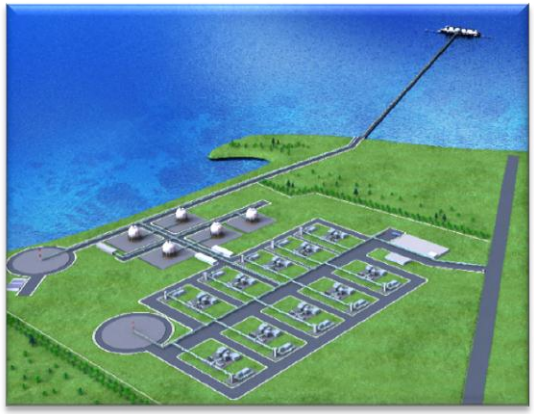
CO2 Free Energy Supply Chain to Japan with Liquid Hydrogen



June, 26th, 2014

Kawasaki Heavy Industries, Ltd.

Kawasaki

Contents

1. Concept of Hydrogen Energy Supply Chain (HESC)
2. Commercial-scale chain
3. Pilot-scale chain
4. Status of Development

Why Hydrogen?

Background

Fossil fuel costs increase with carbon taxes and emissions trading, creating an advantageous situation for low CO_2 fuels.

Need for low CO_2 energies in the world

1. **Nuclear energy** **(Difficulties in Japan)**
2. **Renewable energy** **(Limited in Japan)**
3. **Hydrogen energy from fossil fuels in combination with CCS (CO2 Capture and Storage)**

Future Demand for Hydrogen

・Simulation of hydrogen supply

Review conditions

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

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

・Nuclear power: Up to 50% of total nuclear output

・Up to 15% of Renewable energy（solar &wind) individually

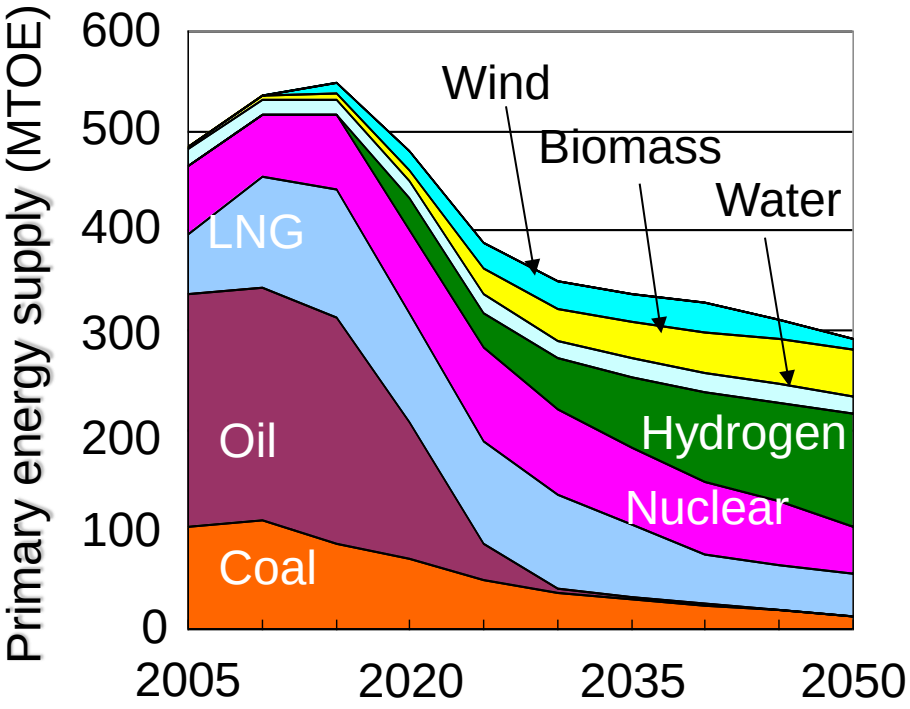
・Difficult to combine with CCS internally

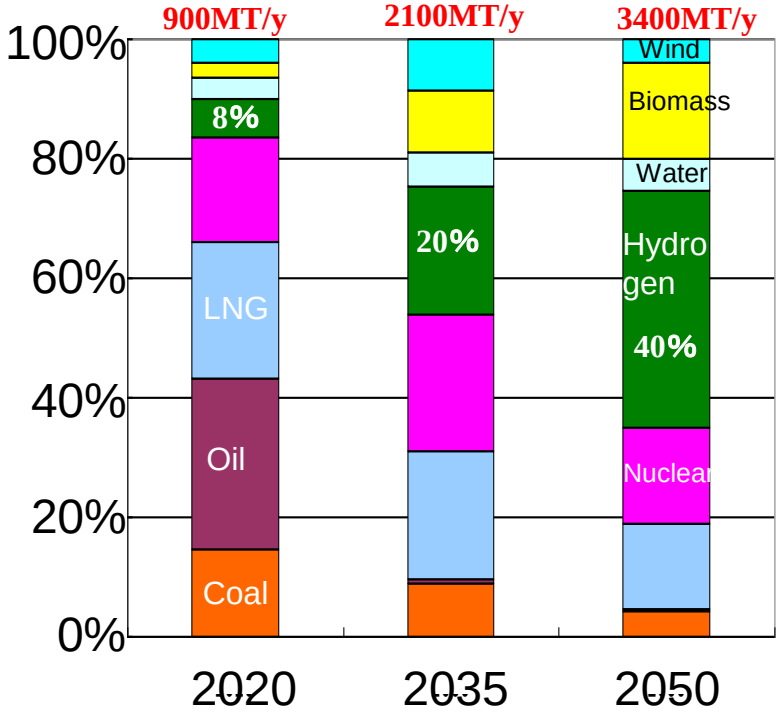
→Calculation of the lowest percentage of strain on citizens caused by energy supply

