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Eco-Mobility 2024

Hydrogen Situation in Japan, Status and Roadmap to 2050+ Mobility Application

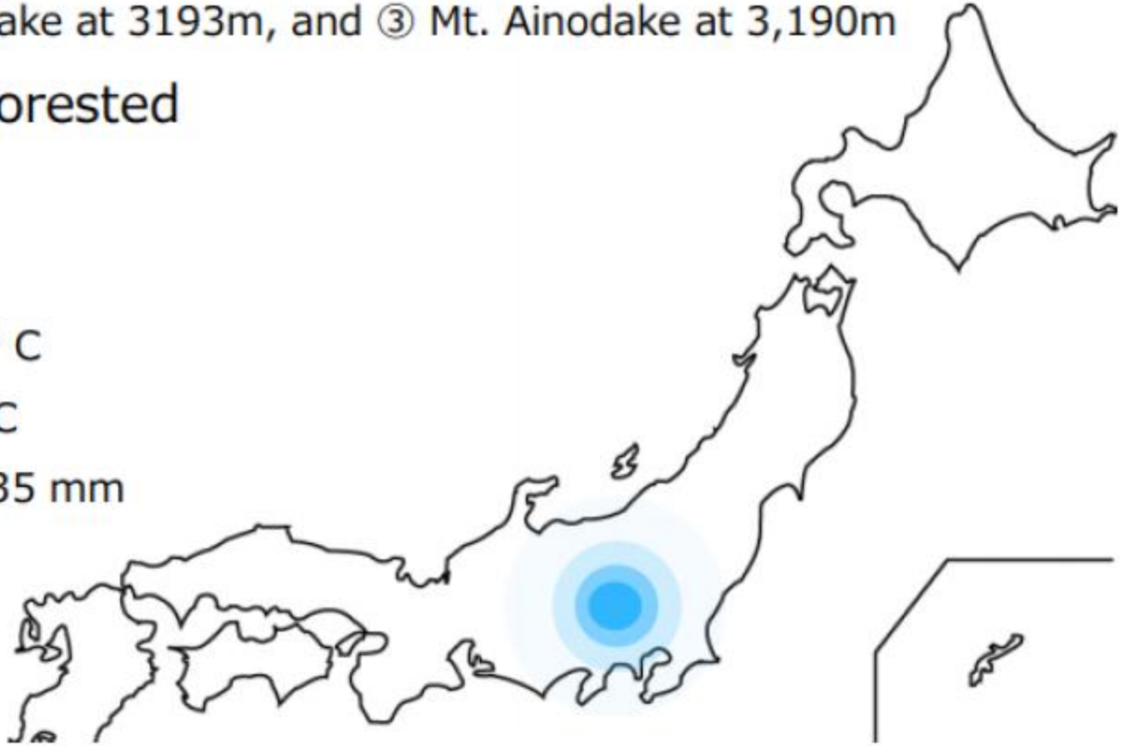
Junji Inukai, Professor
“Clean Energy Research Center” &
“Hydrogen and Fuel Cell Nanomaterials Center”
University of Yamanashi, Japan

Introduction

Yamanashi Prefecture in Japan Aiming to be Hydrogen and Fuel Cell Valley

Yamanashi Prefecture: Basic Information

- Has the three highest-altitude mountains in Japan
  ① Mt. Fuji at 3776m, ② Mt. Kitadake at 3193m, and ③ Mt. Ainodake at 3,190m
- About 78% of the prefecture is forested
- Terrain / Climate
  Basin-shaped land surface
  Average high temperature: 32.5 ° C
  Average low temperature: -2.4 ° C
  Average annual precipitation: 1,135 mm
- Population: 830,000



Miniature of Austria

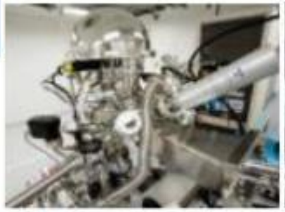
Prepared by Yamanashi Prefecture

YAMANASHI Hydrogen and Fuel Cell Valley

Research and Development Bases for Hydrogen/FC [in the Prefecture's owned land]

- Research and development bases of National project on Hydrogen and Fuel Cells are growing in number in Yamanashi Prefecture.

University of Yamanashi


[Basic research・Technology transfer・Human resource development]

The results of their research and development have been contributing remarkably to the commercialization and penetration of residential fuel cells and fuel cell vehicles.

[Founded by NEDO]

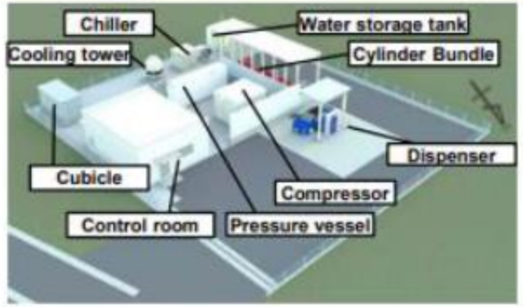
Yamanashi Pref. Industrial Technology Center


[Single cell tests for polymer electrolyte fuel cell]

Establishment of performance evaluation function as a third – party evaluation organization.

[Founded by NEDO]

Hydrogen Technical Center

[Equipment evaluation・Human resource development]

Technology development to reduce the cost of components.

[Founded by NEDO, Managed by HySUT]

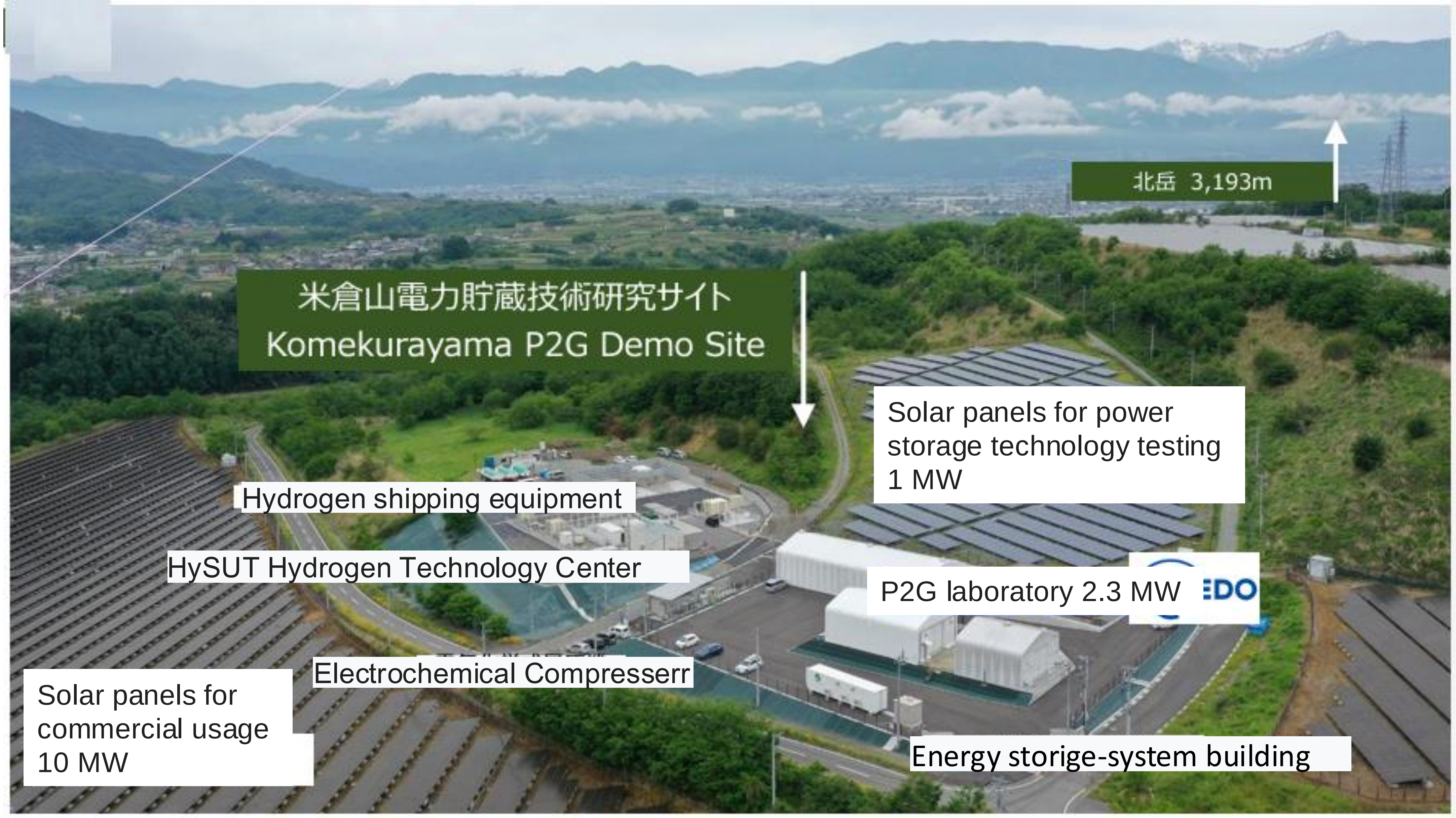
Electric Power Storage Technology site


[Power-to-Gas system demonstration]

Hydrogen production from photovoltaic.
→ Technological development of Power-to-Gas (P2G).

