Development of Global Supply Chain by LOHC-MCH method

Yuji Chishima

Group Leader, Business Development

Hydrogen Business Dept.

Chiyoda Corporation

I. Who are Chiyoda ?

Chiyoda's Philosophy

Chiyoda has provided pioneering engineering solutions for each generation since 1948, and under the current philosophy 'Energy and Environment in Harmony', continues our vision of 'serving society through technology'.

From Coal to Oil, Oil to Gas, Gas to Renewables and New Energy

1948–1970

1960
Mitsubishi Oil Co., Ltd.
Mizushima grassroots refinery

1971–1990

1991–2000

2004
LNG plants for Qatargas Operating Company Limited

2001–2010

2011–2020

2018
World's largest battery power storage system project in Hokkaido, Japan

2015-2020
World's first global hydrogen supply chain demonstration project

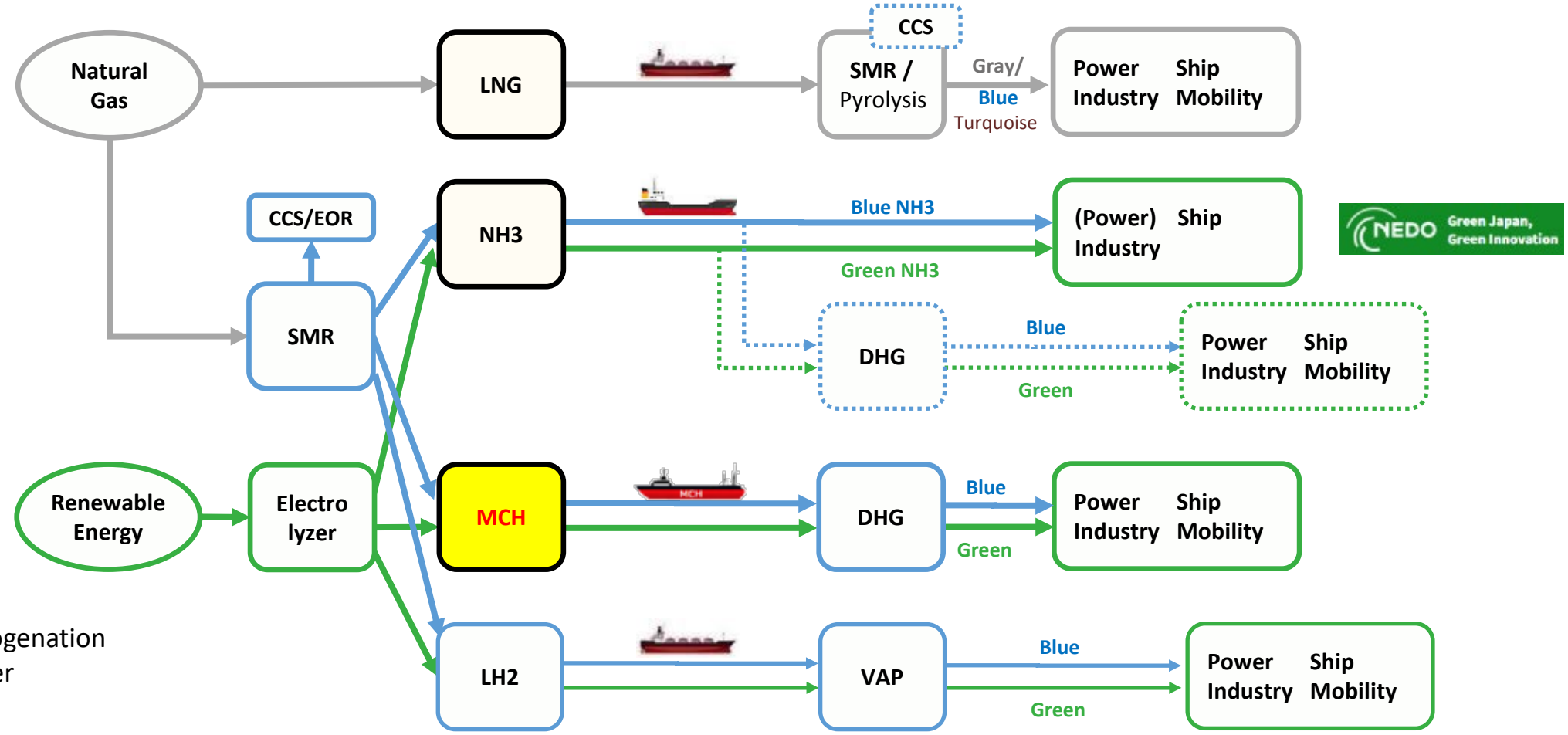
Chiyoda's Vision for the Future

Engineering that shapes the future of energy and the global environment

II. Hydrogen Carriers

Landscape of Hydrogen Carriers

For large scale global H2 supply chain, methylcyclohexane (MCH) as H2 carrier and direct use of ammonia (NH3) are proven, realistic solution now, while LH2 and NH3 with dehydrogenation would co-exist after 2030s.



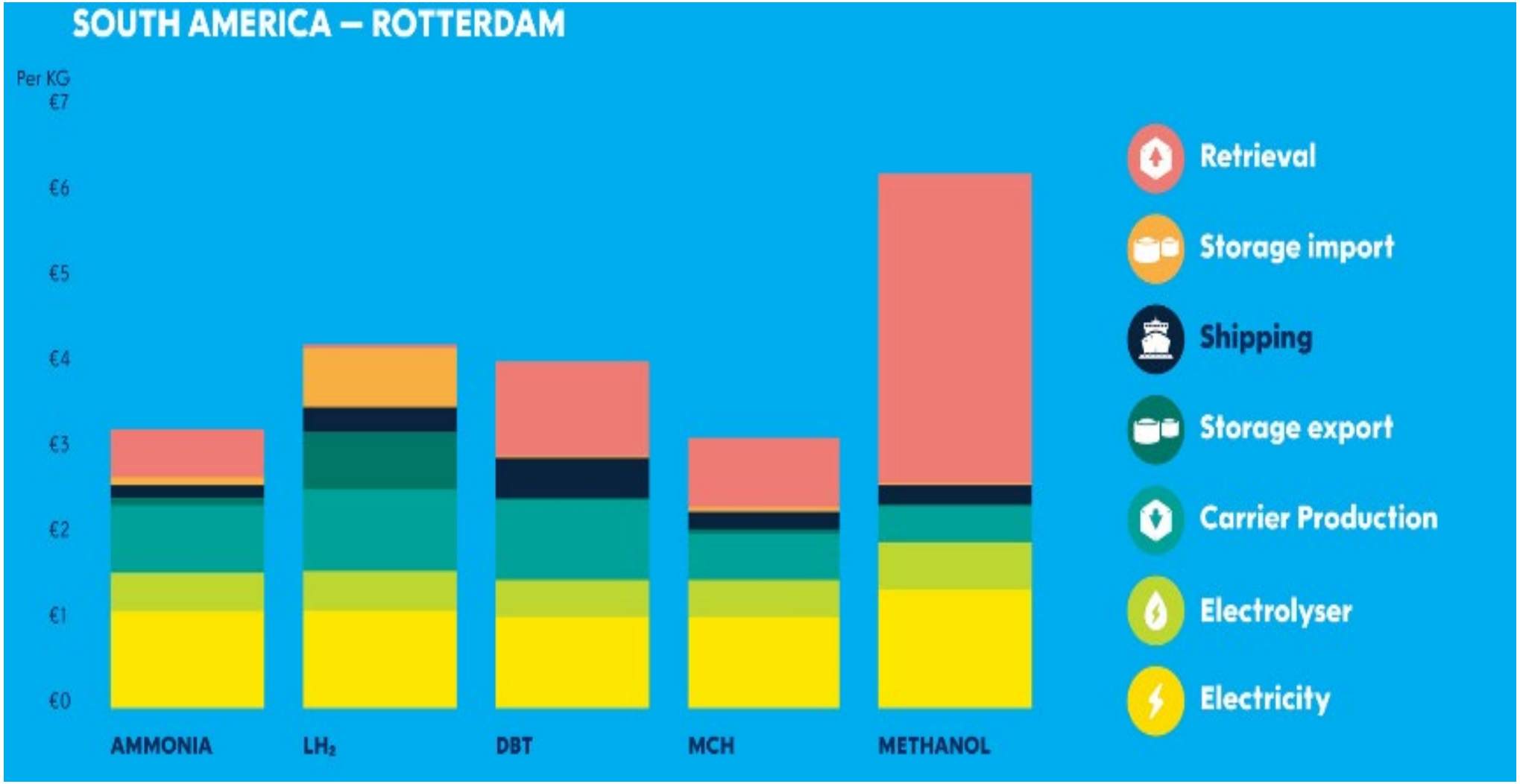
【Note】
DHG : dehydrogenation
VAP : vaporizer

