Hydrogen Economy Roadmap of Korea

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Government of Korea

Contents

I. Implications and Significance of the Hydrogen Economy

What is Hydrogen Economy?

Characteristics of Hydrogen (H_2)

- Hydrogen (H_2, element with **atomic number 1**) is the most abundant element in the universe.
- The use of hydrogen requires advanced technologies, and its major characteristics are: ❶ easily generated from water resources, ❷possible to store in large quantities for long periods of time (energy carrier), and ❸**eco-friendly** (CO_2-free), as the only by-product produced when hydrogen is used to **generate heat or electricity,** through a chemical reaction with oxygen (O_2), is water (H_2O).

Hydrogen Economy

- **An economic system in which hydrogen is an important energy source**, and hydrogen-based energy conversion technologies, such as fuel cells, are developed and utilized to reduce the use of fossil fuels and CO_2 emissions.

⇨ Fostering of future industries + eco-friendly energy

Carbon Economy vs. Hydrogen Economy

	Carbon Economy	**Hydrogen Economy**
Energy Paradigm	Reliant on carbon resources (oil, coal, and natural gas)	Focusing on decarbonized hydrogen
	Dependent on imports (99 percent)	Contributes to energy independence through domestic production
Energy Supply	Centralized energy supply and demand that requires large investment	Distributed energy supply and demand possible with small investment
	Many location-related restrictions and low public acceptability	Few location-related restrictions and high public acceptability
Competition	Competition to develop resources and secure energy resources	Competition to lead technological development and establish economy of size
Environment	Emission of GHGs and air pollutants * CO_2, NOx, SOx, etc.	Eco-friendly with low GHG emissions *By-product = H_2O

◇ Large effects of the hydrogen industry on upstream and downstream industries

□ **(Front Industries) Various new industries, ranging from transportation to energy, can be created.**

○ **(Transportation) A new industrial ecosystem can be created through the use of hydrogen throughout the entire transportation sector,** from passenger cars to commercial vehicles, trucks, forklifts, trains, ships, and airplanes.

* Global automobile market (2017): USD 2 trillion → Even if only 10 percent of vehicles in the global automobile market were converted to hydrogen, the resulting market would be about 1.5 times (USD 125.1 billion) the size of the semiconductor market and about half (USD 419 billion) the size of the display market.

○ **(Energy)** Fuel cells, which are eco-friendly and feature high energy generation efficiency, have emerged as an optimal alternative for distributed energy generation.

* Contribution of fuel cells to power generation worldwide: 215MW in 2013 → 299MW in 2015 → 670MW in 2017 (average annual increase of 225 percent)

< Comparison of Coal/Gas Power Generation and Fuel Cells>

Classification		**Coal**	**Gas (Combined)**	**Fuel Cell**
Capacity		800 to 1,000MW	400MW or more	1KW to100MW
Electrical Efficiency (%)		38 to 45	55 to 60	36 to 60 (90 including heat)
Emissions	SOx (ppm)	50	-	None
	NOx (ppm)	50	25	
	Fine Dust (Mg/Sm3)	10	10	
Construction Period/Location		Years/many restrictions		Months/urban

□ **(Downstream industries)** High levels of value added can be generated in the fields of chemical and mechanical design (hydrogen production, transportation, and storage) materials and parts.

○ As most parts and materials used to produce hydrogen vehicles(FCEV) and fuel cells are produced by small- and medium-sized businesses (SMBs), the expansion of downstream industries will lead to increased investment in and job creation for related downstream companies.

* Number of parts by vehicle type (approximately): 30,000 for internal combustion vehicles, 24,000 for hydrogen vehicles(FCEV), and 19,000 for electric vehicles
* Number of parts used in fuel cells (approximately): 10,000 for fuel cells used for power generation and 4,000 for fuel cells used in homes/buildings

○ Through the process of establishing various types of hydrogen infrastructure, such as eco-friendly hydrogen production facilities, large-scale storage and transportation facilities, and hydrogen fueling stations, continuous facility investment and employment expansion can be induced.

* As the development of more advanced hydrogen production, transportation, and storage methods (water electrolysis, ultra-high-pressure, liquefaction, and liquid phase) progresses, new markets will be formed through the expansion of R&D and investment.

◇ Contribution to energy independence through the generation of eco-friendly energy

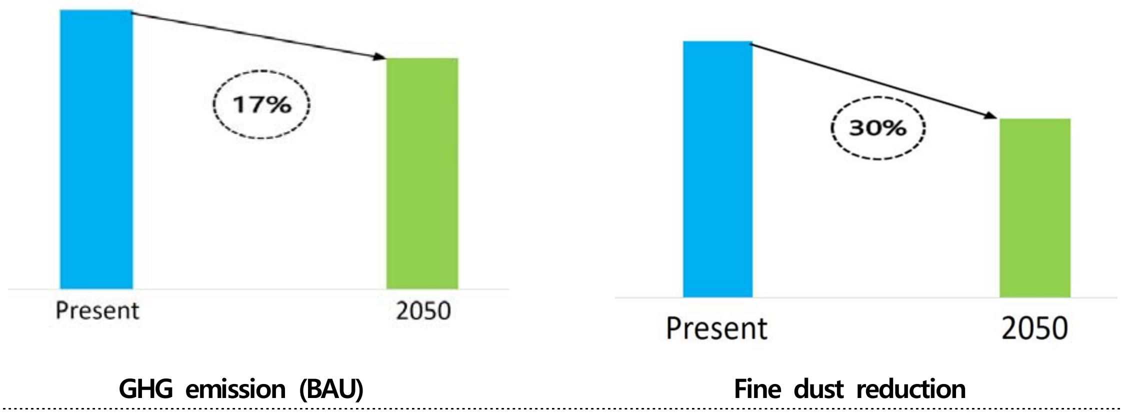
□ **(Eco-friendly energy)** Promotes a safe and clean society by **reducing GHG and fine dust emissions.**

* Korea’s GHG reduction target: 37 percent below BAU levels by 2030

○ Social measures help to reduce fine dust* by using eco-friendly hydrogen in various industries such as transportation and power generation.

* Limitations on automobile use in the Seoul Metropolitan Area, restrictions on the operation of coal-fired powerplants, etc.

< Prospects for Green Effect (McKinsey, 2018)>



○ The use of hydrogen makes it possible to overcome the disadvantages of renewable energy sources, such as solar and wind power, and allows for the formation of complementary relationships that enhance the utilization of hydrogen.

* Conversion of renewable energy into hydrogen to store and transport (P2G: Power to Gas)

□ **(Energy self-sufficiency)** The domestic production of hydrogen through various means, such as hydrogen extraction and water electrolysis, can reduce dependency on foreign energy and thus promote energy independence.

○ The domestic production of hydrogen, through various methods, can reduce import dependence and replace fossil fuels with hydrogen.

* Currently, more than 97 percent of Korea's fossil fuels, which are the country's major source of energy, is secured through imports.

- Korea's energy independence in 2016: 18 percent (ranked 33rd among the 35 OECD countries)

○ In addition to domestic production, hydrogen can also be produced overseas and imported, creating an import diversification effect.