[Founded by NEDO]

Komikurayama P2G Demo Site Est. 2014



Prepared by Yamanashi Prefecture

Welcome to

University of Yamanashi

“Global Professionals at the Heart of the Community”

The University of Yamanashi aims to contribute to society by encouraging cutting-edge, international research that fuses medicine, engineering, and agriculture and lays the foundation for advanced education to develop human resources capable of meeting community needs and thriving on the global stage.

UNIVERSITY OF YAMANASHI

History of Hydrogen Research at University of Yamanashi, Japan

- From 1978, Japanese government has been continuously investing University of Yamanashi to promote education and research on Fuel Cell in Japan.
  (Ministry of Education (MEXT), Ministry of Economy, Trade and Industry (METI))
- University of Yamanashi is one of the largest R&D bases in Japan on the Fuel Cell materials (Electrocatalyst, Electrolytes, etc.).

1978 Ministry of Education: Fuel Cell experimental facility

2001 Ministry of Education: *Clean Energy Research Center*

2007 Ministry of Education: Special Education Program on Clean Energy

2008 Ministry of Economy, Trade and Industry:
Fuel Cell Nanomatrials Center (7 years NEDO Project)

2008 Ministry of Education: Graduate School Upgrading PJ

2011 Ministry of Education: Program for Leading Graduate Schools
Green Energy Conversion Science and Technology

2015 Ministry of Economy, Trade and Industry: *5 years NEDO Project*

2020 Ministry of Economy, Trade and Industry: *5 years NEDO Project*

Why Hydrogen?

Primary and Secondary Energy in Society

Primary Energy – Energy form found in nature

- Fossil fuels（Petroleum, Coal, Natural Gas, etc.)
- Nuclear energy（Uranium）
- Natural energy (Water, Wind, Solar, Geothermal, etc.)
- Biomass

Secondary Energy – Energy created from primary energy

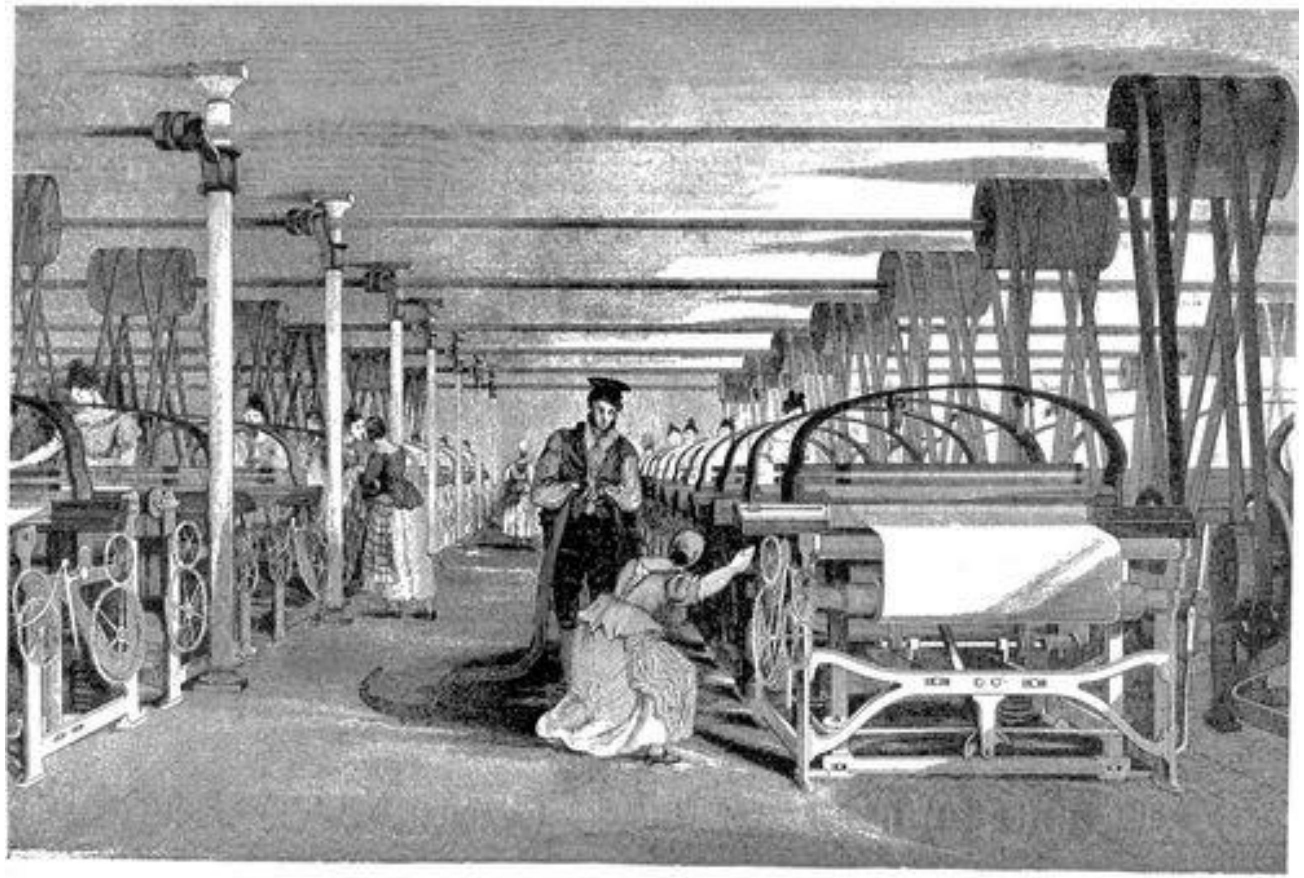
- **Heat**
- **Electricity**
- **Hydrogen**

Heat, Electricity, and Hydrogen are Convertible.

