

Tokyo Olympic/Paralympics As "Hydrogen Olympics"

Fuel Cell Vehicles (FCV) Released

【Power generation】

【Transportation】

【Process usage】

2014 2020 2025

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Concepts of CO_2 Free Hydrogen Supply Chain

Australia

Japan

Low-cost hydrogen production from brown coal

Surplus Renewable Energy

Gasification, Refining

H_2

Liquefaction & Storage

CO_2

Brown Coal

CO_2 Capture Storage (CCS)

CO_2 free H_2

Liquefied Hydrogen Carriers

Liquefied Hydrogen Container

Liquefied Hydrogen Storage Tanks

Use in processes
Semiconductor, solar cell productions
oil refining and desulfurization

Transportation equipment

Refueling station
Fuel cell vehicles

Distributed power generation

Hydrogen gas turbines and engines, fuel cells etc.

Power plants

Combined cycle power plants

Hydrogen Production

Transport & Storage

Utilization

Brown Coal

- Brown coal is a fossil fuel with vast deposit, younger than black coal
- High moisture (50%-60%)
- Difficult to transport due to its spontaneous ignition
- Locally used for coal thermal power generation

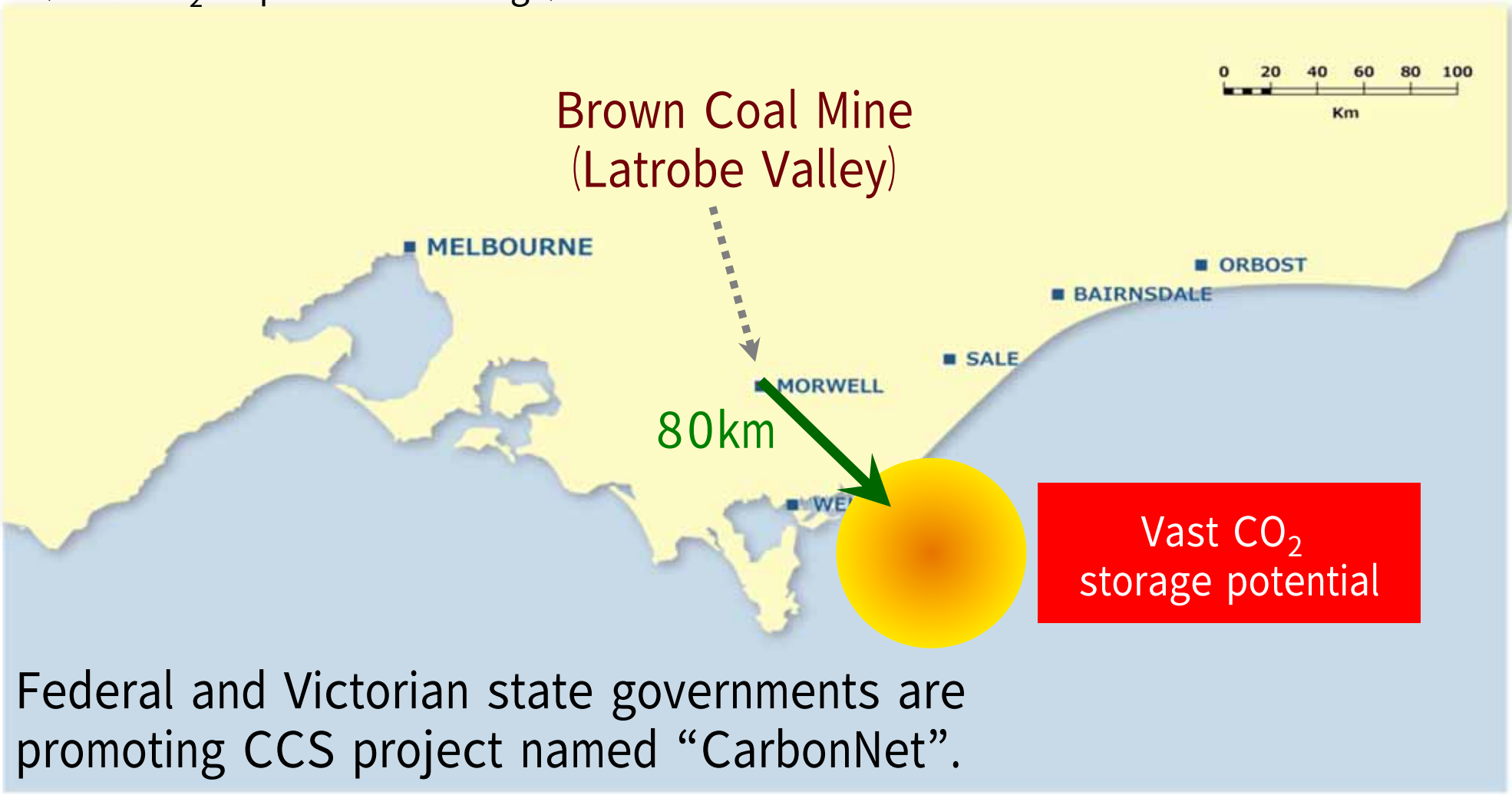
- NO transport makes no trade meaning mining right only “abandoned”, “cheep” and “easy interests” resource.
- Accordingly, hydrogen production from brown coal is one of the most economic schemes.