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

Future Hydrogen Supply

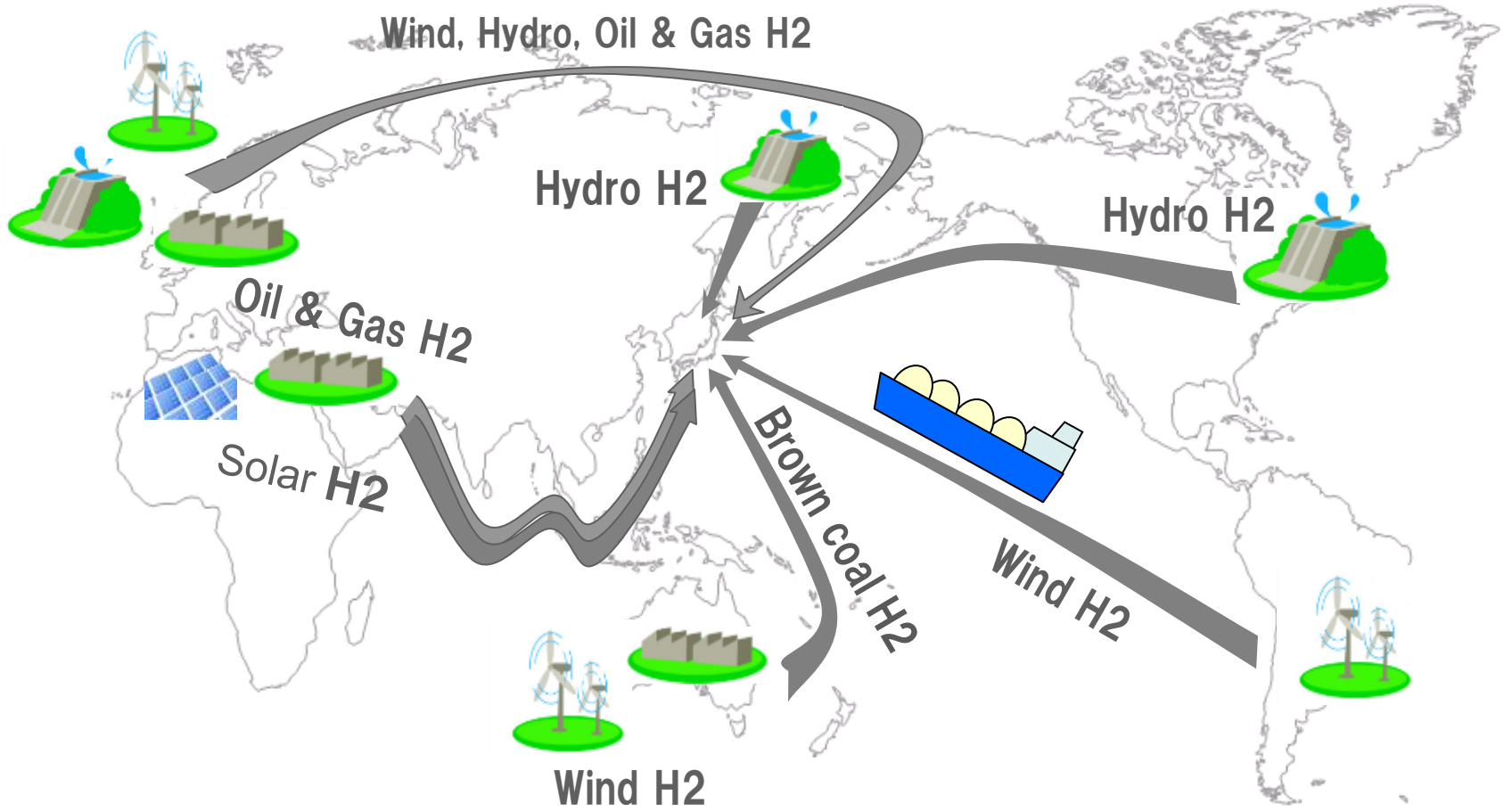
Prediction of hydrogen supply（primary energy supply）





- In 2020 introduction of hydrogen（hydrogen cost: CIF25 yen/Nm^3）
- Switching to CO_2-free fuels is necessary by 2050
- This switch is necessary even if the hydrogen cost is 35 yen /Nm^3 or 45 yen/Nm^3
- Supply for power generation is introduced earlier than that for heat

Hydrogen Potential from Overseas



Hydrogen Energy Supply Chain Concept (HESC)

Australia

Low-cost hydrogen production from unused resources (brown coal)

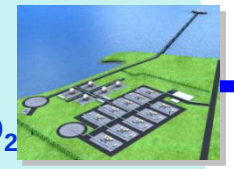
Brown coal

Gasification & Purification

Low CO_2 H_2

CO_2

CCS



Liquefied hydrogen storage

Hydrogen Production

Liquefied hydrogen carriers

Hydrogen Transport and Storage

Liquefied hydrogen trucks

Liquefied hydrogen tanks

Japan

Use in processes
Semiconductor and solar cell production, oil refining and desulfurization, etc.

Power plants
Combined cycle power plants, etc.

Energy equipment

Hydrogen gas engines, gas turbines, boilers, fuel cells, etc.

Transportation equipment

Hydrogen station, Fuel cell vehicles, etc.

Hydrogen Use

KHI's Technology Backgrounds

Australia

Hydrogen Production

Low-cost hydrogen production
from unused resources (brown coal)

Gasification

Brown coal

Hydrogen purification

Liquid hydrogen storage tanks

Hydrogen Transport and Storage

Hydrogen carriers

Hydrogen lorries

Japan

Hydrogen Use

Use in processes
Semiconductor and solar cell production, oil refining and desulfurization, etc.

Power plants
Combined cycle power plants, etc.

Energy equipment
Hydrogen gas engines, gas turbines, boilers, fuel cells, etc.

Transportation equipment
Hydrogen station, cars, etc.


Gasifier

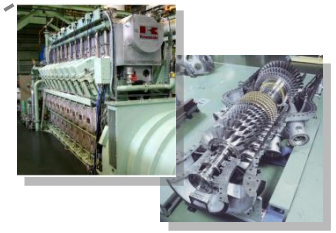

Fertilizer plant


LNG base


Liquid hydrogen tank
(Rocket launch system)