Landscape of Hydrogen Carriers (Key Characteristics)

	LOHC MCH/TOL	LOHC H12-BT/BT	NH3	LH2
H2 Compaction	**1/500**	**1/600**	**1/1300**	1/800
Liquid Phase @	**Ambient**	**Ambient**	- 33℃	**- 253℃**
Leakage Risk – Fire	Moderate	**Low**	Moderate	**High**
Leakage Risk – Toxic	Moderate	**High (Aquatic) Low (General)**	**High**	**Low**
Technology Readiness	**Ready (Large scale)**	**Ready (Small scale)**	**Ready (Direct use)** 2030 - (Cracking)	2030 - 35 (Large scale)
Infrastructure (Transport)	**Existing Chemical Tanker Type-2** (Large size, Abundant)	**Existing Chemical Tanker Type-1** (Small size, Limited)	Existing Chemical Tanker Type-2G/2PG (Liquefied / Pressurized)	**New Dedicated Ship (Cryogenic)**
Infrastructure (Storage)	**Existing petroleum infra.**	**Existing petroleum infra.**	Limited existing LPG/NH3 infra.	**New dedicated LH2 infra.**
H2 Purity	>99.8% (FCV grade after PSA)	>99.9% (FCV grade after PSA)	**75%-H_2 + 25%-N_2 (FCV grade after PSA)**	**99.999% (FCV grade)**

*) H2 yield considered

Landscape of Hydrogen Carriers (Economic Comparison)



(Source) Keynote speech Allard Castelein, CEO Port of Rotterdam Authority, at the 2nd World Hydrogen Summit [2021]

Landscape of Hydrogen Carriers (Safety Assessment)

	NFPA Diamond	NFPA (Health)	NFPA (Flammability)	DOT (Hazard Label) IMDG Class	GESAMP (Aquatic Toxicity/ Biodegradability)	IMO Safety (Ship)
TOL		**2** Can cause temporary incapacitation or residual injury	**3** Can be ignited at ambient conditions	DOT: Flammable Liquid IMDG: Class **3** Flammable Liquids	Acute Toxicity: **3** (Moderately toxic) Chronic Toxicity: **0** (Negligible) Biodegradability: Readily	IMO Ship **Type-3** (least danger) Ambient liquid No boil-off
MCH		**1** Can cause significant irritation	**3** Can be ignited at ambient conditions	DOT: Flammable Liquid IMDG: Class **3** Flammable Liquids	Acute Toxicity: **3** (Moderately toxic) Chronic Toxicity: **1** (Low) Biodegradability: Not readily	IMO Ship **Type-2** (less danger) Ambient liquid No boil-off
LH2		**3** Can cause serious or permanent injury	**4** Burns readily. Rapidly or completely vaporizes at ambient pressure & temperature	DOT: Flammable Gas IMDG: Class **2** Refrig. Liquified Gas	No aquatic impact	IMO Ship **Type-2G** (less danger) -253° C High boil-off
NH3		**3** Can cause serious or permanent injury	**1** Must be preheated before ignition can occur	DOT: Non-Flammable Gas Inhalation Hazard Poison Gas Corrosive IMDG: Class **2** Refrig. Liq. Gas, Toxic Gas	Acute Toxicity: **3** (Moderately toxic) Chronic Toxicity: **2** (Moderate) Biodegradability: Readily	IMO Ship **Type-1G** (more danger) -33° C Moderate boil-off