Use of “Heat” as a Secondary Energy

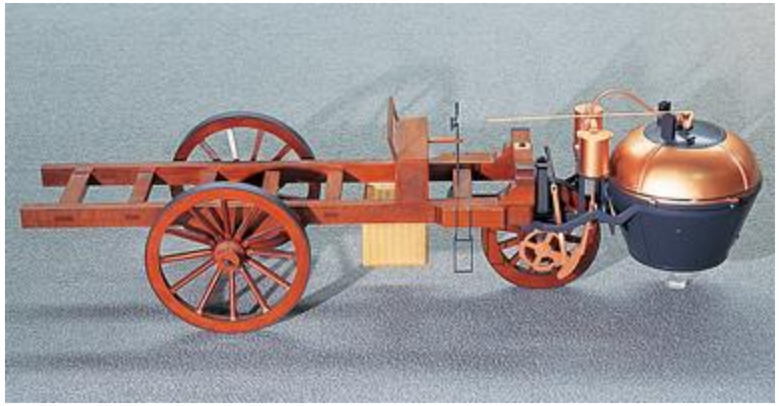
Industrial Revolution: 1760-1840

Heat to Kinetic Energy



Use of “Heat” as a Secondary Energy

Automobiles
Heat to Kinetic Energy



Steam Engine in 1769
Nicolas-Joseph Cugnot

Internal Combustion Engine in 1885
Gottlieb Wilhelm Daimler

Use of “Electricity” as a Secondary Energy

Hydro Power Plant: 1860

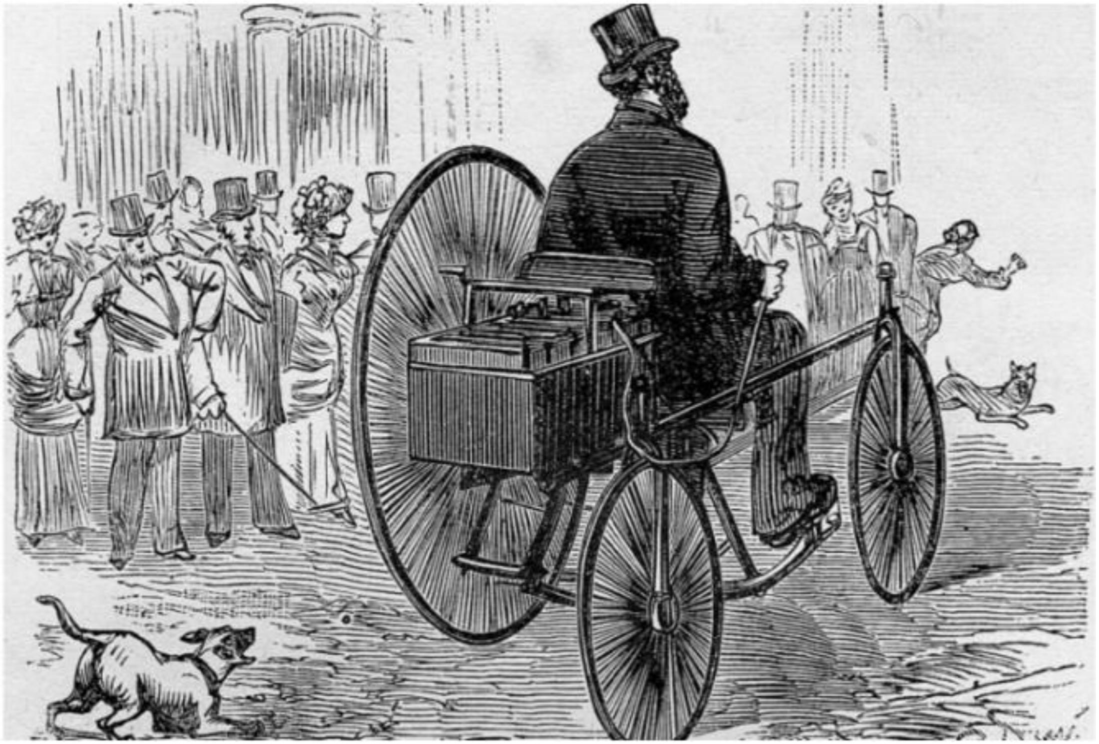
Electric Light: 1878

Coal Power Plant: 1882

Heat to Electricity

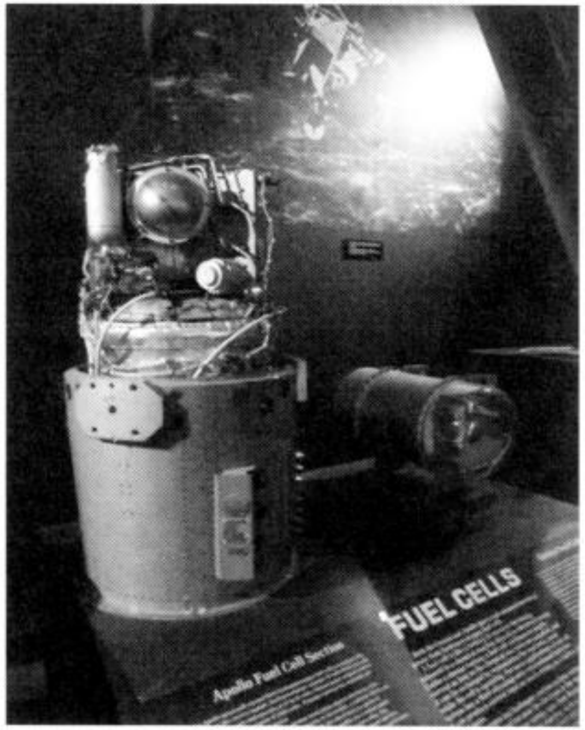
Edison Laboratory

Jedlik Ányos István 1828



Use of “Hydrogen” as a Secondary Energy

Fuel Cell in Gemini: 1965



Stationary FC System Ene-Farm: 2008

FC Car MIRAI: 2014

Hydrogen to Electricity

Racing car with IC Engine: 2021

Hydrogen to Heat

Advantages of hydrogen as a secondary energy

- No loss for longer time
- Carriable
- Natural Energy to Hydrogen
- No CO_2 emission

Hydrogen can be a commodity.

Hydrogen for liquid fuels

1. Ammonia
2. E-Fuel

to be discussed at the end of the talk.

Hydrogen Strategy of Japan

311 Great Earthquake

Tsunami on March 11, 2011

Fukushima Daiichi Nuclear Power Station after 9 years

山梨大学 UNIVERSITY OF YAMANASHI

Japan's Basic Hydrogen Strategy

Source: METI 2023

- **In 2017, Japan formulated the Basic Hydrogen Strategy, the world's first national strategy for hydrogen.**
  - ✓ **Annual hydrogen introduction** (including direct combustion ammonia): Current (approx. 2 million tons)) → 2030 (max. 3 million tons) → 2050 (approx. 20 million tons)
  - ✓ **Cost**: Current (100 yen/Nm^3) → 2030 (30 yen/Nm^3) → 2050 (20 yen/Nm^3 or less) (1Nm^3 = 0.0899kg)
- **On June 6, 2023, the Basic Strategy for Hydrogen was revised.**
  - ✓ Setting a new ambitious target of **12 million tons** of hydrogen and other resources to be introduced by **2040**.
  - ✓ Targeting installation of water electrolysers related to Japanese companies in Japan and abroad in **2030 (15 GW)**
  - ✓ Establishing a support system to build a large and robust supply chain and establish a base of operations.

Large scale power plants type
- Stand-alone gas / coal-fired power plants

Hekinan

Multifunction-intensive type
- Consolidation of petrochemicals, chemicals, steel mills, etc.

Kawasaki

Regional renewable energy production type
- Produce Hydrogen and Ammonia

Yamanashi

Japan's Policy Update

- Japanese government declared its ambition to reduce greenhouse gas emissions to net zero by 2050 in October 2020.
- METI formulated a "Green Growth Strategy Through Achieving Carbon Neutrality in 2050" including "Green Innovation Fund" for supporting 10 years R&DD activities (JPY 2 trillion).
- 1% Hydrogen/Ammonia are positioned in 2030 energy mix by 6th Japan's Strategic Energy Plan (October 2021)
- METI has established new committee to discuss on support measures for the hydrogen supply chain.

Direction: How to promote Hydrogen

NEDO

Goals Cost ($/kg): $3/kg by 2030 & less than $2/kg by 2050

		Short Term (- 2025) Approx. 2 million tons	Mid Term (- 2030) Max. 3 million tons	Long Term (- 2050) 20 million tons
Supply	Existing source (ex. By products)	Maximize utilization as major source	Decarbonization of hydrogen production (with CCUS)	
Supply	Import	Accumulation of knowledge and cost reduction through demonstration project	Development of large-scale international hydrogen supply chain	Further scale up through diversification of hydrogen source
Supply	New domestic source	Accumulation of knowledge and cost reduction through demonstration project	Start up hydrogen production by electrolysis using excess energy from renewables	Scale up hydrogen production by electrolysis, and realizing innovative hydrogen production technology
Demand	Transportation	Expansion to FC trucks in addition to FCVs and FC buses	Launch of ships (FC ships, etc.) to the market	Use of hydrogen and synthetic fuel for aviation
Demand	Power generation	Using of stationary fuel cell and small gas turbine for distributed energy	Commercialization of large-scale hydrogen power generation turbine	Further scale up and function as balancing power
Demand	Industry (raw material)	Conducting technology demonstration project (refinery, steel process, chemical process, etc.)		Realizing hydrogen steel process, green chemical, etc.
Demand	Thermal (Industry, business, household)	Substitute fossil fuels through installation of fuel cell and decarbonization of supply infrastructure using electrolysis and existing gas pipes		Expanding supply through infrastructure development and hydrogen cost reduction

Source: METI

Step by Step approach

Hydrogen in Energy System

Step 3: Widely use of H_2

FCV & HRS

Step 2: Direct use of H_2 as energy source
(Marketization in 2014)

Residential Fuel Cell

Step 1: Bring Fuel Cell Application into the Market
(Marketization in 2009)

ENE·FARM

出典） 岩谷産業

How to Import Hydrogen to Japan

Hydrogen Production in Australia

Hydrogen from brown coal (lignite) produced by J-Power in 2021.

Hydrogen Carrier “Suiso Frontier”

116 m, 8000 tons

1250 m^3 or 75 tons of hydrogen

Kawasaki Heavy Industries’ world-first liquid hydrogen carrier in 2019.

https://youtu.be/WGPkSuIH7uA

Hydrogen Production in Norway

Kawasaki Heavy Industries (KHI) has been looking at using brown coal from the Australian state of Victoria, where supplies are plentiful. However, it is hedging its bets with a project in Norway to derive hydrogen using power from hydroelectric dams and eventually wind farms.

Using Australian coal requires removing its climate-changing carbon and burying it in old oil or gas wells there.

In Norway, KHI has teamed up with Nel Hydrogen, a maker of hydrogen plants, with backers including Japan’s Mitsubishi Corp and Norway’s Statoil. The project aims to demonstrate that liquefied hydrogen can be produced using renewables and delivered to Japan on tankers.

ELSEVIER

International Journal of Hydrogen Energy

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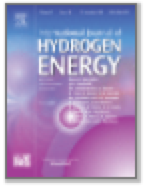
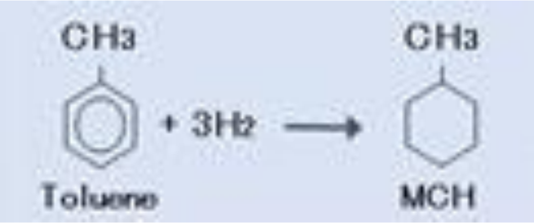


Large-scale production and transport of hydrogen from Norway to Europe and Japan: Value chain analysis and comparison of liquid hydrogen and ammonia as energy carriers

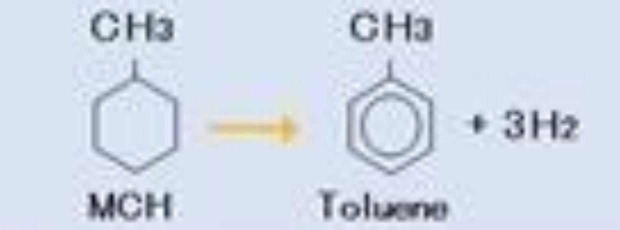
Yuki Ishimoto [a], Mari Voldsund [b], Petter Nekså [b], Simon Roussanaly [b], David Berstad [b], Stefania Osk Gardarsdottir [b]

