Annex 1

Lecture on Hydrogen for Mongolian Energy Experts

4 March 2024

Lecture on Hydrogen for Mongolian Energy Experts

March 4, 2024

Tokyo Office, Chiyoda Corporation

Agenda

10:00~10:40	1. What is hydrogen/fuel ammonia?
	(1) Definition of hydrogen
	(2) Color of hydrogen
	(3) Characteristics of hydrogen carriers
	(4) Safety regulations
	(5) Market trend
10:45~11:25	2. How to produce hydrogen/fuel ammonia?
	(1) Existing production technology
	(2) Future production technology
11:30~12:00	3. How to storage and transport hydrogen/fuel ammonia?
	(1) Storage method
	(2) Transportation methods
13:00~13:25	4. How to use hydrogen/fuel ammonia?
	(1) Use application
	(2) Technology development for usage application
13:30~14:10	5. Hydrogen/fuel ammonia value chain in EAS region
	(1) Value chain approaches
	(2) Ongoing hydrogen/ammonia value chain projects
14:15~14:40	6. Introduction of hydrogen projects led by Japan
14:45~15:00	7. Cost of hydrogen production and supply

1. What is hydrogen/fuel ammonia?

(1) Definition of hydrogen

- Hydrogen is the lightest and most abundant element in the universe, constituting about 75% of its elemental mass.
- Hydrogen is a colorless, odorless, and tasteless gas that is highly flammable and can react explosively with oxygen.
- Hydrogen is commonly found in compound such as water, natural gas, coal, petroleum and biomass.
- Hydrogen is commonly used in various industrial processes, including the production of ammonia, methanol, and petroleum products.
- Hydrogen also has potential as a clean and renewable energy source, as it can be used in fuel cells to generate electricity with only water as a byproduct.

ISO (International Organization for Standardization) has established several standards related to hydrogen. ISO 14687 provides guidelines for the quality of hydrogen fuel. ISO 14687-2 specifically focused on the purity requirements for hydrogen fuel, including limits for impurities such as moisture, carbon dioxide, carbon monoxide, sulfur components, and other contaminants. This standards ensures that hydrogen fuel meets certain quality criteria for safe and efficient use in various applications, including fuel cell vehicles and other hydrogen-powered technologies.

1. What is hydrogen/fuel ammonia?

(2) Color of hydrogen

・Hydrogen is an invisible gas, but depending on the type of production used, different color names are assigned to the hydrogen.
・They are essentially color codes, used within the energy industry to differentiate between the types of hydrogen.
・These color definitions may change over time, and even between countries.

Green hydrogen is made by using clean electricity from renewable energy sources, such as solar or wind power, to electrolyse water, emitting zero-carbon dioxide.
Blue hydrogen is produced mainly from natural gas, using a process called steam methane reforming with by-product of carbon dioxide. The definition includes the use of carbon capture and storage (CCS) to trap and store this carbon.
Gray hydrogen is the most common form of hydrogen production. Gray hydrogen is created using steam methane reforming but without capturing the carbon dioxide in the process.
Turquoise hydrogen is made using a process called methane pyrolysis to produce hydrogen and solid carbon. Turquoise hydrogen may be valued as a low-emission hydrogen, dependent on the thermal process being powered with renewable energy and the product carbon being permanently stored or used.

1. What is hydrogen/fuel ammonia?

Black and brown hydrogen are made by using black coal or lignite (brown coal) in the hydrogen-making process through gasification. These hydrogen are the absolute opposite of green hydrogen in the hydrogen spectrum and the most environmentally damaging.

Pink hydrogen is generated through electrolysis powered by nuclear energy. Nuclear-produced hydrogen can also be referred to as purple hydrogen or red hydrogen.

Yellow hydrogen is a relatively new phrase for hydrogen made through electrolysis using solar power.

White hydrogen is a naturally occurring, geological hydrogen found in underground deposits and created through fracking.

1. What is hydrogen/fuel ammonia?

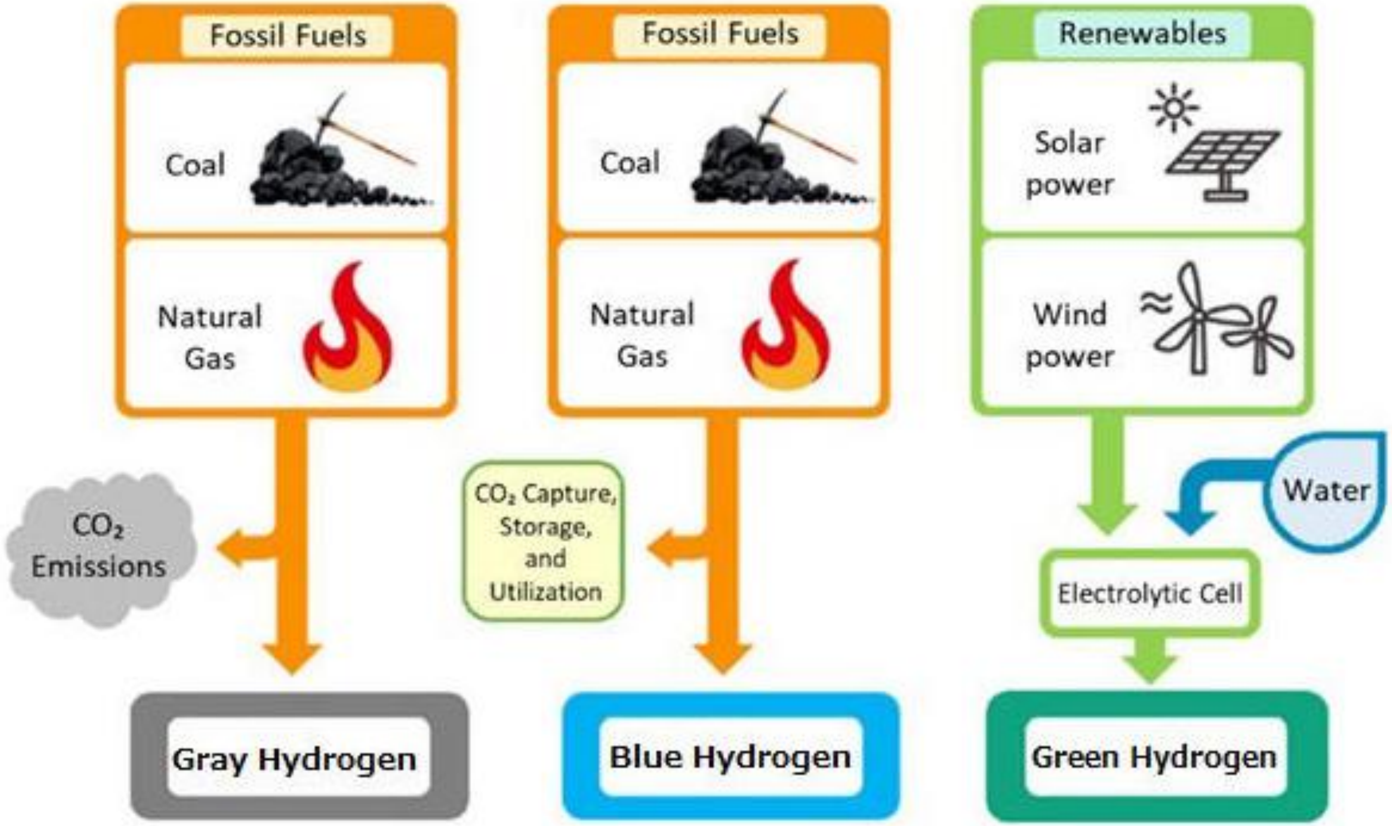
Hydrogen color spectrum

Energy/feedstock		Technology	Color	2021 global production[5]	2020 EU production capacity[6]
Fossil fuels or biofuels	Natural gas	Steam methane reforming (SMR) or autothermal reforming (ATR)	Gray	58 Mt (62%)	10 Mt (91%)
		Methane/biogas pyrolysis	Turquoise	–	
	Black coal	Coal gasification (CG) or partial oxidation (PO)	Black	18 Mt (19%)	
	Brown coal		Brown		
	Fossil fuels	SMR, ATR, CG or PO with carbon capture and storage (CCUS)	Blue	660 kt (0.7%)	58 kt (0.5%)
Electricity	Nuclear	Water electrolysis	Pink	35 kt (0.04%)	12 kt (0.1%)
	Mixed-origin grid		Yellow		
	Renewable		Green		
Natural H_2	Water	Natural resource	White	–	–

Source: The Hydrogen Series – Part 1 Report "Transitioning towards Low-Carbon Hydrogen Production, HAL open science, May 2023

1. What is hydrogen/fuel ammonia?

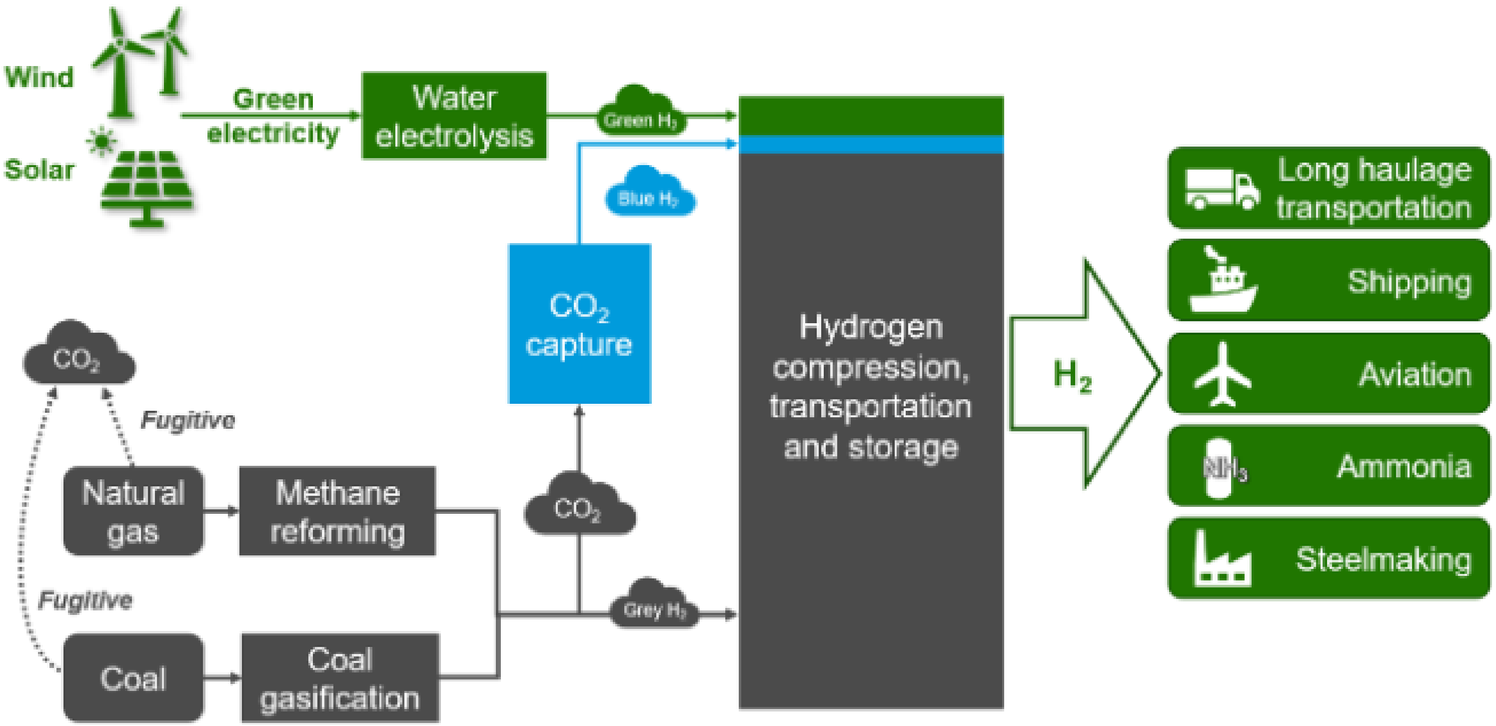
Conceptual diagram of gray, blue, and green hydrogen



Source: https://sj.jst.go.jp/stories/2023/s0626-01p.html (provided by the Agency for Natural Resources and Energy)

1. What is hydrogen/fuel ammonia?

Gray hydrogen dominates current hydrogen production



Source: https://sustainability.crugroup.com/article/energy-from-green-hydrogen-will-be-expensive-even-in-2050

1. What is hydrogen/fuel ammonia?

(3) Characteristics of hydrogen carriers

LOHC, Liquid Hydrogen and Ammonia are all promising hydrogen carriers, each with its own set of advantages and challenges.

■ LOHC (Liquid Organic Hydrogen Carrier)

・LOHC is a type of hydrogen carrier that stores hydrogen in the form of a liquid organic compound.
・It has a high hydrogen storage capacity, typically around 6-8% by weight.
・LOHC is stable and non-toxic, making it safe to handle and transport at ambient conditions and can use existing petroleum-related facilities.
・It can release hydrogen on demand through a catalytic process, allowing for efficient and controlled hydrogen release.
・LOHC is recyclable, meaning the liquid organic compound can be reused multiple times without significant degradation.
・It has a lower energy density compared to liquid hydrogen but provides a more practical and safer method of hydrogen storage and transportation.
・MCH (Methylcyclohexane C_7H_{14}) is one of the representatives of LOHC. The practical applications of the hydrogen supply chain by MCH is being actively pursued by Chiyoda Corporation.

1. What is hydrogen/fuel ammonia?

Global Hydrogen Supply Chain Demonstration Project using MCH

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 towards realizing a decarbonized society.

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*

*1 AHEAD Advanced Hydrogen Energy chain Association for technology Development with Chiyoda Corporation, Mitsubishi Corporation Mitsui &Co Ltd and Nippon Yusen Kabushiki Kaisha as members.
*2 NEDO New Energy and Industrial Development Organization for the Development and Realization of a Hydrogen Society “Demonstration of the Hydrogen Supply Chain by the Organic Chemical Hydride Method Utilizing Unused Energy“

1. What is hydrogen/fuel ammonia?

■ **Liquid Hydrogen**

・Liquid hydrogen is stored at extremely low temperature (-253℃) to maintain its liquid state, which requires specialized cryogenic equipment and can be costly and challenging.

・It has a very high energy density, allowing for a larger amount of hydrogen compared to other hydrogen carriers.

・It is highly flammable and requires careful handling and safety precautions.

・The production and transportation of liquid hydrogen can be energy-intensive and expensive.

■ **Ammonia**

・Ammonia can be stored and transported as a liquid at moderate pressures and temperature, having a lower energy content per unit volume compared to liquid hydrogen.

・It has a high hydrogen content, with approximately 17.6% hydrogen by weight.

・It has a relatively low energy density compared to liquid hydrogen but is still higher than LOHC.

・The storage and handling of ammonia requires certain safety precautions due to its toxicity and flammability.

・Large-scale ammonia cracking, necessary for the use as H_2, is not yet well-established and needs further development.

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1. What is hydrogen/fuel ammonia?

Carrier Comparison Table

Blue : Pros **Red :** Cons

	LOHC - MCH	NH3	LH2
H2 Compaction	**1/500**	**1/1300**	1/800
Liquid Phase @	**Ambient**	- 33 deg-C	**- 253 deg-C**
Leakage Risk (Fire)	Moderate	Moderate	**High**
Leakage Risk (Toxic)	Moderate	**High**	**Low**
Technology Readiness	**Ready** (Large scale)	**Ready (Direct Use)** Around 2030 (Cracking)	2030 - 35 (Large scale)
H2 Purity	Above 99.8%-H_2 (FCV grade after PSA)	**75%-H_2 + 25%-N_2 (FCV grade after PSA)**	**99.999%-H_2 (FCV grade)**
Reaction Condition	**(To MCH) below 250 deg-C below 1MPa** (To H2) 350 - 400 deg-C below 1 MPa	**(To NH3) 400 - 500 deg-C 10-30 MPa (To H2) 700 - 950 deg-C below 1 MPa or above**	**(To LH2) -253 deg-C above 1 MPa (To H2) -253 to Ambient 1 MPa to high pressure**
Infrastructure	**Abundant existing petroleum infra.**	**Limited** existing LPG/NH3 infra.	**New dedicated LH2 infra.**

Source: Chiyoda Corporation

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1. What is hydrogen/fuel ammonia?

(5) Safety Regulations

■ Introduction of current safety and environmental regulations for hydrogen production, transport and consumption in Japan

□ High Pressure Gas Safety Law

- Among the laws and regulations applicable to hydrogen, the "High Pressure Gas Safety Law" plays a central role.
- It regulates the production, storage, sale, movement, and other handling and consumption of high-pressure gases, as well as the production and handling of containers.

□ Other laws related to hydrogen safety

- Fire Service Law (ex. storage and transportation of MCH and Toluene)
- Building Standards Law (ex. Hydrogen Refueling Station)
- Petroleum Complex Disaster Prevention Act
- Road Transport Vehicle Law
- Road Traffic Law

1. What is hydrogen/fuel ammonia?

(5) Safety Regulations

■ Interim Report on Hydrogen Security Strategy in Japan

· On March 23, 2023, the Ministry of Economy, Trade and Industry(METI) compiled an interim report on the Hydrogen Safety Strategy based on discussions at the Study Group on the Formulation of the Hydrogen Safety Strategy.

□ Main contents of the report

In the interim report, three action plans and nine specific measures have been presented in order to build a rational safety regulation system.
In addition, a technology map and process chart for hydrogen safety have been compiled.

□ Technology map

They have organized international standards in the hydrogen field based on the official ISO/IEC website. The number of standards is ISO: 77 , IEC: 30 .
(ISO: International Organization of Standardization, IEC: International Electrotech nical Commission)

The standards were organized into eight categories: general, manufacturing, storage and transportation, transportation sector, power generation sector, industrial sector, civil sector, and others.

Source: Report of the Study Group on the Formulation of Hydrogen Safety Strategy, METI,Japan (2023)

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1. What is hydrogen/fuel ammonia?

(5) Safety Regulations

■ Issues surrounding hydrogen safety in major countries

□ Manufacturing Stage

・In the EU and Germany, the Industrial Waste Directive (IED) requires industrial-scale procedures, including impact assessment, regardless of the scale of production.

・The Environmental Impact Assessment Directive (EIAD) may impose the same requirements on chemical manufacturing plants that emit other hazardous substances, regardless of the manufacturing method or process.

・Construction of facilities such as water electrolysis is limited to industrial areas.

□ Storage Stage

・In the United States, regulations similar to the Pipeline and Hazardous Materials Safety Administration's (PHMSA) new safety regulations for underground natural gas storage facilities may be introduced for underground hydrogen storage facilities.

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Source: Report of the Study Group on the Formulation of Hydrogen Safety Strategy, METI,Japan (2023)

1. What is hydrogen/fuel ammonia?

■ Issues surrounding hydrogen safety in major countries(continued)

□ Transportation Stage

- In the EU, the allowable amount of containers and the weight of trucks are regulated according to the safety factors stipulated in the European Agreement on the International Transport of Dangerous Goods by Road (ADR).
- In the United States, the lack of regulations regarding pipeline transportation in cases where hydrogen concentration and pressure do not meet standards has been viewed as a problem.
- In the EU, there are variations among member countries regarding rules and procedures regarding hydrogen injection through pipelines within the region, creating barriers when connecting countries.

□ Usage Stage

- In the United States, the Compressed Gas Association (CGA) is currently considering developing safety standards for fuel cell vehicles, hydrogen stations, and underground storage of hydrogen.
- In the EU and Germany, traffic restrictions for fuel cell vehicles include prohibiting fuel cell buses and trucks from passing through some tunnels, and possibly restricting parking in underground parking lots, as well as regulations regarding the use of hydrogen as fuel for ships. It has been pointed out that there is no domestic law and no specific regulations are in place..

Source: Report of the Study Group on the Formulation of Hydrogen Safety Strategy, METI,Japan (2023)

1. What is hydrogen/fuel ammonia?

■ Regulation of ammonia in Japan

・As with hydrogen, ammonia falls under the categories of "class 2 gas", "flammable gas", "high pressure gas (depending on conditions)" under the High Pressure Gas Safety Act, and "toxic gas" under the General High Pressure Gas Safety Regulations.

・Ammonia is designated as a ``specified chemical substance" under the Industrial Safety and Health Act.

・Ammonia is designated as a ``deleterious substance" under the Poisonous and Deleterious Substances Control Law,

・ Ammonia is a specified malodorous substance and is subject to regulations under the Offensive Odor Prevention Act.

・ Ammonia is regulated as a specified substance under the Air Pollution Control Law.

・ Ammonia is a substance that requires notification under the Fire Service Act, and this applies when storing or handling 200 kg or more of ammonia.

1. What is hydrogen/fuel ammonia?

(5) Market trend

■ General aspects

・One major trend is **increasing demand** for hydrogen in various sectors, including transportation, industry, and power generation. Hydrogen is considered a versatile and clean energy carrier as it can be produced through various methods.
・Another trend is **growing number of government initiatives and policies** promoting the use of hydrogen. Many countries are recognizing the potential of hydrogen as a key element in their decarbonization strategies and have announced plans to invest in hydrogen infrastructure and research and development.

・Additionally, there has been **increase in private sector investments** in hydrogen-related technologies and projects. This includes investments in hydrogen production, storage, and distribution infrastructure, as well as advancements in fuel cell technology.

・However, there are challenges that need to be addressed. One major challenge is **high cost of hydrogen production**, especially when using renewable energy sources. Additionally, **lack of a widespread hydrogen infrastructures**, e.g., limited availability of hydrogen fueling stations, are barriers to its widespread adoption.