LNG carrier


Hydrogen lorry & container


Gas engine
Gas turbine


LNG power plant

Kawasaki Technologies

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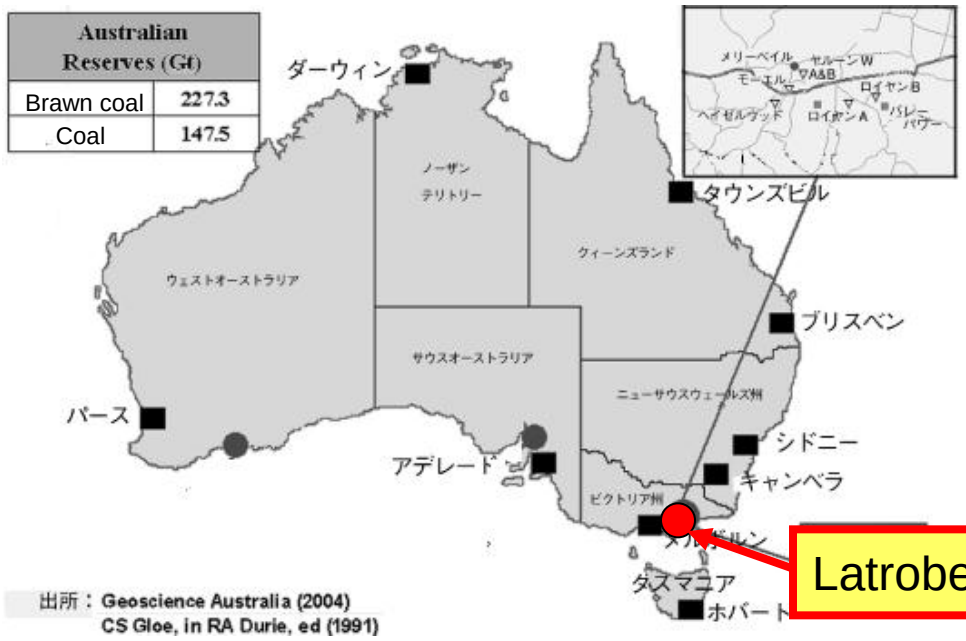
Direct Applications

Improvement & Development

Distribution of Australian Brown Coal

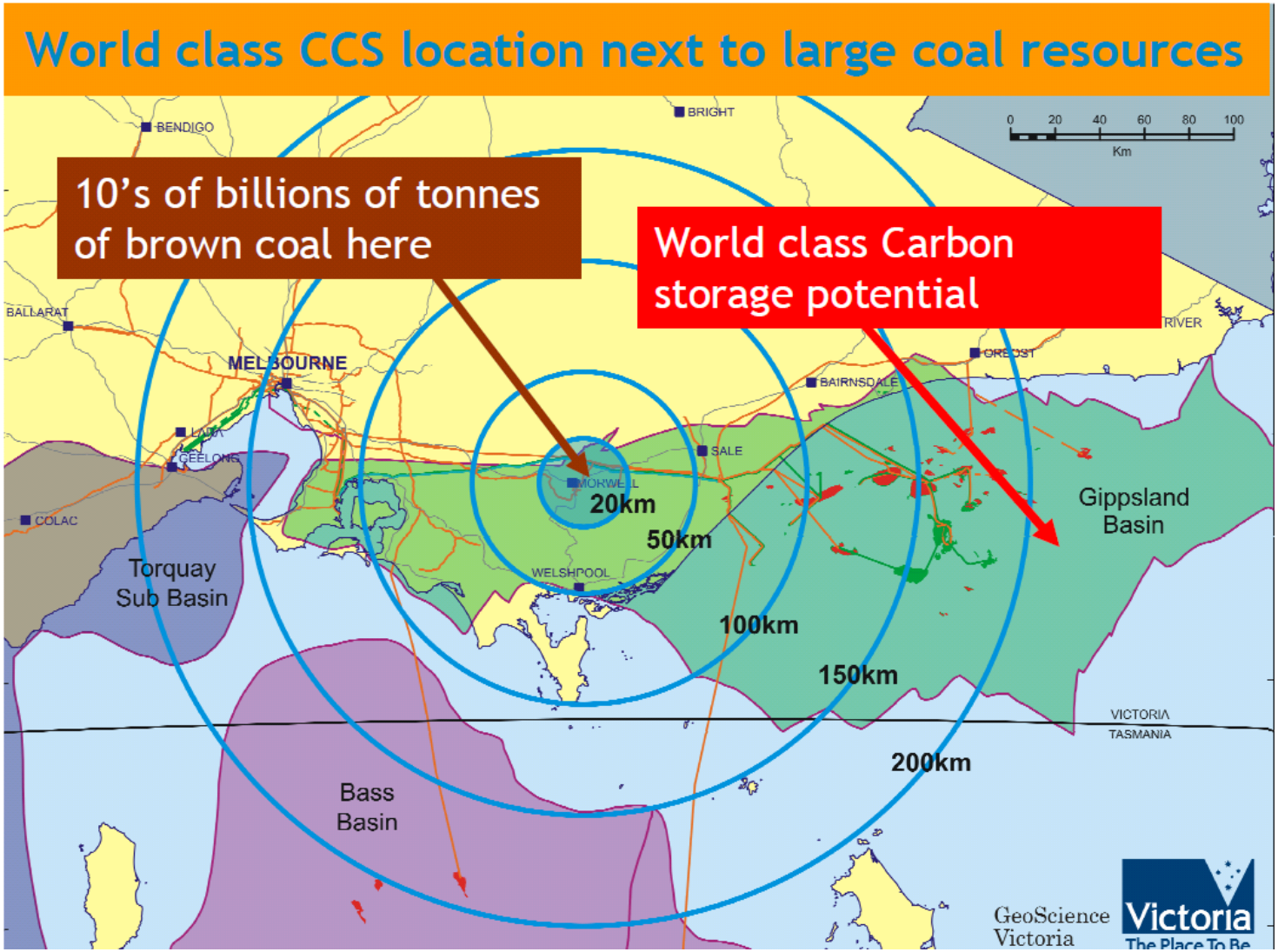
Australian Reserves (Gt)	
Brawn coal	227.3
Coal	147.5