Hydrogen Production in Brunei

Hydrogen production from natural gas / hydrogenation plant in Brunei in 2019



Hydrogen separation in Japan in 2020



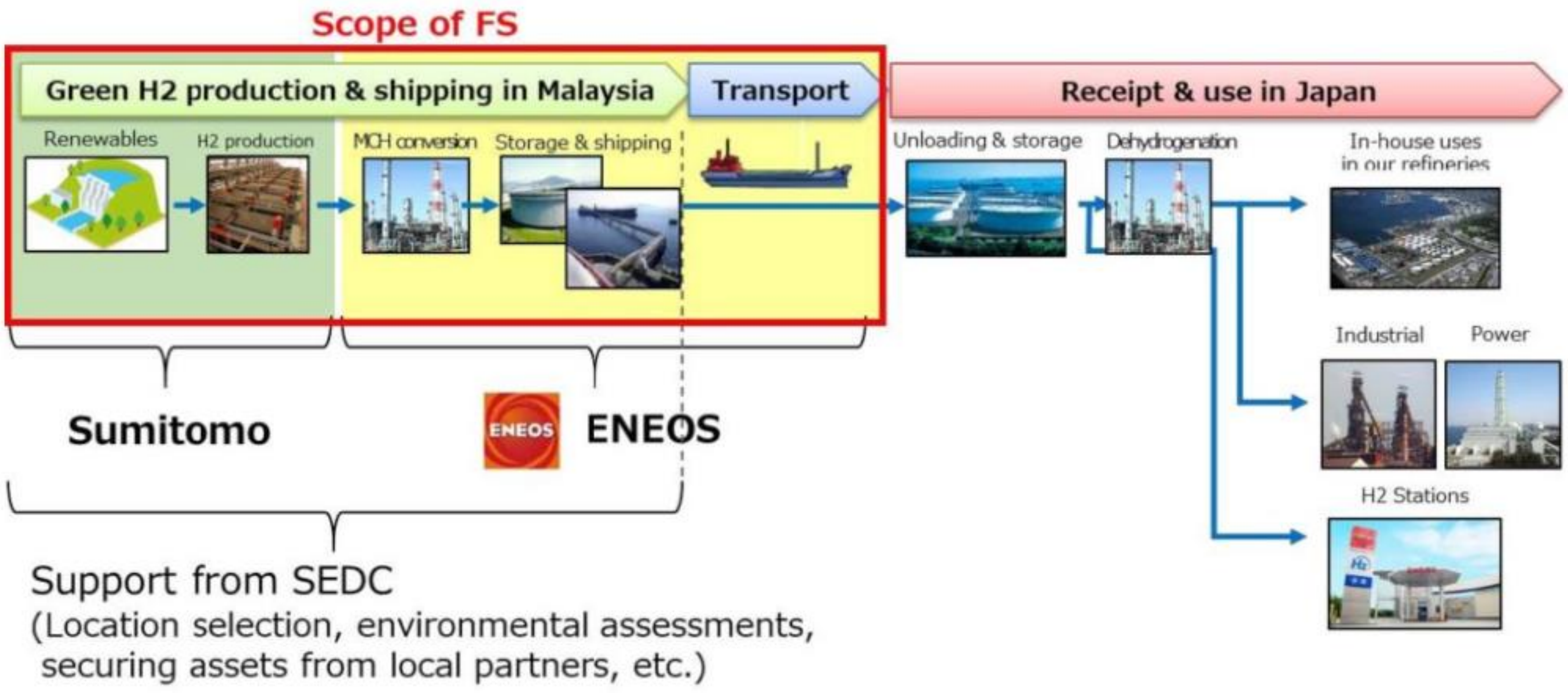
Hydrogen Production in Malaysia

Jera will begin ammonia production free of carbon dioxide emissions through a partnership with a Malaysian state-owned enterprise, PETRONAS.
The two have agreed to use renewable energy, like hydropower, to manufacture ammonia without releasing CO_2. Further details on the production site, as well as production capacity, will be determined at a later date. (February 8, 2021)

ENEOS, Sumitomo and SEDC Energy will start a feasibility study in January 2021, looking at the establishment of a supply chain of green hydrogen produced **using power from hydroelectric power plants in Sarawak**, ENEOS officials said.

SEDC Energy is a wholly owned subsidiary of Sarawak Economic Development Company (SEDC), which manages energy businesses, including downstream petroleum and gas businesses.

The study will look at the production of several tens of thousands of metric tons a year of green hydrogen and converting it into **MCH**. Based on results of this collaboration, ENEOS, Japan's largest refiner, will assess the feasibility of using the transported dehydrogenated CO_2-free hydrogen for desulfurization at its refineries in Japan, the officials said.



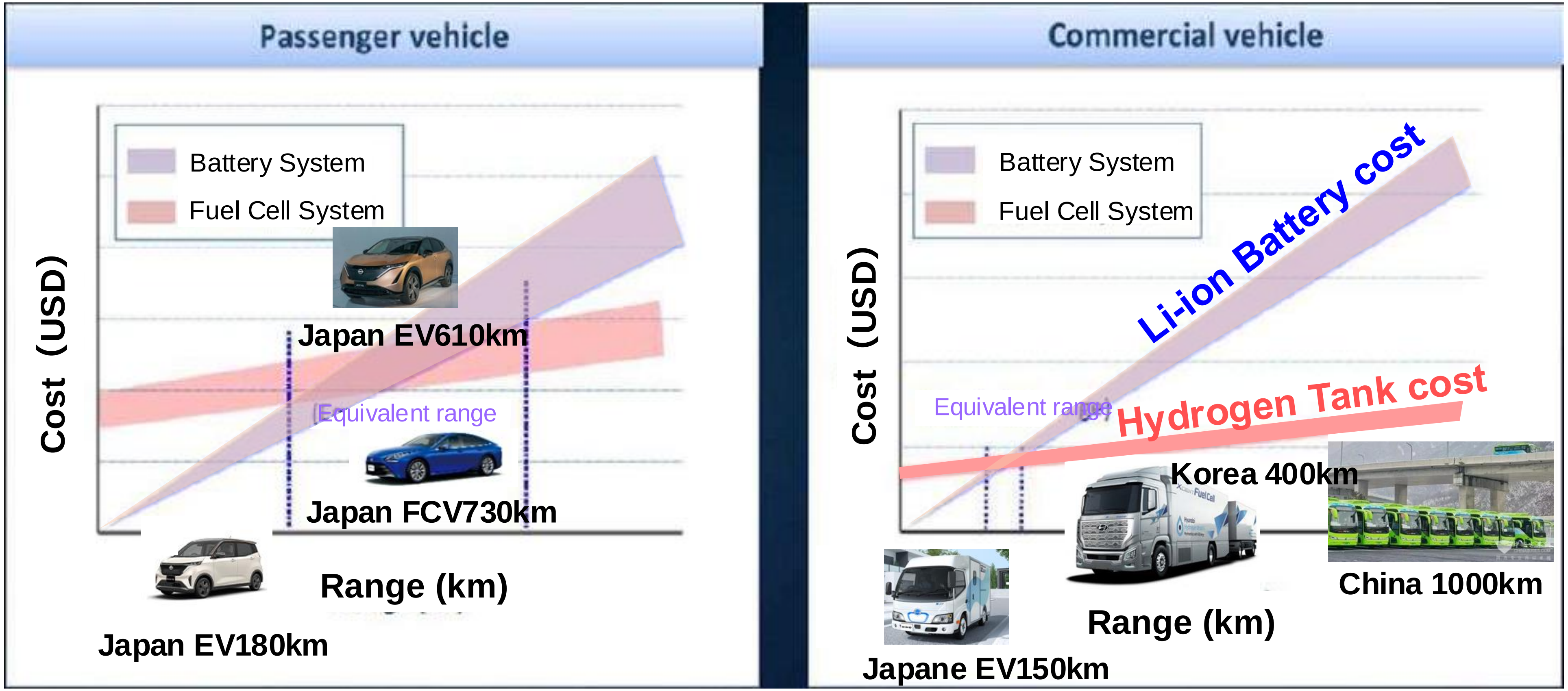
Hydrogen Production in and Transportation from Four Countries

	Australia	Norway	Brunei	Malaysia
Primary Energy	Lignite	Hydro Wind	Natural gas	Hydro Biomass?
CO_2 Capture	Yes	No	Yes	No
Transportation	Liquid H_2	Liquid H_2	MCH	Ammonia MCH

Status of Hydrogen Vehicles

EV and FCV

- For passenger cars, BEVs and FCVs have a wide range of similar cost.
- For commercial vehicles, FCVs have longer ranges with lower cost.