Ⅱ. Trends in the Progress of the Hydrogen Economy

1 Outlook of the Global Hydrogen Economy

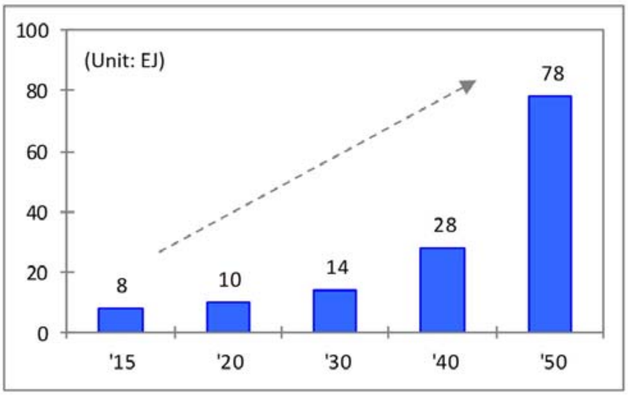
◇ USD 2.5 trillion in value added generated and 30 million jobs created by 2050

□ The global hydrogen fuel cell market has shown rapid annual growth, with the hydrogen industry expected to generate USD 2.5 trillion in value added and create 30 million jobs by 2050 (McKinsey Report).

○ Sharply increasing from 8EJ in 2015 to 78EJ in 2050

- Expected to account for **18 percent of energy demand** (Hydrogen Council, 2018)

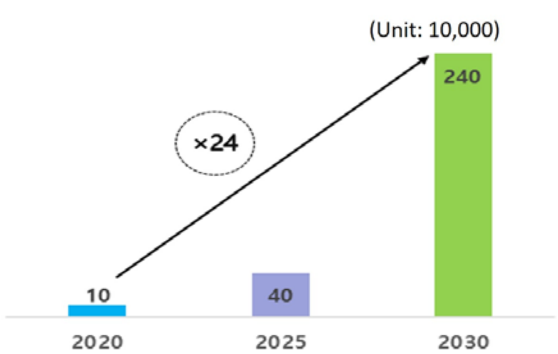
< Global Demand for Hydrogen Energy >



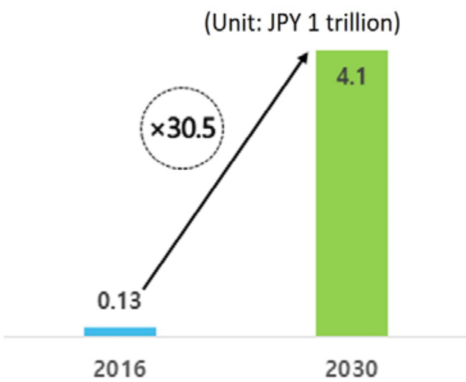
※ 1EJ: 1018 joules = 170MMbbl (oil) = 278TWh (electricity)

○ The transportation sector will drive the increase in demand (including the rapid increase in the demand for fuel cells).

<Outlook of Hydrogen Vehicles(FCEV) Market (IEA)>



<Outlook of the Fuel Cell Market (Fuji Economy)>



- **(Hydrogen vehicles(FCEV))** About 7,800 hydrogen vehicles(FCEV)* have been distributed globally as of 2017 with high competition** among leading countries.

  * Distribution by country as of 2017: 3,562 in the United States, 2,591 in Japan, 725 in the European Union, and 170 in Korea

  ** Distribution target by country (units of 10,000, 2020→2030): 15 → 180 in Germany, 4 → 80 in Japan, and 0.5 → 100 in China

- **(Fuel Cells)** Asian countries will lead the growth of fuel cell market and technological competition will intensify.

  * Asia accounted for 80 percent of fuel cell distribution globally as of 2017.

□ As the use of hydrogen for transportation and power generation increases, the resulting **reduction in CO2 will account for 20 percent**(60 billion tons annually) **of the total required reduction by 2050.**

2 Trends in Major Countries

◇ Fierce Competition in the global market, but hydrogen economy remains in initial stage

○ **(Japan)** H_2 Basic strategies to 2050(December 2017)

- Has been **fostering the hydrogen economy with aim of achieving energy independence**.

- Targets by 2030: 800,000 Hydrogen vehicles(FCEV), 1,200 hydrogen buses, 900 fueling stations, 5.3 million fuel cells for household use, and unit price of power generation of JPY 17/kWh

- Focus on the development of hydrogen supply chain, including liquid hydrogen, P2G, overseas production, and low-cost hydrogen, based on the expansion of Hydrogen vehicles(FCEV) and fuel cells for household use (Ene-Farm).

	Major Content of Japan's Hydrogen Economy Roadmap
Supply	▸ **Establish of international hydrogen supply chain: utilizing unused energy resources abroad, such as brown coal in Australia.** * From 2030, 30,000 tons of hydrogen is expected to be procured annually, with the supply cost being reduced to JPY 30/Nm3. ▸ **Make active use of renewable energy sources and local unused energy resources (waste plastics, by-product hydrogen, etc.).**
Utilization	▸ **Realize stable and massive consumption based on hydrogen generation.** * Aiming to commercialize hydrogen generation technology by 2030 and procure 5 to 10 million tons of hydrogen annually (achieving generation capacity of 15 to 30GW) ▸ **Expand use of hydrogen in transport industry, including Hydrogen vehicles(FCEV), ships, trains, and forklifts.** *** Distribute 200,000 fuel cell electric vehicles and establish 320 fueling stations by 2025.** ▸ **Reduce energy consumption by installing fuel cells in households (Ene-Farm).** * Achieve market independence by 2020 and distribute 5.3 million units by 2030.

○ **(United States)** Hydrogen energy policies being promoted mainly in California

- **Hydrogen energy policies are being pursued in cooperation with private partnerships, mainly in California, and the federal government.**

  * (California) CaFCP, (federal government) H2USA, etc.

- Goals by 2030 (California): 1 million Hydrogen vehicles(FCEV) and 1,000 fueling stations

- Producing hydrogen using surplus electricity from wind power generation and natural gas infrastructure

  * Wind2H2 Project (2007 to 2010): produced hydrogen using wind energy under the supervision of the Department of Energy → hydrogen supplied through the natural gas network

○ **(Germany)** Promoting the hydrogen economy to maximize the utilization of renewable energy

- **Promoting policies that aim to integrate the base of renewable energy supply (50 percent by 2030) and the hydrogen economy**
- Goals by 2030: 1.8 million Hydrogen vehicles(FCEV) and 1,000 hydrogen fueling stations

- Conducting eco-friendly P2G hydrogen production using surplus solar and wind power* and pursuing a gas grid utilization** project

  * Promoting construction of world's largest hydrogen electrolysis facility at the Rheinland refinery (13 million tons annually, between 2017 and 2020)

  ** E-Gas Project of Audi: Supplying methane gas to gas grid (renewable P2G H2 + CO2 (2016)

○ **(Australia)** Establishing hydrogen economy roadmap (August 2018) ⇨ promoting export of hydrogen

- **Leveraging abundant resources to become world's largest hydrogen producer and exporter**
- Implementing project to export hydrogen extracted from brown coal to Japan and promoting the establishment of a fuel cell power plant and distribution of Hydrogen vehicles(FCEV) by state governments

  * HESC Project: extracting hydrogen from brown coal from Latrobe Valley, Victoria → liquefying hydrogen for transport to Kobe, Japan (pilot project to be completed by 2021)

○ **(China)** Declared "China Manufacturing 2025" (2015) and "China Hydrogen Initiatives" (2017)

- Under China Manufacturing 2025, **New energy vehicle was selected as a core industry**. China Hydrogen Initiatives was declared at the International Fuel Cell electric Vehicle Conference

- Goals by 2030: 1 million Hydrogen vehicles(FCEV) and 1,000 hydrogen fueling stations

- Developing hydrogen manufacturing technologies based on renewable and nuclear energy and focusing on hydrogen manufacturing technologies based on coal gasification and methane reforming or oxidizing reactions

  * Heibei : Producing producing hydrogen using surplus wind power (reaching 4MW by 2016 and 10MW between 2018 and 2020)

◇ Competition and Cooperation in the Market

□ **Global companies are engaged to dominate the hydrogen vehicles(FCEV) market,** while **Korean and Japanese companies are competing to lead the fuel cell market.**

○ (Hydrogen vehicles(FCEV)) Small number of companies are leading market and other major car markets are accelerating their entry into the market.

