12th German-Japanese Economic Forum

Large-scale hydrogen storage and transportation technology

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Chiyoda Corporation

April 25, 2018

CHIYODA CORPORATION

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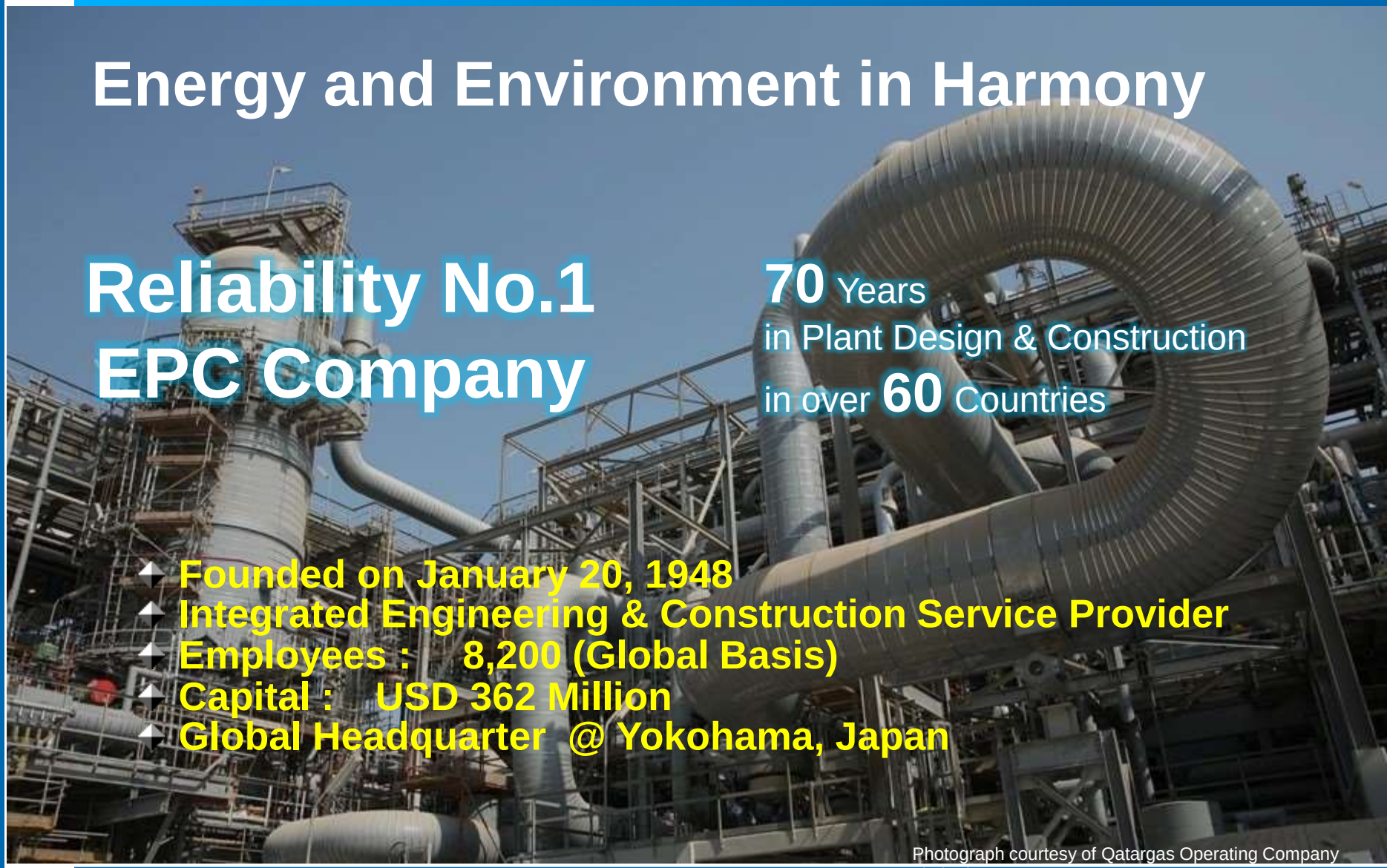
LOHC(*) Liquid Organic Hydrogen Carrier

1.1 CHIYODA in Brief - outline



Photograph courtesy of Qatargas Operating Company

1.2 CHIYODA in Brief - business portfolio

Offshore & Upstream

- Consulting Service
- Offshore EPCI
  (Engineering, Procurement, Construction & Installation)

Gas

- Gas Processing
- LNG
  - Liquefaction
  - Regasification
  - FLNG/FPSO
- Synthesis Gas

Petroleum Refineries

- Clean Fuel
- Heavy oil upgrading
- Chemical Refinery Integration

Petrochemicals & Chemicals

- Methanol
- Synthesis Gas/Fertilizer
- Olefins
- Aromatics
- Speciality Chemicals