Cost： FC：Fuel Cell System ＋2ndary Battery ＋H2 Tank、 Battery System：Battery System
Source： Hydrogen Cabinet Meeting 2018 based on Hyundai Motor material

Items		Japan's Target (in 2030)	Current status (as of July 2022)
Stationary Fuel Cell			
	Regidential Fuel Cell (EneFarm)	5.3 million	439,852 (June 2022)
Mobility			
	Passenger Vehicles	800,000	7,418
	Fuel Cell Buses	1,200	120
Hydrogen Refueling Station			
	Public Stations	900	160



Step by Step approach

NEDO


Hydrogen in Energy System

Step 3: Widely use of H_2

FC Automobiles

Sales in 2023		Domestic 国内	Exported 輸出	Sum 合計
Hyundai	NEXO	10,160	360	10,530
Toyota	MIRAI	850	3,080	3,920

Approximately 50,000 units in all

Number of Hydrogen Stations in 2024

Korea 290, Japan 161

FC Automobiles until November 2023 in China

17,943 units, mostly heavy-duty vehicles

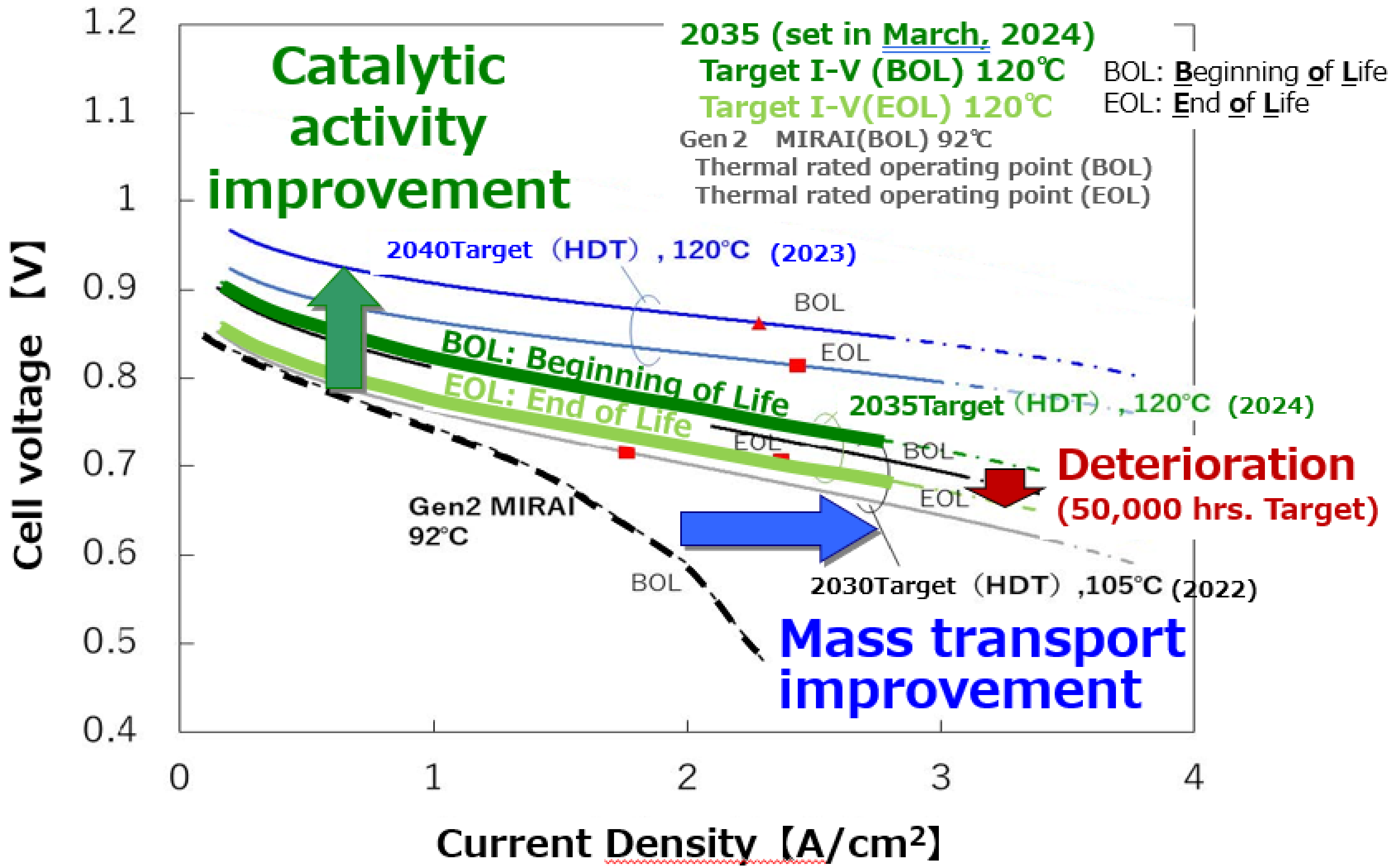
Number of Hydrogen Stations 358

FC automobile developments are now toward HDVs

山梨大学 UNIVERSITY OF YAMANASHI NEDO FC Technology Road Map for HDVs

■ Targeted performance and durability for HDVs

NEDO FC Technology Road Map Committee : Chairman : Akihiro IIYAMA

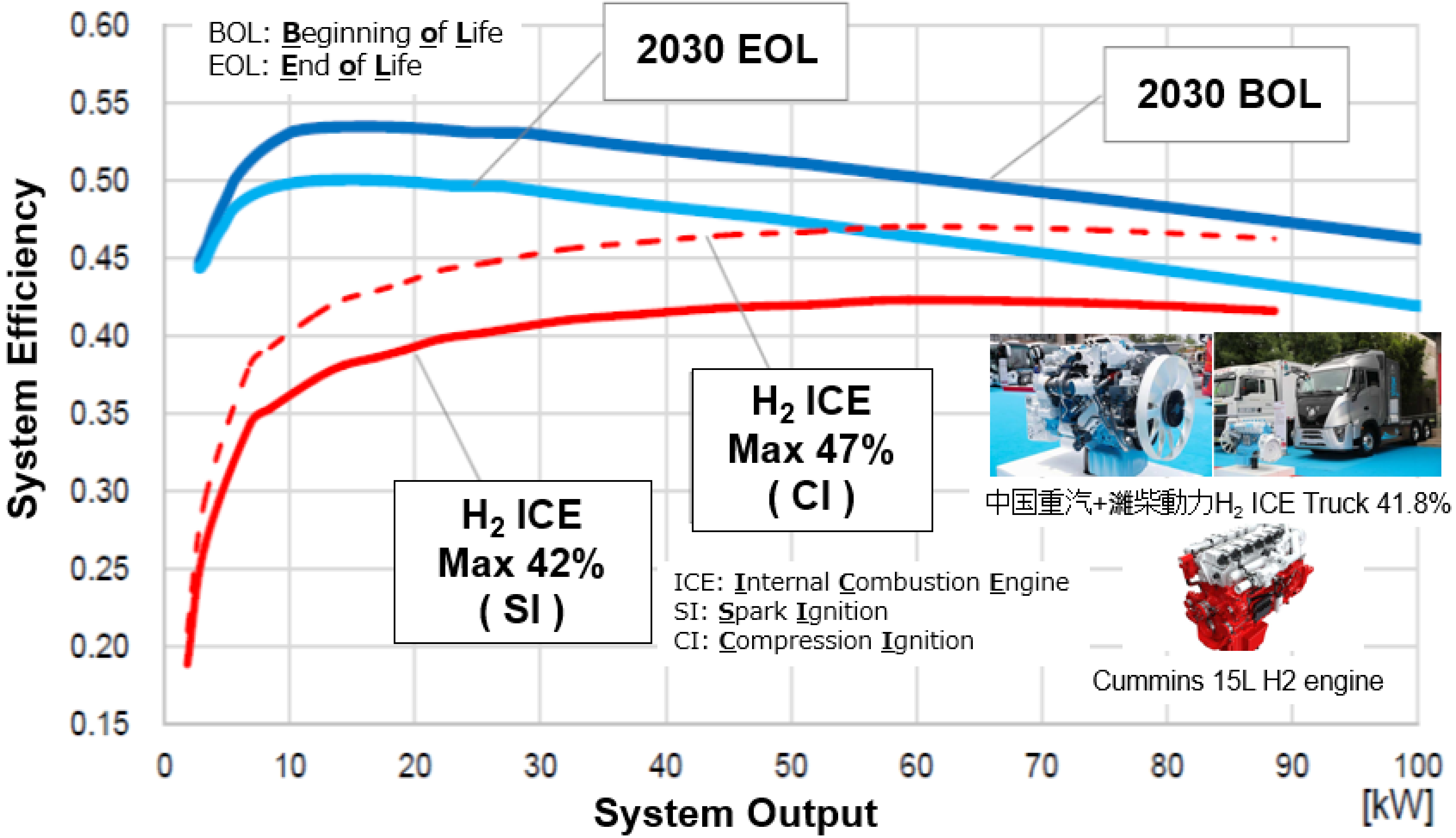


Source : https://www.nedo.go.jp/content/100973009.pdf

Hydrogen, Ammonia and E-fuel for Engines

System efficiency comparison FC vs ICE