< Comparison of Models of Three Companies >

	Hyundai Motor	**Toyota**	**Honda**
Model	Nexo	Mirai	Clarity
Class	SUV (midsize)	Sedan (midsize)	Sedan (midsize)
Fuel Mileage	609 km	502 km	483 km
Price	KRW 70 million	KRW 77,790,000 (JPY 7,240,000)	KRW 82,340,000 (JPY 7,660,000)

* Target year for release of hydrogen vehicles(FCEV): Mercedes-Benz, 2019; Audi, 2020; and BMW/GM/Nissan, 2021

○ **(Fuel Cells)** Competition for R&D and commercialization (Japanese companies for home fuel cell sector / Korean companies for mass power generation)

□ **Global platform for cooperation between companies and between countries** by value chain in the hydrogen industry

○ Cooperation between companies: In the areas of hydrogen production, storage, transportation, and utilization

* **(Production)** HySTRA (Japan) + AGL Energy (Australia) : extracting hydrogen from Australian lignite and transporting it to Japan

(Storage and Transportation) Hydrogenius (Germany) + Zhongshan Broad-Ocean Motor (China): Developing technologies for liquid hydrogen transportation

(Utilization) Bloom Energy (United States) + SoftBank (Japan): entrance of Bloom Energy Japan into the Korean market

○ Hydrogen Council: council of hydrogen and fuel cell companies under the WEF (established in 2017 / Chair: Hyundai Motor / 33 participating companies)

○ Cooperation between countries: International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE),* Hydrogen Ministerial Meeting,** etc.

* International Partnership for the Hydrogen Economy: IEA intra-conference system established in 2003 and participated in by 18 countries, including the United States, South Korea, and Japan

** Council established in 2018, led by Japan, and participated in by the United States, South Korea, Australia, and UAE (since 2018) → aiming to promote partnerships in hydrogen technology development and cooperation on related standards and safety (Tokyo Statement)

3 Current Situation and Future Possibilities

◇ The growth of the hydrogen economy will require **fundamental changes in both economic and industrial structures** and energy sources.

○ As the hydrogen economy is still in the early stage globally, it is important to **acquire this unprecedented new path**

◇ If Korea successfully demonstrates its world-class capabilities and strengths, there is **great potential for the country to grow its hydrogen economy into one of Korean economy and lead the global market.**

○ With competition among countries now intensifying, **the critical time to realize the hydrogen economy is expected to be three to four years from now.**

1 The highest level of hydrogen-related technology

○ **(Hydrogen vehicles(FCEV))** In 2013, Hydrogen vehicles(FCEV) were successfully mass produced for the first time in the world. → Securing global competitiveness by achieving **the world's highest fuel mileage and localizing core parts** (99%, based on number of parts).

○ **(Fuel cells)** Domestic fuel cell companies have their original technologies to secure the highest level of market leadership.

* Company P: technical partnership with FCE (United States) / Company D: M&A with CEP (United States) and FCP (Korea)

2 Sufficient experiences and industrial basis for hydrogen supply

○ Hydrogen is being used in domestic petrochemical complexes mainly in Ulsan, Yeosu, and Daesan. Based on the country's large-scale industrial base, **the domestic industry has secured the technologies necessary to produce hydrogen pipelines and high-purity hydrogen** (approximately 1.64 million tons annually).

○ If there is sufficient demand such as H_2 fuel cell power generation, it is **possible to have a large-scale supply of H_2 with facility expansion and process conversion.**

* Currently, Korea's by-product hydrogen production capacity is about 50,000 tons (equivalent to 250,000 Hydrogen vehicles(FCEV)).

3 Potential national hydrogen supply based on advanced LNG supply chain

○ **With nationwide LNG supply chain,** it is easy to produce and supply stable and economical Hydrogen.

* 143 governor stations that adjust the pressure of natural gas supplied by four intermediate production and supply bases (Incheon, Pyeongtaek, Samcheok and Tongyeong)

◇ To successfully take the lead in the hydrogen economy, it is urgently necessary to ❶**actively advance into the market,** ❷**create an industrial ecosystem by promoting industrial competitiveness in terms of production, storage, and transportation (which are lagging behind utilization),** and ❸**reform the institutional foundation.**

1 New markets for application of hydrogen ⇨ Secure economy and pursue expansion

□ Top-notch technology, but **insufficient use of Hydrogen vehicles(FCEV) and fuel cells**

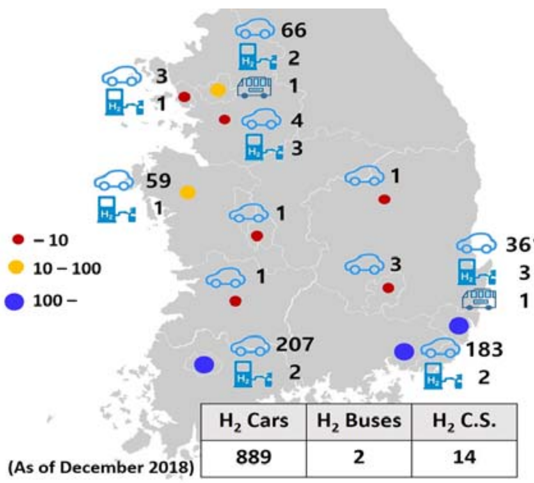
○ **(Hydrogen vehicles(FCEV))** Due to high prices (KRW 70 million), difficulties in use for public transportation, and lack of fueling infrastructure, the numbers of hydrogen passenger cars and buses currently stand at only 889 and 2, respectively.

* As of 2018, there are only 14 hydrogen fueling stations (10 for general users and 4 for research purposes).

○ **(Fuel cells)** Supply fuel cells with capacity of 307.6MW for power generation (41 locations) and 7MW for homes and buildings (3,167 locations) by reducing the burden of the installation costs* and high fuel costs through REC support from the government.

* High cost of fuel cell installation for homes and buildings (KRW 27 million/kW in Korea, but KRW 11 million/kW in Japan)

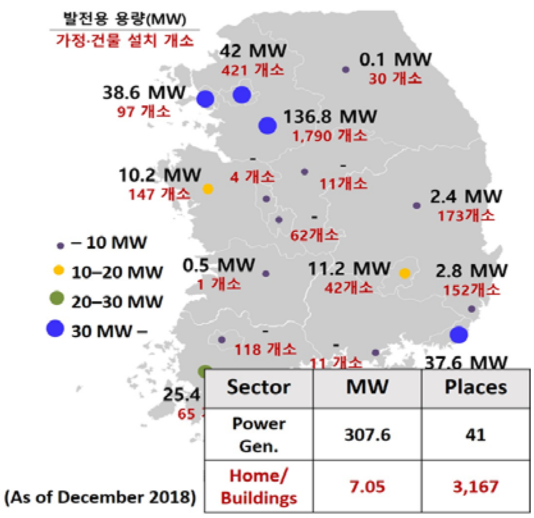
< Hydrogen vehicles(FCEV) and Fueling Stations >



H_2 Cars	H_2 Buses	H_2 C.S.
889	2	14

(As of December 2018)

< Fuel Cells >



Sector	MW	Places
Power Gen.	307.6	41
Home/ Buildings	7.05	3,167

(As of December 2018)

□ Domestic **R&D on hydrogen ships, trains, and drones is currently in the initial stage,** while the United States and Europe are already in the demonstration and commercialization stage.