Pharmaceuticals

- Pharmaceuticals
- Tissue Engineering (iPS cell)
- Laboratories

Green Energy

- Solar Energy
- Biomass Power Generation
- Wind Power
- Energy Storage
- Hydrogen Supply Business

Water Management

- Industrial Water
  - Waste Water Treatment + Recycling
  - Produced Water Treatment

Environmental Protection

- Flue gas desulfurization
- Acid gas/CO2 capture and storage
- Energy conservation

Metals & Mining

- Metallurgical Refining and Smelting

Infrastructure

- Airport
- Transport

General Industry

- Electronic materials
- Food processing

1.3 CHIYODA in Brief - Commitment to CSR

In 1948, Dr. Akiyoshi Tamaki, the founder of Chiyoda, declared;

> **“Chiyoda shall contribute to the welfare of society, not just by simply providing goods and services, but as will be required.”**

In 1972, Chiyoda published “Legacy for the 21st Century" which advocated the need for harmony between industrial development and environment preservation.

Legacy for the 21st Century

Based on this declaration, Chiyoda has established a Group Corporate Philosophy and are committed to fulfilling our corporate social responsibility for society worldwide.

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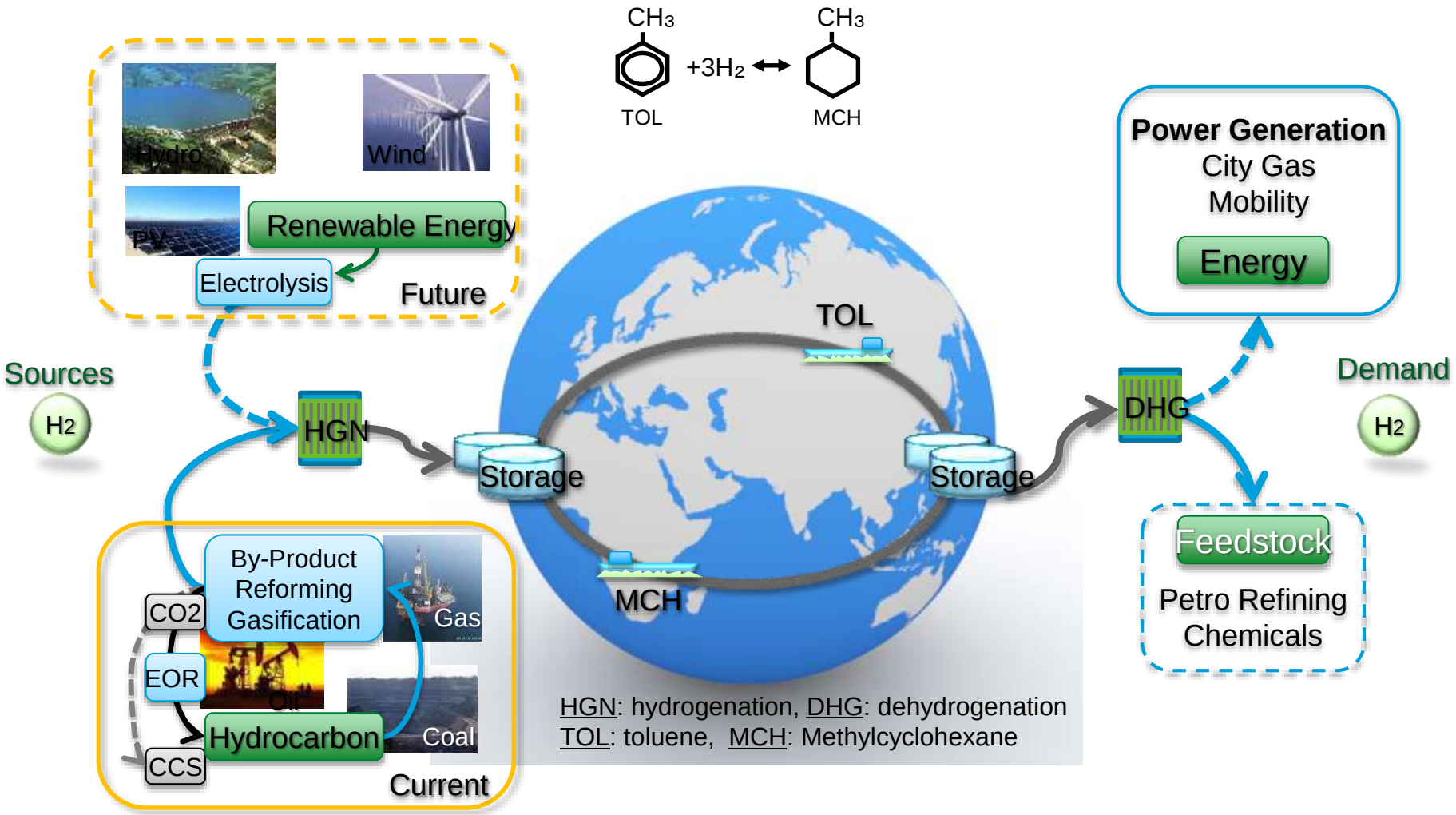
LOHC(*) Liquid Organic Hydrogen Carrier