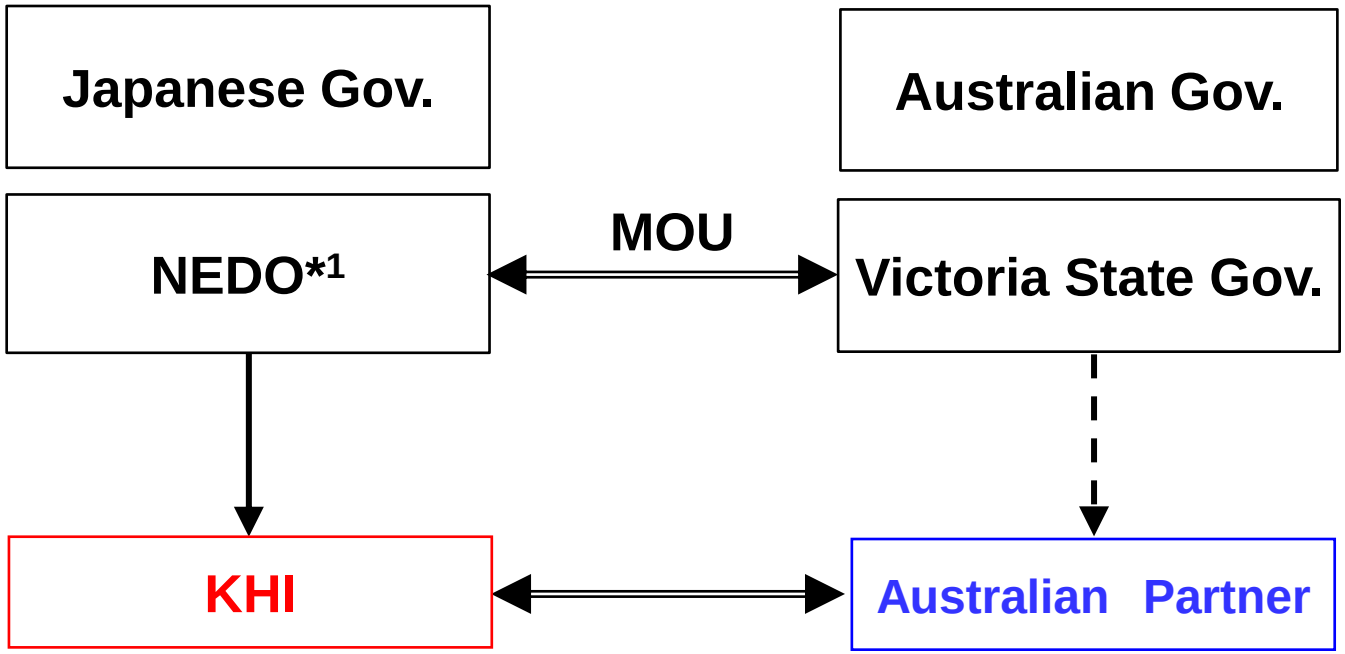
出所：Geoscience Australia (2004)
CS Gloe, in RA Durie, ed (1991)

Open-cast brown coal mining site

Australian Brown Coal Prospect and CO_2 Storage Location



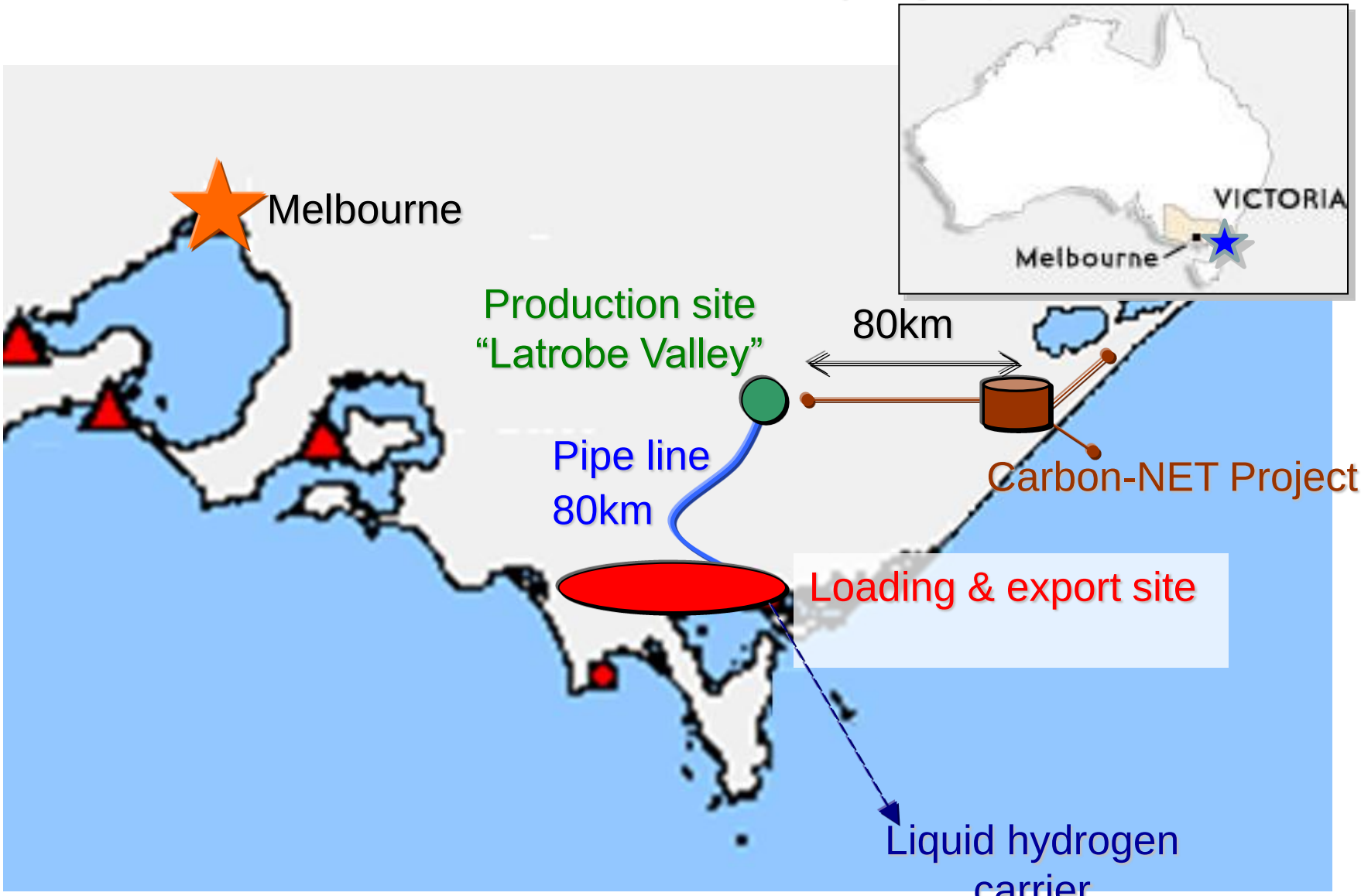
Scheme of Feasibility Study (FS)
（Japan-Australia International Joint Study）



***1: Feasibility Study (FS) was conducted under the support of New Energy and Industrial Technology Development Organization (NEDO)**

Overview of Commercial Chain

Review of technical formation and calculation of hydrogen production cost



F/S Result of Hydrogen Production Plant

Brown coal:	**14,200 t/day**	**4,700,000 t/year (assumed 60% water content coal)**
Hydrogen:	**770 t/day**	**246,000 t/year**
CO_2 :	**13,300 t/day**	**4,400,000 t/year**