1. What is hydrogen/fuel ammonia?

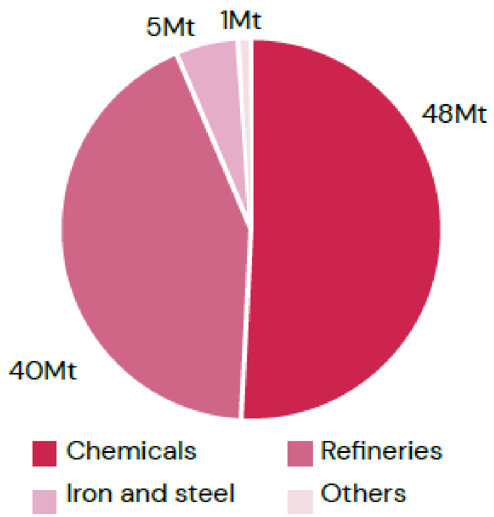
(5) Market trend

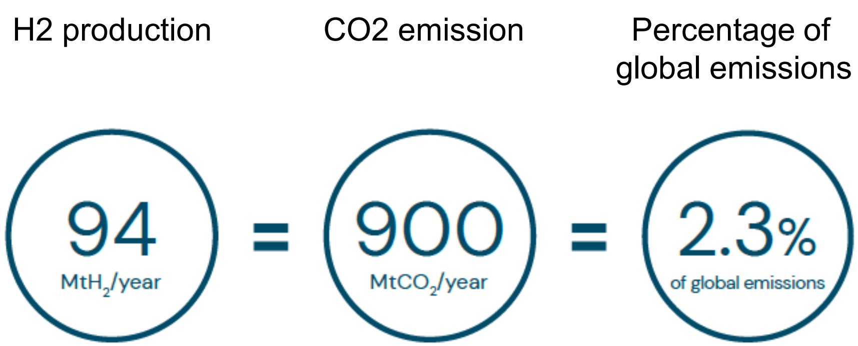
■ Hydrogen production

・About 94 million tons (MT) of hydrogen are produced in 2020 in the world, used for different purposes dominated by chemicals and refineries. For chemicals, methanol accounts for 70% and ammonia accounts for 30%.

・Today's production processes are mainly based on fossil fuels, e.g., steam methane reforming (SMR), and coal gasification (CG).

・Those two processes are particularly carbon-intensive and production of 1 kg of H2 emits 9 kg CO_2/kg-H_2 for SMR, and 20 kg CO_2/kg-H_2 for CG.





Source: The Hydrogen Series – Part 1 Report "Transitioning towards Low-Carbon Hydrogen Production, HAL open science, May 2023

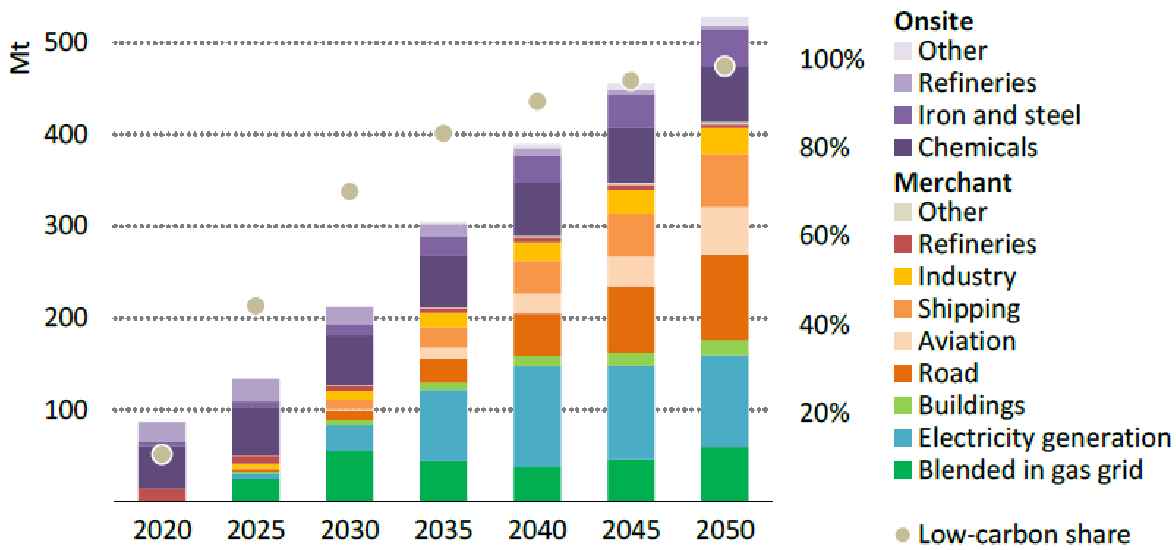
1. What is hydrogen/fuel ammonia?

(5) Market trend

■ Global hydrogen use

・Global hydrogen use expands from 90 Mt in 2020 to more than 200 Mt in 2030 and the proportion of low-carbon hydrogen rises from 10% in 2020 to 70% in 2030.
・The field of hydrogen use is expanding in shipping, road transport, aviation, chemicals, and iron and steel industries.

Global hydrogen and hydrogen-based fuel use in the NZE



Source: Net Zero by 2050 - A Roadmap for the Global Energy Sector -, IEA

1. What is hydrogen/fuel ammonia?

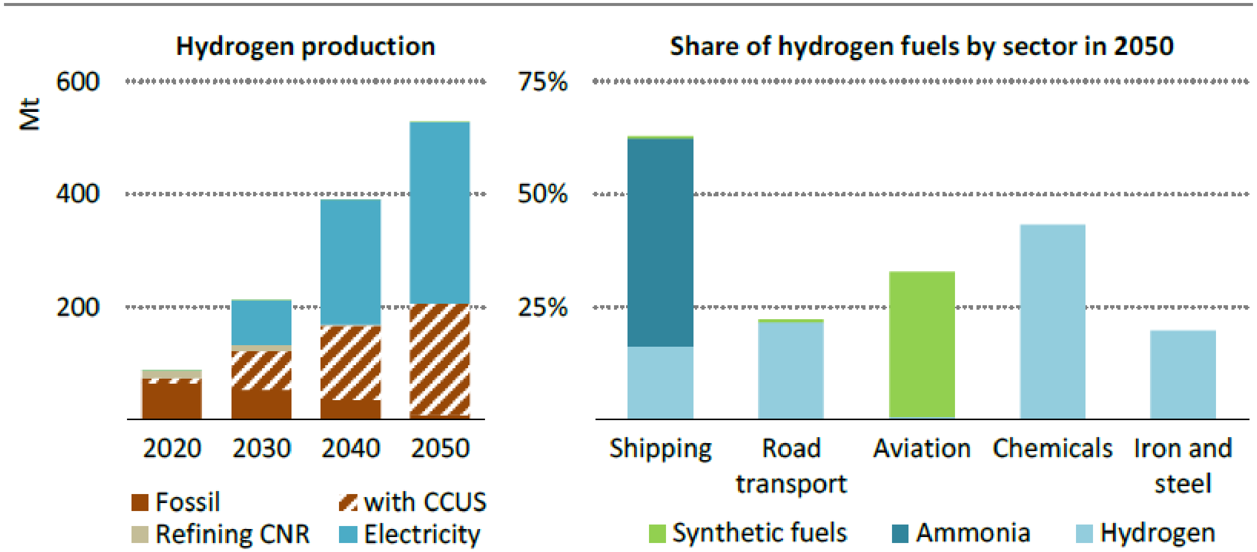
(5) Market trend

■ Global production and demand by sector in the NZE

・Around half of low-carbon hydrogen produced in 2030 comes from electrolysis and the remainder from natural gas and coal with CCUS.

・Ammonia accounts for around 45% of global energy demand for shipping in 2050 in the NZE. Synthetic kerosene meets around one-third of global aviation fuel demand in 2050 in the NZE.

Global production of hydrogen and hydrogen demand by sector



Source: Net Zero by 2050 - A Roadmap for the Global Energy Sector -, IEA

1. What is hydrogen/fuel ammonia?

■ Potential applications of hydrogen and ammonia

・For power generation, flammable hydrogen is envisioned for co-firing in gas-fired power plants, while ammonia is expected to be used for co-firing in coal-fired power plants.
・Ammonia is considered as potential applications in the maritime industry for long-distance transportation due to its high energy density.
・Hydrogen has potential to be used in various applications, such as being a feedstock for industrial processes like direct reduction of iron by hydrogen in steelmaking and synthesis of basic chemicals like methanol.

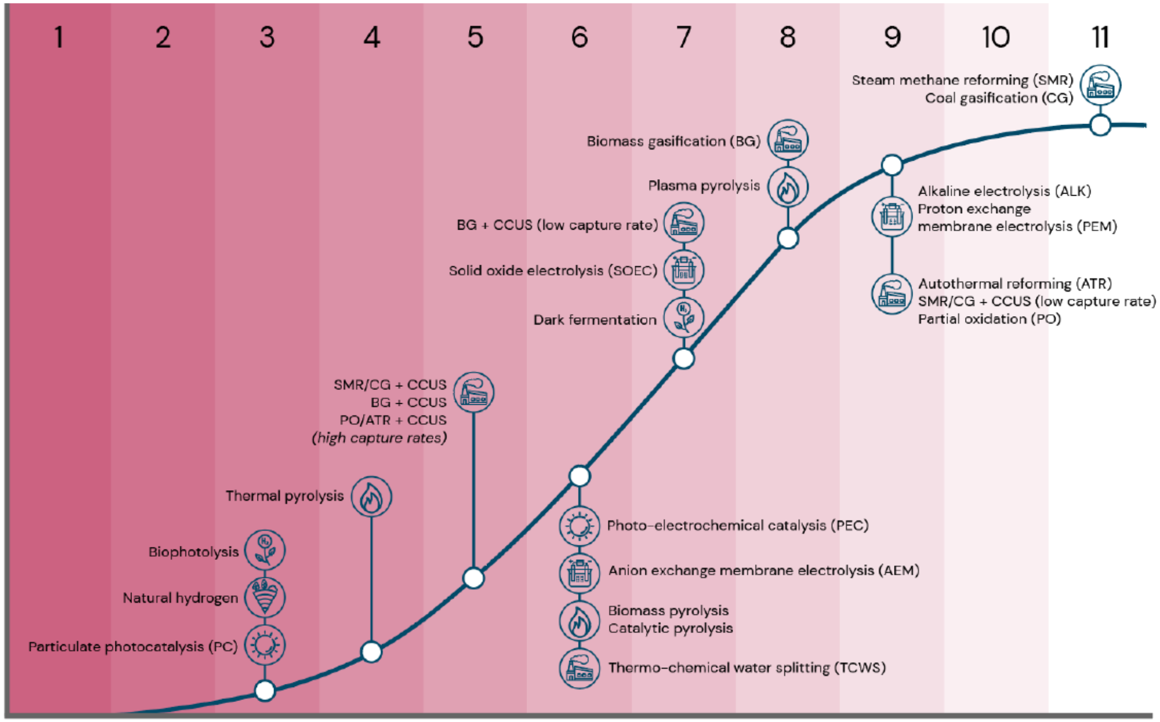
Potential applications for hydrogen and ammonia(direct use)

Use purpose		Hydrogen	Ammonia
Electric power	Co-firing and dedicated firing to coal-fired power generation		O
	Co-firing and dedicated firing to gas-fired power generation	O	O
Non-electric power (Fuel)	Heat utilization (industrial furnaces, etc.)	O	O
	Engine for ship propulsion, etc.	O	O
	Fuel cell for mobility and stationary applications	O	
No-electric power (Feedstock)	Direct reduction of iron by hydrogen	O	
	Synthesis of basic chemicals	O	

Source: “The current situation and future directions of hydrogen and ammonia (in Japanese)”, METI, March 29, 2022

2. How to produce hydrogen/fuel ammonia?

・There are five production routes for hydrogen, thermochemical, electrolytic, pyrolytic, biological, and photolytic. Each of these routes include multiple technologies at different levels of maturity.
・Technology Readiness Level（TRL) is used to give information about the stage of development of a technology. TRL 9, technologies are commercially ready.



Source: The Hydrogen Series – Part 1 Report "Transitioning towards Low-Carbon Hydrogen Production, HAL open science, May 2023

2. How to produce hydrogen/fuel ammonia?

(1) Existing production technology

・Based on the previous TRL curve, existing, commercial and commercial ready, production technologies are listed below.

■ Thermochemical route:

- Steam methane reforming (SMR)
・ Coal gasification (CG)
・ Autothermal reforming (ATR)
・ Biomass gasification (BG)

■ Electrolytic route:

・ Alkaline electrolysis (ALK)
・ Proton exchange membrane electrolysis (PEM)

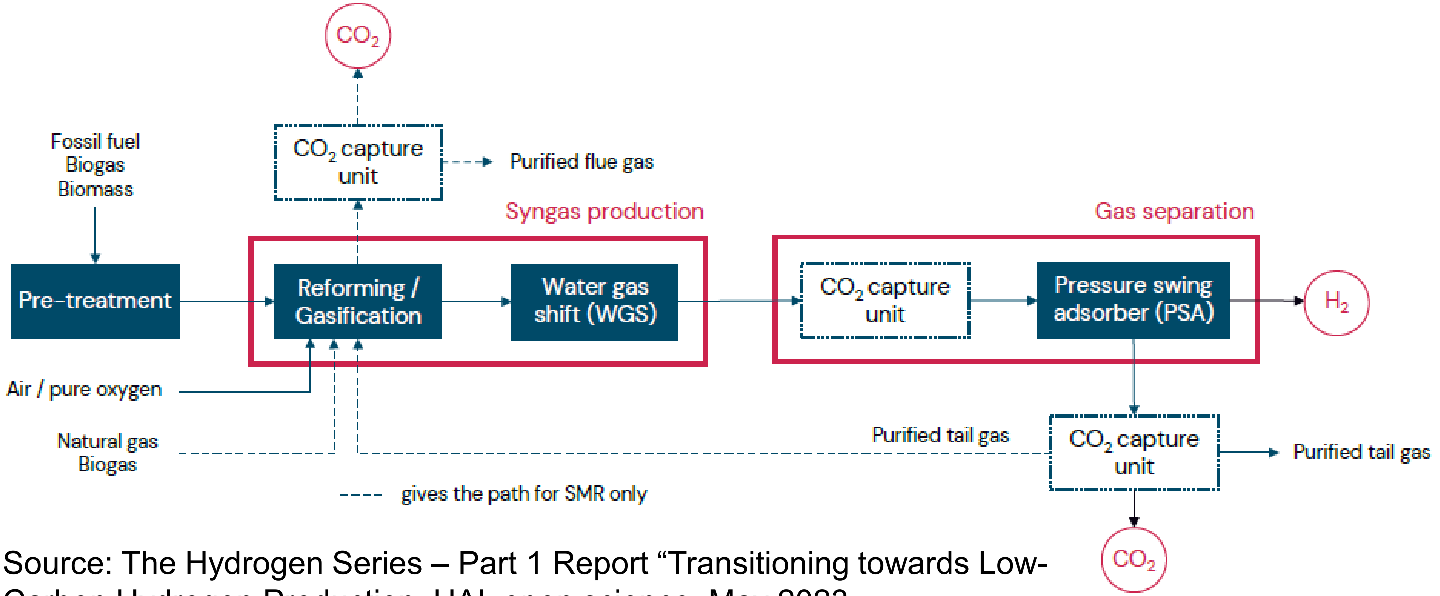
■ Pyrolytic route:

・ Plasma pyrolysis
・ Catalytic pyrolysis (e.g. Hazer process)

2. How to produce hydrogen/fuel ammonia?

■ Thermochemical route

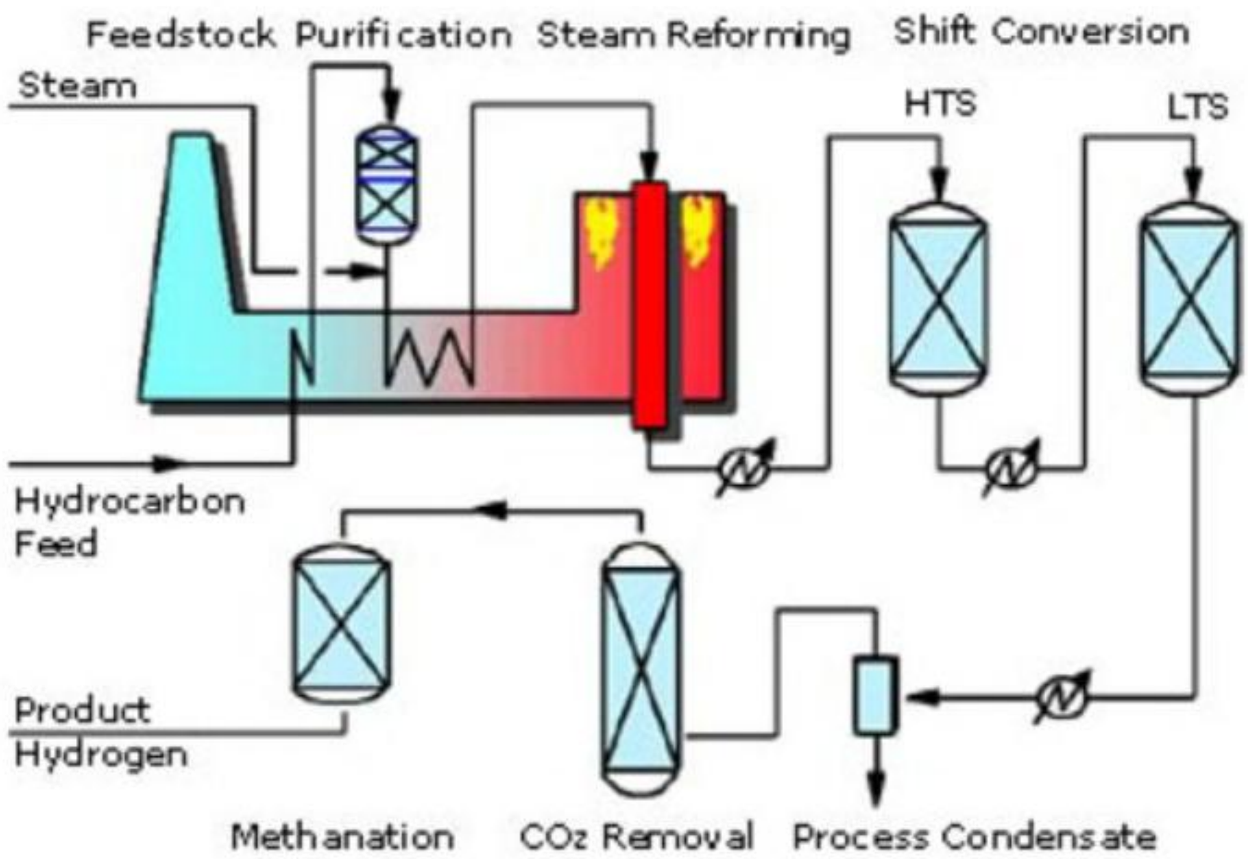
・Thermochemical route involves chemical reactions that occur when applying a certain amount of reaction heat to hydrogen-containing feedstocks.
・This route includes the three most common methods for producing hydrogen, namely Steam Methane Reforming (SMR), Autothermal Reforming (ATR) and Gasification （CG/BG).
・All of these routes generate CO_2 directly, and so Carbon Capture Utilization and Storage (CCUS) is necessary for such processes to produce hydrogen in a low-carbon way.