○ R&D / ◐ Demonstration / ● Commercialization

Classification		Korea	Japan	United States	Europe
Mobility	Hydrogen vehicles (FCEV)	●	●	◐	●
	Others	○(ships/trains)	◐(ships/trains)	●(forklifts)	●(trains)
Fuel Cell Power Generation		●(homes/buildings)	●(homes/buildings)	●(homes/buildings)	●(homes/buildings)
		●(power generation)	◐(hydrogen turbine generation)	●(power generation)	-

2 Improve technical competitiveness ⇨ Expand industrial ecosystem

□ **(Production) Lack of commercializing** technologies for hydrogen extraction methods other than **by-product hydrogen and water electrolysis**

	Difficulties in Producing Hydrogen
By-product Hydrogen	Although the cost of producing by-product hydrogen is low, securing additional supply will require converting the processes at the relevant petrochemical complexes (Ulsan, Yeosu, and Daesan).
Hydrogen Extraction	Despite the potential for linkage to the existing natural gas supply networks, hydrogen extraction depends largely on imports, due to the lack of hydrogen extractor-related technologies. Germany and Japan have secured relevant technologies, and their small-scale extractors are in the initial stage.
Water electrolysis	As Korea's large-scale renewable energy complexes are less advanced than those of developed countries, the development, demonstration, and commercialization of water electrolysis technologies has been delayed.

* Production price (KRW 1,000/kg): 1.5 to 2 for by-product hydrogen, 2.7 to 5.1 for hydrogen extraction, 9 to 10 for water electrolysis

○ In the long term, it is necessary to implement the large-scale water electrolysis method in conjunction with renewable energy (P2G). However, the technological competitiveness of Korean companies is still lacking (60 to 70% of developed countries).

- The United States and Germany have the most advanced technologies for the commercialization of hydrogen production.

* Japan has established a hydrogen production facility that uses water electrolysis power generation (in Hokkaido).

◐ Demonstration / ● Commercialization

		Korea	Japan	United States	Europe
Production	By-product	●	●	●	●
	Extraction	◐	●	●	●
	Water Electrolysis	◐	◐	●	●

□ **(Storage/Transportation)** High-pressure gas storage and transportation is possible, but **liquefaction/liquid-phase* technologies required for long-distance and high-capacity transportation are still in development.**

* (Liquefaction) Liquefied at ultra-low temperatures of –253℃ / Liquid: stored at room temperature, for instance, in the form of ammonia

○ Domestic companies have secured technologies to commercialize the storage and transportation of hydrogen gas at high pressures of around 500 bar.

○ The liquefaction/liquid-phase technologies needed for overseas production and import are currently being developed by SMBs, but are still lacking.

- Europe and the United States have developed advanced liquefaction technologies, but their liquid technologies remains in the development stage.

○ Research / ◐ Demonstration / ● Commercialization

		Korea	Japan	United States	Europe
Storage Method	Gas	●	●	●	●
	Liquefaction	◐	◐	●	●
	Liquid	○	◐	◐	◐

○ Pipelines and tube trailers are available for transportation. To reduce transportation costs, high-pressure and high-capacity storage methods are required.

* Pipelines: Approximately 200 km in petrochemical complex areas (United States : 2,000 km)

* Tube trailers: About 500 tube trailers currently in operation

□ In the United States, Japan, and Europe, a number of globally competitive companies are actively promoting technology development and commercialization.

○ In Korea, **due to the lack of technology development and poor investment conditions**, the industrial ecosystem has been formed **mainly by a small number of SMBs.**

3 Legal and institutional basis ⇨ Securing the driving force for the hydrogen economy

○ **(Policy) Current policies offer only individual plans for Hydrogen vehicles(FCEV) and fueling stations without long term strategies for fostering a comprehensive hydrogen economy.**

○ **(Laws and Institutions) Legal and institutional bases** are needed to support the systematic vitalization of the hydrogen economy and **ensure safety throughout the entire hydrogen cycle.**

Ⅲ. National Vision for the Hydrogen Economy

< Vision >

Becoming the world's leading Hydrogen economy

- Achieving the first place in FCEV and fuel cell markets
- Evolve from a country of fossil resources to a major, eco-friendly producer of hydrogen fuel

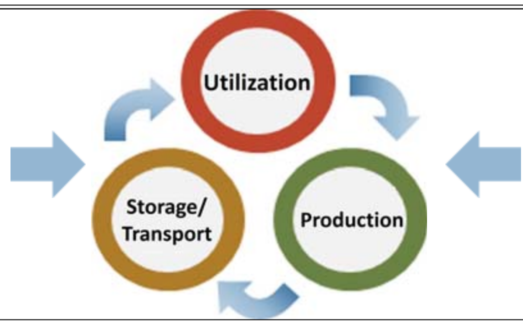
GOALS

		2018	2022	2040
Hydrogen vehicles(FCEV) (export) (domestic demand)		18,000 (900) (900)	81,000 (14,000) (67,000)	6,200,000 (3,300,000) (2,900,000)
Fuel Cells	Power Gen. (domestic demand)	307 MW (in total)	1.5 GW (1 GW)	15 GW (8 GW)
Fuel Cells	Homes/Buildings	7 MW	50 MW	2.1GW
Hydrogen Supply		130,000t/year	470,000t/year	5,260,000t/year↑
Hydrogen Price		-	KRW 6,000/kg	KRW 3,000/kg

PROMOTION STRATEGIES

Basic Orientation

Ensuring safety for entire cycle



Establishing industrial ecosystem of SMBs and middle standing companies

Strategies

	'18 → '22	'22 → '30	'30 → '40
	Preparation of hydrogen economy	**Expansion of hydrogen economy**	**Leadership of hydrogen economy**
	▪Hydrogen industry eco-system ▪Infrastructure and legal/institutional basis	▪Increase in hydrogen use ▪Large-scale supply-demand system	▪Overseas hydrogen production and water electrolysis ▪CO2-free supply-demand system

Private/Public Sectors

Public	▪Support/deregulation ▪Large infrastructure investment	▪Supplementation of industrial ecosystem ▪Preempting international standards	▪Establishment of hydrogen society ▪International leadership
Private	▪Internalization of core technologies ▪Expansion of investment	▪Commercial production system ▪Hydrogen business platform	▪Expansion of private led market ▪Leadership of global market

◇ Roadmap for the Implementation of Hydrogen Economy

☐ Hydrogen Mobility (cumulative)

*( ): domestic demand

MOBILITY		2018	2022	2040
	Hydrogen vehicles(FCEV)	1,800 (900)	81,000 (67,000)	6,200,000 + α (2,900,000)
	Passenger Care	1,800 (900)	79,000 (65,000)	5,900,000 (2,750,000)
	taxis	-	-	120,000 (80,000)
	Buses	2 (Total)	2,000 (Total)	60,000 (40,000)
	Trucks	-	-	120,000 (30,000)
	Fueling Station	14	310	1,200 + α
	Trains, Ships, and Drones	Commercialization and export projects to be implemented before 2030 through R&D and demonstrations		