F/S Result of Hydrogen Loading Base and LH_2 Carrier

Hydrogen liquefaction

Capacity:770 t/day

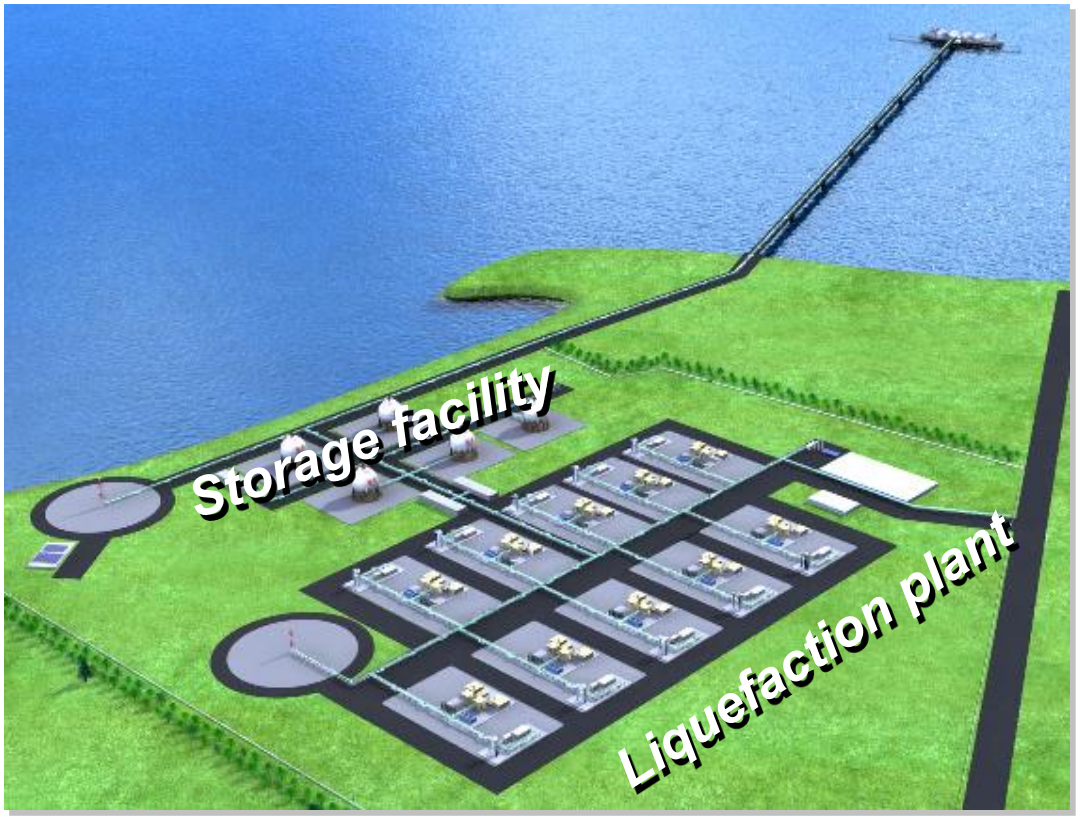
Hydrogen storage facility

50,000 m^3 x 5 tanks

LH_2 carrier (2 ships)