Source: The Hydrogen Series – Part 1 Report “Transitioning towards Low-Carbon Hydrogen Production, HAL open science, May 2023

2. How to produce hydrogen/fuel ammonia?

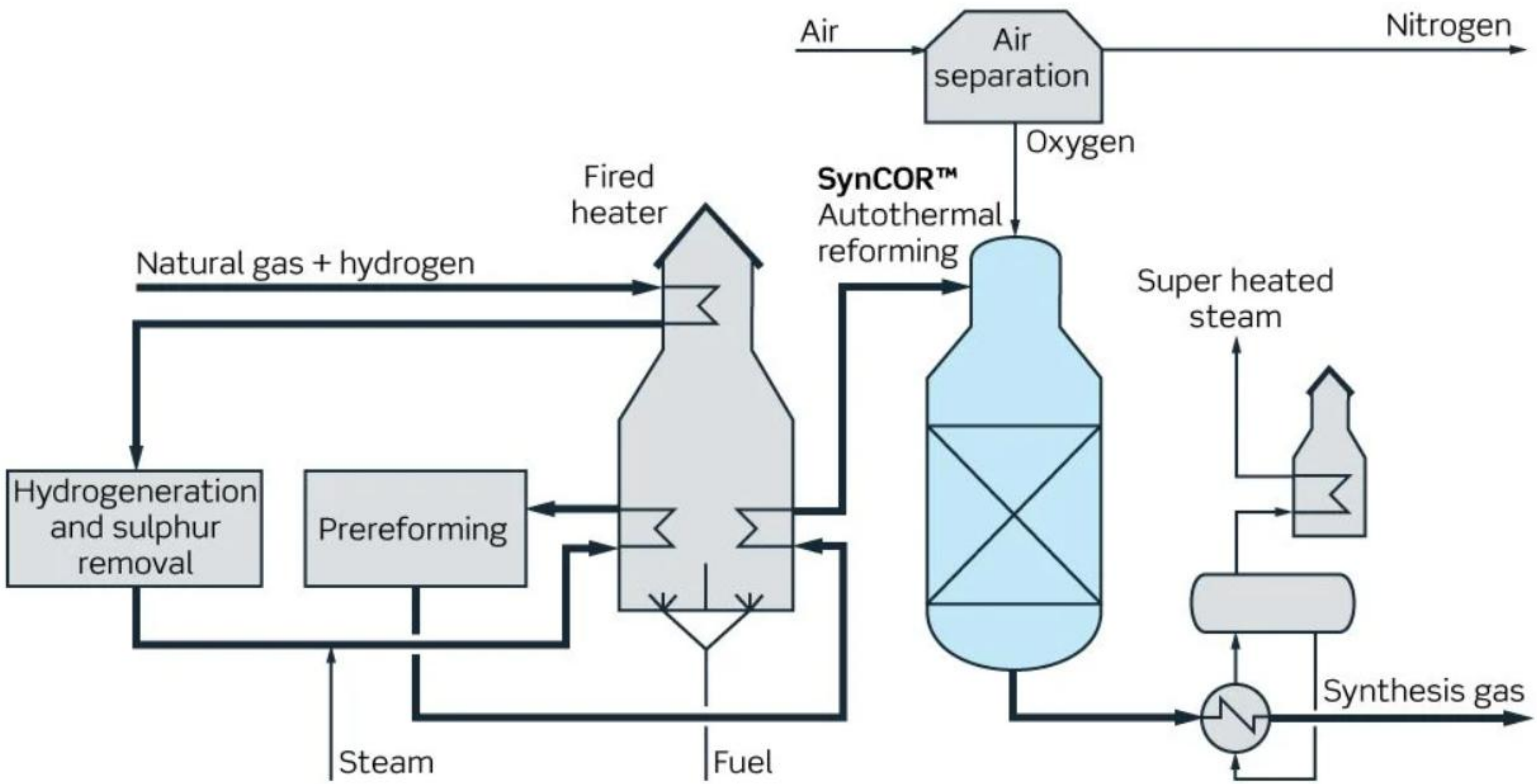
■ **Thermochemical route_Steam methane reforming**



Source: https://www.making-hydrogen.com/steam-reforming-hydrogen.html

2. How to produce hydrogen/fuel ammonia?

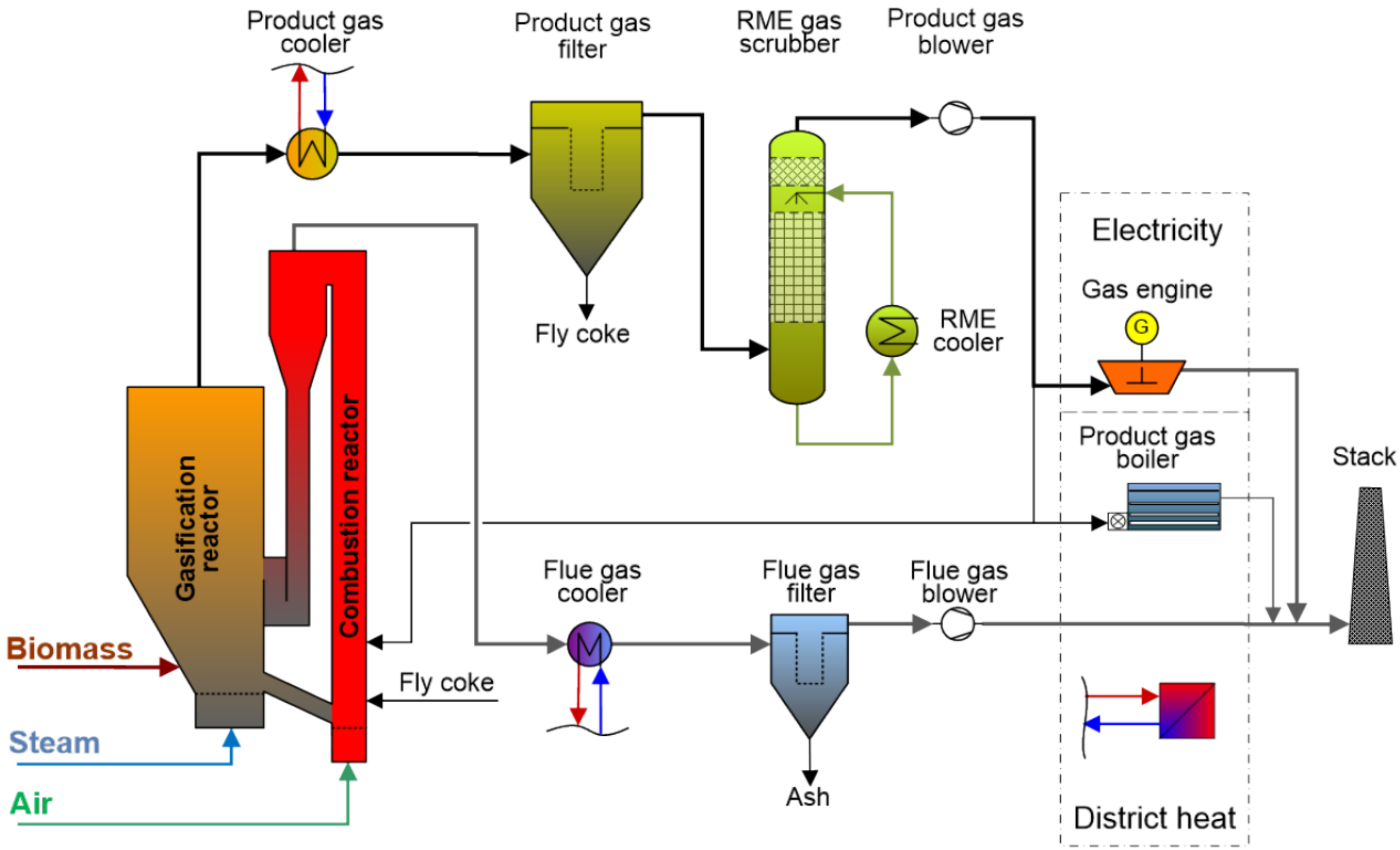
■ **Thermochemical route_Autothermal reforming**



Source: https://www.topsoe.com/our-resources/knowledge/our-products/equipment/syncortm-autothermal-reformer-atr

2. How to produce hydrogen/fuel ammonia?

■ **Thermochemical route_Biomass gasification**



Source: Hydrogen from biomass gasification, IEA Bioenergy: Task 33: December 2018,

2. How to produce hydrogen/fuel ammonia?

■ Electrolytic route

・Four types of electrolysers are under focus, Alkaline electrolyser (ALK), Proton Exchange Membrane (PEM), Solid Oxide (SOEC) and Anion Exchange Membrane（AEM）.
・Among the four types, SOEC and AEM are still at the pre-commercial stage but SOEC could become cost-competitive in the near future due to its high efficiency.
・From the view of cost and availability, ALK is much superior to PEM, on the contrary, from the view of flexibility to the intermittent renewable energy PEM is above ALK.

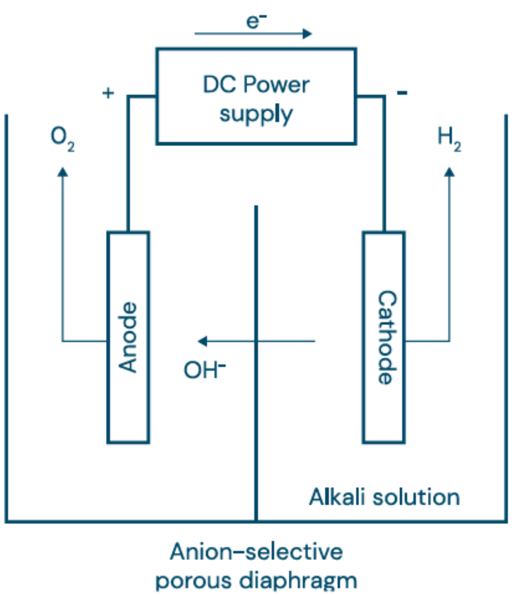
	ALK	PEM	SOEC
Characteristics	Utilization of alkaline solution (KOH)	Compact electrolysis device using noble metal catalyst	High temperature electrolysis using high temperature steam
Efficiency (steady state)	Stack: ~4.8 kWh/Nm_3-H_2 System: ~6.5 kWh/Nm_3-H_2	Stack: ~4.8 kWh/Nm_3-H_2 System: ~6.5 kWh/Nm_3-H_2	Stack: ~3.2 kWh/Nm_3-H_2 System: ~4.0 kWh/Nm_3-H_2
Operation temperature	RT~80℃	RT~80℃	Approximately 700℃
Pros	Most mature technology Upscaling achieved	Space-saving Flexible to intermittent RE	High energy efficiency (further efficiency through waste heat utilization)
Cons	Concentration control of alkaline solution and post processing	Limited noble metal supply Flexible to intermittent RE	Still at technological development

Source: ”Introduction to Hydrogen Energy Business (in Japanese)”, TOSHIBA, March 2023

2. How to produce hydrogen/fuel ammonia?

■ Electrolytic route_ALK

・ALK electrolysis is the oldest and most mature production technology and the most used today (59% of market shares in 2021).
・In ALK, two electrodes are immersed in a concentrated alkaline solution, typically KOH or NaOH.
・Negatively charged hydroxide ions (OH^-) act as charge carriers and cross an anion-selective porous diaphragm.
・Oxygen is thus produced at the anode and H_2 at the cathode.



Alkaline Electrolysis (ALK)

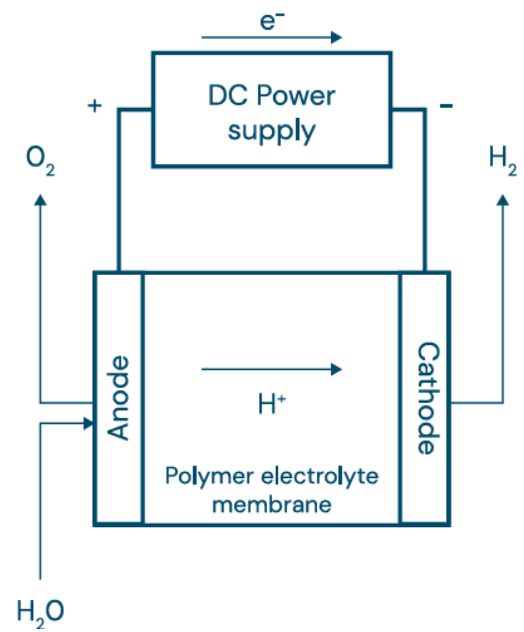
Anode: $2OH^- \Rightarrow 1/2O_2 + H_2O + 2e^-$
Cathode: $2H_2O + 2e^- \Rightarrow H_2 + 2OH^-$

Source: The Hydrogen Series – Part 1 Report "Transitioning towards Low-Carbon Hydrogen Production, HAL open science, May 2023

2. How to produce hydrogen/fuel ammonia?

■ Electrolytic route_PEM

・PEM is a polymer electrolyte membrane that acts as an electrolyte and allows the transport of protons (hydrogen ions) across it while blocking the flow of electrons.
・The advantages of PEM are its higher flexibility, higher operating pressure, smaller footprint, higher current densities, faster response and lower degradation rate with load change, making it particularly suitable for renewable energy integration.
・PEM uses noble metal catalysts like palladium and iridium which increases the total cost of the system.



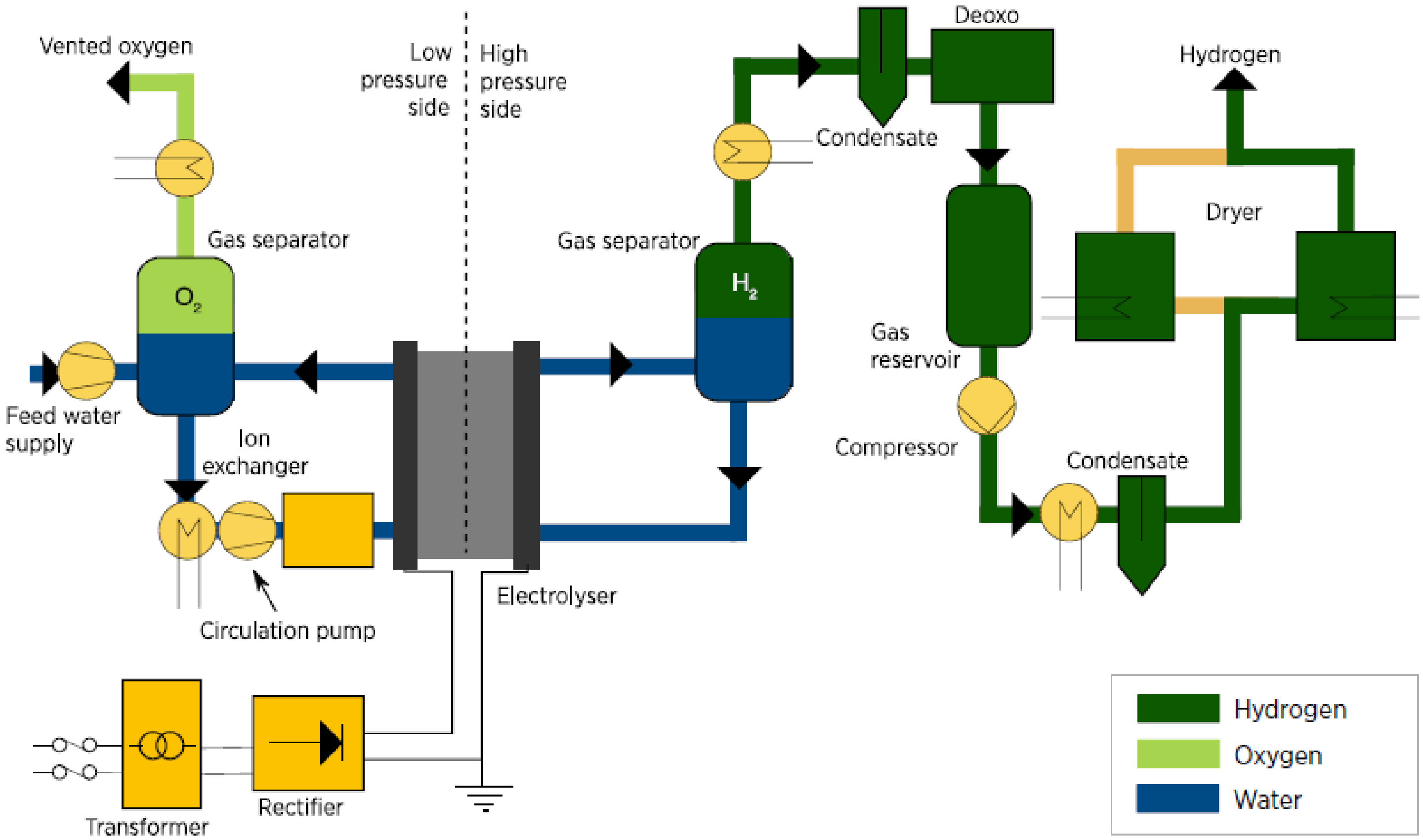
Polymer Electrolyte Membrane (PEM)

Anode: $2H_2O \Rightarrow 4H^+ + O_2 + 4e^-$
Cathode: $4H^+ + 4e^- \Rightarrow 2H_2$

Source: The Hydrogen Series – Part 1 Report "Transitioning towards Low-Carbon Hydrogen Production, HAL open science, May 2023

2. How to produce hydrogen/fuel ammonia?

Typical system design and balance of plant for a PEM electrolyser



Note: This configuration is for a generic system and might not be representative of all existing manufacturers.

Source: IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal, International Renewable Energy Agency

2. How to produce hydrogen/fuel ammonia?

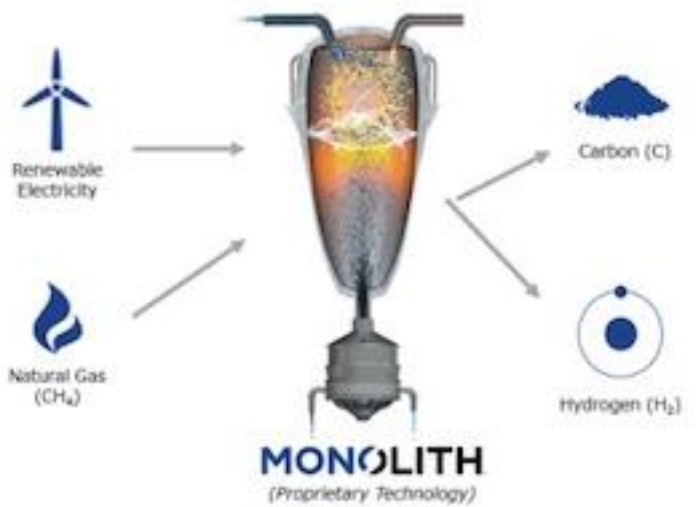
■ Pyrolytic route

・Producing hydrogen through the pyrolytic route relies on the pyrolysis of methane or biomass.
・Pyrolysis is the process of chemical decomposition of methane or biomass that occurs when elevating its temperature higher than 500℃ in the absence of oxygen.
・Thermal decomposition breaks down methane into hydrogen and elemental carbon in reactors that reach temperature of 1,000-1,500℃.
・Catalytic decomposition is preferred because it reduces the operating temperature and the energy required for the decomposition reaction.
・In catalytic decomposition, methane breaks down into hydrogen and carbon over a metal catalyst, which is typically iron- or nickel-based, at temperature typically under 1,000℃.
・Pyrolysis requires 2 times more natural gas than SMR to produce 1 kg of H_2 due to the molar ratio of hydrogen to CH_4 being 2:1 instead of 4:1 for SMR. In the case of SMR, the steam provides another source of H_2 atoms.

2. How to produce hydrogen/fuel ammonia?

■ Pyrolytic route_Plasma pyrolysis

・The electric energy ignites the plasma, an ionized gas, which reaches temperatures in range of 1,000-2,000℃ and split CH_4 into its elements.
・Monolith produces 600kg/h of H_2 using its plasma decomposition technology at their Olive Creek 1 facility since 2020.



Monolith Process

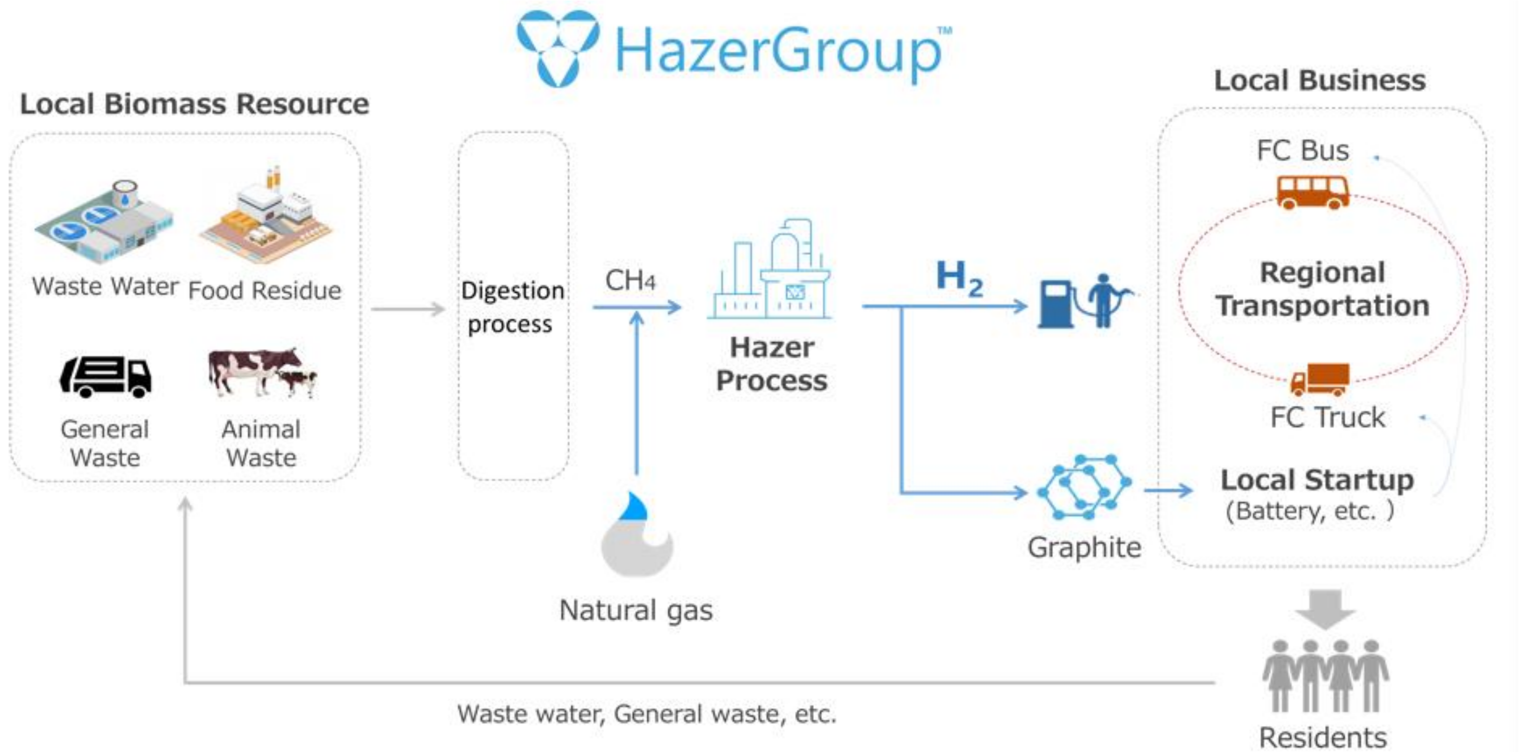
Olive Creek1(OC1), commercial-scale facility in Nebraska, United States

Source: https://www.asiaone.com/business/mitsubishi-heavy-industries-invests-monolith-materials

2. How to produce hydrogen/fuel ammonia?

■ Pyrolytic route_Catalytic pyrolysis

・Hazer Group has a methane pyrolysis technology (catalytic decomposition), and Chiyoda support for scaling up, engineering of their technology development and promotion, business development in Japanese market. (since 2020)



Source: Modified based on Hazer information_https://hazergroup.com.au/about/#hazerprocess

2. How to produce hydrogen/fuel ammonia?

・Commercial Demonstration Plant has been successfully produced first hydrogen and graphite on January 2024.(Perth, Australia 100 tpa Hydrogen, ~380 tpa Graphitic carbon)

Source: https://www.globenewswire.com/news-release/2024/02/01/2821620/0/en/Hazer-Achieves-First-Hydrogen-and-Graphite-at-Commercial-Demonstration-Plant.html

2. How to produce hydrogen/fuel ammonia?

(2) Future production technology

・As future production technologies the following technologies are selected as below.