Australian Brown Coal

Brown coal field to horizon line.
One layer from surface to 250m depth and further underneath.
(Corresponding 240 years of Japans gross generation)

CCS: CO_2 Storage Location

(CCS：CO_2 Capture and Storage)



Federal and Victorian state governments are promoting CCS project named “CarbonNet”.

Liquefied Hydrogen for Mass Transport

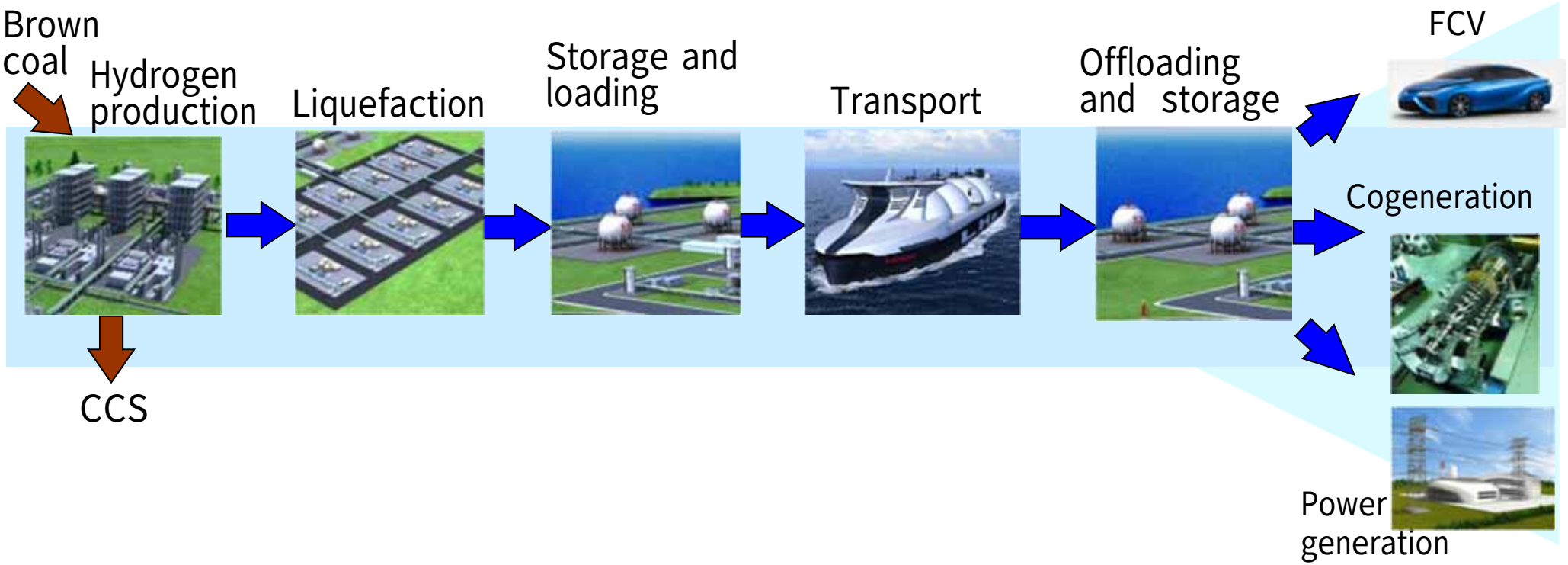
Feature of liquefied hydrogen

- Very low temperature : boiling point at -253°C
- Volume : 1/800 of gaseous states
- Already implemented transportation medium for process usage and space rocket fuel.
- High purity = no need for refinement (readily usable for fuel cell after vaporization)

Storage tanks largest in Japan
(Tanegashima rocket launch base)

LNG carrier ship
(mass energy transport)

Feasibility Study on Commercial Supply Chain



- Ingredient of hydrogen : Victorian brown coal
- Coproduced CO_2 disposal : locally sequestrated ⇒ CO_2 free
- Hydrogen production : 770t/day corresponding fuel for 3 million FCVs or 1GW power station

Cost Evaluation of Feasibility Study(FS)

CIF (Cost Insurance and Freight)
= 29.8yen/Nm^3 (1.96 NOK/Nm^3)

Carrier	9%
Loading base	11%
Liquefaction	33%
Hydrogen pipeline	1%
Production	29%
CO_2 storage	10%
Brown coal	8%