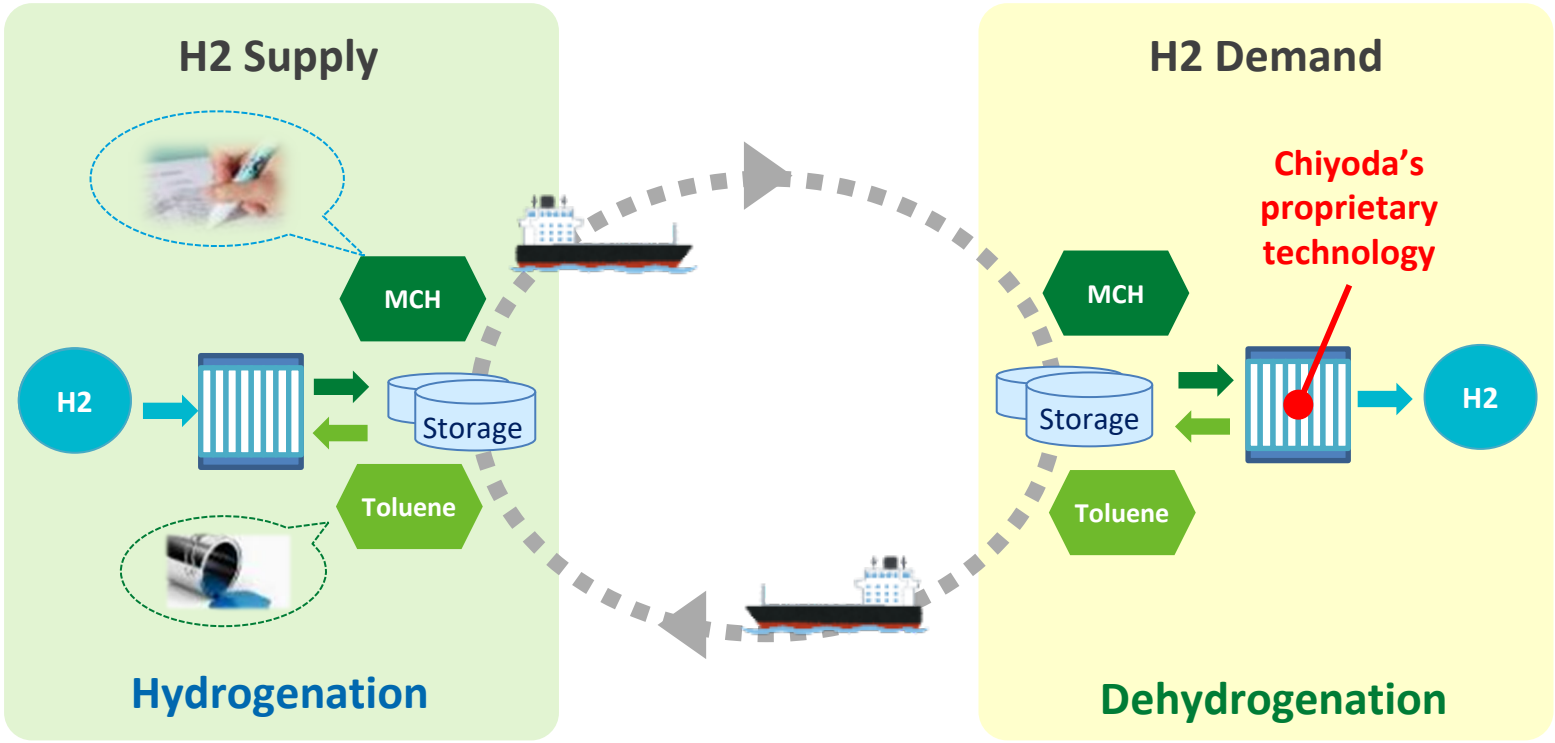
DOT : US Department of Transport, IMDG: International Maritime Dangerous Goods
GESAMP: Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection

III. What is the SPERA Hydrogen™ Technology

MCH Technology (SPERA Hydrogen™) at a Glance

Chiyoda's SPERA Hydrogen technology uses MCH as the hydrogen carrier in a LOHC (*) system, enabling the safe, efficient and commercially viable storage and transportation of hydrogen on a global scale.

LOHC：Liquid Organic Hydrogen Carrier



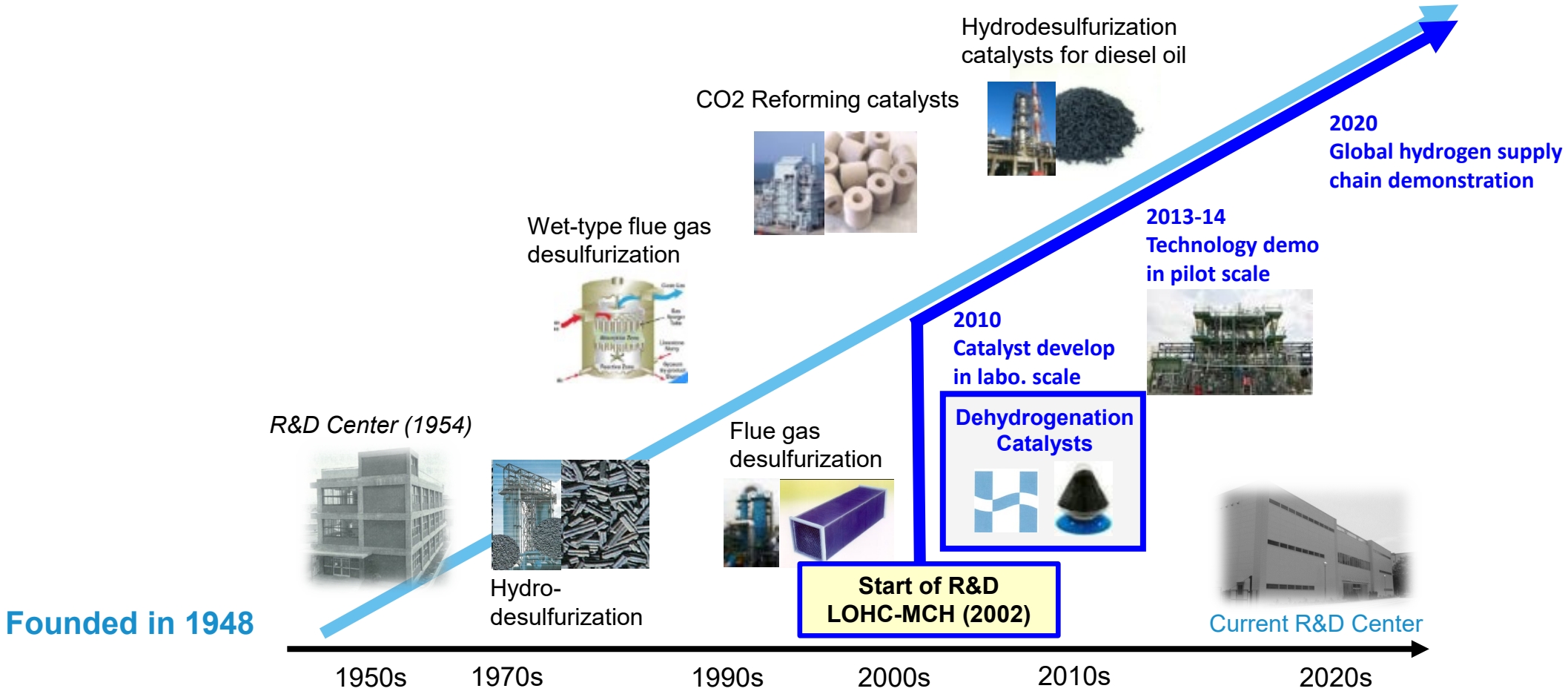
*MCH: Methylcyclohexane　LOHC: Liquid Organic Hydrogen Carrier

Key Features

1. **Easy to Handle**: SPERA Hydrogen, a stable liquid at ambient temperature and pressure, is as easy to handle as petroleum, and suitable for long term storage and long distance transportation.
2. **Existing Infrastructure:** Possible to repurpose, utilize existing petroleum transportation and storage facility (tanks, tanker, pipeline, tank lorry, etc.), standard and regulation, to minimize investment for H2 infrastructure.
3. **Safe with Lower risk:** Safe transportation and storage that is equivalent level to petroleum products, that has already been managed in the society for long term.
4. **Circular System:** H2 is cycled from/to water, and Toluene as H2 carrier (LOHC) are recycled, and heat can be effectively cycled with value added, to develop efficient /sustainable H2 system.

History of Technology Development

Chiyoda commenced R&D of the MCH system in 2002 and developed its proprietary dehydrogenation catalyst on a laboratory scale in 2010 – a significant step forward towards a hydrogen economy and a low carbon society.



1st Global Hydrogen Supply Chain Demonstration

In December 2020, AHEAD successfully completed the worlds first ‘Global Hydrogen Supply Chain Demonstration Project’, an important milestone for the construction of an international hydrogen supply chain.