- Thermochemical route:

  ・Thermochemical water splitting (TCWS)

- Electrolytic route:

  ・Solid oxide electrolysis cell (SOEC)
  ・Anion exchange membrane electrolysis (AEM)

- Photolytic route:

  ・Phot-electrochemical catalyst (PEC)

2. How to produce hydrogen/fuel ammonia?

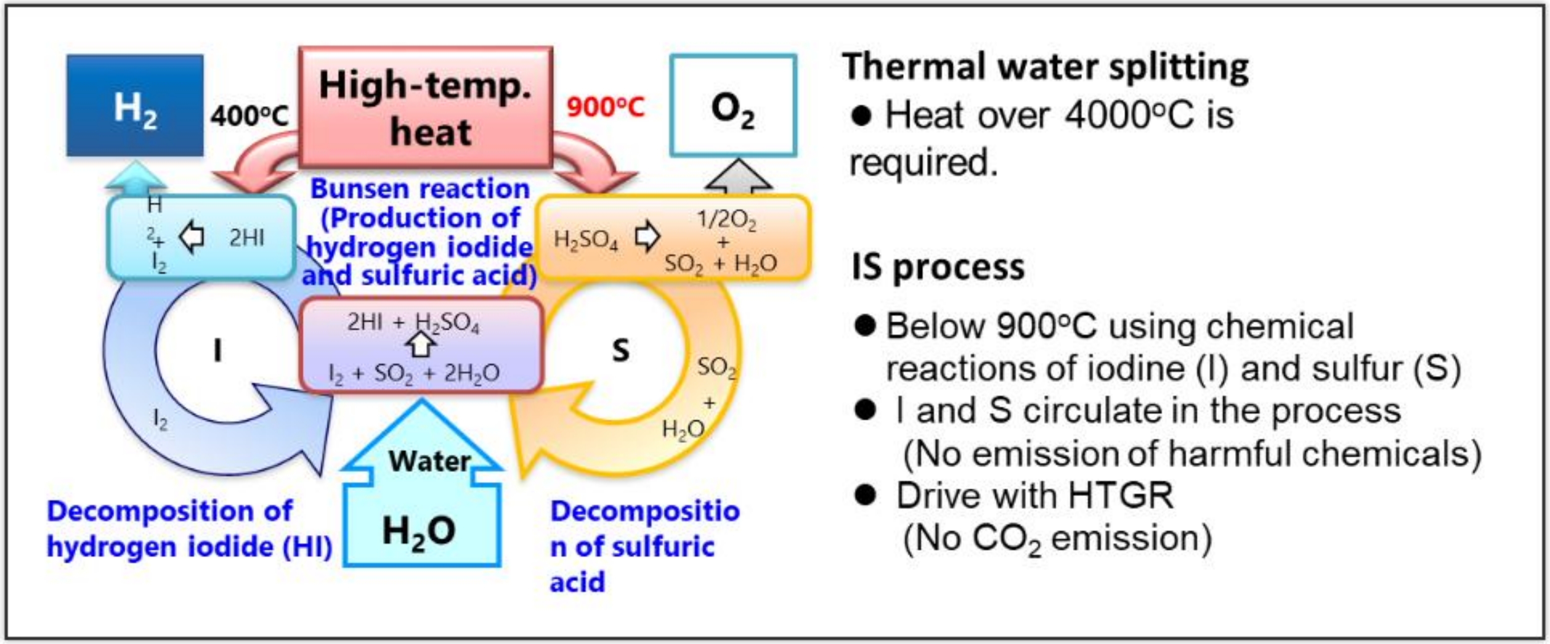
■ **Thermochemical route_Thermochemical water splitting (TCWS)**

・Thermochemical water splitting is a process that relies on high temperature heat to drive chemical reaction cycles to generate hydrogen and oxygen.

・The most promising thermochemical cycle is IS Process, using the iodine-sulphur cycle, because of its prospects for high efficiency.

・Japan Atomic Energy Agency (JAEA) has been conducting a study on the hydrogen production using IS Process since 1980's.

・High temperature heat comes from High Temperature Ga-cooled Reactor (HTGR).



Source: https://www.jaea.go.jp/04/o-arai/nhc/en/research/hydrogen_heat/is/index.html

2. How to produce hydrogen/fuel ammonia?

■ Electrolytic route_Solid oxide electrolysis cell (SOEC)

・SOEC uses high temperature steam water (650-1,000℃) as an electrolyte and a solid oxide membrane between the cathode and the anode.
・SOEC does not require a catalyst for the electrolysis reaction to occur due to being able to operate at high temperature.
・Using high temperature steam, generated by industrial waste heat for example, greatly decreases the power consumption needed for the electrolysis reaction and thus SOEC is the most energy efficient process.

■ Electrolytic route_Anion exchange membrane electrolysis (AEM)

・AEM uses a low concentration alkaline membrane, where OH^- ions serve as charge carriers, which allows to avoid the high concentration corrosive electrolytes used in ALK.
・AEM does not use noble metal catalysts but rather cheap and abundant transition metals.
・AEM shares the high flexibility, compact cell design, high operating pressure and a leakage-free design with PEM and the low cost and high durability with ALK.
・Some improvements around the efficiency, membrane design and catalyst stability and reduction of cell cost are still required for AEM to become a competitive technology in the future.

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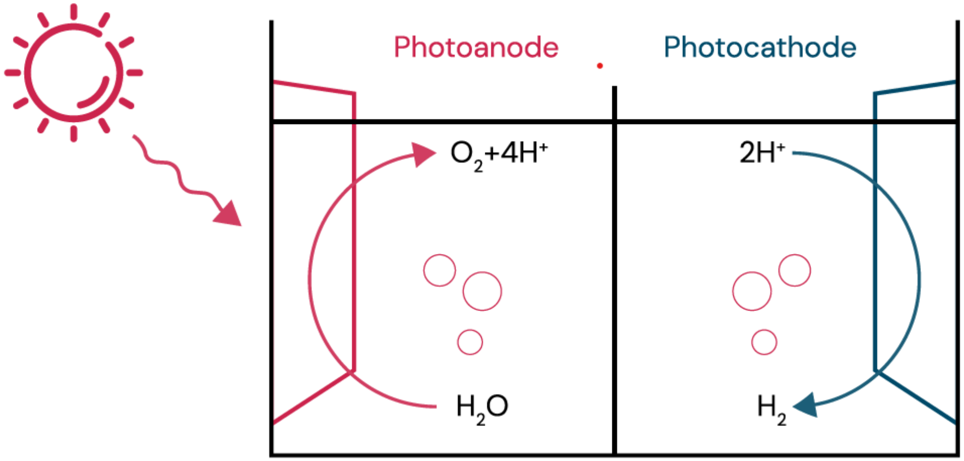
2. How to produce hydrogen/fuel ammonia?

■ Photolytic route_Photo-electrochemical catalyst (PEC)

・The photolytic route typically involves the use of a photocatalyst material which absorbs sunlight and initiates the water splitting reaction.
・PEC could be considered as the combination of an electrolyser and a PV module in a single device, thus having the potential to reduce capital costs and energy losses.
・PEC offers the advantage of direct conversion of sunlight into chemical energy, making them a promising technology for renewable energy production and storage.
・PEC has the advantage of operating at near ambient temperatures, between 25-65℃ and does not need any noble metal catalyst.
・There are still challenges to overcome, such as improving the efficiency and stability of the photoelectrode materials, as well as optimizing the overall system design.
・PECs are an active area of research and development in the field of solar energy conversion.

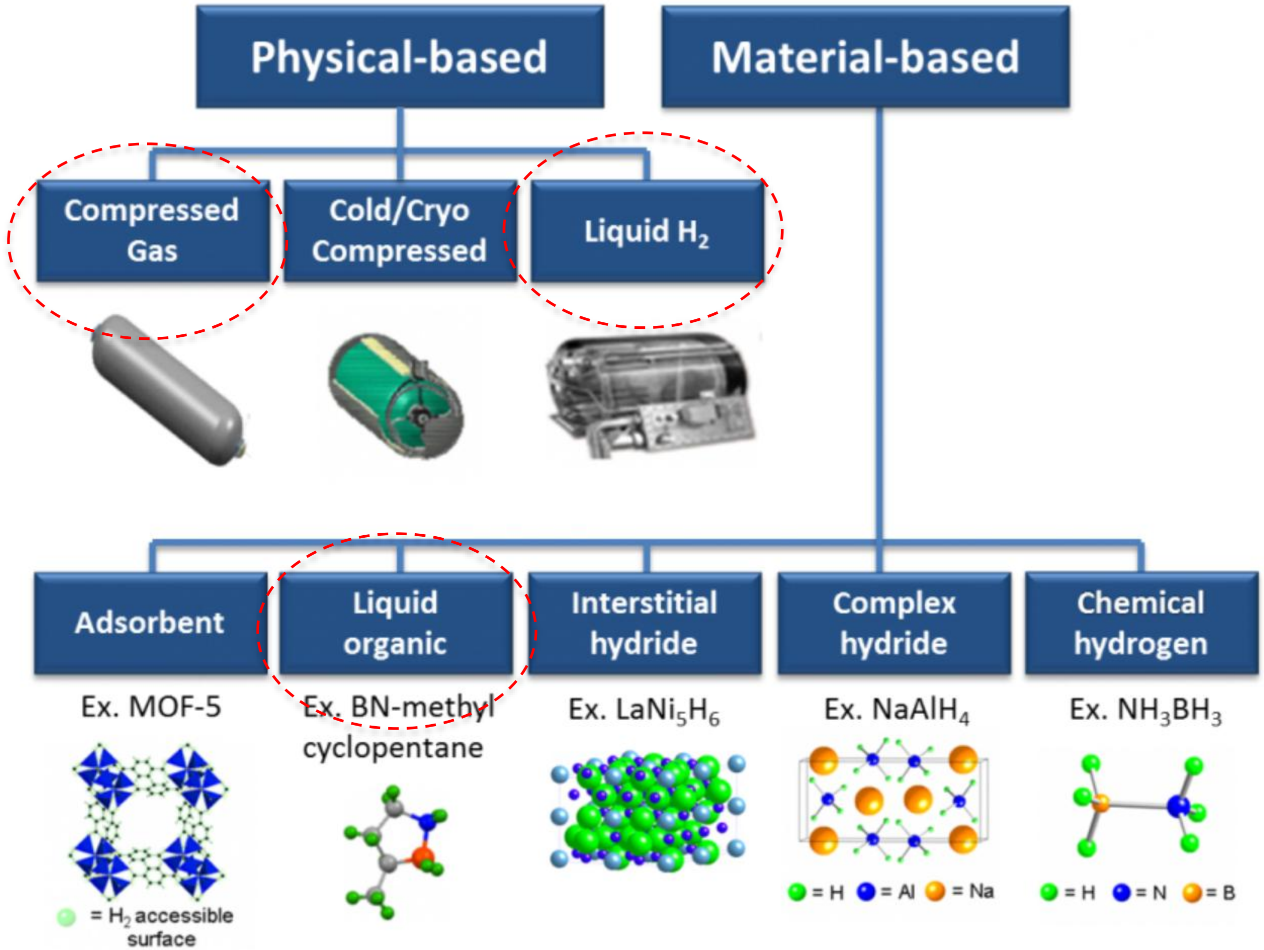


Source: The Hydrogen Series – Part 1 Report "Transitioning towards Low-Carbon Hydrogen Production, HAL open science, May 2023

3. How to storage and transport hydrogen/fuel ammonia?

(1) Storage Method

■ **How is hydrogen stored?**



Source: Hydrogen and fuel cell Technologies office (USDOE)

3. How to storage and transport hydrogen/fuel ammonia?

(1) Storage Method

■ Comparison of physical properties in liquid state

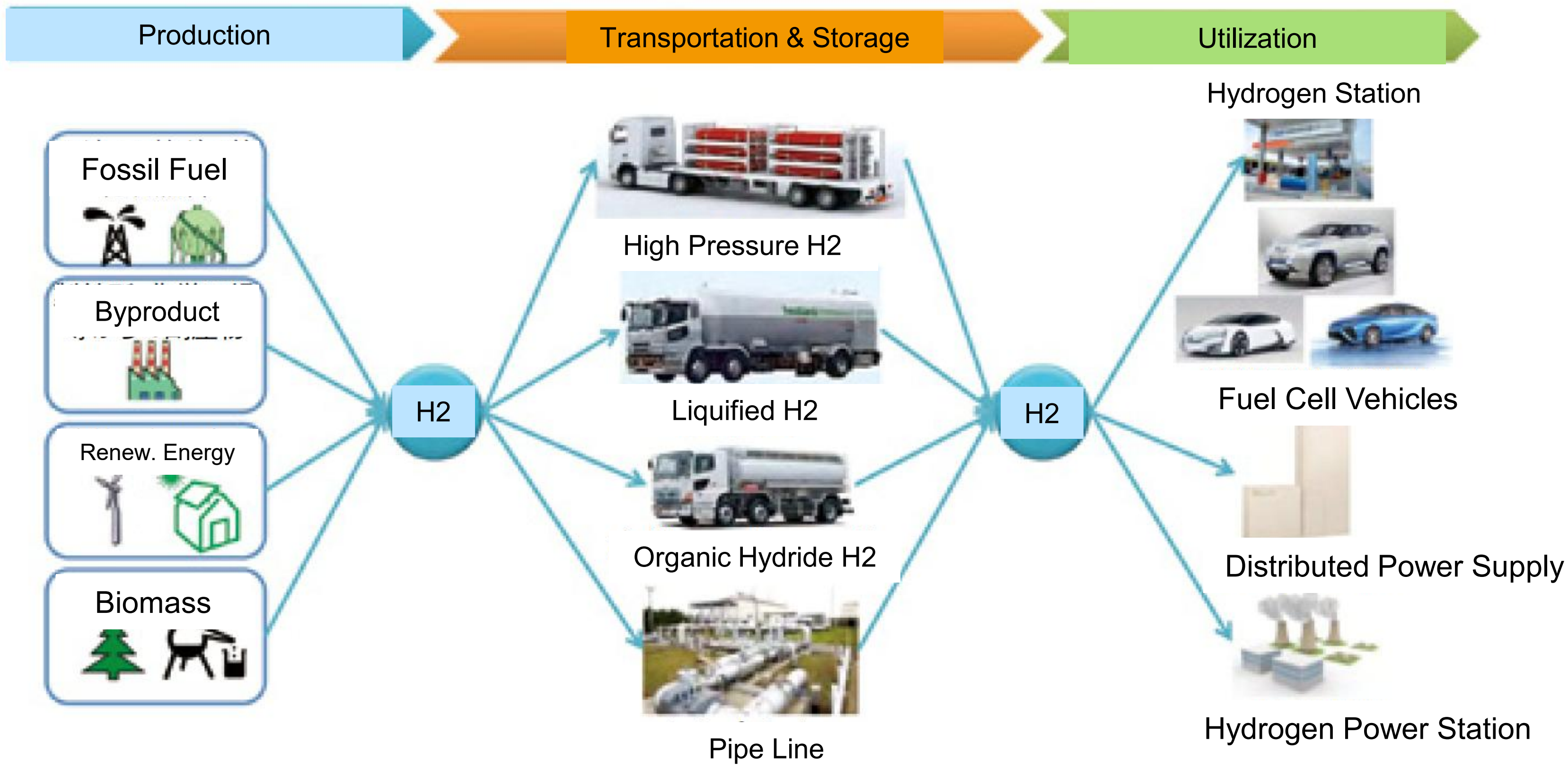
compound	hydrogen	methane(LNG)	propane(LPG)	ammonia	MCH
Boiling point at atmospheric pressure °C	-253	-162	-42	-33.4	100.9
Liquefaction pressure at 20°C	-	-	0.86	0.857	-
Liquid density kg/L	0.071	0.422	0.578	0.674	0.769（20°C）
Latent Heat of vaporization kJ/L (kJ/kg)	31.6(446)	226(510)	247(426)	923 (1,370)	264 (344)
Melting Point °C	-	-	-188	-77.7	-126.6
Flash point °C	-	-187.7	-104.4	132	-4
Hydrogen Content(wt%)	100	-	-	17.8	6.16

- Hydrogen can be stored in gas or liquid form, but the conditions for storing it as liquid are more stringent than for LNG.
- MCH is a liquid at room temperature, so existing petroleum tanks can be used.
- The physical properties of ammonia are close to those of LPG, so LPG tanks can be used with a slight modification.
- Increasing the size of the ammonia tank requires higher strength materials and consideration of SCC.

3. How to storage and transport hydrogen/fuel ammonia?

(2) Transportation Methods

- Hydrogen transportation and storage methods



Source: Hydrogen energy white paper NEDO,Japan 2015

3. How to storage and transport hydrogen/fuel ammonia?

(2) Transportation Methods

■ Storage and transportation of compressed hydrogen gas

20MPa Trailer

45MPa Trailer

	Cylinder		Cardle		Trailer	
Internal Volume(L)	46,7	50.0	46.7×10	50×30	660×20	715×22
Filling pressure （MPa)	14.7	19.6	14.7	19.6	19.6	19.6
Loading(Sm3)	7	10	70	300	2,640	3,200
Total weight(kg)	50	70	1,000	2,500	19,950	20,470

- NEDO conducted a demonstration of a 45MPa class hydrogen trailer. A cylinder made of composite container is used to avoid weight increase due to high pressure.
- Technical standards have been revised to raise the maximum filling pressure for containers for compressed hydrogen transportation vehicles from 35MPa to 45MPa.
- According to the current road law, vehicles are considered to be carrying dangerous goods, and cannot be passed through undersea tunnels or tunnels longer than 5km.

Source: Hydrogen energy white paper NEDO, Japan 2015

3. How to storage and transport hydrogen/fuel ammonia?

(2) Transportation Methods

■ Storage and transportation of Liquified hydrogen

Portable cryogenic container

container

Lorry

- Portable ultra-low temperature containers (145-350L), containers (2-46m3), and lorries (23m3) are used.
- The amount of boil-off generated by the latest containers is less than 1%/day.
- Liquefied hydrogen has a temperature of -253℃.
- It is also necessary to comply with laws and regulations such as the High Pressure Gas Safety Act.
- Kawasaki Heavy Industries has obtained basic approval from Nippon Kaiji Kyokai for cargo storage equipment for liquefied hydrogen carriers.

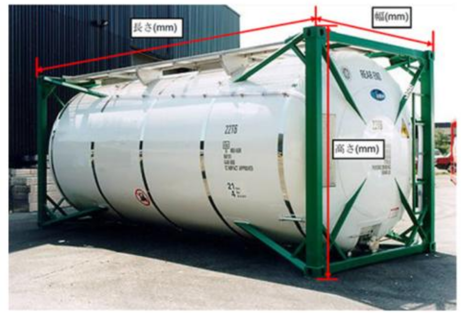
Source: Hydrogen energy white paper NEDO, Japan 2015

3. How to storage and transport hydrogen/fuel ammonia?

(2) Transportation Methods

- Storage and transportation of Liquified Organic Hydrogen Carrier

Chemical Lorry(*1)



ISO Tank Container(*2)

Container loading work at a railway depot(*3)

- The development of transport using MCH as a hydrogen carrier is progressing due to its low melting point and low toxicity.
- Under Japan's Fire Service Act, toluene and MCH are classified in the same category as gasoline and kerosene, making it possible to utilize existing petroleum infrastructure.
- In the NEDO demonstration (2019-2021), 24-26kL ISO tank containers were adopted and used for TOL transport from Japan to Brunei and MCH transport from Brunei to Japan.
- When transporting MCH in a 26kL container, the amount of hydrogen transported is approximately 13,000Nm3. "

Source: Hydrogen energy white paper NEDO, Japan 2015
*1 FGHD HP *2 NYK Trading Co. HP *3 JAPEX HP

3. How to storage and transport hydrogen/fuel ammonia?

(2) Transportation Methods

- Transportation of hydrogen gas using Pipe Line

・Construction of a full-scale hydrogen pipeline will require considerable infrastructure investment, resulting in large initial costs.

・For short-distance transportation of several kilometers, the pressure during transportation is often less than 1 MPa, which means that compressors are not required, making it easy to maintain at low cost.

・It is necessary to consider ensuring safety in the design, construction, and maintenance of hydrogen pipelines.

・France's Air Linde has a hydrogen pipeline with a total length of 830 km near the borders of France, Belgium, and the Netherlands, and also has a hydrogen pipeline with a total length of 240 km in North Rhine-Westphalia, Germany.

・Germany's Linde has a 140km hydrogen pipeline near Leipzig.

・Air Products and Chemicals in the United States has a hydrogen pipeline network in Louisiana, Texas, and California, with a total length of 560 km.

・Germany's Frankfurt Hydrogen Station uses by-product hydrogen from a soda electrolysis plant in an adjacent industrial park as its source, and is connected by a 1.7km hydrogen pipeline with a pressure of 90MPa.

・Hydrogen stations in Taurus, California, U.S.A. are supplied with hydrogen from a hydrogen pipeline built in the area.

Hydrogen energy white paper NEDO, Japan 2015

3. How to storage and transport hydrogen/fuel ammonia?

(2) Transportation Methods

■ Transportation of hydrogen gas using Pipe Line(continued)

・In Japan, Kitakyushu Hydrogen Town supplies by-product hydrogen from steelworks through a 1.2km pipeline. This pipeline is buried in a public road, and the durability evaluation of the carbon steel pipes used is underway.