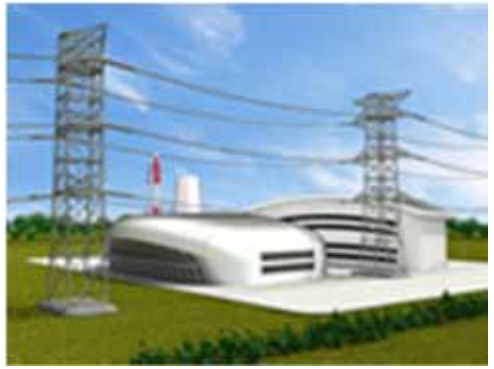
【Scale】

3 million FCVs or 1GW power station

Items above production use Japanese technologies and products

⇒ Half of the consideration returns to Japan

FCV

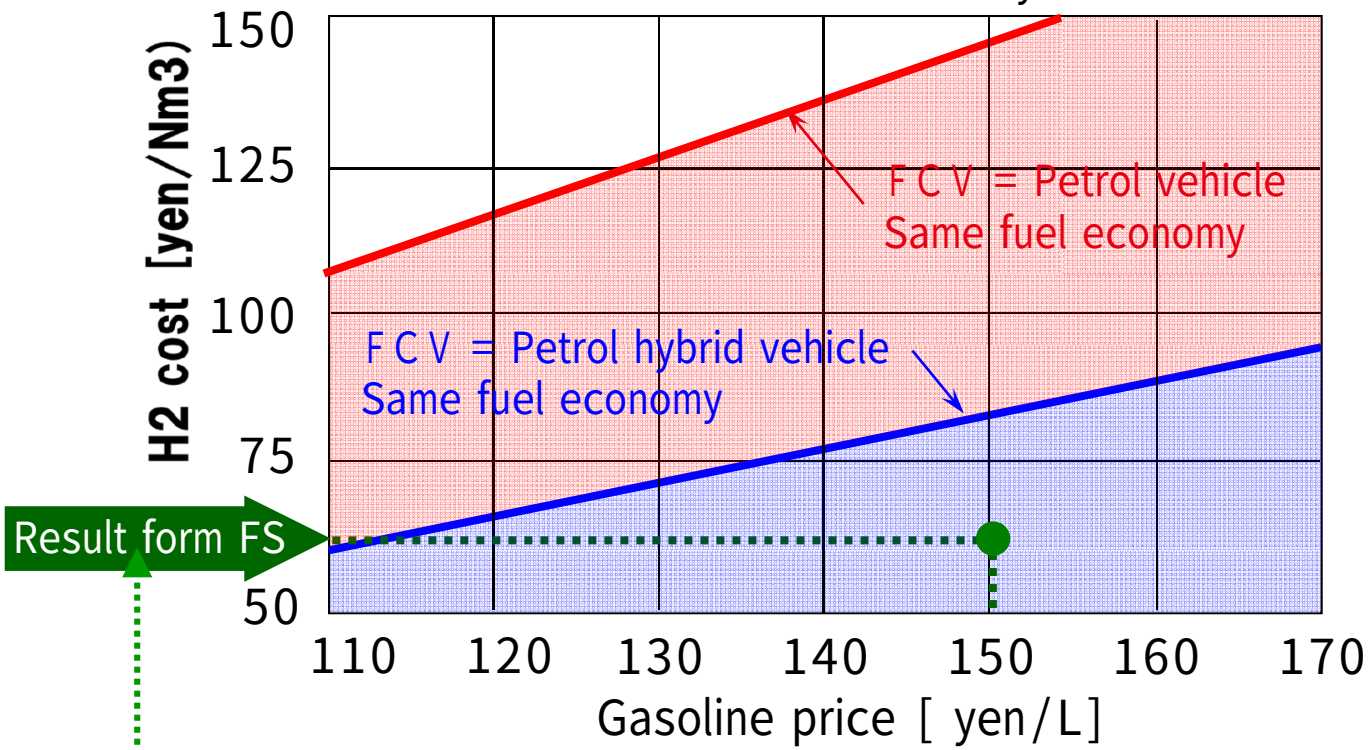


Hydrogen power station

Comparison of Fuel Economy; FCV vs Existing

Hydrogen fuel provides benefit to the present petroleum price.
Further benefit is expected if petroleum price goes up in the future.