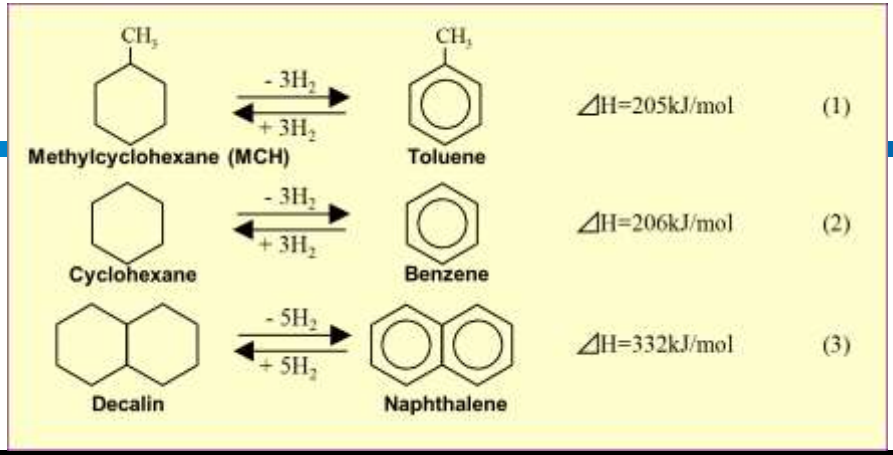
2.1 Outlook in Hydrogen Supply Chain



2.2 Features of MCH-Toluene System

Long term storage & long distance transport	Chemically stable Very minor loss by long tern storage & long distance transport
Easy to handle	Liquid under ambient temperature & pressure Approx. 1/500 in volume
Use of existing oil infrastructure	Physical property is similar to petroleum oil
Reduced risk of H2 storage & transport	Risk for H_2 storage & transport is reduced to the one of petroleum oil.
Combination of Proven technologies	Combination of conventional equipment except for new catalyst for dehydrogenation.

2.2 Features of MCH-Toluene System



		MCH—Toluene		Cyclohexane–Benzene		Decalin–Naphthalene	
		Methylcyclohexane	Toluene	Cyclohexane	Benzene	Decalin	Naphthalene
Fomula		C_7H_{14}	C_7H_8	C_6H_{12}	C_6H_6	$C_{10}H_{18}$	$C_{10}H_8$
M.W.		98.19	92.14	84.16	78.11	138.25	128.17
State at room temp.		Liquid	Liquid	Liquid	Liquid	Liquid	Solid
Density (g/cm^3)		0.7694	0.8669	0.7791	0.8737	0.8963	0.9752
mp. (℃)		−126.6	−95.0	6.5	5.5	cis : −43.0 trans : −30.4	80.3
bp. (℃)		100.9	110.6	81.0	80.1	cis : 194.6 trans : 185.5	218.0
Hydrogen storage density	(wt%)	6.2	−	7.2	−	7.3	−
	($kg-H_2/m^3$)	47.4	−	56.0	−	65.4	−
Amount for 5kg-H_2 storage	(kg)	81.2	17.6	17.9	14.8	68.6	63.6
	(L)	105.5	87.9	89.3	73.9	76.5	65.2

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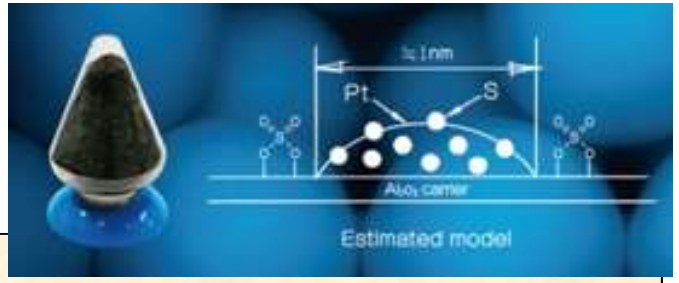
2.3 Advantages - Utilization of Existing Infrastructure