Description	
Scale	210 tons/year at facility scale (Maximum)
Duration	2020
Hydrogen Supply	Brunei Darussalam (Hydrogen production)
Hydrogen Demand	Kawasaki City, Japan (Fuel for gas turbine power plant)
Transportation	ISO tank containers (Container ship/truck)
Business Scheme	Established by AHEAD Funded project by NEDO**

* Advanced Hydrogen Energy Chain Association for Technology Development (Chiyoda, Mitsubishi Corporation, Mitsui & Co., Nippon Yusen Kabushiki Kaisha)

** New Energy and Industrial Technology Development Organization : National research and development agency that creates innovation by promoting technological development necessary for realization of a sustainable society

(Reference) *https://www.chiyodacorp.com/media/210202_e.pdf*

1st Global Hydrogen Supply Chain Demonstration (Photos)

Hydrogenation

MCH Transport (Inland)

MCH Transport (Marine)

Dehydrogenation

Dehydrogenation Section

Chiyoda's proprietary catalyst

H2 mixed Power Generation

Utilize hydrogen for GT fuel from dehydrogenation as Japan's first

2nd Global Hydrogen Supply Chain Demonstration (Tanker Transportation)

AHEAD has achieved a world's first milestone of transporting hydrogen, in the form of MCH, and this achievement demonstrates the viable long-term storage and transportation of hydrogen in the form of MCH by tanker on a global scale.

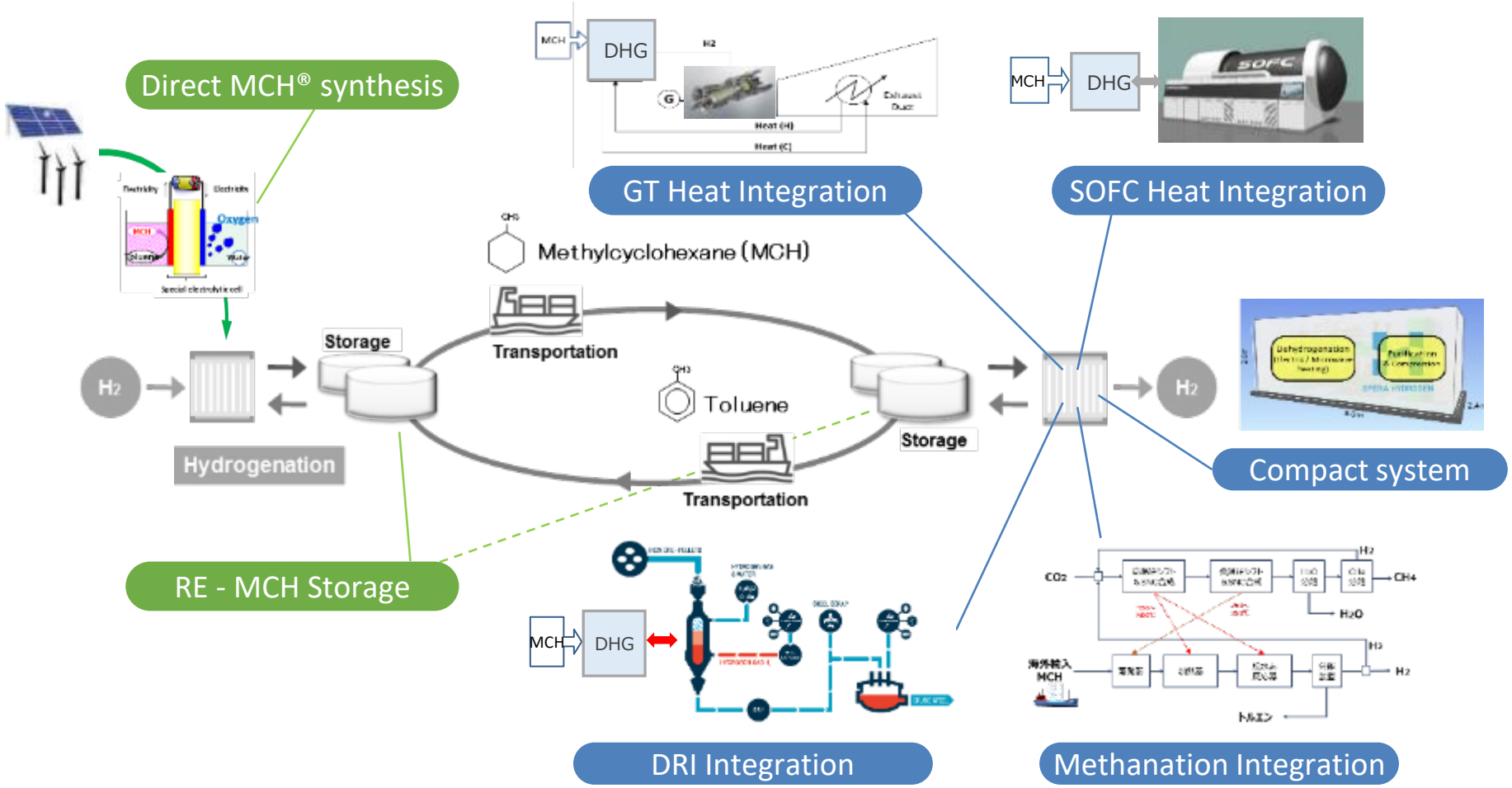
- AHEAD manufactured MCH in Brunei Darussalam, for transportation to an ENEOS petroleum refinery in Japan.
- For supplying MCH to the ENEOS refinery, this ENEOS's demonstration project supported by CROS*1 has been conducting.
- The first chemical tanker arrived at the refineries receiving facility on 4 February 2022, and the MCH was fed into the refinery.

*1 CROS : Consortium for Resilient Oil Supply System

(Reference) https://www.chiyodacorp.com/media/20220208_E_R1.pdf

Further MCH Technology Development

Chiyoda is further developing technologies and system integration from upstream to downstream to optimize and reduce total H2 value chain cost.