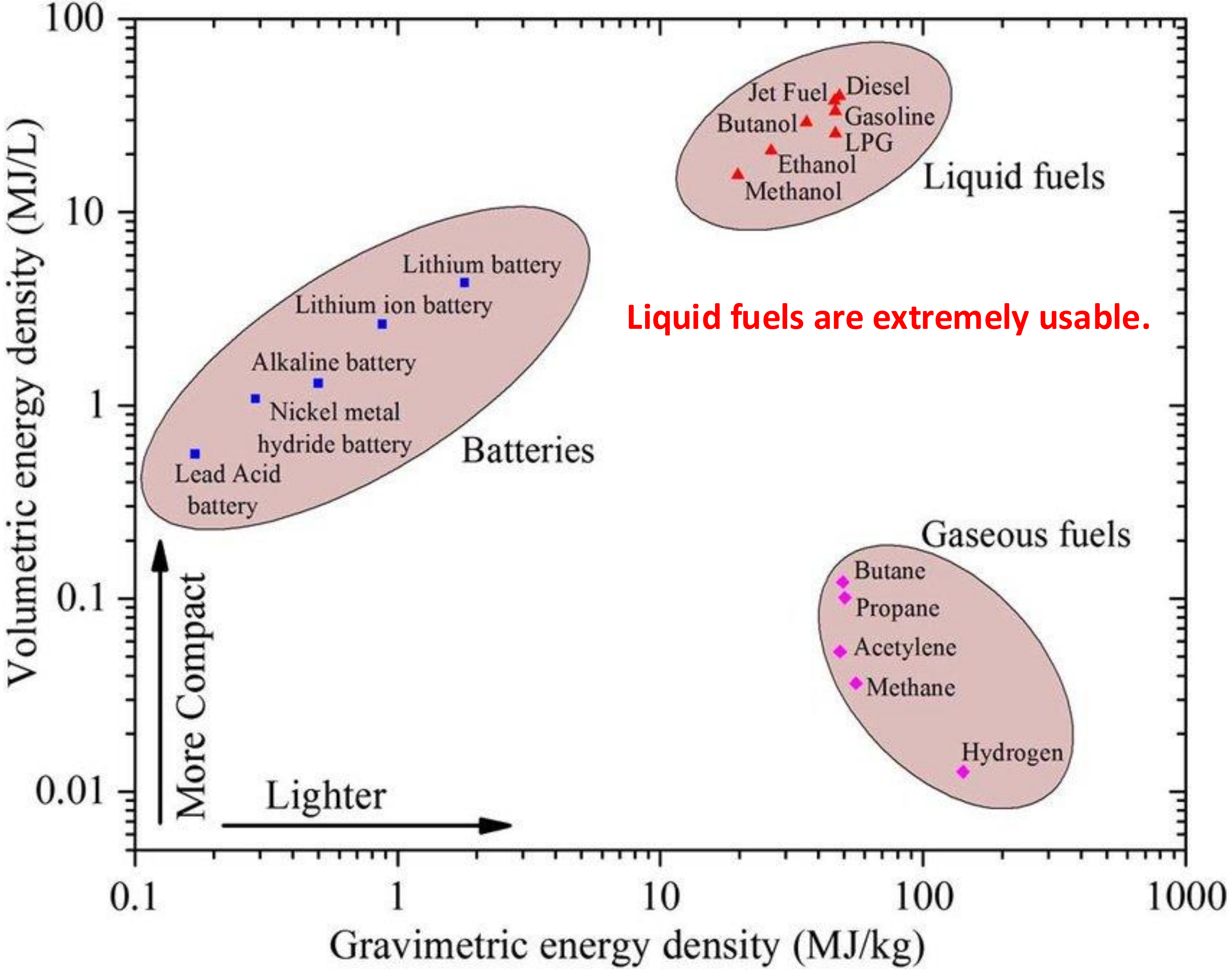
- Efficiency is competitive with hydrogen engines in the high-load range. Fuel cell efficiency must be improved t



Source: NEDO FC Technology Roadmap(https://www.nedo.go.jp/content/100944011.pdf)

Ammonia is very easy to carry

Ammonia engine for automobiles are studied, but for the use of the ammonia engine, need to be solved the leakage and the formation of NO_X.



Volumetric and gravimetric energy density of liquid fuels are the highest.

Basic synthesis method of E-Fuel has been established.

Green Hydrogen and CO_2 are required.

No increase of CO_2 in the atmosphere.

Little change in automobile production.

Very suitable to long-flight airplanes

Cost is high (ca. 7 EUR / L).

Green Hydrogen and CO_2 (Possibly from biomass or atmosphere)

Conclusions

1. Importance, present status, and road map of hydrogen use until 2050 In Japan were summarized.

2. Hydrogen will be used for fuel cell vehicles and ICE vehicles.

3. Ammonia will be used during transportation and in power stations. For automobile use is not yet clear.

4. E-fuels will be possibly used after 2050 for ICSs.

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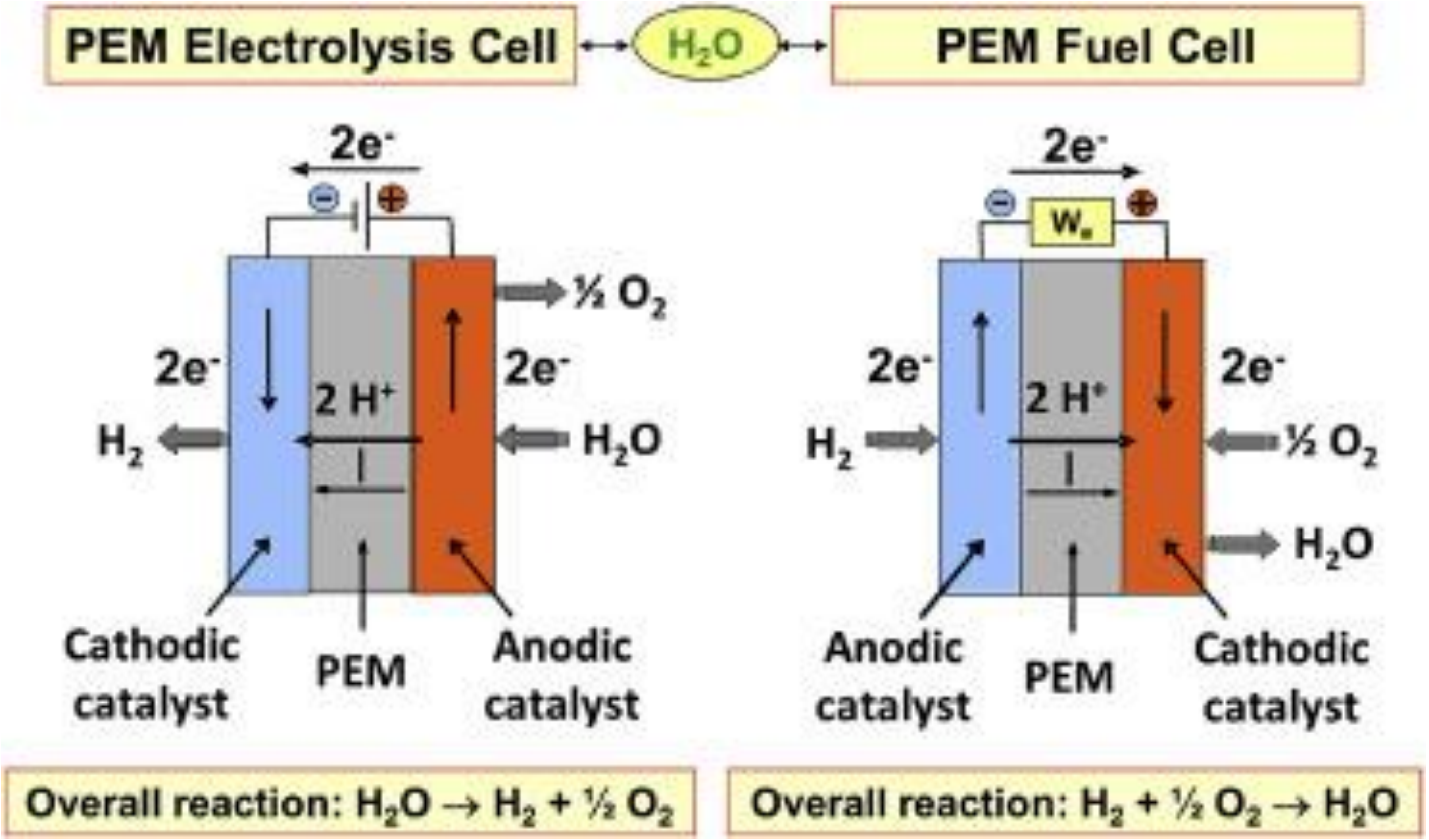
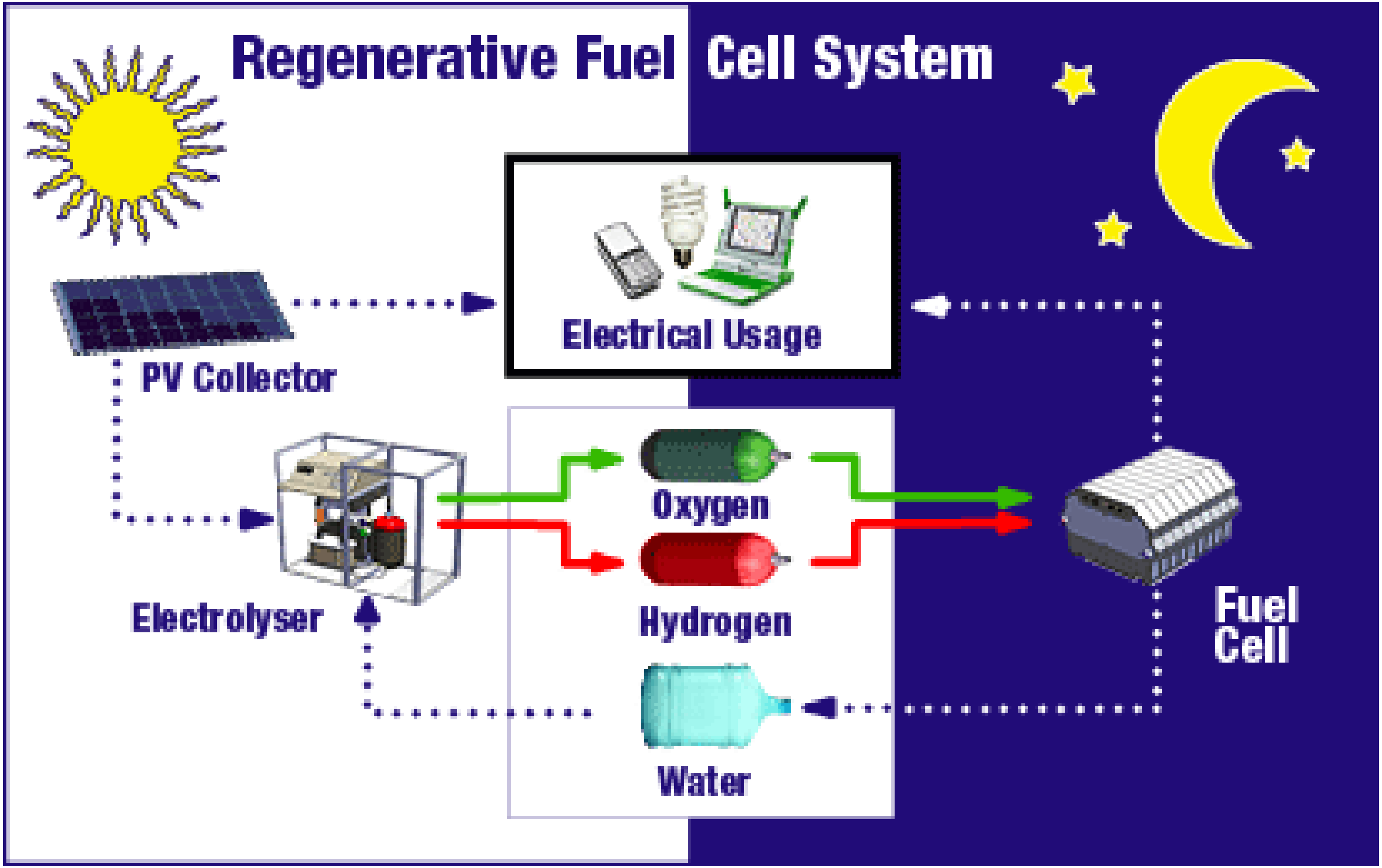
UNIVERSITY OF YAMANASHI
地域の中核 世界の人材