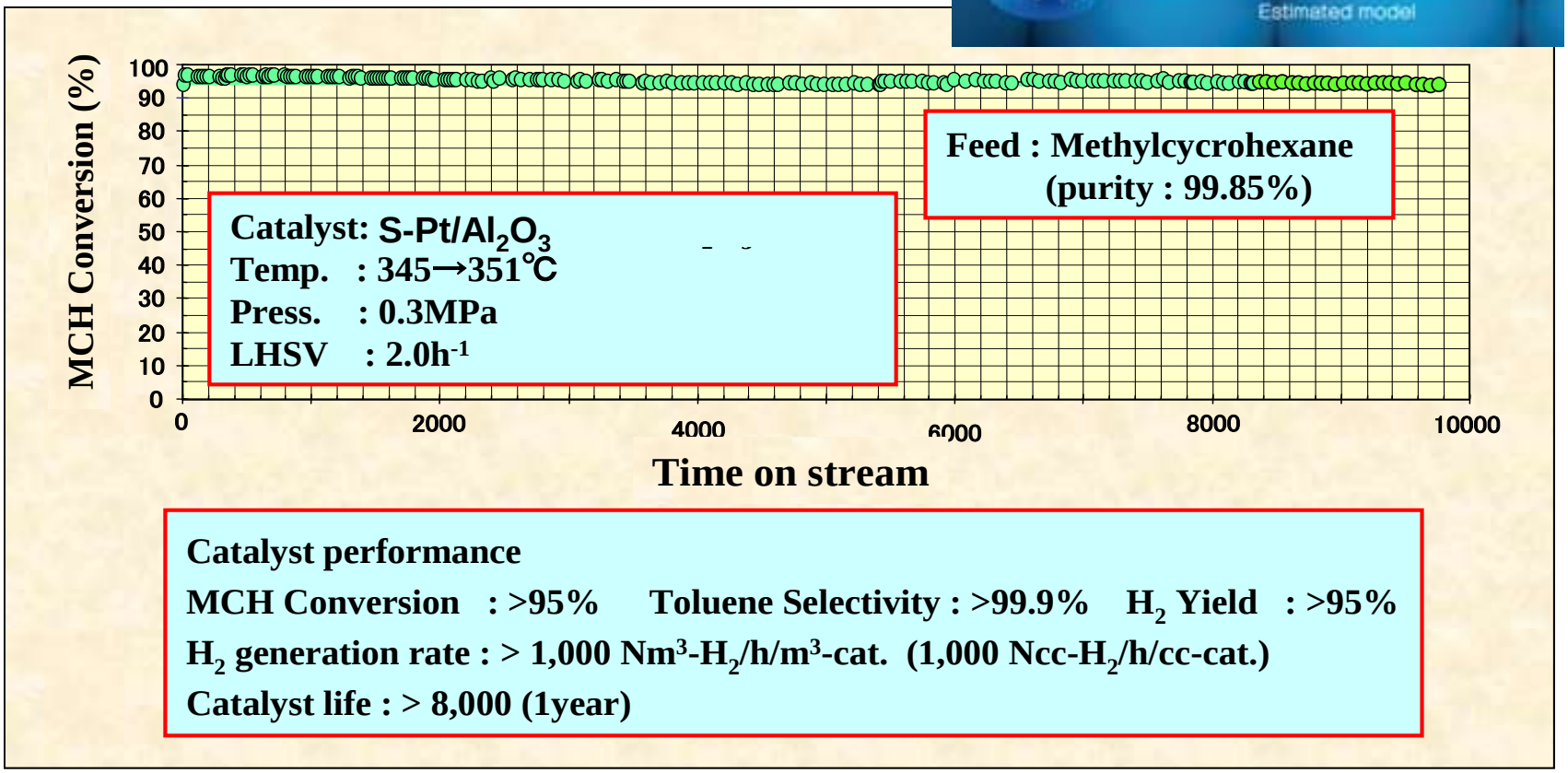
Hydrogen storage
in the liquid state
by conventional tank

Hydrogen transportation
by conventional tanker,
pipeline, tanker truck

2.4 Performance at Laboratory

- Catalyst developed by Chiyoda
- Life longer than 1 year was confirmed
- Chiyoda's self fund