Further MCH Technology Development : Direct MCH® Synthesis

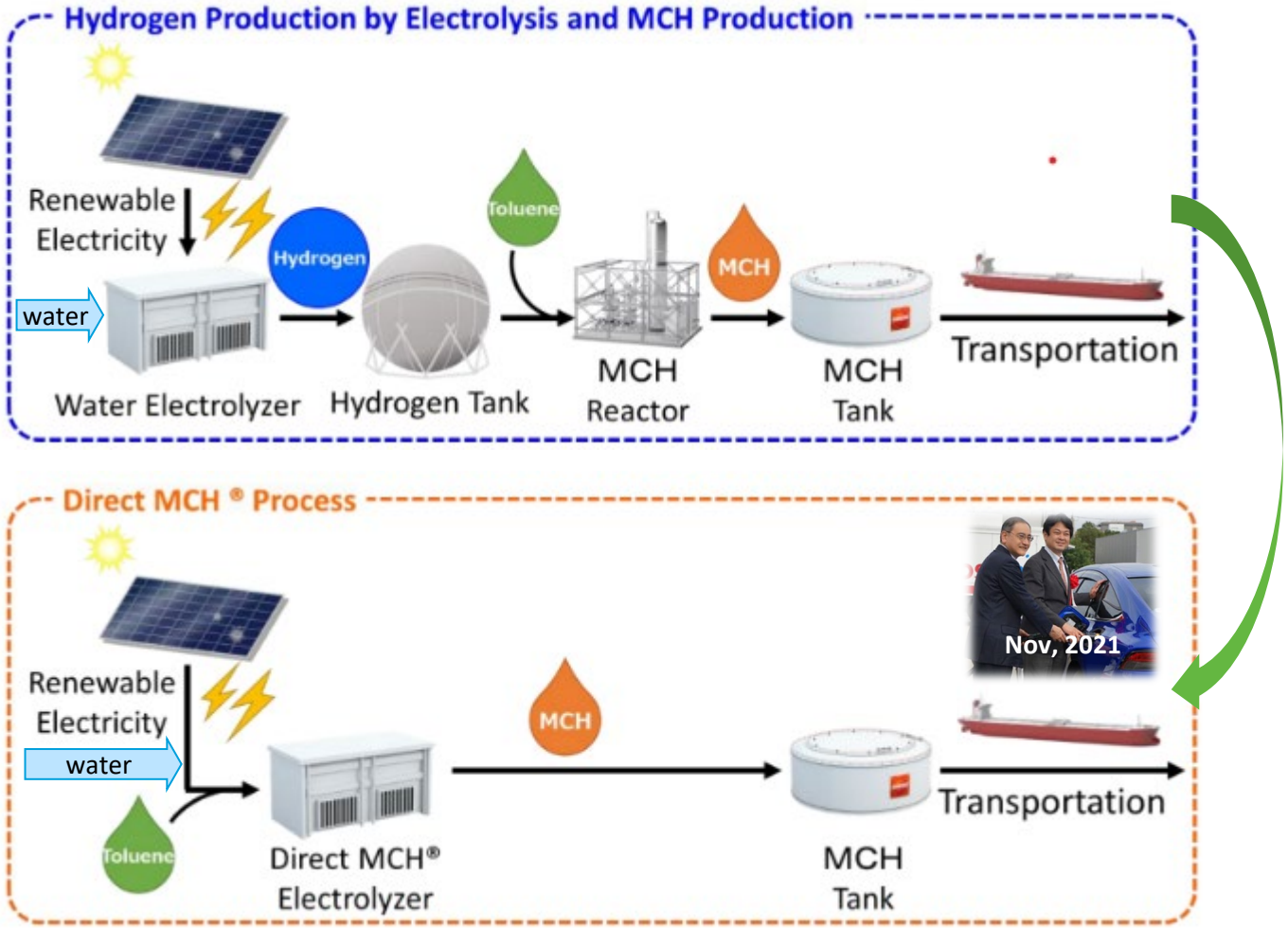
Direct MCH® Synthesis technology has been developed at laboratory scale in 2019, successfully fill the green hydrogen by Direct MCH to FCEV in 2021, and is under scaling up stage toward commercialization around 2030.

➢ **Existing Technology (Electrolysis + MCH)**

- Hydrogen is produced by water electrolyzer, and hydrogen is converted to MCH by hydrogenation process (MCH Reactor).
- Hydrogen gas tanks and MCH reactor are required for this technology.

➢ **New Technology (Direct MCH® synthesis)**

- MCH is directly produced from renewable electricity, water and toluene, not through hydrogen production.
- Hydrogen gas tanks and MCH reactor are NOT required for this technology.



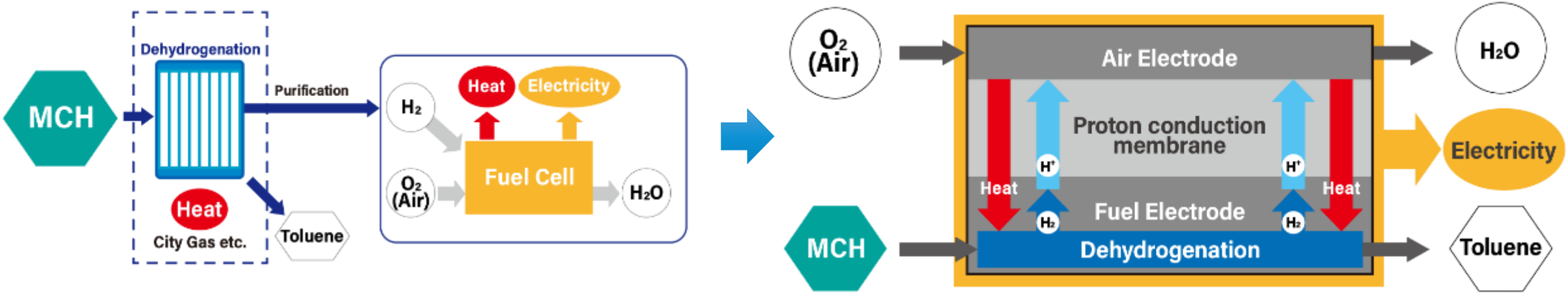
Further MCH Technology Development : MCH Direct Fuel Cell

“ New Fuel Cell System (MCH Direct Fuel Cell) ” that use MCH as a fuel is under R&D phase.

- Develop new medium-temperature fuel cell that is operated under temperature range for dehydrogenation (below 400 deg-C)
- Realize high efficiency energy conversion system with excellent heat balance and cost balance.

Conventional Fuel Cell System

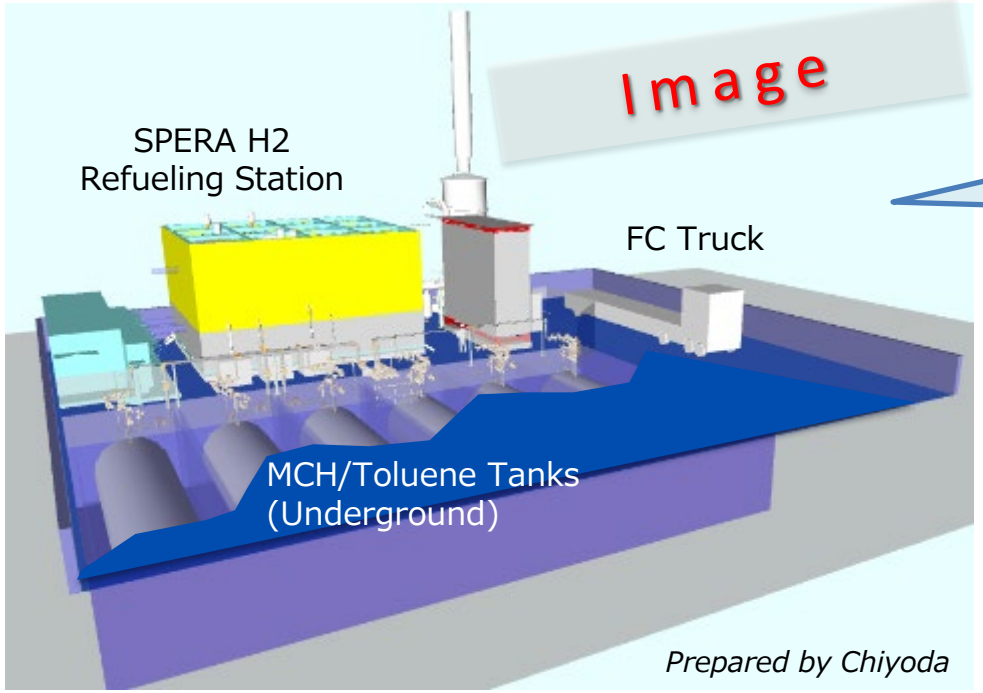
New Fuel Cell System



Further MCH Technology Development : SPERA Hydrogen Refueling Station

Smaller size dehydrogenation package for H2 distributed demand, such as refueling station, has been demonstrated in 2018, and is under optimization stage to realize downsizing and automation.