Thank you for your attention!

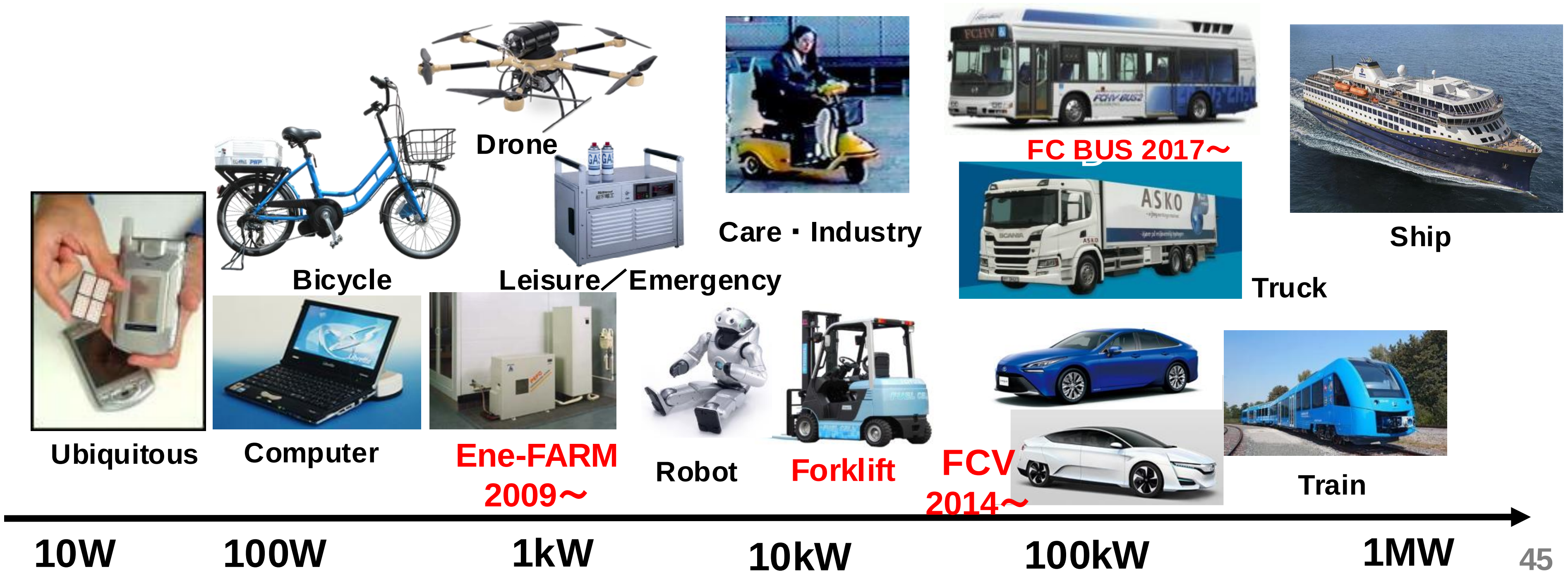

PEM Electrolysis Cell
H2O
PEM Fuel Cell
2e-
2e-
2 H+
H2
½ O2
H2O
Cathodic catalyst
PEM
Anodic catalyst
Overall reaction: H2O → H2 + ½ O2
W
Anodic catalyst
Cathodic catalyst
Overall reaction: H2 + ½ O2 → H2O

Electrolyzer and Fuel Cell


Regenerative Fuel Cell System
Electrical Usage
PV Collector
Oxygen
Hydrogen
Electrolyser
Fuel Cell
Water

Fuel Cells

- **Efficient** Higher efficiency than Thermal power generation
  - **Fuel Cell** : about **60%**
  - Thermal Power plant : about 40%
- **Various applications under development**



Residential Fuel Cell System and Fuel Cell Vehicle

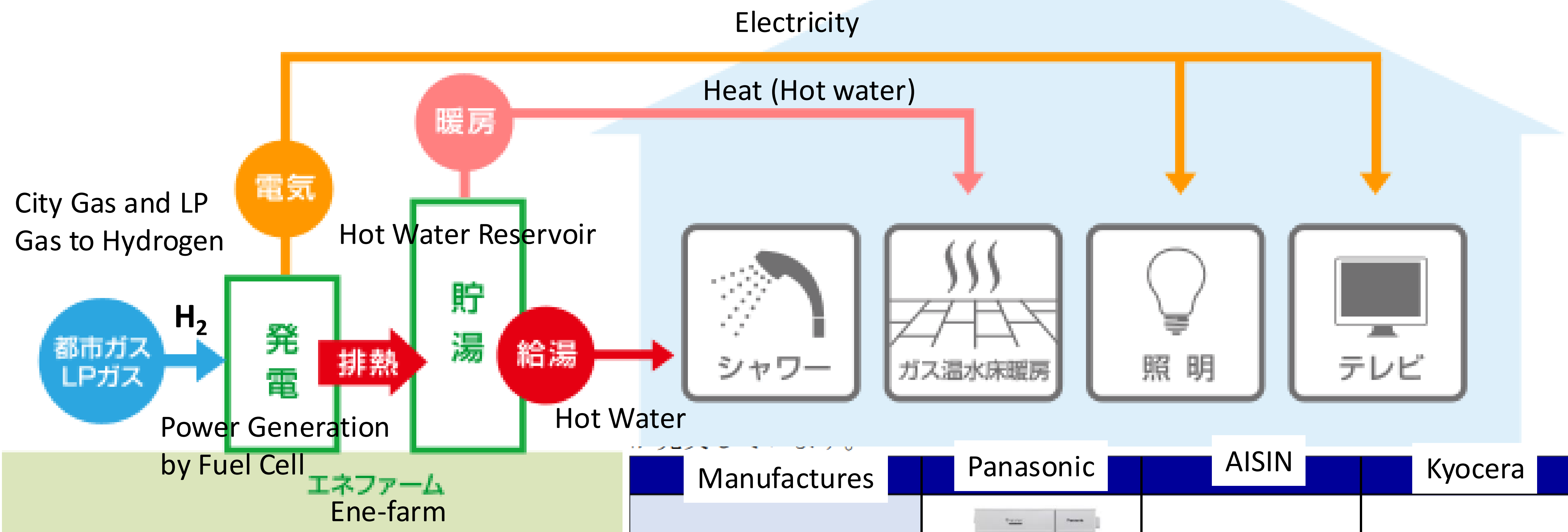
Toyota MIRAI

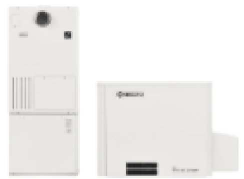
Panasonic Ene-farm

Three companies sell Ene-farm in 2024.