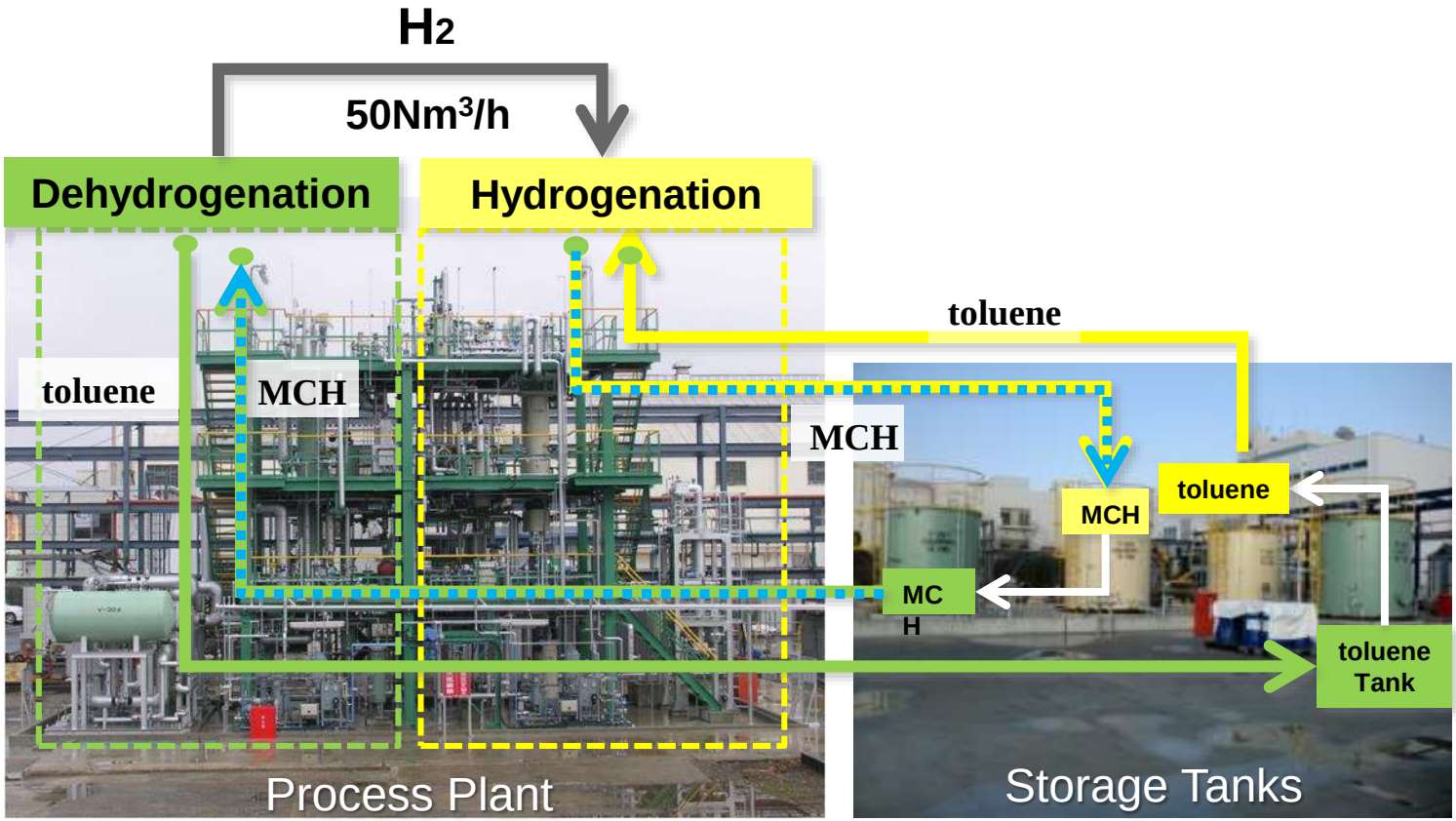




2.5 Demo plant at R&D Center

After development of dehydrogenation catalysts, which is the key technology of organic chemical hydride method, Chiyoda has constructed the demonstration plant in R&D Center, Yokohama.

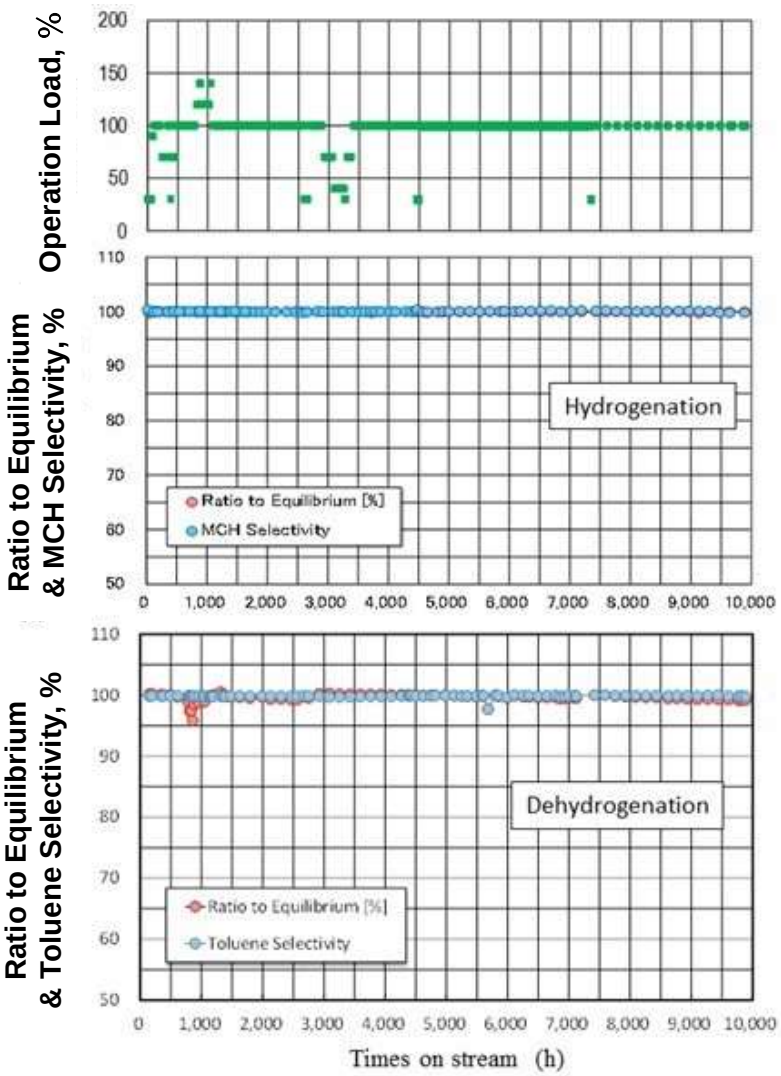
From April 2013 to November 2014, about 10,000hrs demonstration operation has been successfully conducted, and the expected performance and life of the proprietary catalyst has been confirmed.