Cited from Toyota's material



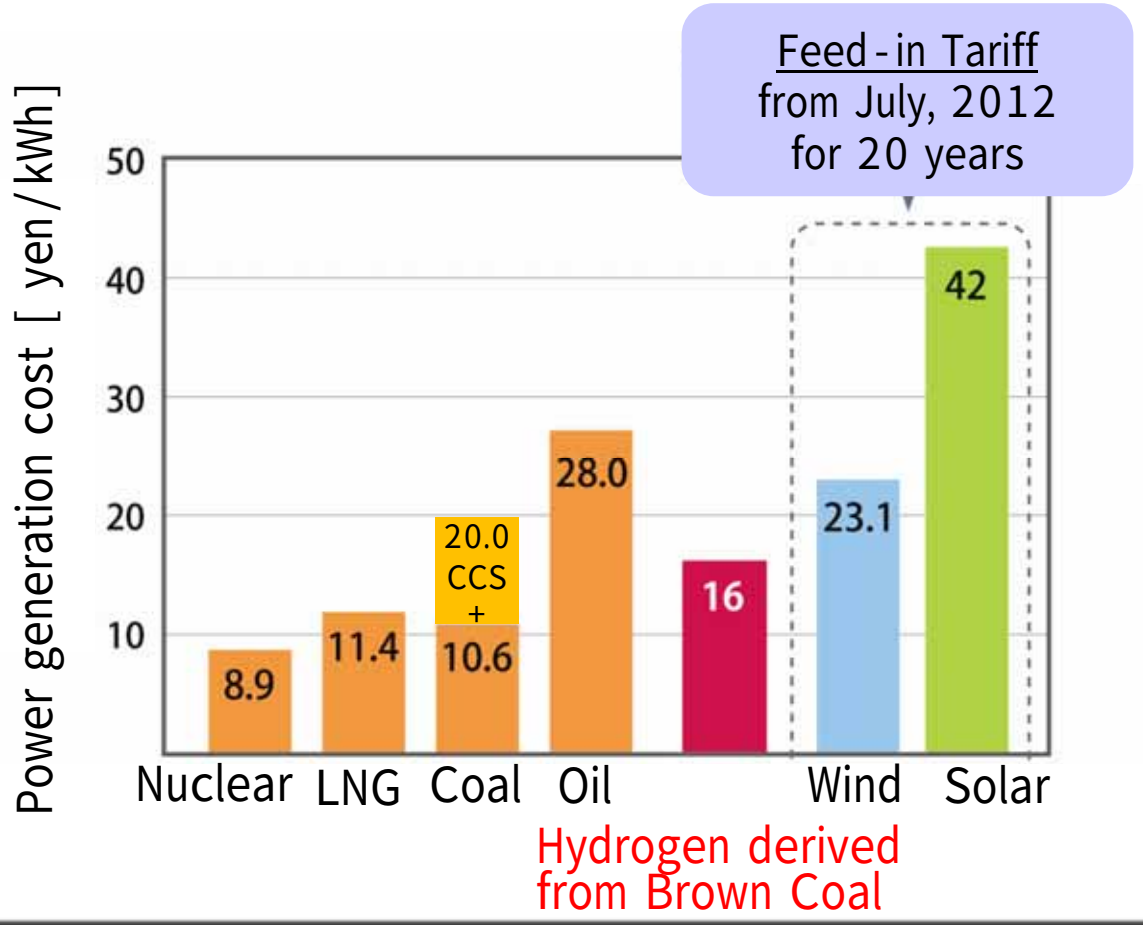
FCV's
Well to Wheel
CO_2 emission
=5.8 g/km,
when hydrogen of
this FS used

Cost at refueling station = H_2 CIF: \30 + Onshore cost: \30 = 60\/Nm³ = 680\/kg (45NOK/kg)

Comparison of Unit Cost of Power Generations

Most cheap among CO_2 free energies, though more expensive than the fossil and nuclear powers.

Cheaper, more stable and vast as compared to the renewables.



Concept of Mass Hydrogen Introduction

Refueling station

FCV

Industrial demand
(Cogeneration, furnace)

Fuel cell Hydrogen GT/GE

Hydrogen reduction iron-making

Oil refining desulfurization

Low cost CO_2 free hydrogen

Mass supply

Hydrogen production from fossil energy

Renewable Energy Hydrogen (future shift)

Mass demand

Hydrogen power generation

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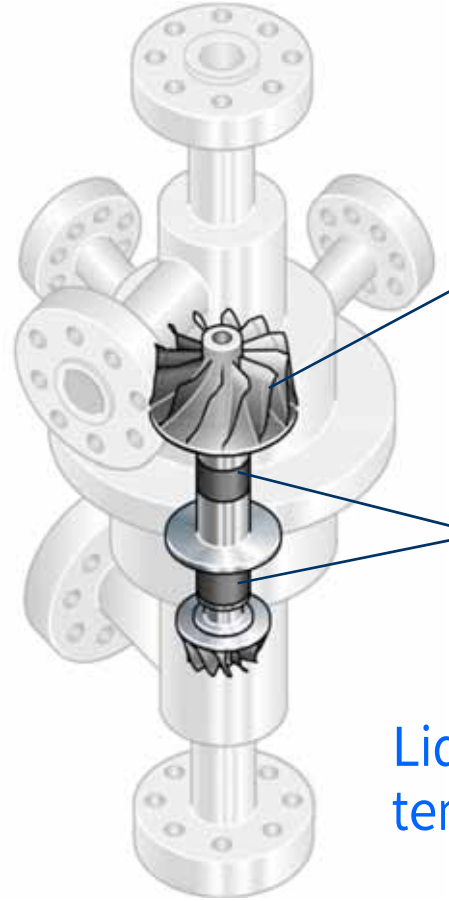
Hydrogen Liquefaction