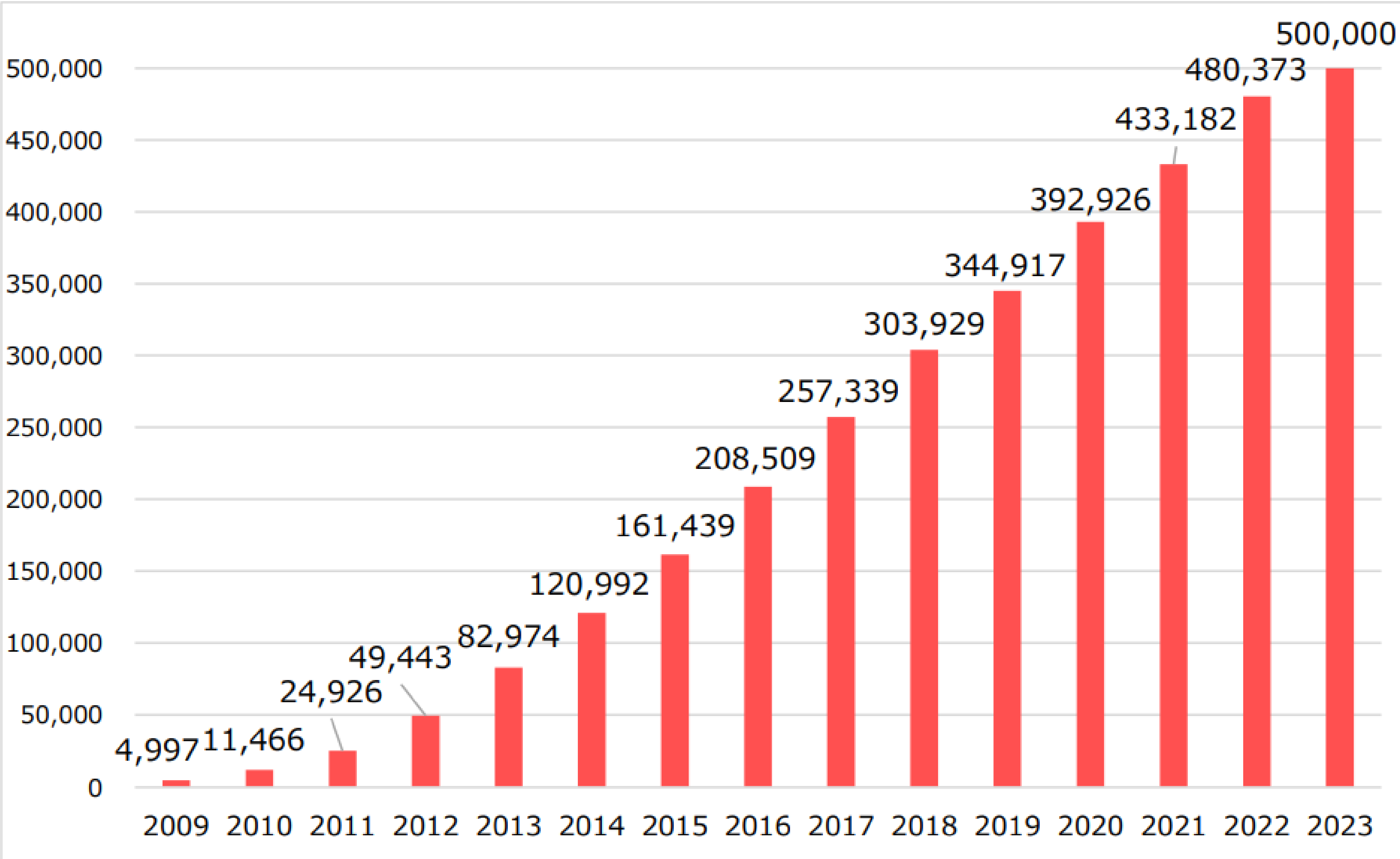
Two Japanese companies sell FCV in 2024.

Residential Fuel Cell



Manufactures	Panasonic	AISIN	Kyocera
Outlook			
FC type (Output) ※7	PEFC（700W）	SOFC（700W）	SOFC（400W）
Electricity/Total Efficiency	41.0%/98.0%	55.0%/87.0%	50.0%/85.0%
Gas	City/LP	City/LP	City

Ene-Farm Sales until November 2023

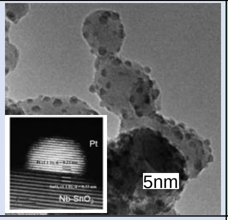
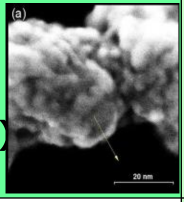
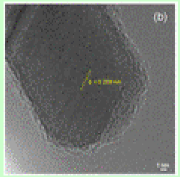
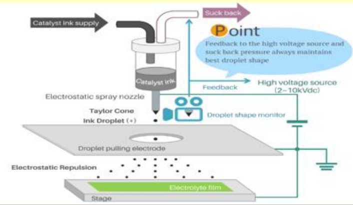
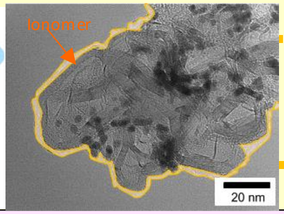
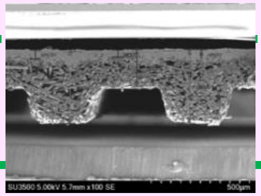


Ene-Farm Partners

Research in University of Yamanashi

Hydrogen and Fuel Cell Nanomaterials Center

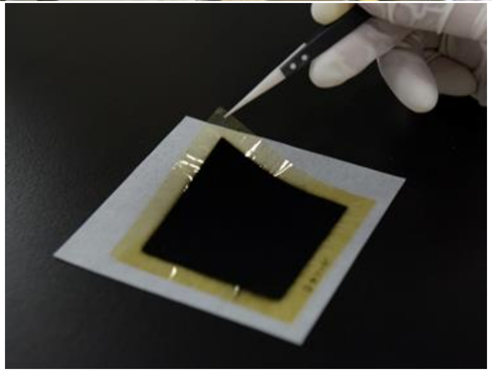
Research areas on H_2, FCs, and Electrolyzers

	PEM-FC	PEM-WE	AEM-WE
Catalyst	**Pt/Pt alloy catalyst** with ceramics or carbon supports 	**IrO_2 catalyst** with higher activity (→ reduced loading) 	**Non-Precious Metal** Catalyst 
Electro-lyte	**PEM** hydrocarbon -based membranes, ionomers and reinforcement layers 		**AEM** hydrocarbon-based membranes, ionomers and reinforcement layers
MEA	**Mechanism analysis** for degradation, & performance improvement 	**Mechanism analysis for degradation,& performance improvement**	**Design of water electrolysis MEAs and their high performance and durability**
Process	**Electro-Spray coating method**  		
Others	**Flat Metal Separator with Grooved GDL** 		

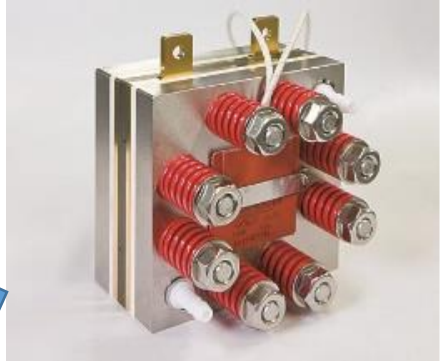
Fuel Cell and Electrolyzer Researches

- Fuel cell prototyping and evaluation capabilities
  - the most fulfilling of all Japanese universities.
- Possible to synthesize catalyst and electrolyte membranes, prepare catalyst coating membranes, assemble various cells, and evaluate performance and durability in one building.

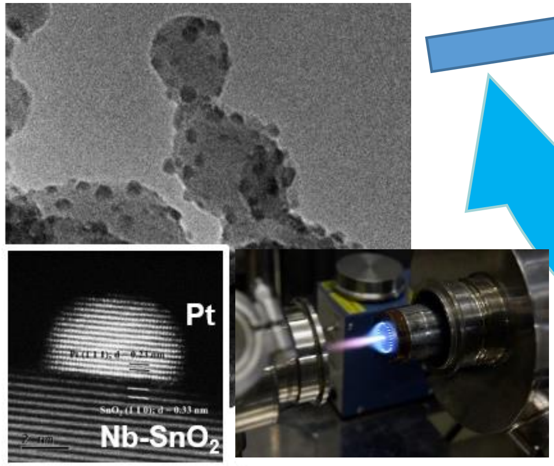
Synthesized electrolyte membrane



Catalyst coated membrane



Assembled single fuel cell



Synthesized ceramic support and supported Pt catalyst

Single fuel cell test stands

Materials development for FC-HDVs