2.5 Demo plant at R&D Center

Hydrogenation of Toluene

- MCH Selectivity



Yield of H_2 Storage: > 99%

Dehydrogenation of MCH

- Toluene Selectivity

Yield of H_2 Generation: > 98%

Operating performance: April 2013～Nov. 2014（about 10,000hr）

H_2 consumption / generation：50Nm^3/h

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LOHC(*) Liquid Organic Hydrogen Carrier

3.1 The World's First Global Hydrogen Supply Chain Demonstration Project

- Using LOHC Technology, Chiyoda and its partners established the Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD), and started the world's first global hydrogen supply chain demonstration project toward 2020 when the Tokyo Olympic & Paralympic Game takes place.

Advanced Hydrogen Energy Chain Association for Technology Development

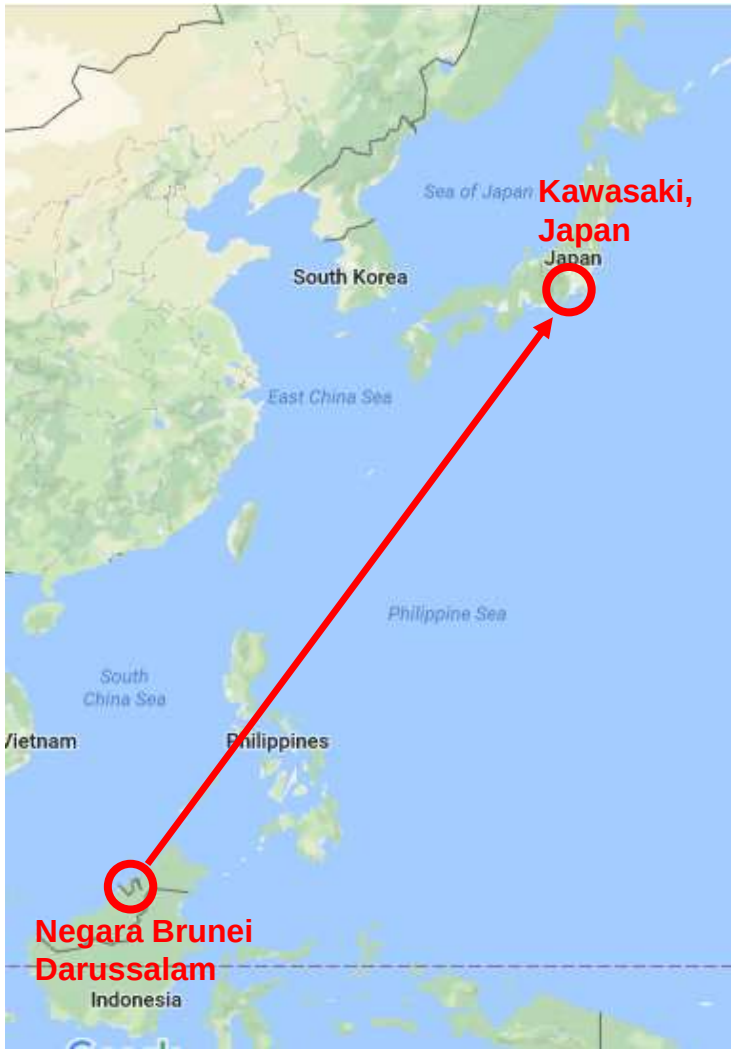
CHIYODA CORPORATION　Mitsubishi Corporation　MITSUI & CO.　NYK LINE NIPPON YUSEN KAISHA

<Planed Schedule>

2015	2016	2017	2018	2019	2020
Phase 1: FS & Basic design		Phase 2: Design, Construction, Commissioning			Demonstration

3.1 The World's First Global Hydrogen Supply Chain Demonstration Project

Project Outline



Project Scale

Supply of 210 tons (max) of Hydrogen in 2020, equivalent to filling 40,000 Fuel Cell Vehicles.