* Domestic demand / Proportion of Hydrogen vehicles(FCEV) among all cars (cumulative)

◻ Hydrogen Energy (cumulative)

*( ): domestic demand

ENERGY			2018	2022	2040
	Fuel Cells	**Generation**	307.6MW	1.5GW (1GW)	15GW + α (8GW)
		Households/Buildings	7MW	50MW	2.1GW + α
	Hydrogen Gas Turbine		Technology development to be completed by 2030		

◻ Hydrogen Supply and Prices

SUPPLY & DEMAND		2018	2022	2030	2040
	Supply (=Demand)	130,000 tons/year	470,000 tons/year	1.94 million tons/year	5.26 million tons/year
	Supply Methods	①By-product hydrogen (1%) ②Hydrogen extraction (99%)	①By-product hydrogen ②Hydrogen extraction ③Water electrolysis	①By-product hydrogen ②Hydrogen Extraction ③Water electrolysis ④Overseas production ※ ①+③+④ : 50% ② : 50%,	①By-product hydrogen ②Hydrogen Extraction ③Water electrolysis ④Overseas production ※ ①+③+④ : 70% ② : 30%,
	Hydrogen Price	- (Policy price)	KRW 6,000/kg (Initial market price)	KRW 4,000/kg	KRW 3,000/kg

Ⅳ. Promotion Plan for the Hydrogen Economy

◈ Leading hydrogen economy focusing on FCEV and fuel cells

UTILIZATION

■ Accelerate the utilization of hydrogen, especially in the transportation and energy sectors

Transportation	❶ Increase price competitiveness and expand supply of Hydrogen vehicles(FCEV) ❷ Expand use of hydrogen taxis and buses for public transportation ❸ Promote use of hydrogen trucks in the public sector ❹ Increase accessibility by increasing the number of hydrogen fueling stations nationwide ❺ Find other applications, such as hydrogen ships, trains, and drones
Energy	❶ Supply hydrogen fuel cells for power generation and achieve commercialization to enable their export ❷ Expand use of hydrogen fuel cells in households and buildings ❸ Review and develop hydrogen gas turbines as a commercial energy generation source

PRODUCTION

■ Transition production paradigm from grey hydrogen to green hydrogen

Grey Hydrogen	❶ Utilize hydrogen produced as a by-product of refining and petrochemical processes ❷ Conduct large-scale hydrogen extraction based on nationwide LNG network
Green Hydrogen	❶ Reduce cost of water electrolysis and promote mass production of hydroge ❷ Introduce mass overseas CO_2-free hydrogen

STO/TRANS

■ Reduce cost of hydrogen distribution by establishing efficiency mass infrastructure

Storage	Convert from high-pressure gas storage to high-efficiency liquefaction and liquid and solid storage
Transportation	Reduce cost of hydrogen distribution by establishing high-efficiency, high-capacity hydrogen storage and transportation systems

SAFETY

■ Promote systematic safety management measures, including the enactment of the Hydrogen Safety Act and establishment of the Hydrogen Safety Support Center

■ Raise public awareness of the safety of hydrogen

IND ECOSYSTEM

Technological Innovation	**Professional Personnel**
Cross-ministerial technology roadmap	Develop hydrogen safety and core technologies
Standardization	**Establishment of social infra**
Preempt global hydrogen standards	Establish base for the hydrogen economy
Legal Base	**International Cooperation**
Enact Hydrogen Economy Act	Implement Open Innovation
Export Industry	**SMBs and Middle-standing Companies**
Achieve Hydrogen vehicles(FCEV) and fuel cell export industrialization	Foster hydrogen as a hidden champion of downstream industries

1 Establishment of the World's Best Hydrogen Utilization System

1. Mobility

1 Hydrogen vehicles(FCEV): : Establishment of Clean Transportation Infrastructure

Hydrogen vehicles(FCEV) Supply and Major Challenges

1 Expansion of Hydrogen vehicles(FCEV) and Fueling Stations (cumulative)

Annual production of 100,000 by 2025
(Starting commercial production)↓

*( ): domestic demand

Sectors		2018		2022		2040
Hydrogen vehicles(FCEV)	Total	1,800 (900)	➡	81,000 (67,000)	➡	**6,200,000** (2,900,000)
	Cars	1,800 (900)	➡	79,000 (65,000)	➡	**5,900,000** (2,750,000)
	taxis	➡				**120,000** (80,000)
	Buses	2 (Total)	➡	2,000 (Total)	➡	**60,000** (40,000)
	Trucks	➡				**120,000** (30,000)
Fueling Stations		14	➡	310	➡	**1,200**

2 Major Projects

○ **(Expansion) Expanding clean transportation infrastructure,** including hydrogen passenger cars, buses, taxis, etc. (by 2022), and **greatly increasing the number of hydrogen fueling stations** to support such expansion.

- **Building production facilities for all types of hydrogen vehicles(FCEV),** including passenger cars, buses, taxis, and trucks (by 2030).

○ **(Institutions) Providing subsidies for each type of hydrogen vehicles(FCEV) and supporting the cost of fuel for commercial hydrogen vehicles(FCEV),** including buses and taxies.

- Reducing subsidies in the long term, as hydrogen and hydrogen fueling prices fall.

○ **(Export) Sales and export of hydrogen fuel cell systems** for vehicles and leading the **mutual growth of SMBs.**

1. Hydrogen Passenger Cars

◈ Domestic Supply (cumulative): 65,000 by 2022 → 2,750,000 by 2040

◈ Expand production capacity and localize the production of all parts

◇ Ensuring Price Competitiveness by Expanding Production Capacity

○ Expand **annual production** to 35,000 by 2022, and **100,000** vehicles (50,000 for domestic use + 40,000 for export) by 2025,

- **(Reduce the price of Hydrogen vehicles(FCEV))** When annual production reaches 35,000 cars, the price of Hydrogen vehicles(FCEV) is expected to drop to KRW 50 million range. When annual production reaches 100,000 cars, the price is expected to drop to a level similar to that of internal combustion cars.
- The subsidy for Hydrogen vehicles(FCEV) purchases will be phased out gradually as the price of Hydrogen vehicles(FCEV) falls. **The subsidy will be eliminated when the price of Hydrogen vehicles(FCEV) becomes competitive with that of internal combustion cars.**

○ Develop systems for the mass production of parts and secure technologies to reduce the prices of core parts of hydrogen fuel cells (stacks, hydrogen storage vessels, etc.) by 2022.

◇ Localizing the main parts of Hydrogen vehicles(FCEV) 100%

○ **Increase the localization rate of Hydrogen vehicles(FCEV) main parts to 100 percent by 2022** through the expansion of technology development support.

- Invest in R&D to improve technology for the production of parts and create a parts production ecosystem (KRW 300 billion, based on the Preliminary Feasibility Study).

* Develop hydrogen fueling technology (40 to 80 percent), membrane electrode assemblies, gas diffusion layers, air compressors, hydrogen storage vessels, etc.

◇ Expand basis for increasing the demand for Hydrogen vehicles(FCEV)

○ Introduce exclusive insurance to ease the burden of high premiums on consumers (by 2020).

* Because of the low level of popularization of hydrogen cars, the insurance industry is in a position that makes it difficult to launch exclusive products for such vehicles.

○ Improve safety by preparing measures to prevent collisions, rollovers, and fires (by 2022) and increase hydrogen storage capacity (by 2030).