	H2 Supply (Nm^3/h)	H2 volume (kg/truck)	Number of Trucks (truck/hour)	Number of dispenser (set)
For FC truck	2,000	100	2	1



- **H2 delivery** : 2,000 Nm3/h
  (= 3.3 MW for FC power generation)
- **Land requirement** : 460 m2
  (incl. utility, compressor, storage for refueling.)

NEDO Pilot Project (2016 – 18)

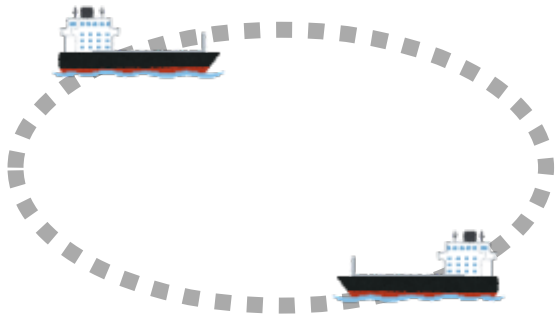
MCH Hydrogen Value Chain Collaboration

Chiyoda and Axens has concluded Joint Commercial Cooperation Agreement on Nov. 2022, that bring strong synergies allowing fast track approach for MCH supply chain implementation with single point of contract.

AX-CYD License Commercial Package

Axens
Powering integrated solutions

- Hydrogenation (HGN)
- Licensor's expertise



CHIYODA CORPORATION

- Dehydrogenation (DHG)
- Engineering expertise

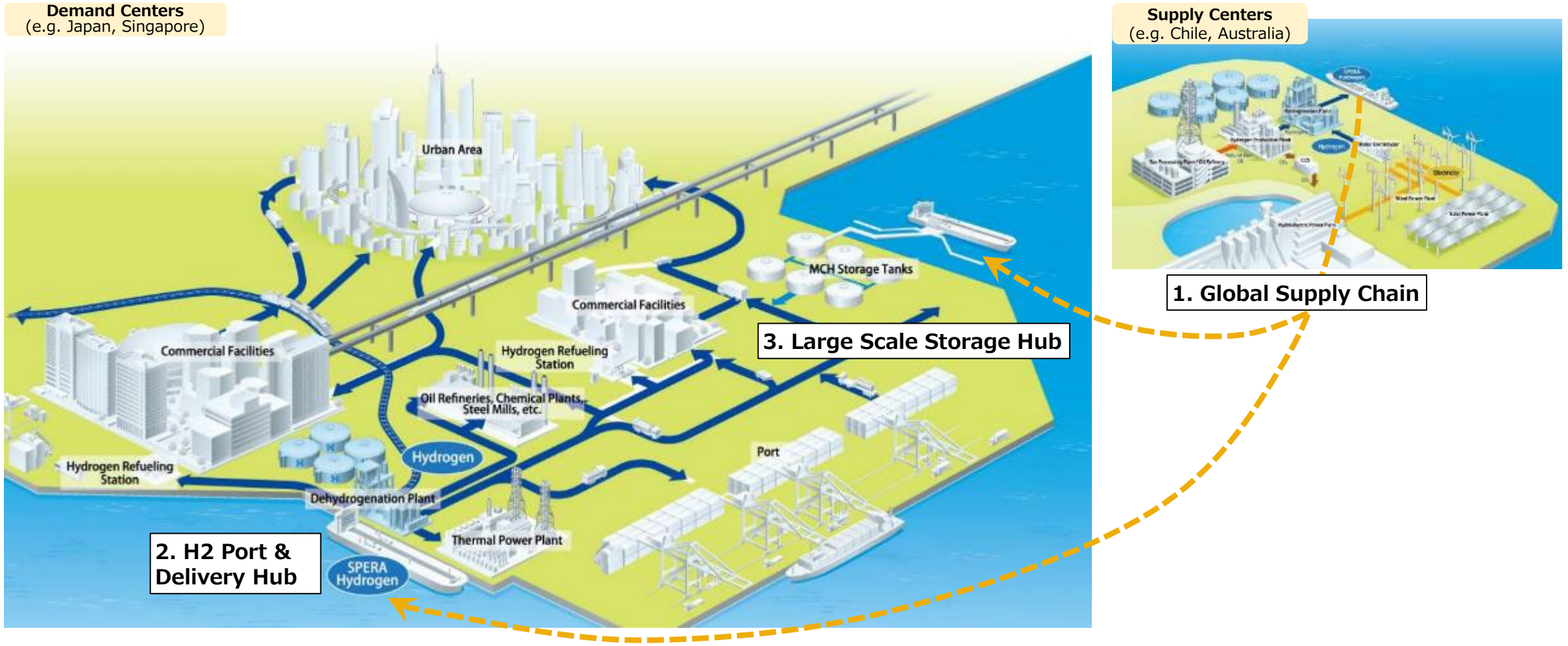
Client

- Supply Chain Operator
- Refineries
- Hydrogen Trader
- Supply-Demand Aggregator
- Transportation Service