Loading Hydrogen : 238,500 t/year

Cargo tank : 40,000m^3x 4 tanks

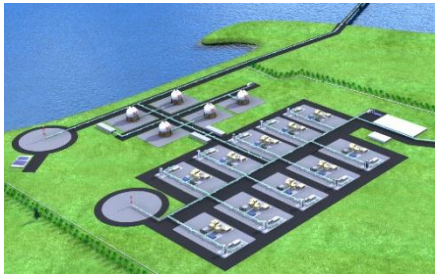


F/S Result of Delivered Hydrogen Cost

CIF (Cost Insurance and Freight)
=29.8 yen/Nm³

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

Loading quantity: 238,500 t/year



Delivered hydrogen quantity
225,400 t/year

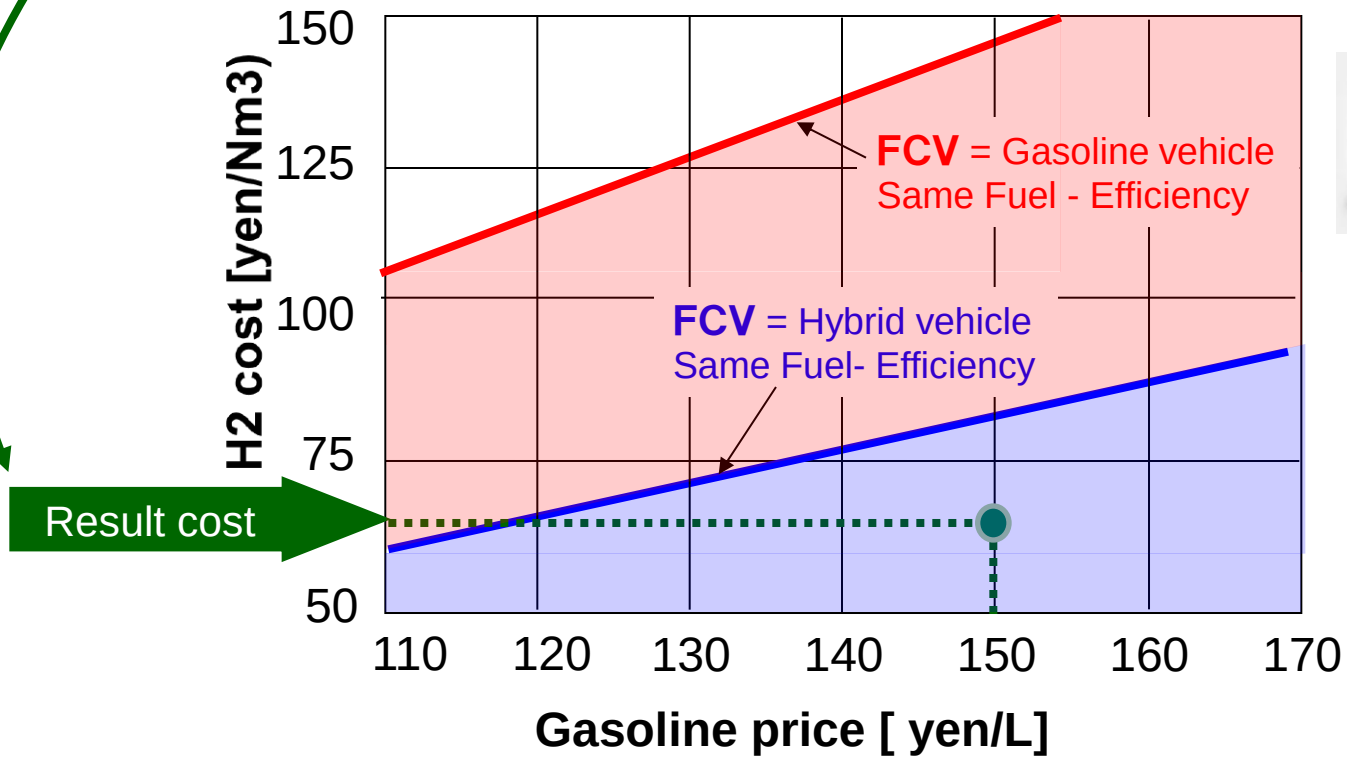
FCV (Fuel Cell Vehicle) : 3 million

Hydrogen power plant : 650 MW

Evaluation of FCV use in Japan

Hydrogen filling station price [yen/Nm3]

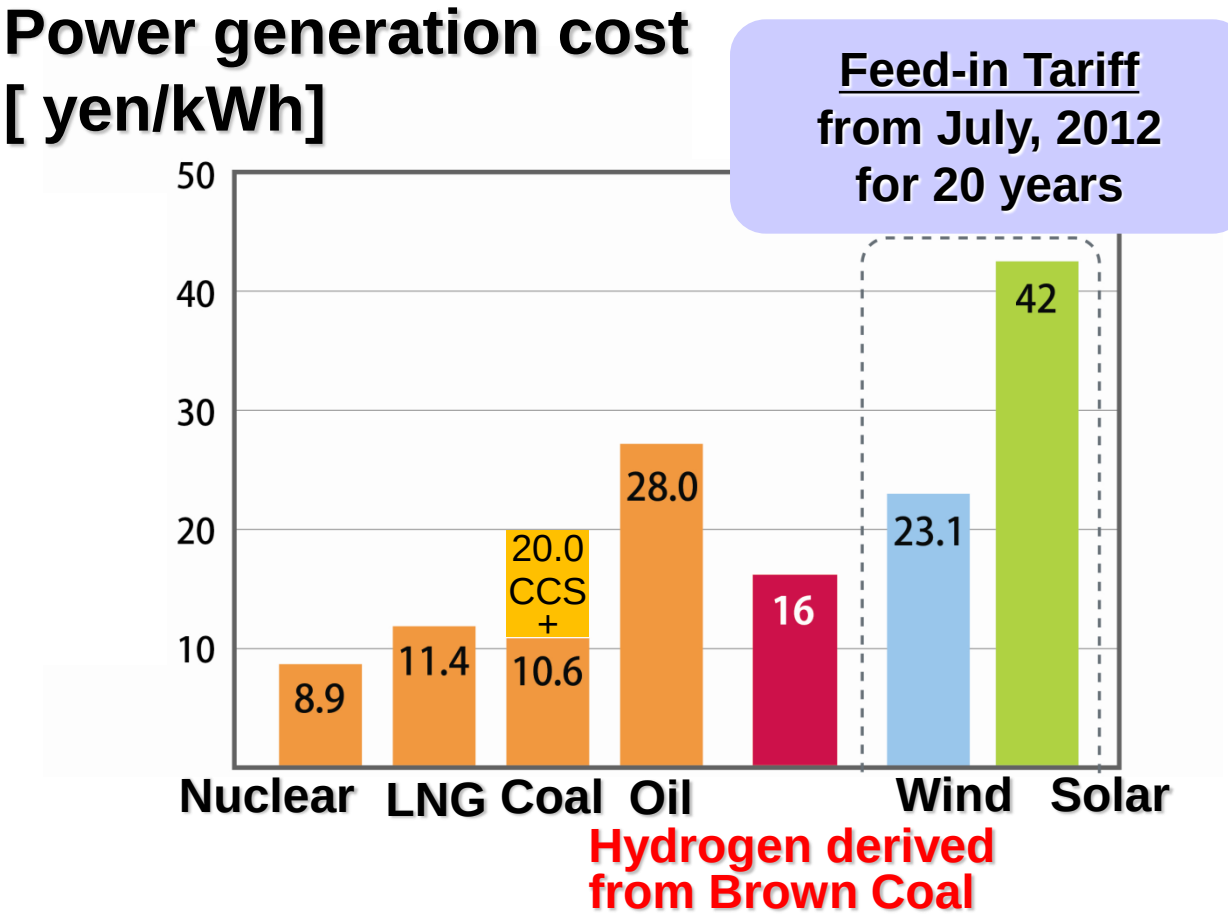
Filling station cost = CIF cost + 30 yen/Nm3 = 60 yen/Nm3



Well to Wheel CO_2 emission =5.8 g/km

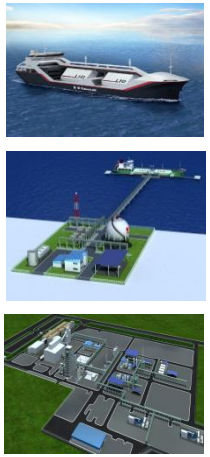
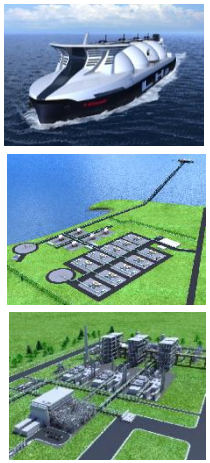
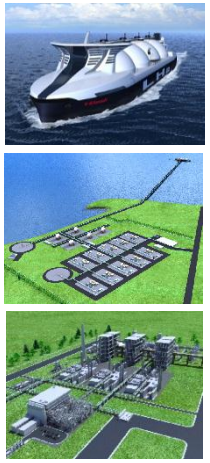
In fuel economy, FCV is more competitive than Hybrid vehicle.

Evaluation of Power Generation in Japan



Result cost is more competitive than wind and solar.