2. Hydrogen Taxis

◈ Domestic supply (cumulative) : 80,000 by 2040

◈ After the pilot project in 2019, hydrogen taxis will be supplied extensively nationwide from 2023.

◇ Expand nationwide after completion of pilot project (in Seoul)

○ **Implement hydrogen taxi pilot project,** in conjunction with hydrogen fueling stations in central urban areas (Seoul) → **Supply hydrogen taxis in major cities by 2021 → Expand supply of hydrogen taxis nationwide by 2023**

○ Establish plans to analyze the performance of key parts and improve the problems discovered by operating 10 hydrogen taxis in actual road environments over 200,000km.

* 10 core parts that influence vehicle longevity, such as fuel cell stacks, operating devices (air supply, hydrogen supply, and thermal management systems), hydrogen storage devices, electrical devices, etc.

- Provide **support for expenses necessary for the demonstration of hydrogen taxis** and rental of Hydrogen vehicles(FCEV).

* Car prices: Approximately KRW 25 million for an LPG taxi and KRW 37 million for a Hydrogen vehicle(FCEV) (including subsidy support)

** Over nine years of operation, parts such as the fuel cell stack (KRW 50 million) of hydrogen taxis need to be replaced at least once or twice.
→ Taxi mileage over nine years: approximately 530,000km for private taxis and 720,000km for corporate taxis

< Foreign and Domestic Cases >

- **(France)** 100 hydrogen taxis are currently in operation in Paris (Tuscon: 75, Mirai: 25).
  → Planning to expand to 600 by 2020
- **(Sweden)** The taxi company O2O is currently conducting a hydrogen taxi pilot project (operating Tucsons in Stockholm).
- **(Ulsan)** Ten hydrogen taxis were in operation between 2016 and 2018 (by three companies).

○ Increase in longevity of Hydrogen vehicles(FCEV) ⇨ **160,000km in 2018 → 300,000km by 2022 → 500,000km by 2030**

○ Develop technologies to improve vehicle longevity based on analysis of the durability of parts of hydrogen taxis with high mileage.

3. Hydrogen Buses

◈ Domestic supply (cumulative): 2,000 by 2022 → 40,000 by 2040

◈ Expand the supply of hydrogen buses for express/city bus routes nationwide.

◇ Implement pilot projects to expand the supply of hydrogen buses

○ **(City Buses)** Supply 35 hydrogen buses in seven major cities* in 2019, with the aim of replacing **2,000 city buses with hydrogen buses by 2022.**

* 7 in Seoul, 5 in Busan, 3 in Ulsan, 6 in Gwangju, 5 in Changwon, 4 in Asan, and 5 in Seosan

** Pilot project to supply 35 buses in 2019 → 300 buses in 2020→ 665 buses in 2021 → 1,000 buses in 2022

- (Metropolitan buses) Introduce hydrogen buses on intercity bus routes as a pilot project in 2021, based on hydrogen fueling stations on highways, and supply hydrogen buses for all intercity bus routes by 2030.

◇ Replace police buses with hydrogen buses

○ Purchase two hydrogen buses in 2019* **and operate them for demonstration purposes until the end of 2020.**

* Hyundai is developing a full-sized hydrogen bus that satisfies the requirements of police buses (passengers, cargo space, etc.) and expects to complete development in the second half of 2019 and deliver the bus to the National Police Agency.

○ After the demonstration process is complete, police buses currently in operation that have exceeded their operational lifespan (eight years) will be promptly replaced with hydrogen buses. **All police buses will eventually be replaced with hydrogen buses.**

◇ Build hydrogen bus infrastructure

○ Establish hydrogen composite transfer centers offering both fueling and maintenance services at major traffic hubs in metropolitan areas by 2021 and introduce hydrogen buses on new bus routes and existing bus routes that require more buses.

○ Install hydrogen fueling stations at highway rest stops, CNG fueling stations, innovative cities, etc.

* Sign MOU on installing hydrogen fueling stations at public bus garages (first half of 2019, in cooperation with local governments and transportation associations).

◇ Enhance economic and institutional support for hydrogen buses

○ **Review the amount of fuel cost support based on the results of research** and in consideration of the fine dust reduction effect of hydrogen buses and **support the cost of bus purchases for the replacement of existing buses.**

* Fueling rate structure for CNG buses: including purchase cost (central/local governments), subsidies for fueling stations (local governments), bus fuel cost subsidies, oil price subsidies, etc.

○ Provide incentives, such as relaxed licensing standards for transportation companies introducing eco-friendly vehicles like hydrogen buses, and grant extra points when selecting M-bus (broad buses) business operators

* For instance, weighing up on eco-friendly buses (hydrogen buses, etc.) when calculating the number of licensed buses operated by city bus transportation businesses (bus transportation companies with 40 or more buses).

◇ Increase the fuel economy, lifespan, and safety of hydrogen buses

○ **(Fuel economy/lifespan)** Increase fuel economy and **operational lifespan of hydrogen buses by more than 50 percent and five times**, respectively, compared to current levels.

* Fuel Economy: 10km/kg by 2018 → 12km/kg by 2022 → 15km/kg or higher by 2030
Lifespan: 160,000km by 2018 → 500,000km by 2022 → 800,000km or longer by 2030

○ **(Safety)** Develop technologies and prepare **safety standards** for hydrogen buses **to prevent rollovers and collisions.**

- Develop technologies for vehicles and parts to protect passengers of hydrogen buses and lead the development of technologies for Hydrogen vehicles(FCEV) to reflect international standards.

* GTR (Global Technical Regulation)

○ **(Dedicated Parts)** Design for hydrogen buses, motors, high-pressure hydrogen storage vessels, high-voltage converters, etc.

4. Hydrogen Trucks

◈ Domestic supply(cumulative): Supply 30,000 hydrogen trucks by 2040, following the completion of development efforts

◈ Launching medium-sized trucks (five-ton) in 2021 and heavy trucks (30-ton) in 2024.

◇ Convert public special freight vehicles to Hydrogen trucks

○ Developing and demonstrating the technology of **5-ton H_2 trucks** (special freight vehicles*) by 2020

* **Including garbage trucks (including garbage collection), honey wagons, sprinkler trucks, etc.**

○ Start a hydrogen truck pilot project* for the public sector in 2021

- Promote the **gradual transition from domestic special freight vehicles** (approximately 14,000 units) to hydrogen trucks* **(starting with five-ton trucks).**

* Install (and expand) special devices such as garbage collectors, street sweepers, and street washers on five-ton hydrogen trucks.

- After the pilot project is completed, consider ways of including commercial vehicles in the public eco-car obligatory purchase targets.

◇ Converting private freight trucks to Hydrogen trucks

○ Complete the development of technogies for the production of parts for **10-ton hydrogen trucks** by 2020 and demonstrate such trucks by 2022.

- **Carry out a logistics and transportation demonstration project** for the conversion of general freight trucks* into hydrogen trucks (by 2021).

* Number of registered general freight trucks in 2018: 2,530,000 general freight cars (2,070,000 small, 310,000 medium, and 150,000 large trucks)

○ **Secure the technology to reduce the prices*** of parts exclusively for large hydrogen trucks (five or more tons) and achieve the complete localization of hydrogen truck production by 2030

* Preliminary feasibility studies are underway to improve the performance of electrical devices, motors, reducers, and fuel cell stacks

2 Hydrogen fueling stations: ensure the early expansion of stations and their economic efficiency

◈ Domestic supply (cumulative) : 310 stations in 2022 → 1,200 stations in 2040

◇ Hydrogen fueling stations: expand support ⇨ Ensure stable power supply

○ Provide installation subsidy to promote the initial expansion of hydrogen fueling stations.