Hydrogen Supply

Hydrogen will be produced by Steam Reforming from the processed gas derived from the Natural Gas Liquefaction Plant of Brunei LNG Sdn. Bhd.

Hydrogen Demand

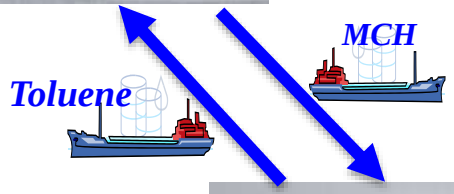
Fuel for the Keihin Refinery Thermal Power Plant, an affiliate of TOA OIL Co., Ltd.
TOA OIL Co Ltd. is owned by SHOWA SHELL SEKIYU K. K..

NEDO Support

2/3 of this project is funded by NEDO (New Energy and Industrial Technology Development Organization, Funding agent of Ministry of Economy, Trade & Industry).

3.1 The World's First Global Hydrogen Supply Chain Demonstration Project

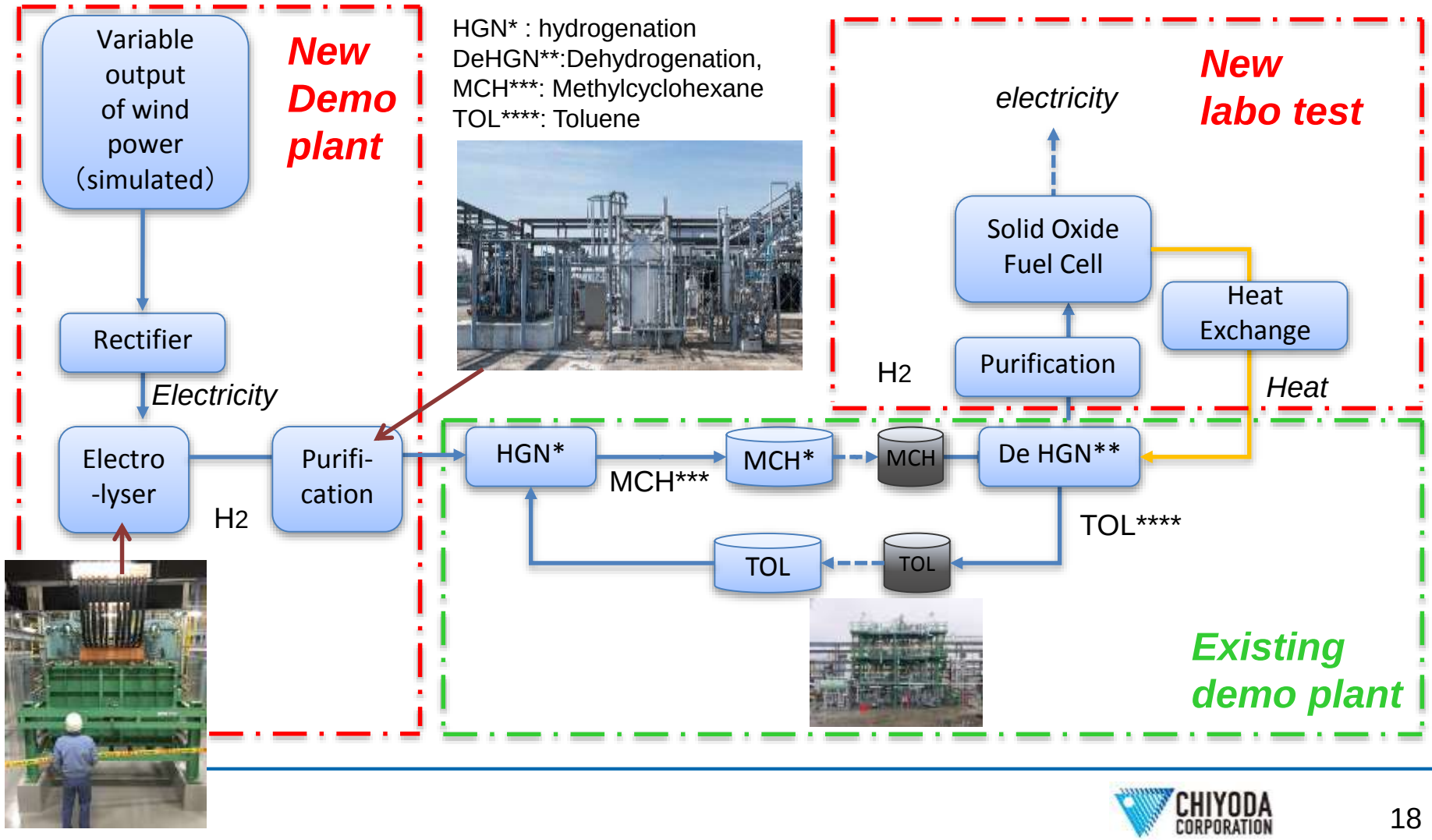
Brunei Hydrogen Production & Hydrogenation Plant (Image)