Production ➡ Trans./store. ➡ Utilization

Original key hard, expansion turbine, realizes hydrogen liquefaction system



- Very high revolution
- Hydrogen gas bearing

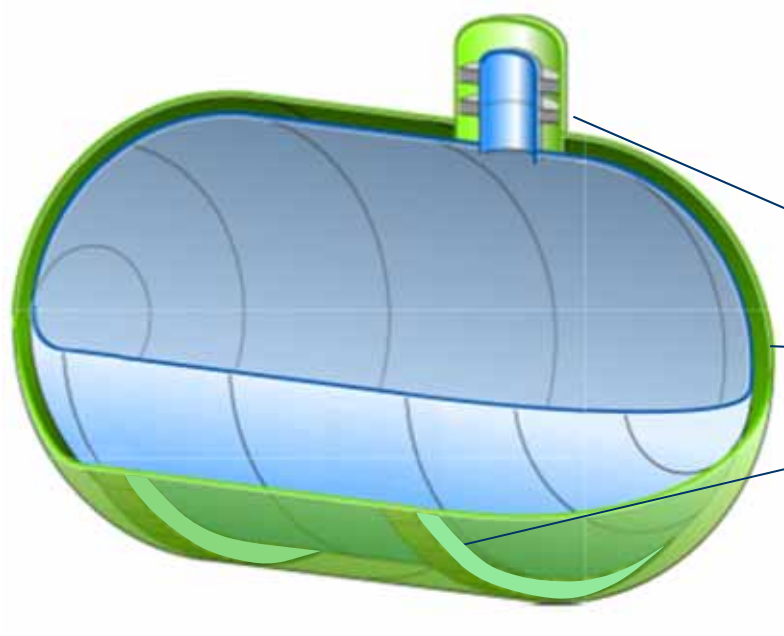
Liquefaction temperature：-253℃

Liquefied Hydrogen Carrier Ship

For realization of the world first liquefied hydrogen carrier ship

Production → Trans./store. → Utilization

2500m^3 freight pilot ship



Cargo tank

- Unique dome structure to keep vacuum
- Vacuum dual shell with stainless steel
- Highly insulated support structure

Approval in principal is provided from ClassNK

Storage of Liquefied Hydrogen

Production → Trans./store. → Utilization

Liquefied hydrogen tank

Specifications	
Type	Spherical double-shelled tank
Volume	540m^3
Pressure	0.686MPa + vacuum
Temperature	-253°C
Thermal Insulation	Vacuum perlite powder insulation

Boil off rate: 0.18%/day

Onshore Transport of Liquefied Hydrogen

Production → Trans./store. → Utilization

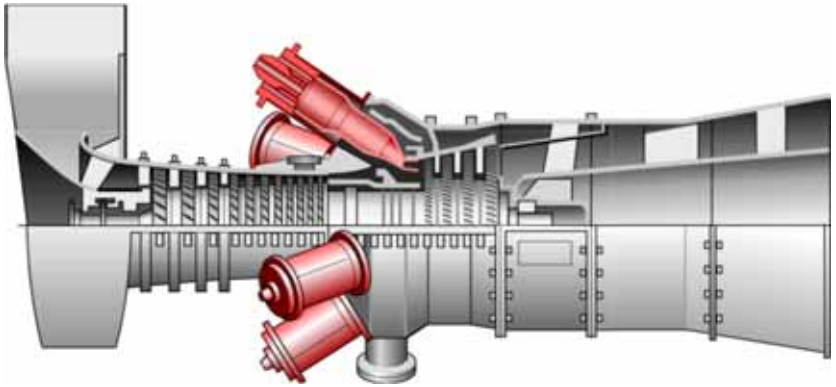
Liquid hydrogen container truck

Specifications	
Type	ISO 40ft-type container
Volume	45.6m^3
Liquid H2 Load Capacity	2.9 tons
Thermal Insulation	Vacuum multilayer insulation
Auxiliary	Evaporator for pressurized gas