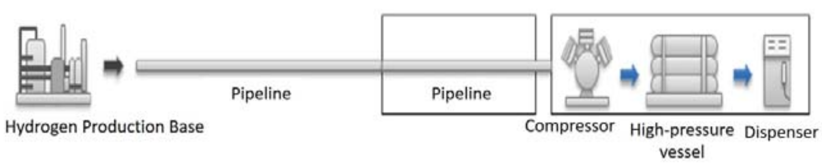
- Establish hydrogen fueling stations in transportation hubs, including central urban areas and highway rest stops, and bus and taxi garages.

* Status of support for hydrogen fueling stations: Ministry of Environment (ME): providing 50 percent of installation cost per station (KRW 1.5 billion limit) / Ministry of Land, Infrastructure and Transport (MLIT): providing KRW 750 million per hydrogen fueling station located on highways

- Provide different installation subsidies by type of fueling station to promote the expansion of different types of fueling stations in accordance with regional characteristics.

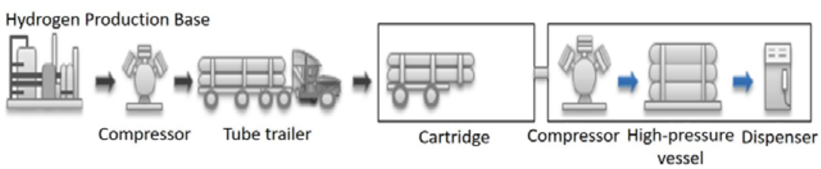
< Hydrogen Fueling Station Types and Installation Costs >

❶ **Hydrogen Pipeline Connection Type** (based on existing networks in three cities, 200km)



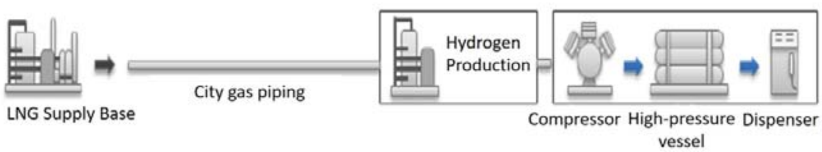
◈ **About KRW 2.7 billion**
‣Facility construction : KRW 1.8 billion
‣Site construction: KRW 0.9 billion

❷ **Hydrogen Gas Transportation Type** (based on tube trailers)



◈ **About KRW 2.6 billion**
‣Facility construction : KRW 1.7 billion
‣Site construction: KRW 0.9 billion

❸ **City Gas Extraction Type** (based on installed extractors)



◈ **About KRW 5.6 billion**
‣Extractor installation : KRW 2.2 billion
‣Facility construction : KRW 2.1 billion
‣Site construction: KRW 1.3 billion

○ Offer subsidies for operation of hydrogen fueling stations to induce construction cost reductions and generation of additional revenue.

* Installation subsidy in Japan: support provided for 50 to 66 percent of installation cost (approximately KRW 1.8 to 2.9 billion) / Japan's operating subsidy: 66 percent (up to KRW 2.2 billion)

- Allow multiple contracts for fueling stations for private-public SPC,* support SPC finance and taxation,** and develop business models for hydrogen fueling stations (leasing of Hydrogen vehicles(FCEV), etc.).

* HyNet (Hydrogen Network): Korea Gas Corporation, Hyundai Motor, suppliers, and fueling equipment companies plan to build about 100 hydrogen fueling stations with government subsidies by 2022.

** In the case of CNG, the standard number cars is set according to the size of each fueling station.

○ Expand private-led autonomous hydrogen fueling stations.

- Expand the market for autonomous fueling stations and convert LPG and CNG fueling stations into dual-function fueling stations capable of dispensing hydrogen.

* Using the 2,027 LPG fueling stations (as of October 2018) nationwide

< Strategies for Installation of Hydrogen Fueling Stations >

<table>
<tr><th>2018</th><th>2019</th><th>2022</th><th>2040</th></tr>
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<tr>
<td>Establish 14 fueling stations mainly in hub cities.</td>
<td>Establish cumulative total of 86 fueling stations to form regional transportation networks.</td>
<td>Establish cumulative total of 310 fueling stations nationwide while expanding and connecting the regional networks.</td>
<td>Establish cumulative total of 1,200 fueling stations nationwide.</td>
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Hydrogen Fueling Station Roadmap (by 2022)

Establish 14 fueling stations mainly in hub cities in 2018.

◦ Establish 14 stations nationwide by the end of 2018.

◦ Located in Ulsan, Changwon, and Gwangju, with local governments actively supplying Hydrogen vehicles(FCEV), along with the Seoul Metropolitan Area

	Seoul	Ulsan	Changwon	Gwangju	Hongseong	Total
H2 Cars	61	361	204	207	28	861
CHARC STA	2	3	2	2	1	10*

* Excluding four fueling stations established for research purposes

Establish cumulative total of 86 charging stations mainly as part of regional fueling/transportation networks by the end of 2019.

◦ **Build cumulative total of 86 fueling stations* by the end of 2019, in accordance with the plan to supply Hydrogen vehicles(FCEV) and fueling stations by region.**

* 14 established in 2018 + 29 carried forward in 2018 + 43 to be established in 2019

◦ **Build regional fueling station networks connecting cities throughout five regions (Seoul metropolitan, central, Yeongnam, Honam, and Gangwon areas) → 68 fueling stations***

* Seoul metropolitan 17 (Seoul 6, Gyeonggi 6, Incheon 5), Central 12 (Chungnam 4, Chungbuk 5, Daejeon 3), Yeongnam 15 (Ulsan 7, Gyeongnam 6, Busan 2), Honam 9 (Gwangju 8, Jeonbuk 1), Gangwon 5, and private 10

◦ **Establish fueling stations at transportation hubs along the Gyeongbuk Expressway where traffic is heavy→18 fueling stations**

Establish cumulative total of 310 fueling stations nationwide, connecting regional networks, by 2022.

◦ Establish **cumulative total of 310 fueling stations** by 2022.

* Establish 100 stations through private SPC (from 2019).

◦ **Expand regional networks** and **significantly increase number of fueling stations in five regions → 150 stations**

◦ **Connect regions** served by **major highways (Gyeongbu, Seohaean, Yeongdong, Namhae**, etc.) and transportation hubs → **160 stations**

* Traffic on major highways (2017): 490,000 on Gyeongbu, 160,000 on Seohaean, 220,000 on Yeongdong, and 160,000 on Namhae

◇ Deregulation on Hydrogen Fueling Systems

○ Relax restrictions, such as location limitation, separation distance, self-charging, etc.