IV. Ongoing SPERA Hydrogen™ Project

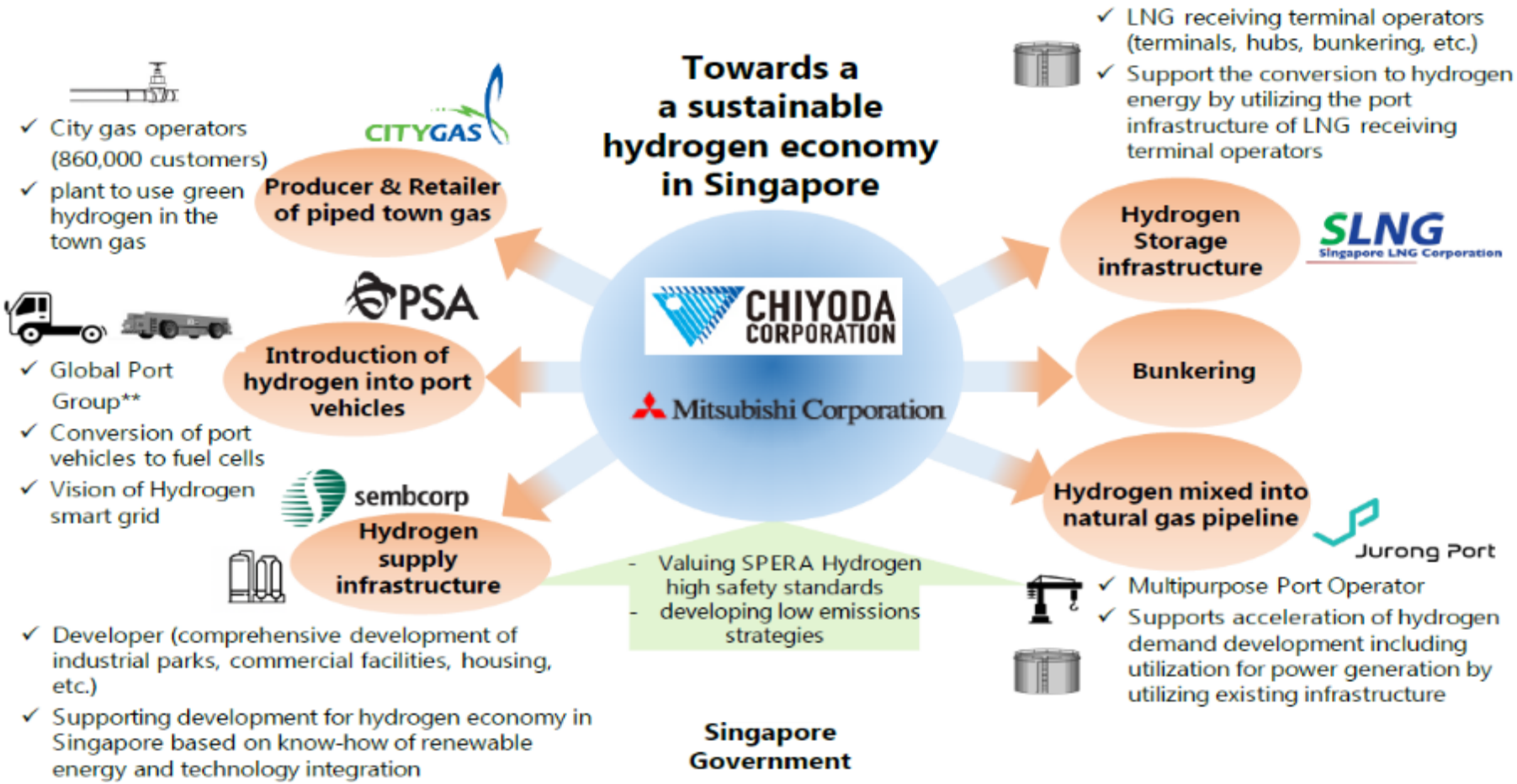
SPERA Hydrogen Use Case

There are 3 major use cases (Global Supply Chain / H2 Port & Delivery Hub / Large Scale Storage) by using MCH Technology, to seamlessly link between global hydrogen supply chain, storage and domestic distribution.



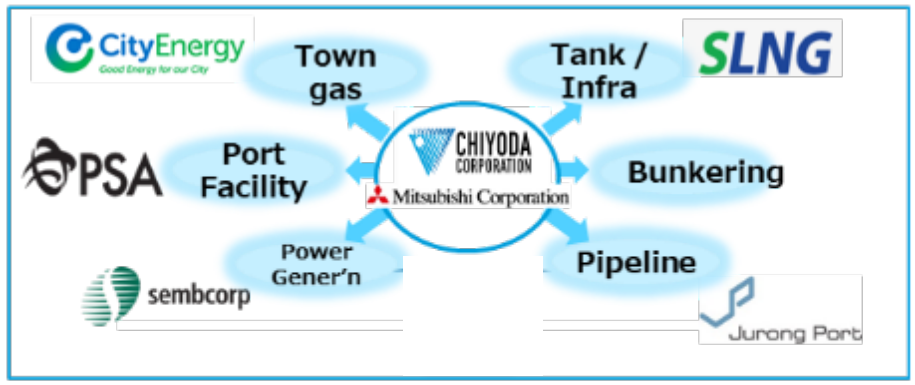
1. Global H2 Supply Chain Projects : Singapore Hydrogen Project

The Singapore government announced its Long-Term Low-Emissions Development Strategy (LEDS) in 2020, aiming to halve peak emissions by 2050. Chiyoda and Mitsubishi signed an MOU with 5 Singaporean companies on March 2020 to conduct feasibility studies for a H2 import value chain using SPERA Hydrogen in cooperation with the government.



1. Global H2 Supply Chain Projects : Singapore Hydrogen Project

To achieve net zero in Singapore by 2050, Singapore and Japanese companies strongly collaborate with government support, to develop global H2 supply chain by MCH, toward the operation start in 2026.



Mar 2020 MOU with 5 Singaporean companies

Mar 2022 Award for LCER Fund
University and industry research collaboration

Singapore Government

"Low-carbon hydrogen has the potential to be a major decarbonisation pathway towards net zero by 2050, which could supply up to 50% of our power needs, by then."