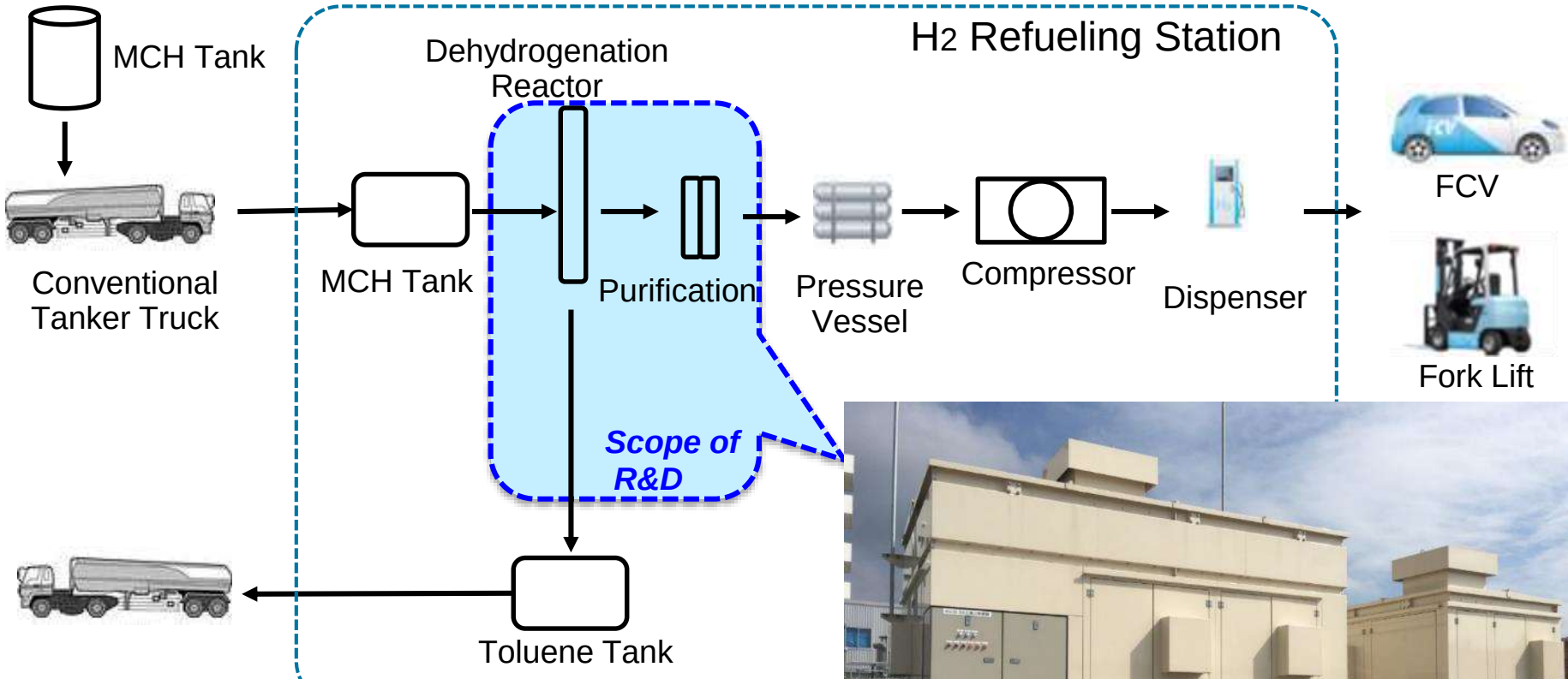
Kawasaki Dehydrogenation Plant (Image)

3.2 Power to X

- Demonstration project to produce hydrogen by variable renewable energy.
- From 2014 to 2018.
- 100 % funded by NEDO



3.3 Dehydrogenation + Purification for Hydrogen Refueling Station



R&D Items

- Down sizing and cost down of dehydrogenation unit
- Purification system：ISO14687-2
- Hot oil unit for dehydrogenation reaction heat supply
- Heat management, etc.

- 1/2 of project cost was funded by NEDO.

Acknowledgement

Part of this presentation is based on results obtained from the following projects commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

- Demonstration of the Hydrogen Supply Chain by Organic Chemical Hydride Method Utilizing Unused Energy
- Research and development about a storage, the use of the renewable energy with hydrogen (Organic Hydride)
- Minimization and cost reduction of dehydrogenation facility for hydrogen refueling station on organic chemical hydride

We express words of gratitude to NEDO/METI.

Thank you very much for your attention.

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