Hydrogen Gas Turbine Generator

Production → Trans./store. → Utilization

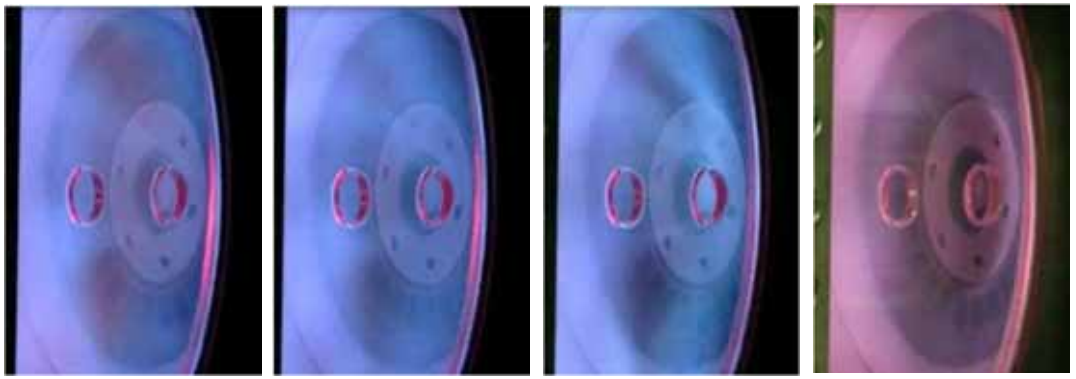
Combustion technologies being developed



Key hard : combustor

Hydrogen burner

- Original burner attains stable combustion and suppression of NOx emission
- Fuel flexible with hydrogen and natural gas



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Progress of Hydrogen Project

Technologies of Kawasaki

2014 "Strategic Energy Plan"

2020 TOKYO 2020 Tokyo Olympic/Paralympic

2025

LNG

Liquefied Hydrogen

Pilot Chain

Commercial Chain

Feasibility Study on Pilot Chain(10t/day)

Hydrogen production plant from brown coal

Loading base

2500m³ Liquefied hydrogen carrier ship

Conceptual design is completed

Capital cost is roughly estimated

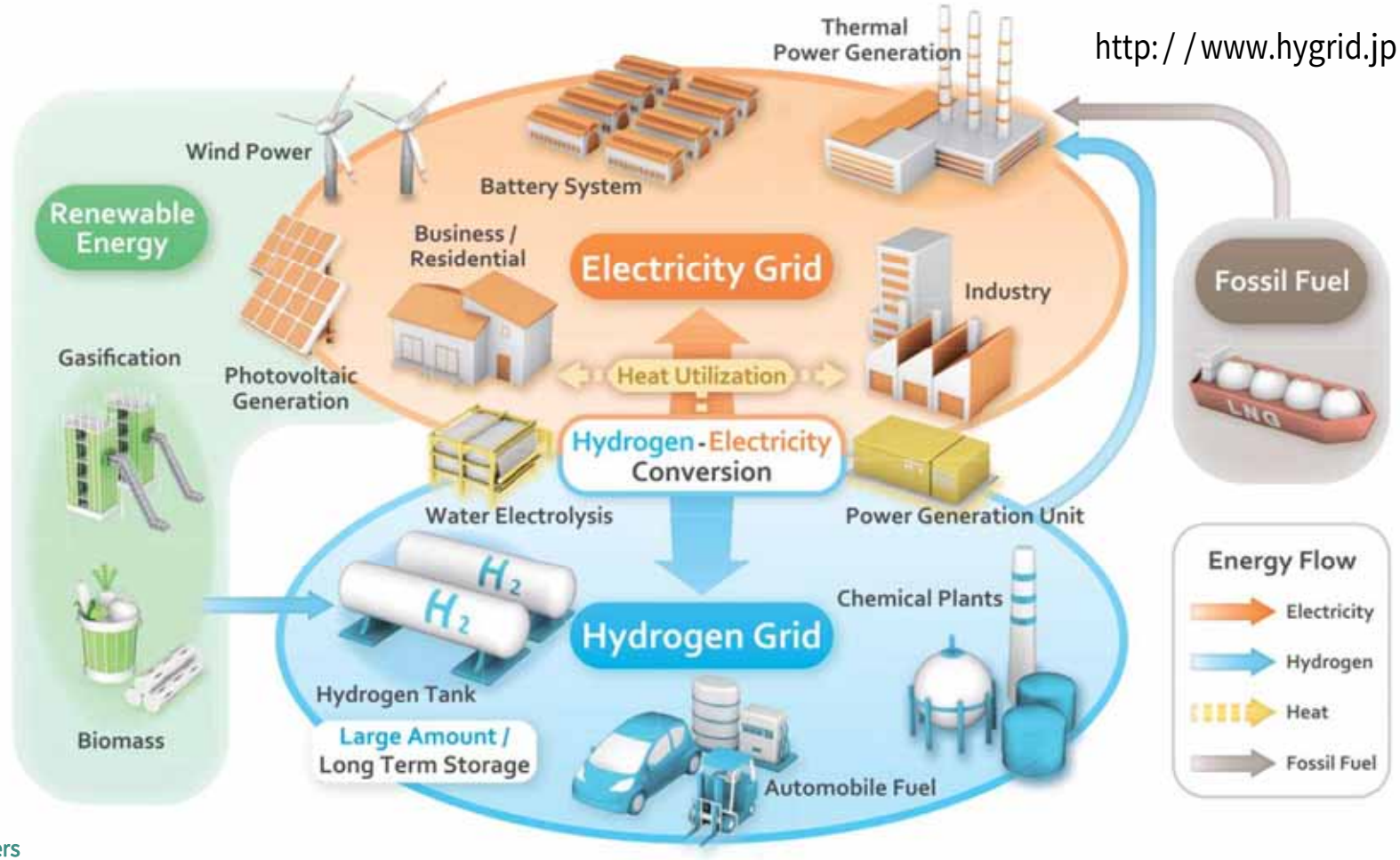
→ Move onto basic design

Cargo containment system of pilot-scale liquefied hydrogen carrier ship is provided world first approval in principal