・Demonstration Project of hydrogen gas transportation in Japan

Installation Area	Installation Condition	pressure	piping material	Inner diameter	transportation distance
Kawasaki City	Buried (public road)	midium (0.7MPa)	CS	100mm	～1 km
Shunann City	Exposure (on site) Buried (public road)	midium (0.7MPa)	SUS	38mm	～1 km
Kitakyushu city	Buried (public road)	midium to low (0.1MPa)	CS	100mm	～1 km
Harumi district in Tokyo	Buried (public road)	midium to low (＜0.1MPa)	CS	150mm(OD)	～1 km

Ministry of the Environment of Japan, HP

3. How to storage and transport hydrogen/fuel ammonia?

(2) Transportation Methods

■ Transportation of Liquid Ammonia

・The technology to synthesize ammonia in large quantities from various fossil fuels and nitrogen has been established for about 100 years.
・Regarding storage and transportation, there are regions where infrastructure such as storage tanks, pipelines, tankers, and trucks is already in place.
・In the United States, an ammonia pipeline with a total length of 4,950 km has been constructed across states.
・Ammonia tankers are generally refrigerated vessels and are also used as liquefied petroleum gas (LPG) tankers.
・Regarding land transportation, tank trucks and trailers are used for transportation.

Liquid Ammonia Lorry(*)

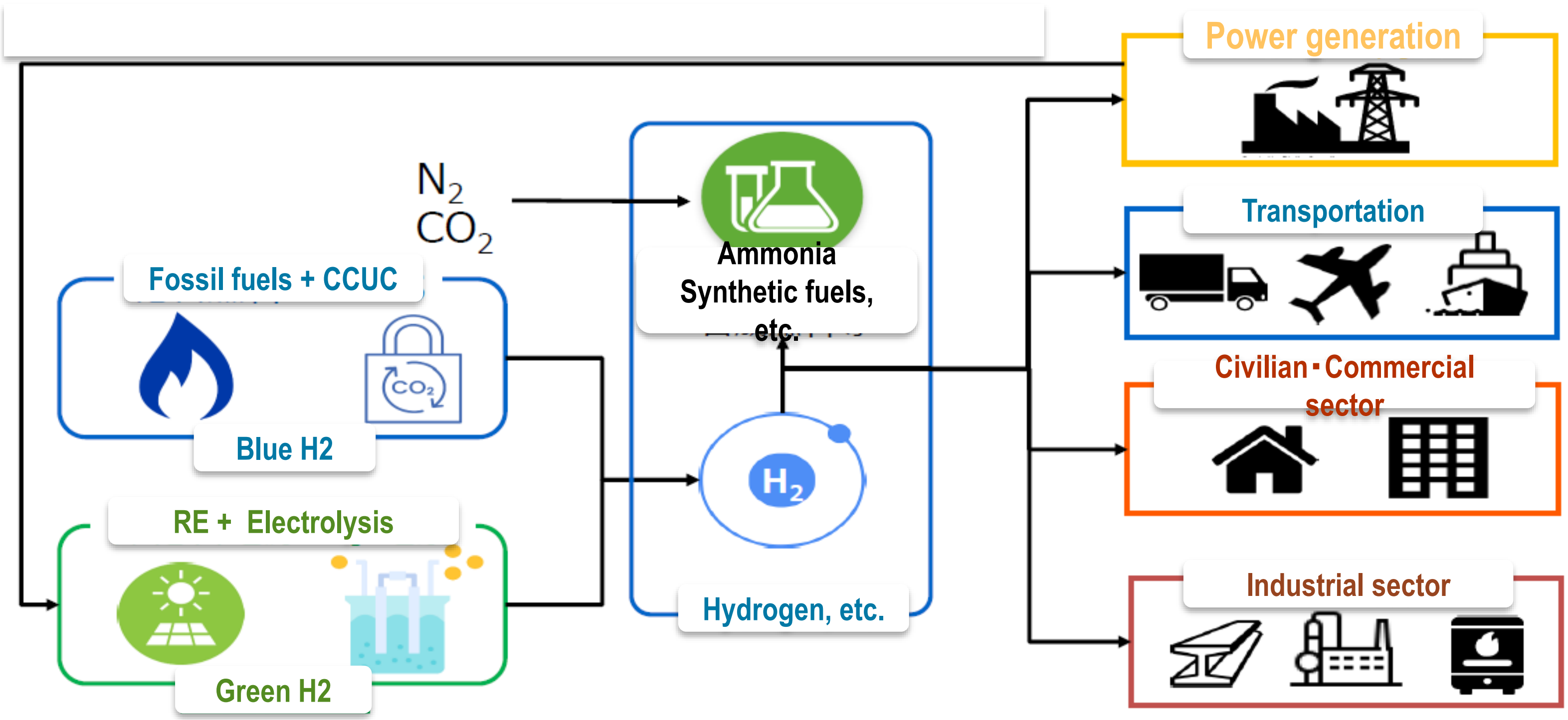
* FGHD HP

4. How to use hydrogen/fuel ammonia?

(1) Use application

・Hydrogen has a wide range of uses and is considered a promising alternative energy source due to its abundance, environmental benefits, and potential for renewable energy production.

■ **Green hydrogen and related fuels, supply sources and demand destinations**

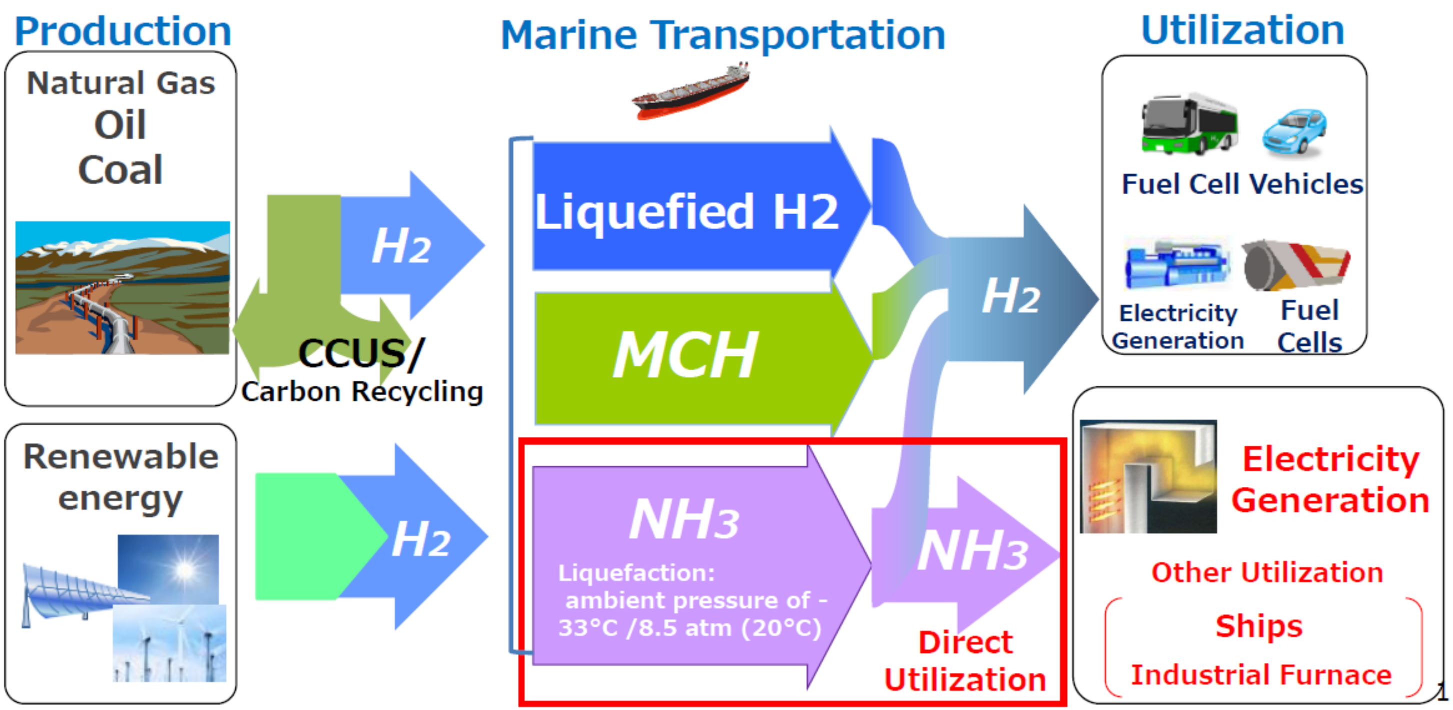


Source: "The current situation and future directions of hydrogen and ammonia (in Japanese)", METI, March 29, 2022

4. How to use hydrogen/fuel ammonia?

■ Fuel ammonia, production and utilization processes

・Ammonia is not only positioned as one of the hydrogen carriers, but also be used directly for electricity generation as a zero emission fuel.
・Ammonia does not emit CO_2 during combustion and becomes one of effective alternative fuels for addressing global warming.



Source: "Ammonia Strategy and Policy in Japan", METI, December 2, 2022

4. How to use hydrogen/fuel ammonia?

(2) Technology development for usage application

・Future hydrogen usage technologies encompass a wide range of applications and innovations that aim to harness the potential of hydrogen as a clean and versatile energy source.
・Key future technologies related hydrogen usage are listed below.

■ Hydrogen Fuel Cells
・Fuel cells convert hydrogen and oxygen into electricity, with water as the only byproduct.
・Future advancements in fuel cell technology aim to improve efficiency, reduce costs, and increase the durability and lifespan of fuel cells.
・Efforts to improve the efficiency include advancements in catalyst materials, membrane design, and system optimization.
・Higher efficiency fuel cells will lead to greater energy output for a given amount of hydrogen fuel and contribute to overall energy savings.
・Reducing the cost of materials, manufacturing processes, and system components, such as catalysts and membranes, and additionally, economies of scale, improved production techniques, and increased competition are expected to make fuel cells more economically viable.
・Increasing the durability and lifespan of fuel cells is focused on improving the stability and longevity of fuel cell components, such as catalysts, membranes, and bipolar plates.

4. How to use hydrogen/fuel ammonia?

■ Hydrogen in Industry

・Future technologies aim to integrate hydrogen into industrial processes to reduce carbon emissions.

・For example, direct hydrogen reduction steelmaking eliminates the need for fossil fuels in steel production, resulting in significant carbon emission reductions.

■ Hydrogen in Energy Storage

・Hydrogen can serve as an energy storage medium for intermittent renewable energy sources like solar and wind.

・Excess electricity generated during periods of high production can be used to produce hydrogen through electrolysis, which can then be stored and used to generate electricity when renewable energy supply is low.

・This enables the balancing of energy supply and demand and enhances grid stability.

■ Hydrogen Storage and Transportation

・Efficient and safe storage and transportation methods are crucial for the widespread adoption of hydrogen as an energy carrier.

・Future technologies focus on enhancing hydrogen storage density and developing advanced storage systems, such as liquid organic hydrogen carriers, solid-state hydrogen storage materials, and compressed hydrogen gas systems.

4. How to use hydrogen/fuel ammonia?

■ Hydrogen in Heat and Power Generation

・Hydrogen can be utilized in cogeneration systems that simultaneously produce electricity and heat for industrial processes or district heating.

・Future technologies aim to improve the efficiency of hydrogen-based heat and power generation systems.

■ Hydrogen in Aviation and Maritime

・Hydrogen is being explored as a potential fuel for aviation and maritime industries to reduce their carbon footprint.

・Hydrogen fuel cell-powered aircraft and hydrogen combustion engines for ships are being researched and developed.

・These technologies have the potential to provide zero-emission alternatives for these sectors.

■ Power-to-Gas and Power-to-Liquid

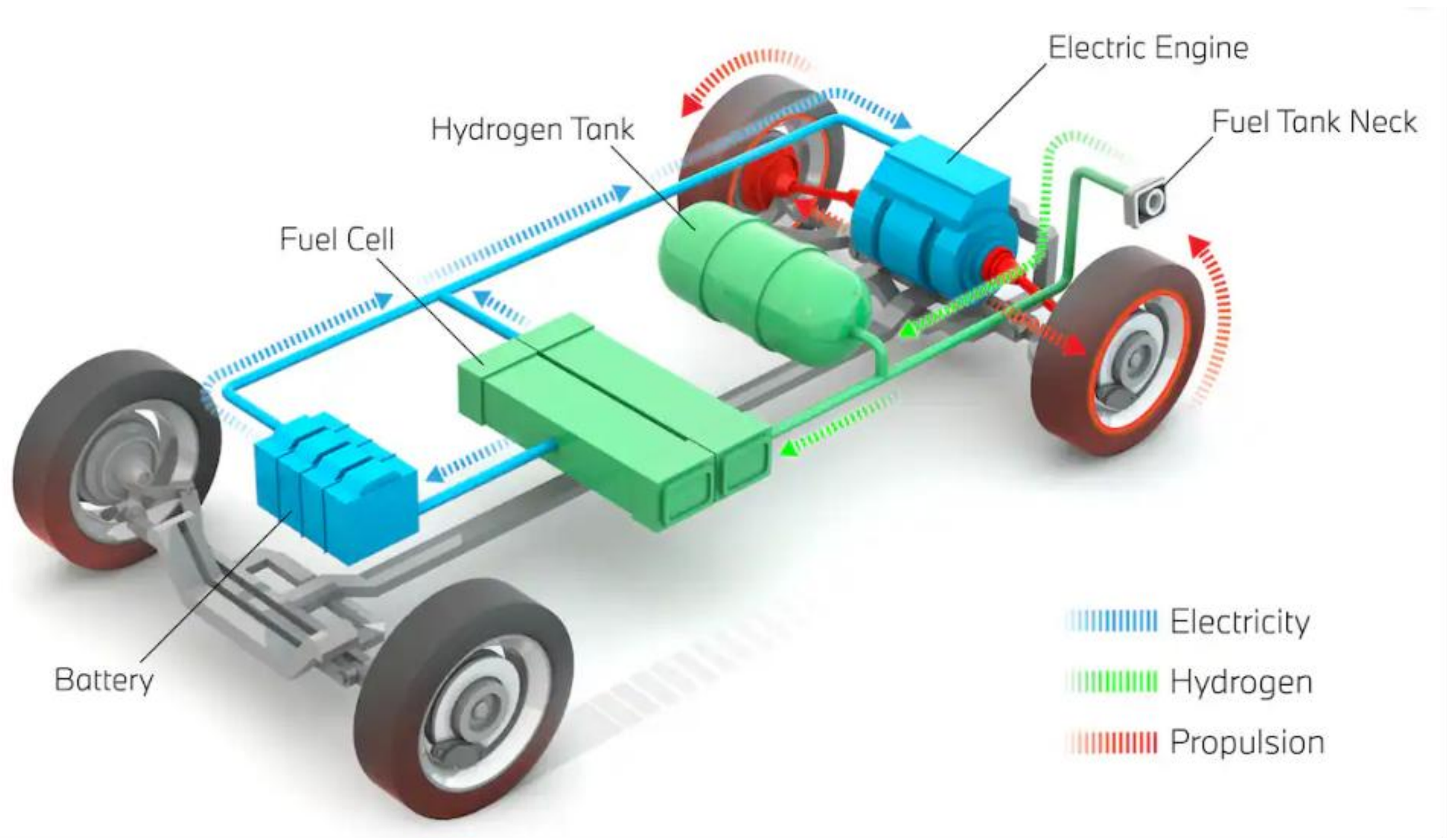
・Power-to-gas and power-to-liquid technologies involve using excess renewable electricity to produce hydrogen or synthetic fuels.

・Power-to-gas technologies convert surplus electricity into hydrogen through electrolysis, which can then be stored or used directly.

・Power-to-liquid technologies utilize hydrogen and captured carbon dioxide to produce synthetic fuels like methane, methanol, or even aviation fuels.

4. How to use hydrogen/fuel ammonia?

■ **Fuel Cell Vehicle (FCV)**



Source: https://www.bmw.com/en/innovation/how-hydrogen-fuel-cell-cars-work.html

4. How to use hydrogen/fuel ammonia?

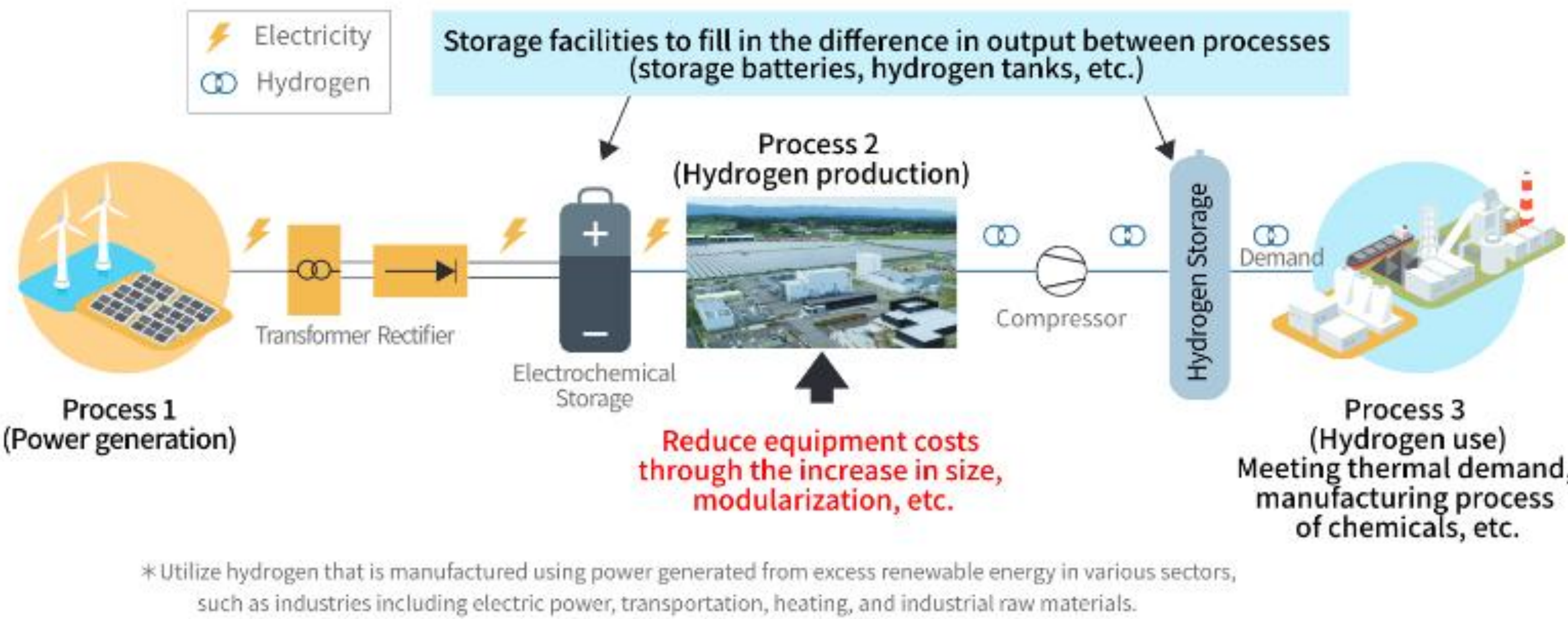
Comparison of FCV to Electric Vehicle (EV) and Highbrid Vehicle (HV)

	Features	Benefits	Challenges
FCV Fuel Cell Vehicle	･Generate electricity through a chemical reaction of H2 and O2 ･No use of fossil fuel.	･Zero CO2 emissions ･Low electric engine	･Vehicle price higher than other drive systems ･Fewer hydrogen stations
EV Electric Vehicle	･Driven by electricity charged by the on-board battery	･Zero or low CO2 emissions while driving ･Quiet motor	･Risk of running out of battery power while droving ･Takes time to recharge battery
HV Hybrid Vehicle	･Use both engine and motor ･Recharged while driving using engine and regenerating energy	･Low fuel consumption ･No need to recharge battery ･Low CO2 emissions while running ･Low engine noise	･Unable to run on electricity alone

4. How to use hydrogen/fuel ammonia?

■ Power-to-X_system's structure

・The Power-to-X scheme is a concept that involves converting surplus renewable energy into another form of energy or fuel.
・The surplus energy is typically generated from sources like solar or wind power, and instead of wasting it, the Power-to-X scheme aims to utilize and store it for future use.



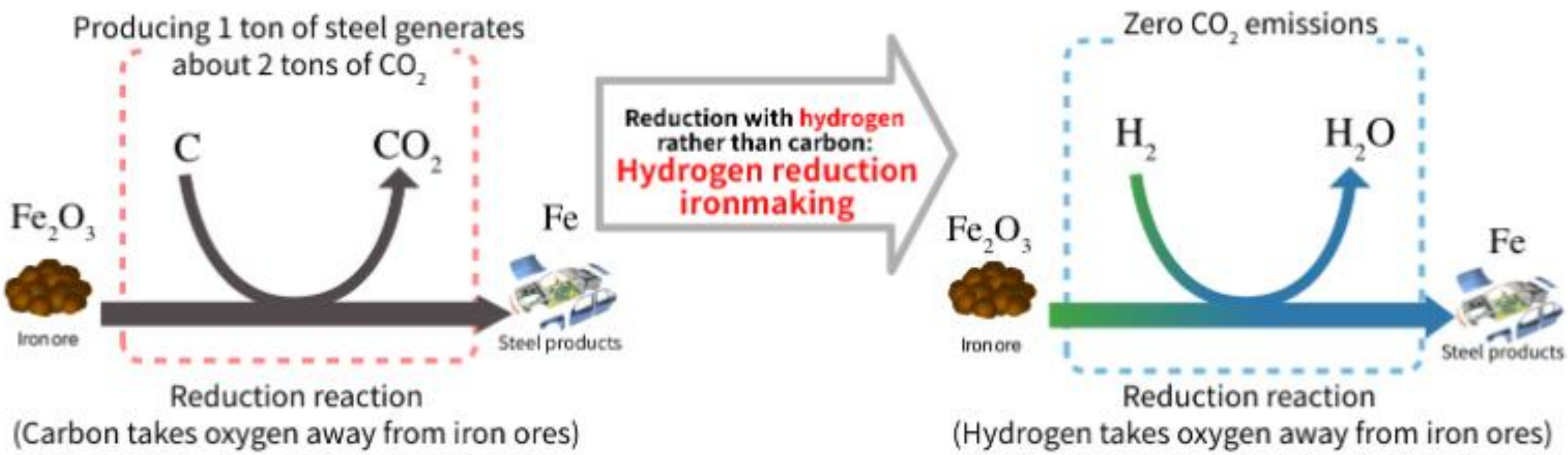
Source: https://green-innovation.nedo.go.jp/en/project/hydrogen-production-water-electrolysis-utilizing/

4. How to use hydrogen/fuel ammonia?

■ Direct hydrogen reduction ironmaking

・Traditional steelmaking processes, such as the blast furnace route, rely on the use of coal or coke as a reducing agent, which leads to significant greenhouse gas emissions.
・In direct hydrogen reduction steelmaking, hydrogen is used as the primary reducing agent instead of carbon-based materials.
・The hydrogen gas acts as a reducing agent, stripping oxygen from the iron oxide and forming water vapor as a byproduct.