Hydrogen Power Generation in the Future

	Pilot	Commercial Demo. 2 Ships (p.15)	40 Ships	80 Ships
	10t/day H2	770t/day H2	15,400t/day H2	30,800t/day H2
				
Yen/Nm³:CIF	Technical Demo.	30Yen/Nm³	24Yen/Nm³	18Yen/Nm³
H2 supply	2,000t/year	225,000t/year	4,500,000t/year	9,000,000t/year
Power generation	7MW	650MW	13,000MW	26,000MW
Cost of Electricity		16Yen/kWh	14Yen/kWh	11Yen/kWh
Portion in Power in Japan ≒ CO2Reduction		0.5% 3,000,000t	10% 60,000,000t	20% 120,000,000t

Features of CO_2Free Hydrogen Chain

- **Production of hydrogen from reserved fossil fuel**
  → Possible to produce on a large-scale and ensure security
- **CO_2 emitted by producing hydrogen is locally separated and stored.**
  → Environmentally friendly
- **Requires for technical knowledge of using hydrogen**
  → Increase in industrial competing power
- **Requires no purchase of expensive natural resource**
  → Control leakage of natural wealth

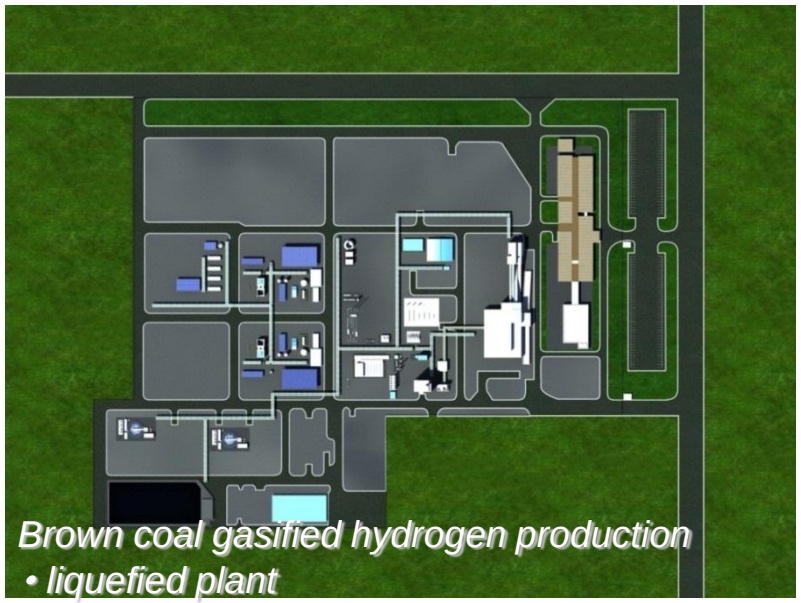
※Meets the required energy condition in the future

Next step

- **It was found that commercial-scale HESC is technically and economically feasible.**
- **However, before commercialization, technical demonstration, safety verification and demonstration of stable operation to potential investors are necessary with pilot-scale HESC.**

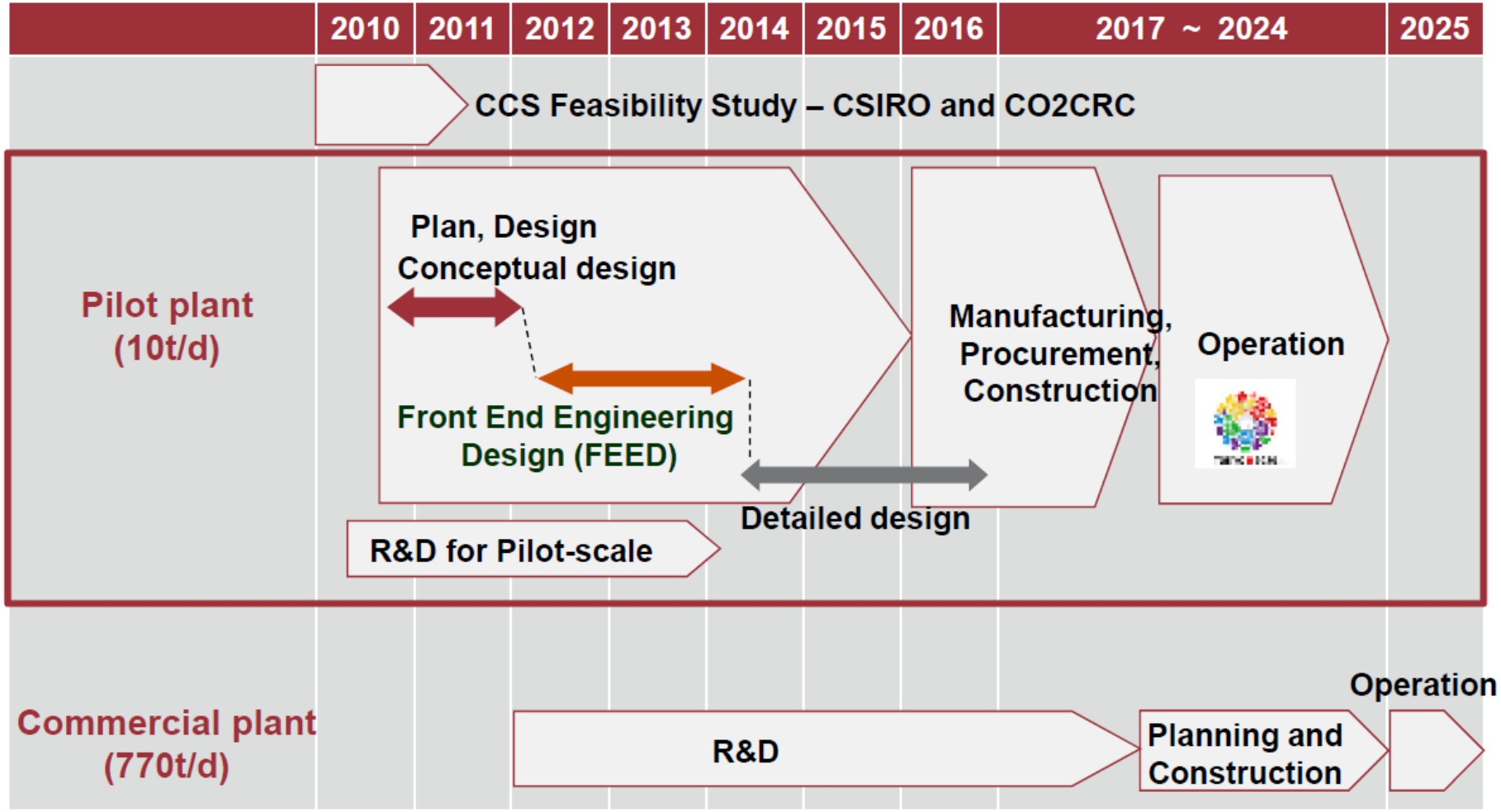
Then as a next step, conceptual design of pilot-scale HESC has been conducted.