“HyGrid” Society for The Study on Smart Energy

Society comprised of diversified energies via electricity and hydrogen

http://www.hygrid.jp/index_E.html

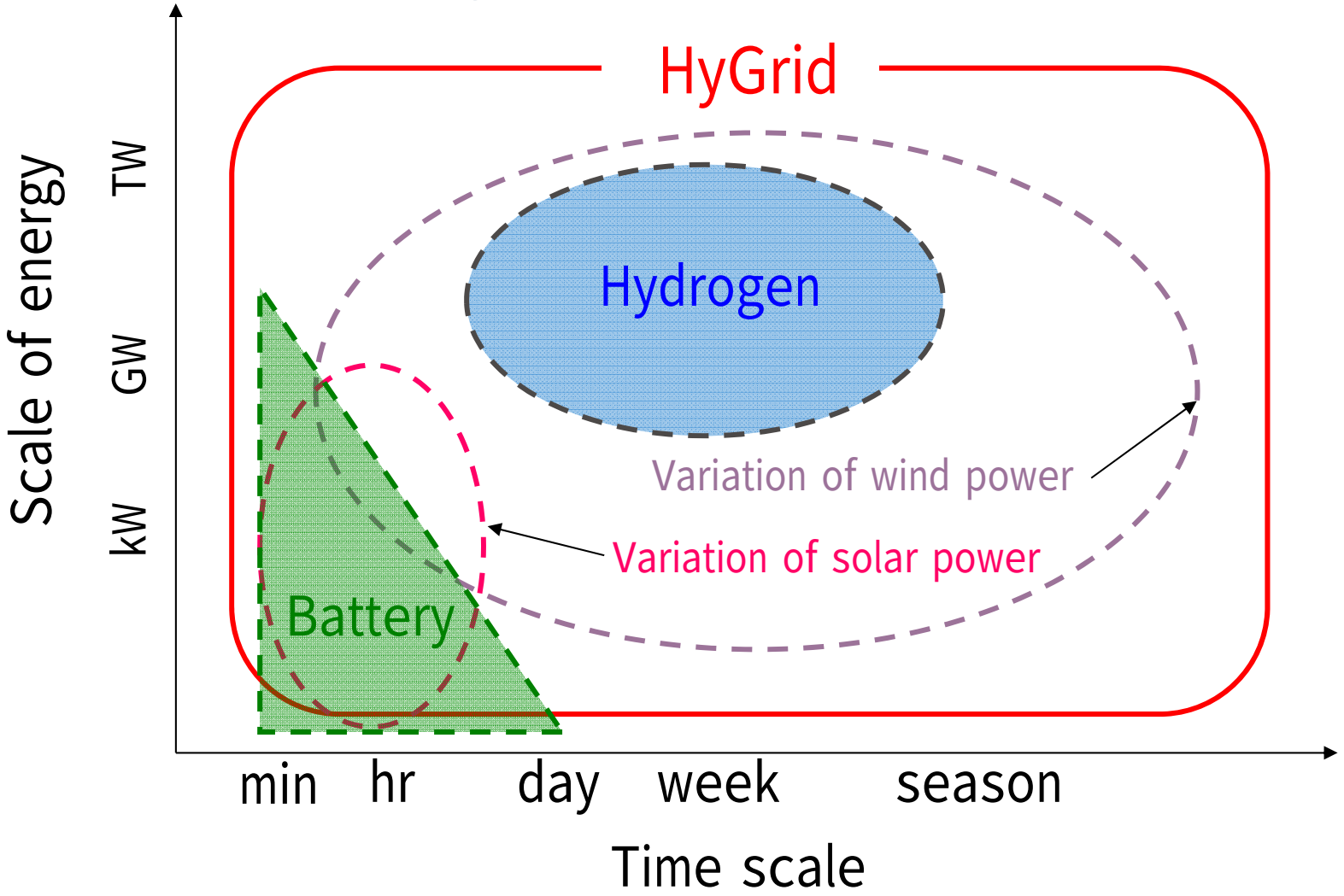


◆Members

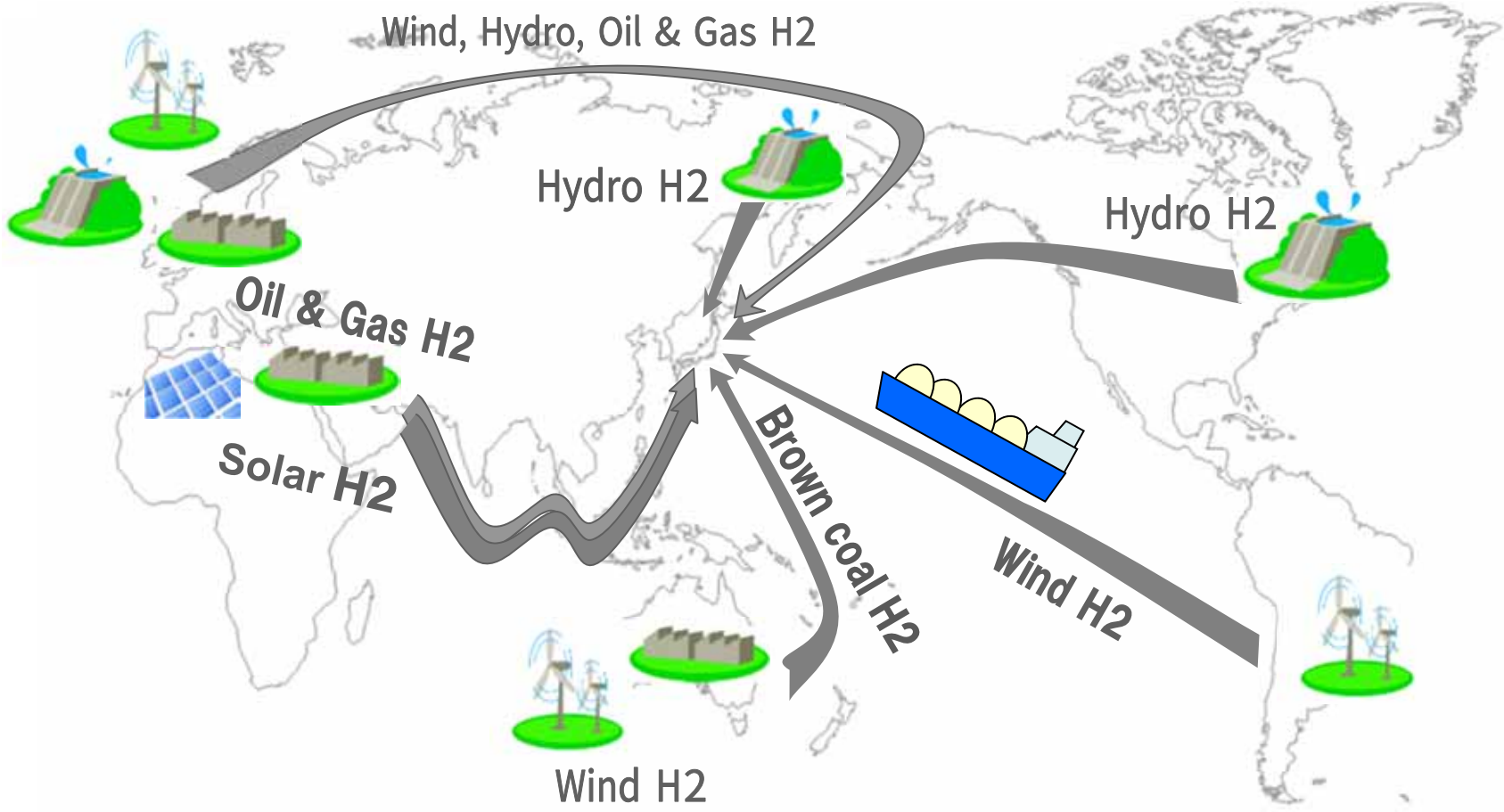
Iwatani corp., Kawasaki Heavy Industries, Ltd.(chair), International Institute for Carbon-Neutral Energy Research (I2CNER), Research Institute for Systems Technology , Technova Inc.(secretariat), Toyota Motor Corporation, Toyota Tsusho corp., Nissan Motor Co., Ltd., Honda R&D Co., Ltd., Mitsui & Co., Ltd., Roland Berger Strategy Consultants. (As of Dec., 2013)

Aim of HyGrid

Compensate large fluctuation of renewable energies



Hydrogen Potential from Overseas



Impact of CO_2 Free Hydrogen Supply Chain

①Stable Supply

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

→ Contribute energy security (Australian brown coal corresponds 240 years of gross generation in Japan)

②Environment

・No CO_2 emission when used (Only water is emitted)

→"Ultimate clean energy"

③Increase Industrial Competitiveness

・Wide use of hydrogen brings Industrial growth

→ Deployment of Infrastructure export.

・For resource rich countries, hydrogen production started from fossil fuel gradually shifted to the renewables. → Sustainability!

Thank you for your attention

Create new value - for a better environment and a brighter future for generations to come

"Global Kawasaki"

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