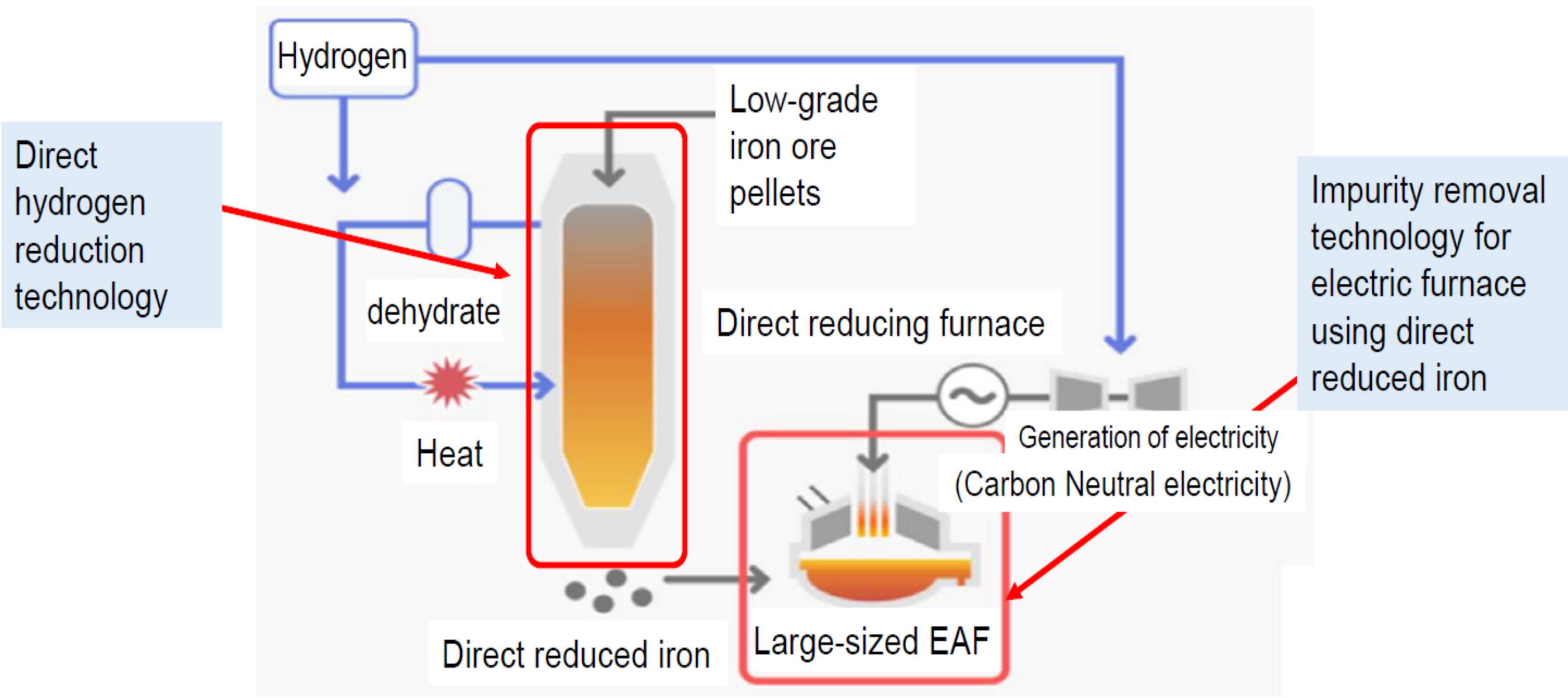
Image of hydrogen reduction ironmaking



Source: https://green-innovation.nedo.go.jp/en/project/utilization-hydrogen-steelmaking/

4. How to use hydrogen/fuel ammonia?

・By 2030, demonstrate that direct hydrogen reduction technologies that use low-grade iron ore can cut CO_2 emissions by 50% or more versus existing blast furnace method.



Source: “Activity of Japanese Steelmaking Industry to Combat Global Warming”, The Japan Iron and Steel Federation, March 2023

5. Hydrogen/fuel ammonia value chain in EAS region

- EAS member countries ：ASEAN+6 Total 16 countries

The East Asia Summit (EAS) is a regional forum held annually by leaders of, initially, 16 countries in the East Asian, Southeast Asian, South Asian and Oceanian regions, based on the ASEAN Plus Six mechanism.

ASEAN :10 member countries

Original 5 Indonesia, Malaysia, the Philippines, Singapore, and Thailand.

5 countries subsequently joined,

Brunei , Vietnam , Laos , Myanmar , Cambodia

+6 : Japan, China, South Korea, India, Australia, New Zealand

- AZEP (Asia Emission Zero Community 11 countries)
  member countries ：Japan, Australia, Brunei, Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, Vietnam

Cooperation field: Solar power, wind power, hydropower, geothermal power, biomass, hydrogen/ammonia, liquefied natural gas (LNG), synthetic fuels, CCUS, energy conservation, industrial decarbonization

5. Hydrogen/fuel ammonia value chain in EAS region

(1) Value chain approaches

■ **"Demand and Supply Potential of Hydrogen Energy in East Asia – phase 3 " (ERIA 2018)**

・Contents Chap 1 Introduction
Chap 2 Hydrogen Supply Potential
Chap 3 Optimal Hydrogen Supply Chain in East Asia
Chap 4 East Asia Summit Hydrogen Working Group Meetings

□ Implication of Chapter 3 results

・A hydrogen value chain - to connect both hydrogen production and demand sites – must be established.

・Generally, MCH has an advantage in short and middle distance and small and mid-volumes. Yet liquified hydrogen has an advantages with middle to long distance and middle to large volumes.

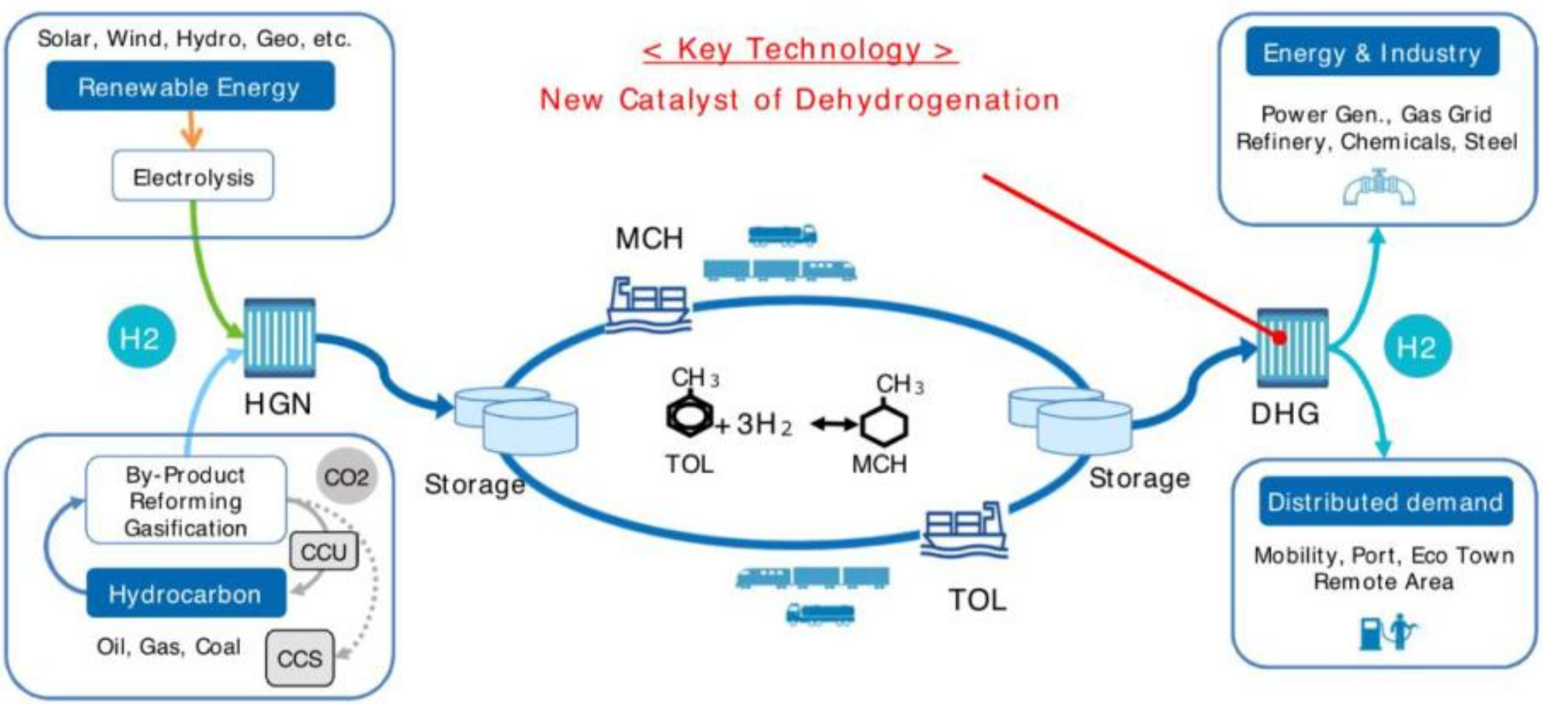
・If Australia and New Zealand transport their hydrogen to Japan and Korea, a hydrogen supply network can be established within ASEAN. Brunei Darussalam and Indonesia can still transport their hydrogen to Japan and Korea.

5. Hydrogen/fuel ammonia value chain in EAS region

(1) Value chain approaches

- **"Demand and Supply Potential of Hydrogen Energy in East Asia – phase 3 " (ERIA 2018)** (continued)

Figure 4.1. Methylcyclohexane Hydrogen Supply Chain



Source: Chiyoda Corporation.

5. Hydrogen/fuel ammonia value chain in EAS region

(1) Value chain approaches

- "Demand and Supply Potential of Hydrogen Energy in East Asia – phase 3 " (ERIA 2018) (continued)

Table 2.16. Hydrogen-Producing Potential from Unused Energies
(million normal cubic metres)

	Production Potential		Demand Potential	Sufficiency Rate	
	Max	Min		Max	Min
Australia	21,502	7,169	13,974	154%	51%
Brunei Darussalam	1	1	1,775	0%	0%
Cambodia	5	1	352	1%	0%
China	1,204	395	163,408	1%	0%
India	1,057	352	11,990	9%	3%
Indonesia	1,501	500	44,807	3%	1%
Japan			29,252	0%	0%
Korea, Republic of			41,558	0%	0%
Lao PDR	13	3	9	137%	34%
Malaysia	42	16	24,034	0%	0%
Myanmar	49	12	1,263	4%	1%
New Zealand	3,370	1,123	1,065	317%	106%
Philippines	49	16	4,551	1%	0%
Singapore			15,098	0%	0%
Thailand	192	63	12,993	1%	0%
Viet Nam	85	29	3,668	2%	1%
	29,070	9,681	369,796	8%	3%

Lao PDR = Lao People's Democratic Republic.
Source: Authors' calculations, ERIA (2020).

5. Hydrogen/fuel ammonia value chain in EAS region

(1) Value chain approaches

- "Demand and Supply Potential of Hydrogen Energy in East Asia – phase 3 " (ERIA 2018) **(continued)**

Table 3.1. Supply Amount of Hydrogen
(million normal cubic metres)

Country	Amount
Australia	284,313
Brunei Darussalam	26,979
Indonesia	209,603
Malaysia	128,667
New Zealand	22,828

So

Table 3.2. Demand Amount for Hydrogen

(million normal cubic metres)

Country	Amount
Japan	302,811
Korea, Republic of	193,609
Malaysia	106,474
Singapore	14,707
Thailand	54,788

Source: ERIA (2019a).

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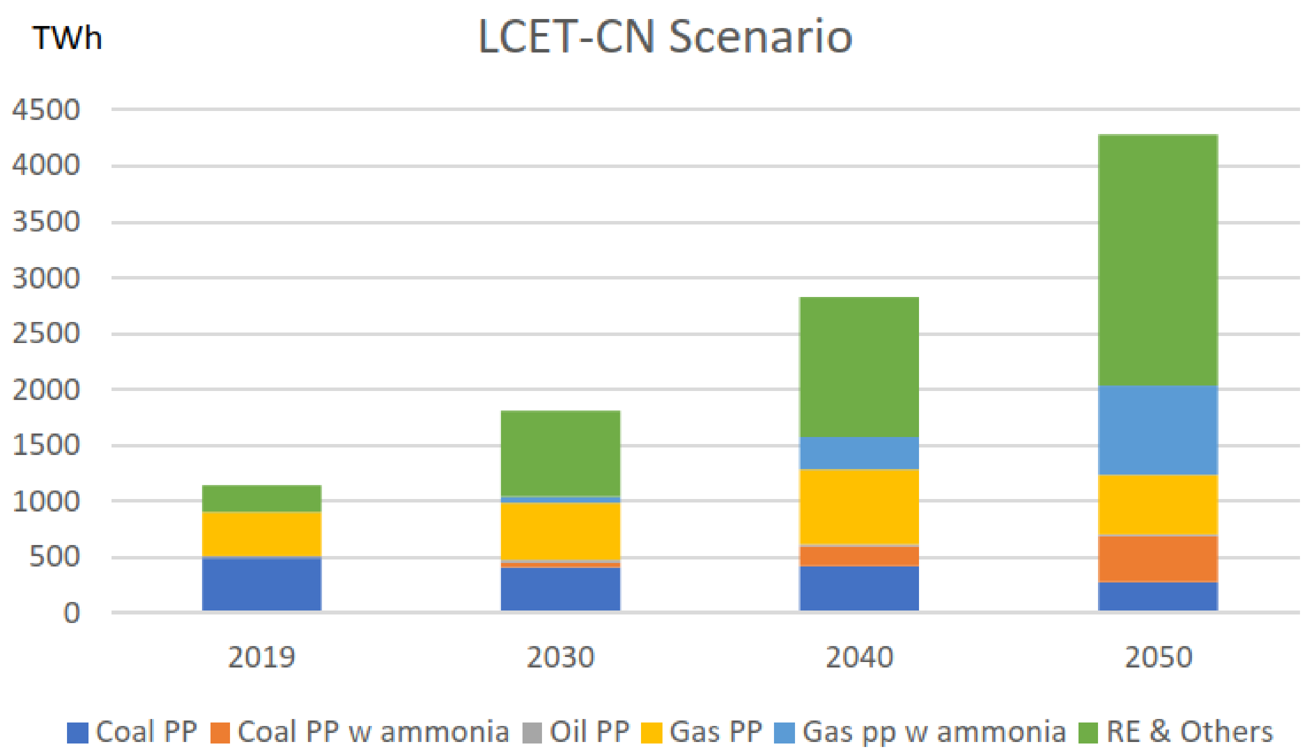
5. Hydrogen/fuel ammonia value chain in EAS region

(1) Value chain approaches

■ **Issues and Challenges of Fuel Ammonia in EAS Region (ERIA Sept 2023)**

Forecast of Ammonia Cofiring Power Generation in ASEAN



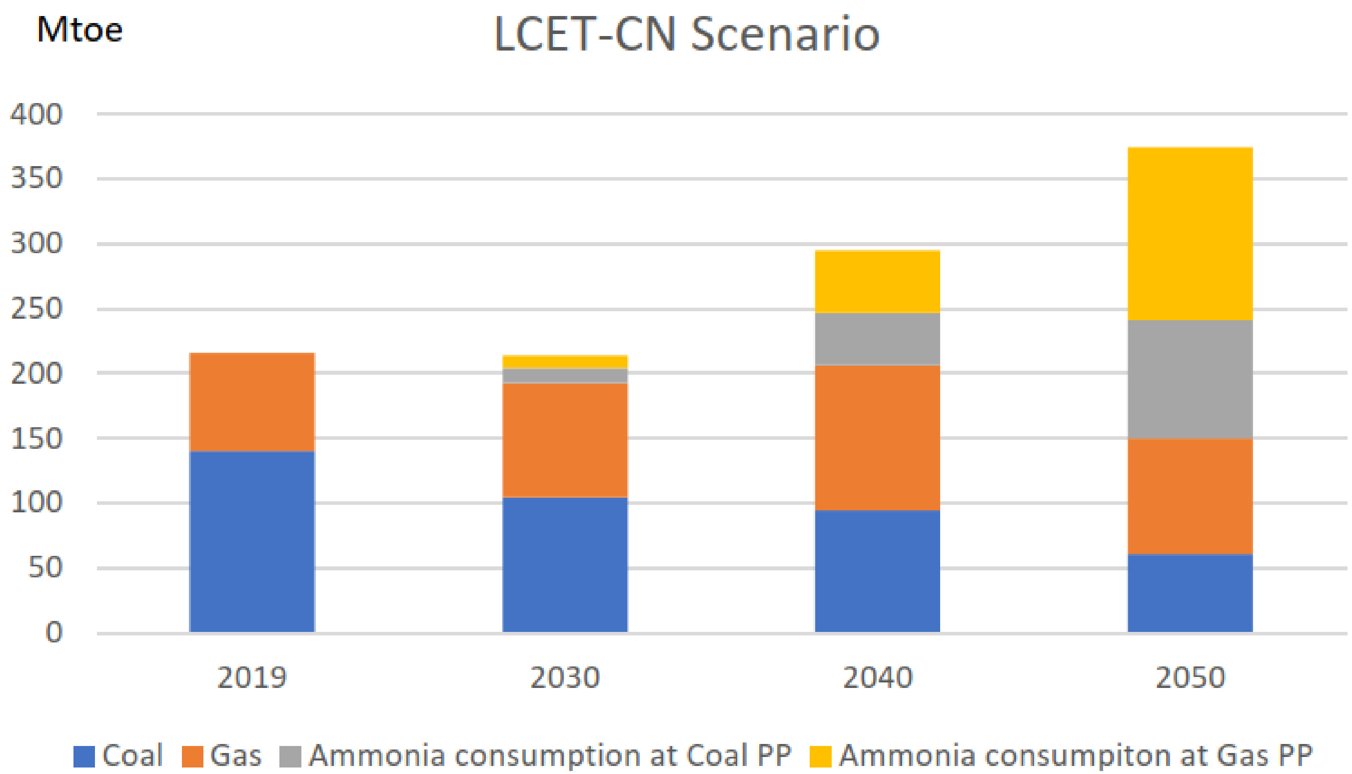
・LCET-CN：Low Carbon Energy Transition – Carbon Natural
・Assumption： Ammonia cofiring ratio at both coal PP and gas PP 10% by 2030, 30% by 2040, 60% by 2050

5. Hydrogen/fuel ammonia value chain in EAS region

(1) Value chain approaches

- Issues and Challenges of Fuel Ammonia in EAS Region (ERIA Sept 2023) (continued)

Forecast of Ammonia Consumption ASEAN



Mtoe：million ton of oil equivalent

5. Hydrogen/fuel ammonia value chain in EAS region

(1) Value chain approaches

■ Issues and Challenges of Fuel Ammonia in EAS Region (ERIA Sept 2023) (continued)

□ Conclusion

・Hydrogen and fuel ammonia will contribute to reduce CO_2 emissions in final energy consumption sectors and power sector in EAS region. Because both fuels are combusted same as fossil fuels but not emit CO_2.

・Need to increase awareness of fuel ammonia through holding forum, conference and workshop in ASEAN Region.

・Demonstrate use of fuel ammonia such as power generation in ASEAN region.

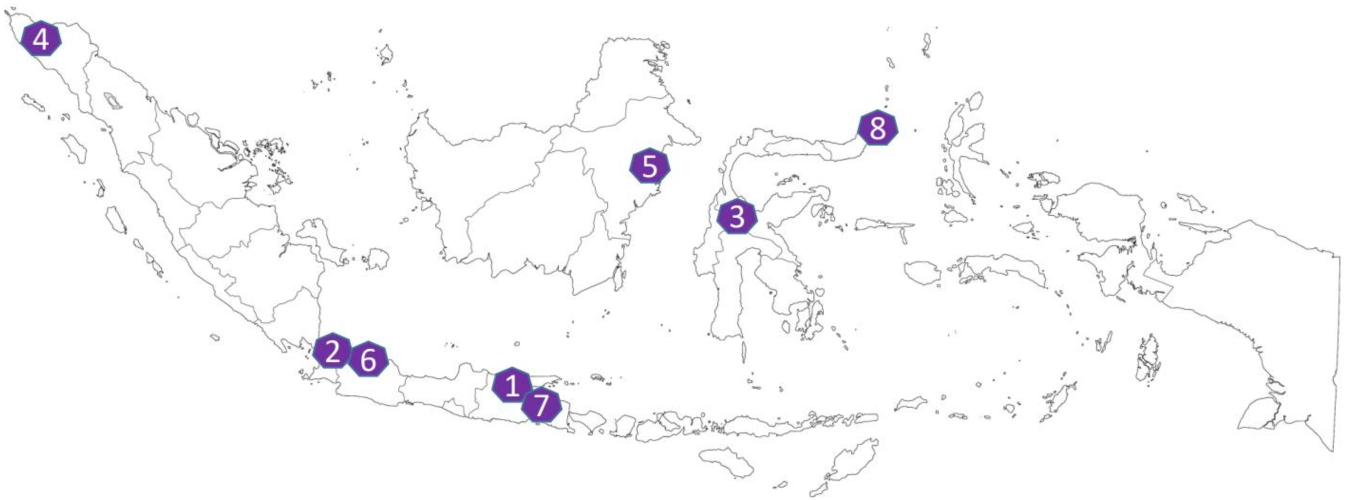
・Initiate fuel ammonia cofiring coal power generation at low cofiring level such as 5 -10% and gradually raise the cofiring ratio year by year.