Pilot Chain (10t/d) Conceptual Design

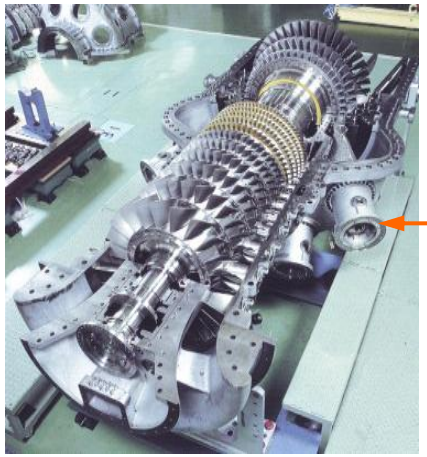


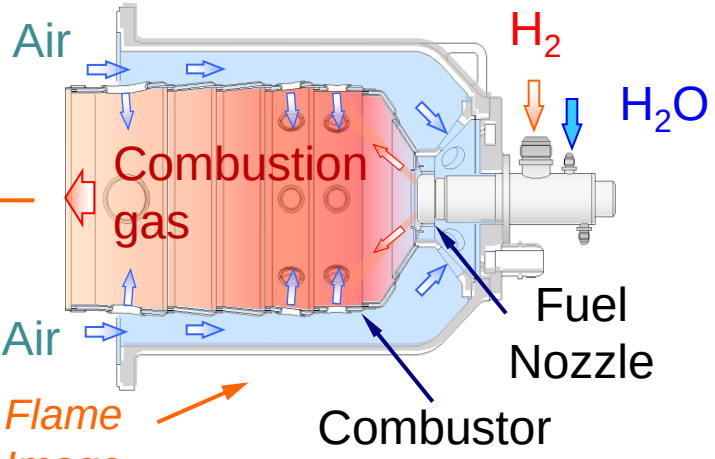
Pilot chain is under front end engineering and design(FEESD)
The small scale LH2 carrier was provided world first AiP from Class NK.
AiP : Approval in Principle

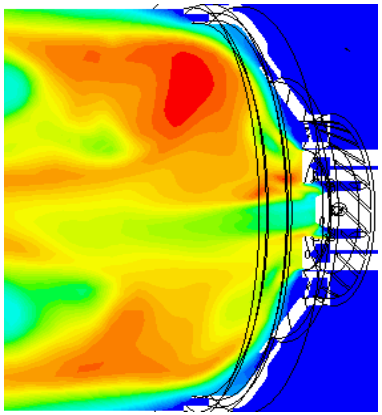
Grand schedule of the project



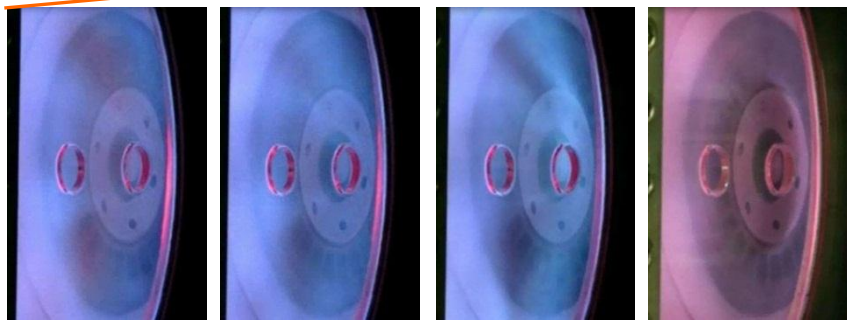
H2/NG Flexible Fuel Gas Turbine





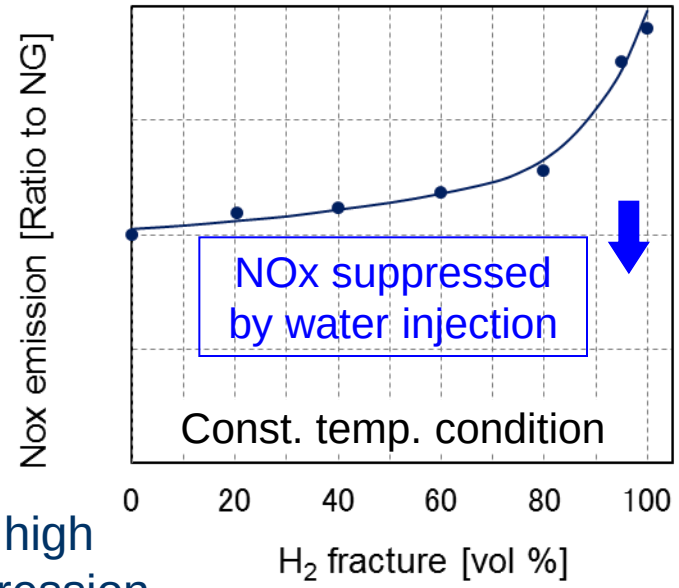


CAE with CFD



NG	100%	60%	20%	--- %
H_2	--- %	40%	80%	100%

Pure H_2



Issue: Flame temperature and velocity of hydrogen high
⇒ Protection from burnout and NOx emission suppression

High Pressure Gas Trailer

45MPa bottles made with carbon fiber composite material

2012 NEDO corporative task with HySUT and JX Nippon Oil & Energy

Specifications of trailer	
Length※	10,260mm
Width	2,500mm
Height	3,500mm
Weight※	19,310kg
Number of bottles	24
H_2 capacity	260kg

Specifications of 45MPa bottle	
Length	3,025mm
Dia.	436mm
Weight	220kg
Pressure	45MPa
In. volume	300L
Category	Type3

※ Trailer head not included

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Liquid Hydrogen Container

Specifications of container	
Type	ISO 40ft
In. volume	45.6m^3
Dry weight	22.3ton
H_2 Capacity	2.9ton
Insulation	Vacuum laminated
Auxiliary	Pressurization heat exchanger

1,000m3 Tank for Test Manufacturing

9m diameter same as 3,000m3 tanks for the pilot chain

- Fabrication Technology for 3-D Curved Panel
- Insulation Tech.
- Vacuum Tech.
- ・
- ・
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Thank you for your attention