2020 — 2021 — 2022 — 2026 — 2050

Oct 2021
Strategic Partnership
with Sembcorp & Mitsubishi

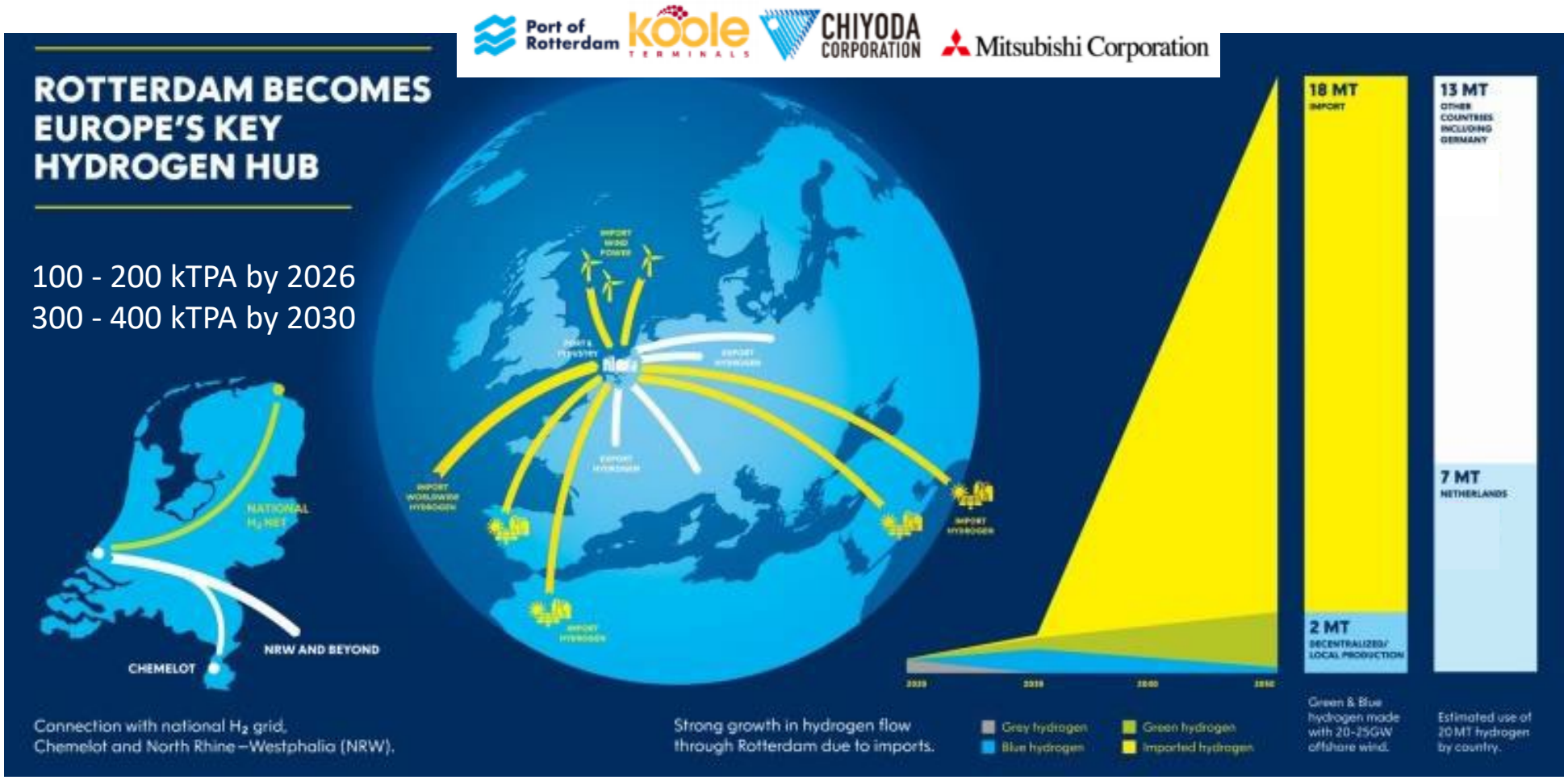
sembcorp
CHIYODA CORPORATION
Mitsubishi Corporation

Oct 2022
MOU advancing to Pre-FEED study
with Sembcorp & Mitsubishi

2026
Dehydrogenation Commercial Plant
to commence operation

1. Global H2 Supply Chain Projects : European Hydrogen Project (Rotterdam)

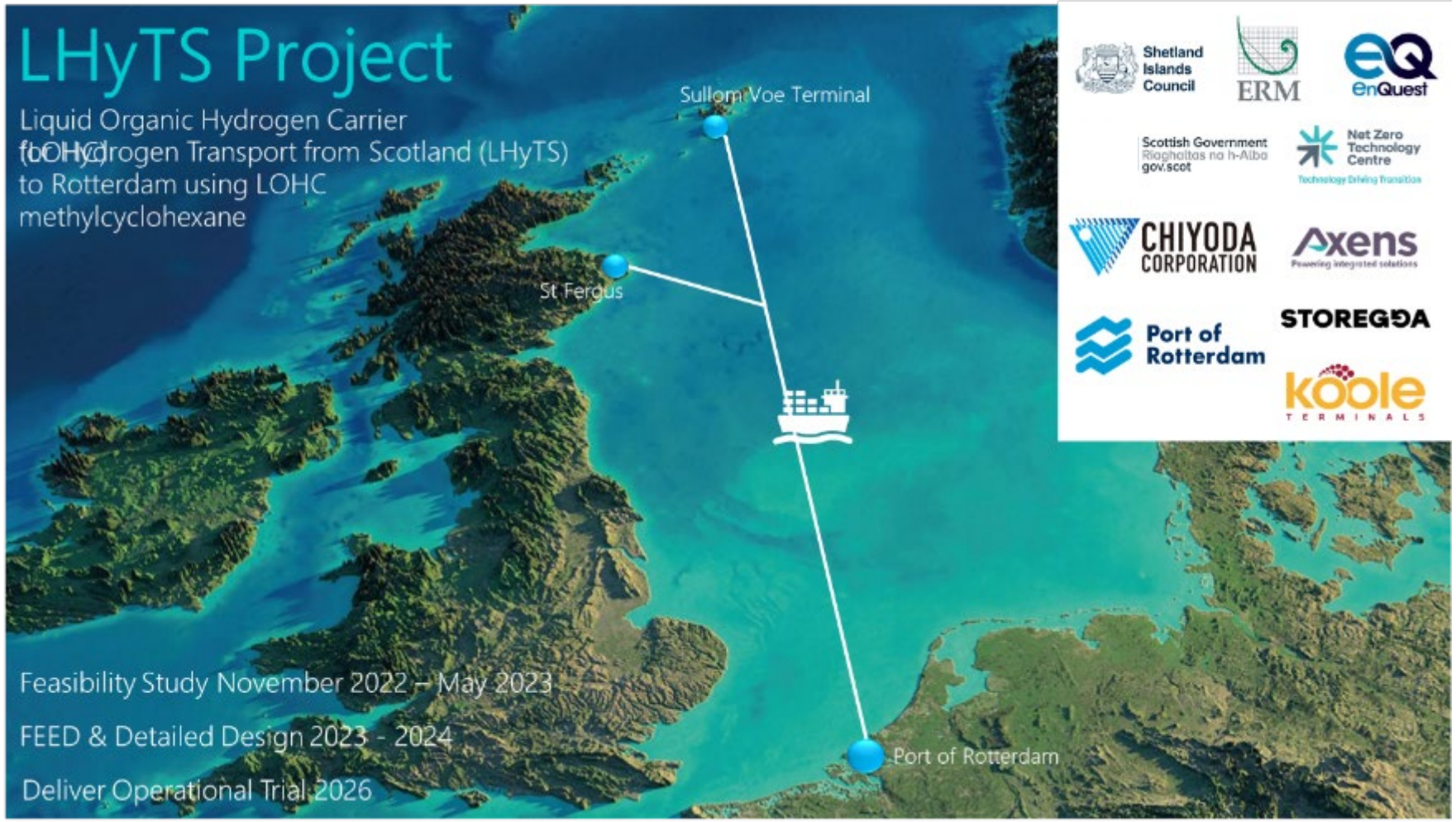
The Port of Rotterdam (POR) released its Hydrogen Master Plan in May 2020, aiming to become the H2 import hub of NW-EU by importing 20 MTPA of H2 by 2050. PoR, Koole Terminals, Mitsubishi and Chiyoda signed an MOU in July 2021 to jointly study importing H2 on an international scale using SPERA Hydrogen



(Reference) https://www.portofrotterdam.com/sites/default/files/2021-06/hydrogen-economy-in-rotterdam-handout.pdf
https://www.chiyodacorp.com/media/20210730_E.pdf

1. Global H2 Supply Chain Projects : European Hydrogen Project (LHyTS Project)

The LHyTS project (10 organizations) seeks to demonstrate that LOHC in the form of MCH can be successfully transported at scale, providing an export route to the Port of Rotterdam and other European destinations.



Thank you !