・Key factors for cost down of fuel ammonia
  ・expand fuel ammonia demand
  ・innovative production technologies of fuel ammonia

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ Indonesia



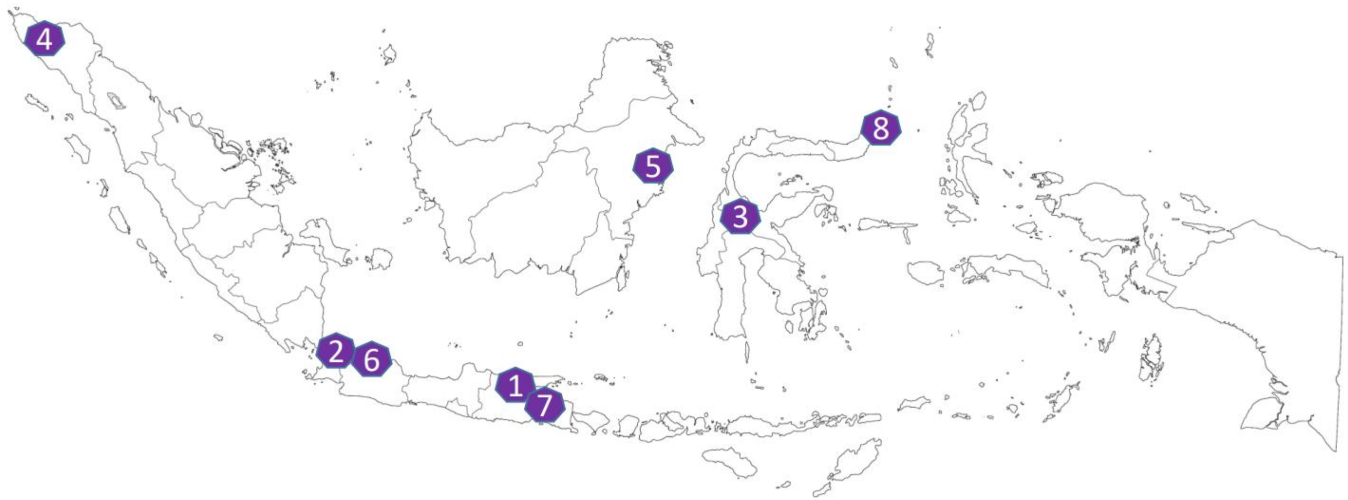
Map	Business Content	Situation
①	**A small amount of ammonia co-fired in the existing boiler of Gresik thermal power plant**	in progress
②	**Conducting feasibility study and field survey regarding ammonia co-firing at Suralaya coal-fired power plant**	in progress
③	**Conducting joint research on blue/green hydrogen and ammonia value chain**	in progress
④	**Started feasibility study for green ammonia production at a fertilizer factory in Aceh province**	in progress

Source : JETRO HP, JETRO：Japan External Trade Organization

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ **Indonesia(continued)**



Map	Business Content	Situation
⑤	**Examining advanced operation and decarbonization of existing ammonia and urea plants**	in progress
⑥	**Survey on hydrogen co-combustion at existing gas-fired power plants (GTCC)**	in progress
⑦	**Conducting a business feasibility study on green ammonia production and sales and mixed combustion in power generation boilers in East Java**	in progress
⑧	**Conducting feasibility study on green hydrogen production and transportation business using geothermal power generation**	in progress

Source : JETRO HP

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ Malaysia

□ Applying ammonia co-firing technology to coal-fired power plants and building a carbon-free ammonia supply chain

• In October 2021, IHI jointly with Petronas and power giant Tenaga Application of ammonia co-firing technology to coal-fired power plants Verified and renewable energy derived green ammonium services including the production of blue ammonia derived from ammonia and natural gas. The feasibility study project will be carried out until February 2022.

• In October 2022, IHI and JERA will begin construction of thermal power generation in Malaysia. Introducing the use of fuel ammonia for decarbonization Jointly make recommendations to Indonesian stakeholders regarding expansion, etc. An MoU (memorandum of understanding) was signed to consider and implement the project.

□ Sarawak State Hydrogen Production Project

• 220,000 tons of green hydrogen and 630,000 tons of green ammonia and 600,000 tons of blue ammonia per year.

• In April 2022, Petros in Sarawak will move gas to Darul Hana. Multis supplying phosphorus, diesel, electricity or hydrogen A station was opened. Hydrogen as fuel by 2024 Build a mass transportation system

Source : JETRO HP & JOGMEC HP (JOGMEC：Japan Organization for Metals and Energy Security

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5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ the Philippines

□ **Applying ammonia co-firing** technology **to coal-fired power plants**

- JERA Co., Ltd. has signed a memorandum of understanding with Aboitiz Power Corporation to begin a joint study on co-firing ammonia at coal-fired power plants in order to decarbonize the company's business.
- This memorandum stipulates that the feasibility of co-firing ammonia in coal-fired power plants and the establishment of a hydrogen and ammonia supply chain in the Republic of the Philippines will be investigated.

□ **Strengthening cooperation in the energy field with Indonesia**

- On January 10, the Philippine Department of Energy and Indonesia's Department of Energy and Mineral Resources signed a memorandum of understanding (MOU) to strengthen cooperation in the energy field.
- Through cooperation with Indonesia, the Philippines is expected to indirectly benefit from economic, environmental, and geopolitical areas such as electric vehicles (EVs) and alternative fuels such as hydrogen, ammonia, and biofuels. .

Source : JERA HP 2023.2.10 & JOGMEC HP 2024.1.31

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ Singapore

□ National Hydrogen Strategy

- CO_2 emissions in 2020 were 49.7 million equivalent tons. 97.9% of these emissions come from three sectors: power generation, manufacturing, and transportation, including shipping, aviation, and land .
- For this reason, the government has announced a policy to encourage the introduction of hydrogen in each of the three sectors.
- In particular, with regard to power generation, in order to promote decarbonization in the power generation field, Singapore needs to use low-carbon alternative fuels such as
  ① natural gas
  ② solar power
  ③ electricity imports from neighboring countries
  ④ hydrogen.
- Among these four supply switches, hydrogen is expected to become an important fuel for power generation in the future.

Source : JETRO HP

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ Singapore (continued)

□ Hydrogen-fired power plant to be completed in 2026

- In August 2022, Keppel Infrastructure Holdings will build Singapore's first hydrogen-fired power plant (600,000 KW), in the south of the country. It was announced that it would be installed on Jurong Island in the west.
- It is a state-of-the-art gas turbine combined cycle (GTCC) power plant designed to run on fuel containing 30% hydrogen. The company is also considering eventually transitioning to 100% hydrogen fuel.
- The engineering, procurement and construction (EPC) contract for the power plant was awarded to a consortium of Mitsubishi Power Asia Pacific, a member of the Mitsubishi Heavy Industries Group, and local engineering firm Jurong Engineering.
- The power plant is expected to be completed in the first half of 2026.

□ Manufacture ammonia in India and supply it to Japan

The aims of this collaborative project are

- to produce inexpensive green ammonia in India, which has high competitiveness in renewable energy, and to contribute to Japan's decarbonization;
- green ammonia is affected by fluctuations in gas prices. To contribute to Japan's energy security by building a supply chain with India, which is not a traditional fuel supplier.

Source : JETRO HP

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ Singapore (continued)

□ Accelerating hydrogen project collaboration with foreign countries

◆**Japan**

- Joint development to build ammonia fuel supply chain for ship
- Strategic alliance to realize hydrogen value chain business
- Feasibility study on methanation business to synthesize methane from CO2 and hydrogen
- Joint study of commercialization in the field of decarbonization
- EPC contract for construction of a power plant with hydrogen power generation in mind on Jurong Island
- Strategic partnership regarding quantitative risk assessment of ammonia-only gas turbine power plants
- Collaboration in green hydrogen and ammonia fields
- Jointly considering promotion of carbon neutrality through the use of green ammonia for power generation

◆**Chile**

- Hydrogen technical cooperation

◆**Australia**

- Cooperation in research on low-carbon solutions such as hydrogen supply chain

Source : JETRO HP

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ Thailand

□ Carbon neutral industrial park concept

- Feasibility study of a "carbon neutral industrial park" that integrates the development, production, use, and storage of renewable energy including hydrogen
- Feasibility study and demonstration experiment to introduce clean energy to Mahbtabut Industrial Park in eastern Thailand

□ Hydrogen Station

- PTT (PTT Public Company Limited) has opened its first hydrogen station in Chonburi province in the south. (November 8, 2022)
- PTT will explore challenges for expanding the introduction of hydrogen energy.

□ Building a green hydrogen/ammonia value chain

- Construction of a series of supply chains for the production, storage, transportation and use of clean hydrogen and ammonia derived from renewable energy in southern Thailand, and supply within and outside Thailand.

Source : JOGMEC HP

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ Vietnam

□ Production of Green Hydrogen and Ammonia

- TGS Green Hydrogen has begun construction of a green hydrogen factory in Ben Tre province in southern Vietnam that utilizes German hydrogen production technology, and commissioning is scheduled to begin in the first quarter of 2024.
- The plant will produce 24,000 tons of green hydrogen and 150,000 tons of ammonia per year.
- After that, the company plans to increase its production capacity to 60,000 tons per year of hydrogen, 375,000 tons of ammonia, and 490,000 tons of oxygen per year.

□ Collaboration with JOGMEC on hydrogen and ammonia production

- JOGMEC has agreed to pursue joint business opportunities with Vietnam for hydrogen and ammonia production.

Source : JOGMEC HP

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5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ China

□ Hydrogen energy medium- and long-term development plan (2021-2035)

Year	Content
2025	Create the institutional and policy environment for the development of the hydrogen energy industry, improve the industry's innovation ability, master core technology and manufacturing capabilities, and build a relatively well-developed supply chain and industrial system. Have approximately 50,000 fuel cell vehicles and numerous hydrogen filling stations. The amount of hydrogen produced using renewable energy will reach 100,000 to 200,000 tons per year, reducing carbon dioxide emissions by 1 to 2 million tons per year.
2030	Build a technological innovation system for the hydrogen energy industry and a hydrogen production and supply system using clean energy
2035	Build a technological innovation system for the hydrogen energy industry and a hydrogen production and supply system using clean energy

Source : JETRO HP

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ China (continued)

□ Industrial innovation application model project during the 14th five-year plan period

Field	Content
Traffic	Verification of transportation using **hydrogen** fuel cell trucks in specific areas, use of fuel cell vehicles in public service fields such as city route buses, and application verification of 70MPa **hydrogen** storage cylinder vehicles
Storage	Taking into consideration the demand for renewable energy, integrated storage tanks and **hydrogen** filling stations will be installed to promote decentralized production and local use of hydrogen energy.
Power Generation	implementing a microgrid model that combines **hydrogen** and electricity, and promoting the application and practice of fuel cell cogeneration supply.
Industry	Build a **hydrogen** production model using renewable energy as an alternative to fossil fuels

Source : JETRO HP

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ China (continued)

□ Construction of Hydrogen Pipeline

・In April 2023, China National Petroleum Corporation (PetroChina, CNPC) announced plans to install a long-distance hydrogen pipeline. A 400km pipeline will be installed between Inner Mongolia (Ulanchab City), which has resources suitable for green hydrogen production, and Beijing City (China Petrochemical Yanshan Petrochemical), which is a major consumption area.

・At the time of operation, the transportation capacity was 100,000 tons per year, and it is planned to increase to 600,000 tons in the future.

・It will be the longest hydrogen pipeline in China, spanning three provinces and cities: Inner Mongolia Autonomous Region, Hebei Province, and Beijing City.

□ Ammonia Co-firing Test

・According to local media on November 30, China Energy conducted an ammonia co-firing test under high load conditions at the 600MW coal-fired power generation unit of China's Shenhua Taishan Power Plant in Guangdong Province. The test run went smoothly with an ammonia combustion rate of 99.9%.

Source : JETRO HP

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ Korea

□ Hydrogen/Ammonia Plan

- 2023： SK E&S is constructing a hydrogen liquefaction plant within SK Incheon Petrochemical.
- 2023：plan to liquefy petrochemical plant byproduct hydrogen and begin supplying 30,000 tons of liquefied hydrogen per year to the metropolitan area, including Seoul.
- 2025： 250,000 tons of natural gas-derived blue hydrogen will be produced annually, and raw gas will be procured from SK E&S/GS's Boryeong LNG terminal.
- In the long term, promote green hydrogen using renewable energy such as solar and wind power.
- Build a CO2-free hydrogen value chain.
- 2022.2 The Korean Alliance has signed an agreement with Sarawak State Economic Development Corporation (SEDC) of Malaysia to supply
  - 7,000 tons of hydro-derived green hydrogen (local consumption)
  - natural gas-derived blue hydrogen for export to South Korea.
  - 600,000 tons of blue ammonia
  - 630,000 tons of green ammonia
  - 460,000 tons of green methanol.

Source : JOGMAC HP

5. Hydrogen/fuel ammonia value chain in EAS region

(2) Ongoing hydrogen/ammonia value chain projects

■ Korea (continued)

□ Hydrogen/Ammonia Power Generation Demonstration Promotion Group

- Korean government plans to make carbon dioxide (CO2)-free power generation using ammonia and hydrogen fuel 13.8% to 21.5% of the power supply mix in 2050 under the "2050 Carbon Neutral Scenario.‘’
- Hydrogen power generation is currently underway. Complete the technological development of hydrogen co-firing limit evaluation and combustion optimization for gas turbines by 2024, complete the demonstration of 50% hydrogen co-combustion at a scale of 150 megawatts (MW) by 2028, and achieve 30% or more hydrogen co-combustion by 2035.
- After commercializing mixed combustion power generation, the aim is to commercialize exclusively hydrogen combustion by 2040.
- Furthermore, for ammonia power generation, the company plans to complete demonstrations of 20% mixed combustion by 2027, and to put 20% mixed combustion into practical use at 24 of its 43 coal power plants, or more than half, by 2030.

Source : JETRO HP

6. Introduction hydrogen/fuel ammonia projects led by Japan

(1) Basic hydrogen strategy of Japan 2023.6.6(*1)

- Assuming S (Safety) + 3E (Energy Security, Economic Efficiency, Environment).

- In addition to the current **hydrogen** introduction targets of up to
  3 million tons/year in 2030 and
  around **20 million** tons/year in 2050,
  a new target of around **12 million** tons/year (including NH3) will be set in 2040.

- Aim for **hydrogen** supply cost (CIF) to be
  30 yen/Nm3 in 2030,
  20 yen/Nm3 in 2050, and
  ammonia supply cost to be in the high 10s/Nm3 (hydrogen equivalent) in 2030.

- From the late 2020s to 2030. In **hydrogen/ammonia** power generation, Japan aims to realize a wide range of co-firing rates, including not only the conventional co-firing rate but also single-firing.

- For low-carbon hydrogen and ammonia supply companies, consider a scheme that provides long-term support for the difference (part or all) between the standard price and the reference price.

*1 Ministerial Meeting Related to Renewable Energy and Hydrogen, etc.

6. Introduction hydrogen/fuel ammonia projects led by Japan

(1) Basic hydrogen strategy of Japan 2023.6.6 (continued)

- In the electric power field, hydrogen is highly flammable and is expected to be co-fired in gas-fired power plants.
- Ammonia has a relatively slow combustion speed and is assumed to be co-fired in coal-fired power plants.
- Hydrogen has the potential to be used for a variety of purposes, including as a raw material for industrial processes.
- Due to its high energy density, ammonia is also expected to be used in the field of ships that travel long distances, such as in international transportation.

Comparison of physical properties related to combustion

Fuel Type	Hydrogen	Ammonia	Methane(LNG)	Propane(LPG)	Common Coal
Higher Heating Value (MJ/kg)	141.8	22.5	55.5	50.4	26.1
Higher Heating Value(MJ/Nm3)	12.7	17.1	39.6	99.0	NA
CO2 Emitting Coefficient (kg-CO2-MJ)	0	0	0.0503	0.0596	0.0913
Burning rate in air(m/s)	2.65	0.09	0.37	0.43	NA
Combustion range in air(vol%)	4.0～75.0	15.5～27	5.3～14.0	2.4～9.5	NA
minimum ignition energy(mJ)	0.02	170	0.29	0.26	NA
Adiabatic flame temperature (℃)	2,110	1,800	1,950	1,995	NA

CHIYODA CORPORATION

6. Introduction hydrogen/fuel ammonia projects led by Japan

(1) Basic hydrogen strategy of Japan 2023.6.6 (continued)

Applications (major classification)	Applications (medium classification)	Hydrogen	ammonia
Electricity	Mixed combustion/exclusive combustion for coal-fired power generation		○
	Mixed combustion/exclusive combustion for gas-fired power	○	
non-power (Fuel)	Heat utilization (industrial furnaces, etc.)	○	○
	Engines for ships, etc	○(Short to medium distance)	○(Long distance)
	Fuel cells for mobility/stationary use, etc	○	
non-power (Raw material)	Hydrogen reduction iron manufacturing	○	
	Total basic chemicals	○	

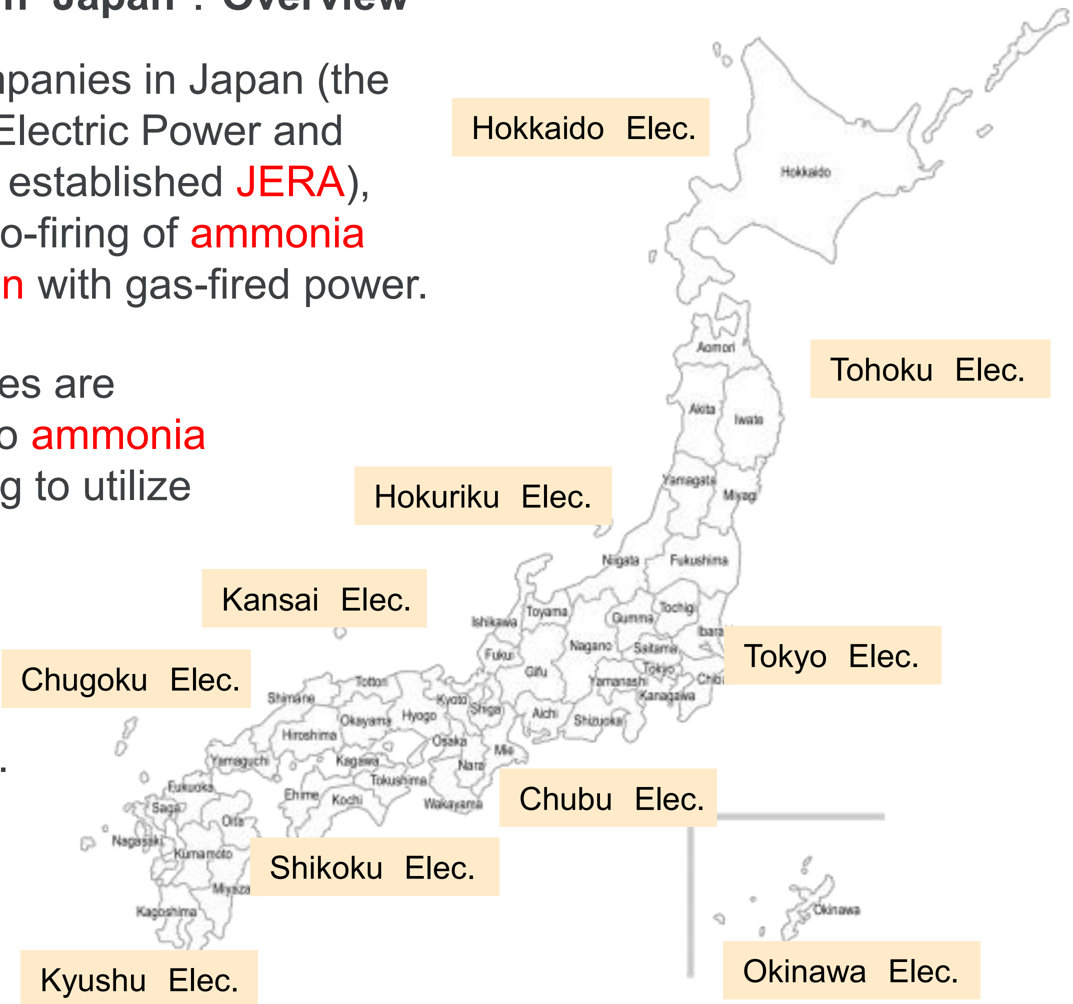
6. Introduction hydrogen/fuel ammonia projects led by Japan

(2) Hydrogen / Ammonia Project in Japan : Overview

- There are nine electric power companies in Japan (the thermal power divisions of Tokyo Electric Power and Chubu Electric Power have jointly established JERA), and each company is promoting co-firing of ammonia with coal-fired power and hydrogen with gas-fired power.

- Oil companies and other companies are developing infrastructure related to ammonia import, storage, and supply, aiming to utilize their existing facilities.

- Meanwhile, demonstration tests of hydrogen supply chains using government funds are progressing. (Hydrogen production from Australian lignite - international transportation of liquid hydrogen, MCH production in Brunei - international transportation, etc.)



6. Introduction hydrogen/fuel ammonia projects led by Japan

(3) Hydrogen Project in Japan

Site	Place	Participating companies	Summary of plans and results	Source
Electricity storage technology research site	Yamanashi Pref. Komekurayama, Kofu city	Yamanashi Pref. Tokyo Electric Power Company Holdings Toray Co.	・Development of a hydrogen gas production system (Power to Gas System) by electrolysis of water using renewable energy ・Demonstration of hydrogen shipping equipment, hydrogen trailers, pure hydrogen boilers, etc. ・Main equipment: PEM type water electrolysis device (500kW x 3 large stack), hydrogen storage alloy tank system (3,500m3)	Yamanashi Pref. HP

Panoramic view of Komekurayama research site

P2G experimental research building exterior

Inside the P2G experimental research building

6. Introduction hydrogen/fuel ammonia projects led by Japan

(3) Hydrogen Project in Japan

Site	Place	Participating companies	Summary of plans and results	Source
Fukushima Hydrogen Energy Research Field (FH2R)	Fukushima Pref.	METI Fukushima Pref. Toshiba Energy System Co Iwatani Co. Tohoku Electric Power Co.	At FH2R, the world's largest 10MW hydrogen production equipment uses electricity from 20MW of solar power installed on a 180,000m2 site to electrolyze water at a rate of 1,200Nm3 per hour (at rated operation) hydrogen will be produced, stored and supplied.	NEDO HP

Panoramic view of Fukushima Hydrogen Energy Research Field (FH2R)

6. Introduction hydrogen/fuel ammonia projects led by Japan

(3) Hydrogen / Ammonia Project in Japan

Site	Place	Participating companies	Summary of plans and results	Source
Niigata Thermal Power Station	Niigata Pref.	Tohoku Elec.Co., Ltd	Hydrogen co-firing demonstration at Niigata Thermal Power Plant Group 5 (109,000 KW) will begin in October 2023, and will be the first hydrogen co-firing test in Japan for a commercial gas combined cycle thermal power plant. Hydrogen co-firing rate: 1% by volume	Tohoku Elec. HP (2023.9.26)
Reihoku Thermal Power Station	Kumamoto Pref	Kyushu Elec.Co., Ltd	Study and technology establishment for co-firing 1% hydrogen and 20% ammonia	Kyushu Elec. HP(2023.4.7)
Chubu Area	Aichi, Gifu,Mie Pref.	Local government, private sector	Target values for demand Hydrogen ton/y / Anmonia ton/y 2030: 230,000 / 1,500,000 2050: 2,000,000 / 6,000,000	Aichi Pref. HP (2023.3.27)

6. Introduction hydrogen/fuel ammonia projects led by Japan

(4) Ammonia Project in Japan

Site	Place	Participating companies	Summary of plans and results	Source
Hekinan Thermal Power Station	Hekinann, Aichi Pref.	JERA IHI	Aiming for 20% ammonia co-firing at Hekinan Thermal Power Station Unit 4 (1 million kW). The initial plan was to run for four years from 2121.6 to 2125.3, but the 20% co-firing demonstration test is scheduled to start one year earlier at the end of 2023. Signed agreement with Mitsui & Co. to procure fuel ammonia	JERA HP 2021.5.24 2022.5.31 2023.6.16
Mizushima Thermal Power Station	Kurasiki, Okayama Pref.	Chugoku Elec.Power Co., Ltd.	Ammonia co-firing test conducted at Mizushima Power Station Unit 2	Chugoku Elec.HP 2021.6.29
Gushikawa Power Station	Gushikawa Okinawa Pref.	Okinawa Elec.Power Co.,Ltd Tsubame BHB KHI	・Survey on the possibility of co-firing ammonia for local production and consumption ・Local ammonia production and supply survey ・Ammonia co-firing modification investigation	Okinawa Elec.HP 2022.6.11

6. Introduction hydrogen/fuel ammonia projects led by Japan

(4) Ammonia Project in Japan (continued)

Site	Place	Participating companies	Summary of plans and results	Source
Tokuyama Refinery	Shunan, Yamguchi Pref.	Iidemitsu, IHI	・Utilize existing facilities such as storage facilities and petrochemical equipment at Idemitsu's Tokuyama office. ・Consideration of establishing an ammonia import base and demonstration of ammonia co-combustion in a naphtha cracking furnace	Idemitsu HP 2021.6.25
Shunan Industrial Complex	Shunan, Yamguchi Pref.	Idemitsu Toso Tokuyama Nihon-Zeon	・Consideration of creating an ammonia import base using existing storage facilities at Tokuyama Plant ・Consideration of ammonia supply infrastructure to industrial complex companies	Idemitsu HP 2022.8.10

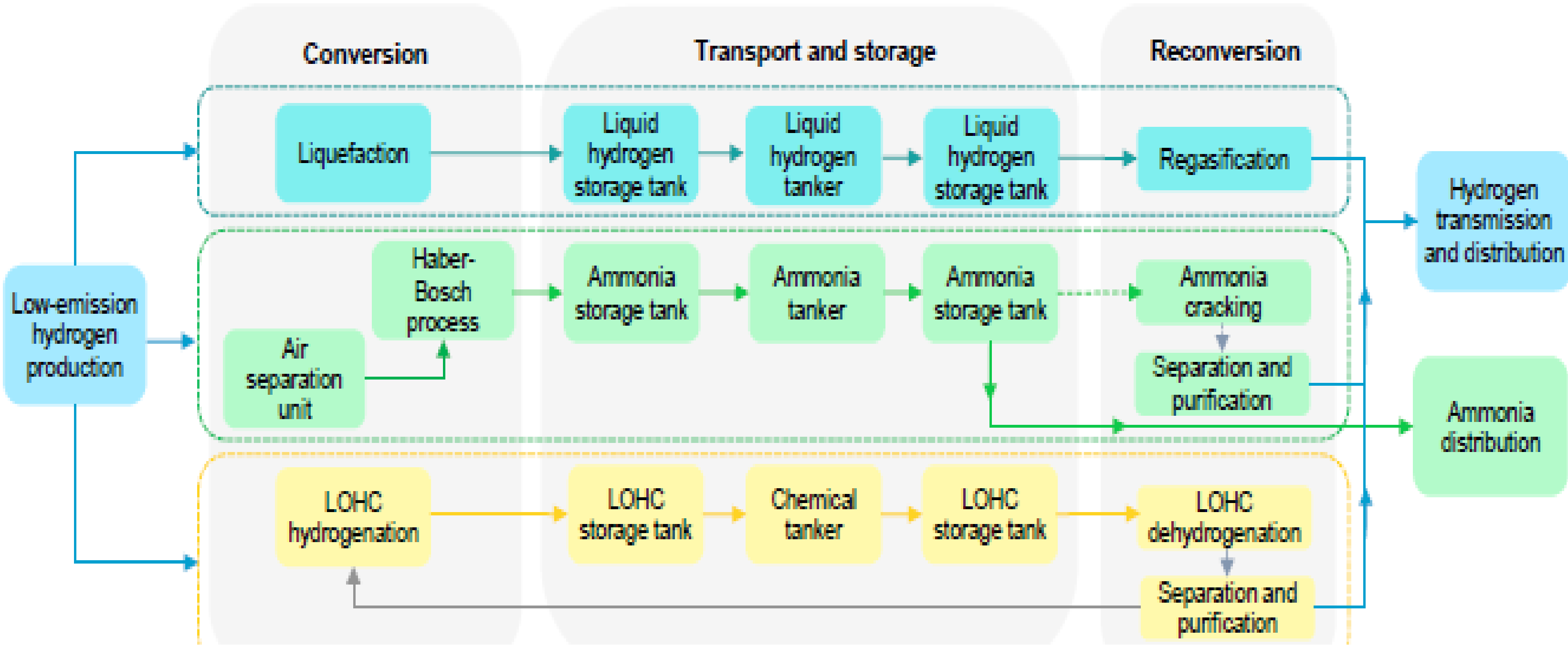
6. Introduction hydrogen/fuel ammonia projects led by Japan

(4) Ammonia Project in Japan (continued)

Site	Place	Participating companies	Summary of plans and results	Source
Namikata Terminal	Imabari Ehime Pref.	Shikoku Elec.Power Co. Taiyo Sekiyu Taiyo Nissan Matsuda Mitsubishi Co. Namikata Terminal MC Clean Energy	・It is envisaged that the existing LPG tanks at Namikata Terminal will be converted to ammonia tanks and the terminal will become a hub terminal that will handle approximately 1 million tons of ammonia annually by 2030. ・Organizing schedules and legal and regulatory issues ・Considering efficient use of Namikata terminal, measures to increase demand, etc.	Shikoku Elec HP 2023.4.14
INPEX Higashi Kashiwazaki	Kashiwazaki Niigata Pref	INPEX JGC Daiichi Jitsugyo	1) Demonstration of production of blue hydrogen and supply of clean electricity using it (raw material is domestic natural gas) (700ton-H2/y) 2) Production of ammonia using a recently developed low-temperature, low-pressure synthesis process	INPEX HP 2023.7.12
Tomato-Atsuma Power Station	Hokkaido	Hokkaido Elec. Power Co.,Ltd	It is assumed that coal will be mixed with ammonia and burned at the Tomato-Atsuma thermal power plant.	Nikkei Shimbun 2022.9.15

7. Cost of hydrogen production and supply

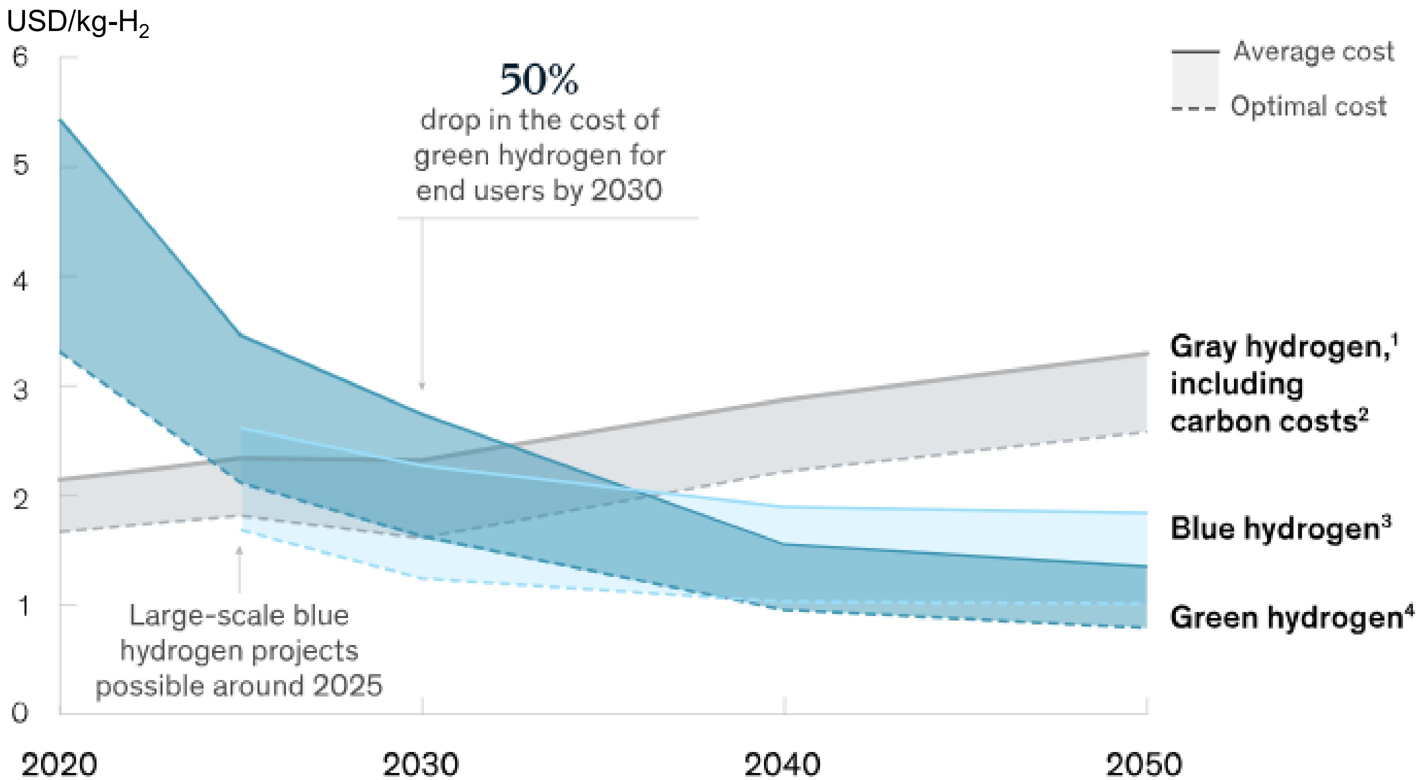
・The cost of hydrogen production and supply can vary depending on several factors, including the method used, scale of production, and the source of energy.
・The distribution and storage Infrastructure costs also play a significant role in the overall supply cost of hydrogen.
・Additionally, transportation costs can be significant if the hydrogen needs to be transported over long distances.



Source: IEA Energy Technology Perspectives 2023

7. Cost of hydrogen production and supply

Projected global production cost of hydrogen

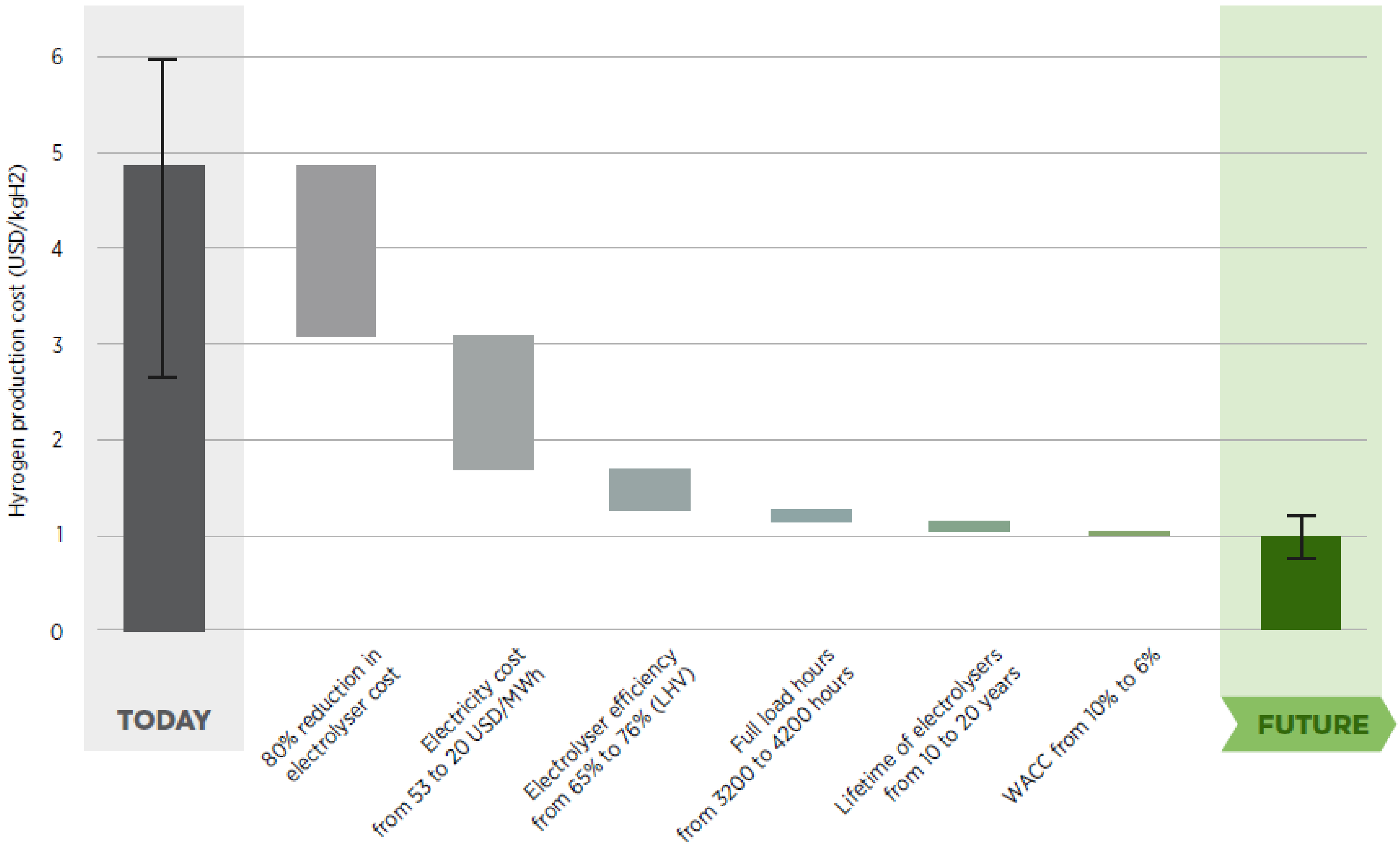


[1]Steam methane reforming (SMR) without carbon capture, utilization, and storage (CCUS).
[2]Based on projected average global CO_2 costs of $57/ton (2030), $94/ton (2040), and $131/ton (2050). For Saudi Arabia, CO_2 costs are assumed to be $33/ton in 2030, $69/ton in 2040, and $105/ton in 2050.
[3]Gas prices of $2.60 to $6.80/MMBtu (approximately $3/MMBtu in Saudi Arabia).
[4]Refers to the cheapest green hydrogen, which is provided by solar energy.
Source: McKinsey Hydrogen & Derivatives Flows Model, October 2022

Source: “The clean hydrogen opportunity for hydrocarbon-rich countries”、McKinsey & Company, November 23, 2022

7. Cost of hydrogen production and supply

Combination of cost reductions in electricity and electrolysers

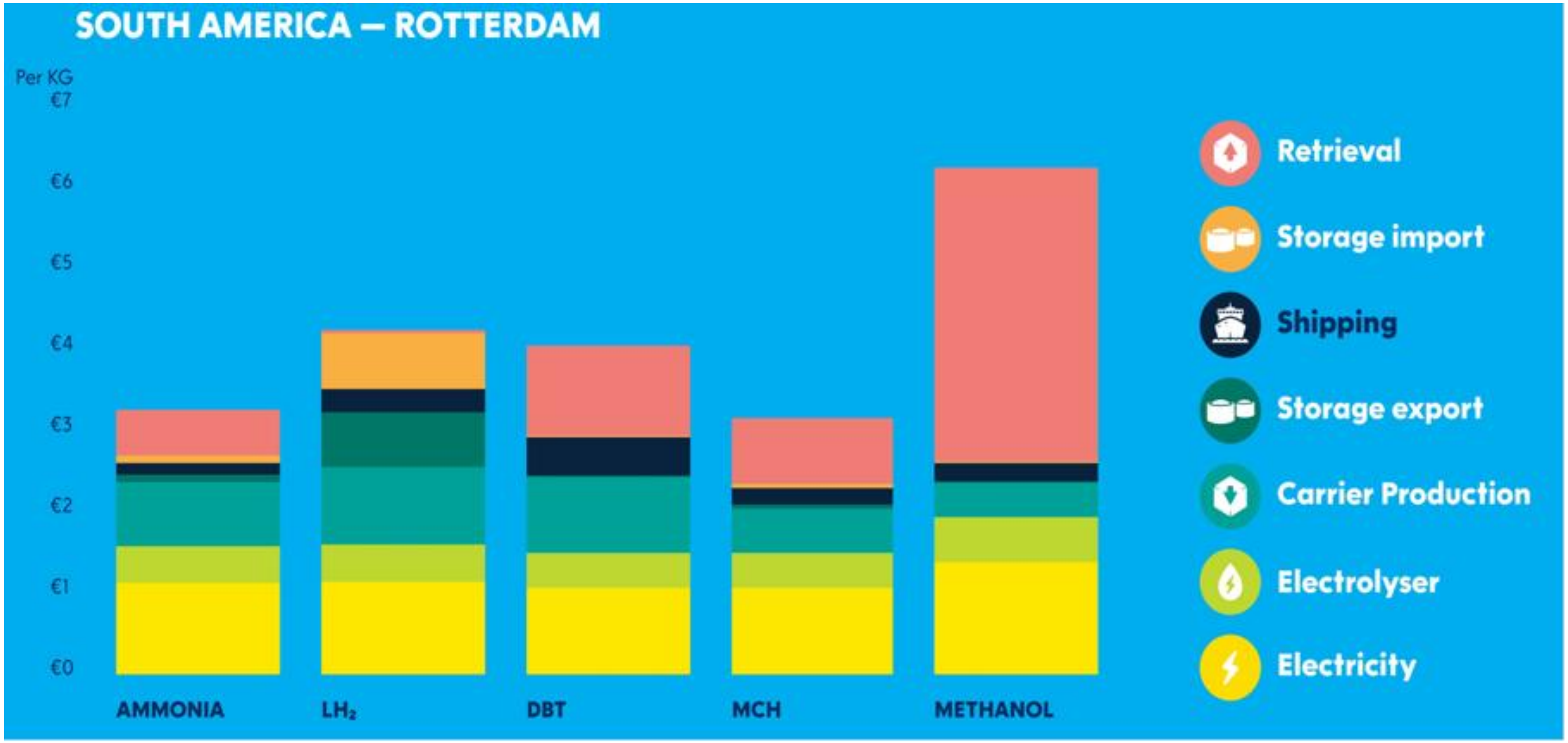


Source: IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal, International Renewable Energy Agency

7. Cost of hydrogen production and supply

・As for the hydrogen costs for each carrier, an example of the results of cost estimation by third-party organizations is provided below.

Hydrogen carriers: Supply chain cost comparison



Source: Speech by Allard Castelein, CEO Port of Rotterdam Authority at the 2nd World Hydrogen Summit, 2021

Energy and Environment in harmony

Thank you!

Баярлалаа