* Completed: permit installation of dual-function and portable fueling stations, establish requirements for liquid hydrogen fueling stations, allow installation of fueling stations at bus garages located in development-restricted areas, etc

< Deregulation on Hydrogen Fueling Systems >

Detailed Tasks	Deregulation	Authority	Plan
‣ Allow first- or third-party advertising for eco-friendly vehicle fueling stations	Allow first- or third-party advertising for hydrogen fueling stations → Create additional revenue	MOIS	Jan. 2019
‣ Relax regulation requiring hydrogen fueling stations to be installed 30 meters from the nearest railway line	Deregulate after safety verification is completed by research service	MOTIE	Mar. 2019
‣ Allow private contracts for the installation of eco-friendly car fueling stations in national or public areas	Allow private contracts and reduce rents for the lease of national or public properties	MOTIE	Mar. 2019
‣ Strengthen standards for hydrogen transportation vessels	Raise fueling pressure (35→45MPa) and storage volume (150→450L)	MOTIE	Mar. 2019
‣ Allow drivers to fuel their Hydrogen vehicles(FCEV) themselves	Deregulate after completing research and receiving industry feedback	MOTIE	Mar. 2019
‣ Allow installation of hydrogen fueling stations (larger than 3,000m^3) without the approval of city planning division	Allow installation of hydrogen fueling stations without the approval of city planning division	MOLIT	June 2019
‣ Allow installation of hydrogen fueling stations in semi-residential and commercial facilities	Promote easing of restrictions on semi-residential and commercial areas through consultation with local governments	MOLIT	June 2019
‣ Strengthen qualifications for safety managers of hydrogen fueling station	Qualify those who have completed relevant training courses, in addition to gas engineers	MOTIE	June 2019

○ Until the related regulations are relaxed, the government plans to use the “regulated sandbox” of the Industrial Convergence Promotion Act **to install hydrogen fueling stations in downtown areas and at public buildings** (such as Government Complex Sejong).

◇ Advance hydrogen fueling station technologies and improve safety

○ Achieve total localization of hydrogen fueling stations by 2030 through the localization of core parts, such as compressors, high-pressure valves, storage containers, and fueling technology.

○ Reduce the cost of installing hydrogen fueling stations by developing large-scale hydrogen fueling technology, including technologies that enable fueling rates of one to two tons per day and liquid hydrogen fueling.

* 10MM/kg in 2018 → 6MM/kg in 2022 → 3MM/kg in 2030

Plans to Stabilize Fueling Prices of Hydrogen Fueling Stations

1 Goals for Pricing of Hydrogen Fueling

Time	Present	2022	2030	2040
Prices	- (policy price)	KRW 6,000/kg (initial market price)	KRW 4,000/kg	KRW 3,000/kg

* Japan: KRW 11,308/kg at present → KRW 3,392/kg in 2030 → KRW 2,262/kg in the future (based on the exchange rate as of January 2019)

2 Task of Pricing: Connect with Hydrogen Production, Storage, and Transportation

❶ **Production:** reduce hydrogen production costs by realizing economies of scale through the **production of massive amounts of extracted hydrogen, improvement of power generation efficiency, and negotiation of hydrogen import prices.**

- **Prepare economically viable hydrogen production portfolio through the diversification of hydrogen production methods,** such as biomass and microorganisms.
  - * Ex: Develop technology for the production of marine biohydrogen (between 2009 and 2019 / KRW 3.8 billion in 2019).
- **Prepare the lowest-cost hydrogen production plans,** in consideration of the characteristics of each region.
  - * Ex: by-product hydrogen (Ulsan, Yeosu, and Daesan), hydrogen extraction (Seoul, Gyeonggi, and Gangwon), and renewable energy (Jeonnam, Gyeongnam, and Jeju)

❷ **Storage/transportation: reduce transportation costs by increasing storage efficiency through the development of liquid/liquefied hydrogen technologies and mass transportation using hydrogen pipelines.**

- **Establish hydrogen storage facility** for each base station **to stabilize hydrogen supply and demand** and prepare base to distribute hydrogen at a constant price.

❸ **Hydrogen fueling stations: maintain subsidies for the installation of hydrogen fueling stations until the price of hydrogen reaches the target level and establish operating subsidies.**

- **Gradually reduce subsidies** as the price of hydrogen declines.

❹ **Stabilize price of hydrogen: introduce an appropriate base price for hydrogen and stabilize the market price through hydrogen supply management and trading system.**

3 Hydrogen ships, trains, drones, Etc.

1. Hydrogen ships: promote eco-friendly ships as promising means of transportation in the future

		Present	2022	2025	Since 2030
Technology Goals	Coastal Ships	Developing ship-related technologies	▶Verify fuel cell system for ships	▶ Improve performance through empirical verification	▶Expand application in the field
	Ocean Ships		▶Develop stack modularization technologies	▶ Verify MW-class fuel cell system	▶Expand supply of large ships

□ **(Necessity)** In response to IMO environmental regulations, the development and demonstration of technologies has been carried out mainly in Europe by using hydrogen fuel cells as a power source for the propulsion systems of ships

□ (Status of technology) Korea has been **conducting technology development and demonstrations since 2017.**

* Develop and demonstrate PEMFC system for fine dust/emission-free ships (2017 to 2021, Korean Register of Shipping, KRW 6.3 billion).

○ Develop hydrogen fuel cell technology (large size, PEMFC) through technology partnerships between global electrical companies and fuel cell manufacturers.

* Siemens (Germany) and PowerCell (Sweden) have developed a fuel cell-based marine power generation system and obtained AIP from DNV GL (June 2018).

* ABB (Swiss-Sweden) and Ballard (Canada) started the joint development of 3MW marine fuel cells (June 2018).

□ Direction of development: establish the direction of technology development by separating the development of coastal ships (small and medium) and ocean-going ships (large) while simultaneously building relevant infrastructure.

○ Coastal ships: fuel cell system for ships rated at up to several hundred kilowatts by 2022 → technology verification through demonstration by 2025 → expand to the private sector by 2027

* The relevant technology will first be applied to government vessels and verified and then expanded to the private sector.

○ Ocean-going ships: modularize fuel cell stacks and develop integrated system by 2025 → secure performance and safety of MW-class fuel cell system by 2027 → apply to large ships by 2030

* Application to large ships will be divided into auxiliary power and propulsion power depending on system capacity.

○ Infrastructure: bunkering infrastructure for hydrogen fuel cell ships, legal and institutional support, and grant funding for application to fuel cells on ships

2. Hydrogen trains: Creation of a Clean, Safe Railway Environment

	Present	2022	2025	2030
Technology Goals	Conducting R&D for hydrogen trains	▶Hydrogen fuel cell: secondary battery hybrid power system	▶ Improve performance through empirical verification	▶ Expand supply

□ Necessity: To reduce greenhouse gas emissions, eco-friendly trains must be introduced in the subway system. In addition, energy-independent railway vehicles need to be put into operation to reduce the necessity for power infrastructure.

□ Status of technology: R&D* on hydrogen trains started in April 2018, with commercialization being promoted through the verification of stability and efficiency. As of yet, the supply plan has not been completed.

* Research period/expenses: April 2018 to December 2022 / KRW 26 billion (government: KRW 23 billion, private: KRW 3 billion)

○ Overseas, hydrogen trains are in trial operation in Germany (and are expected to go into service in 2020).

* Also railroad manufacturers and fuel cell companies are working together on demonstration projects.

□ Development direction: replace diesel trains with hydrogen trains gradually and plan to operate hydrogen-powered railway vehicles (with technology development to be completed by 2022).

○ The replacement of existing diesel trains (4400 series, 59 cars) is expected to reduce annual carbon emissions by 30,000 tons, nitrogen oxide emissions by 486 tons, and fine dust by 89 tons.

○ The introduction of hydrogen trains on new routes (nine sites, 85.32km), in accordance with the light rail construction plan, is expected to reduce annual carbon emissions by 5,000 tons, compared to the existing feed method.

○ The introduction of hydrogen trains will reduce the cost of building and maintaining power infrastructure,* such as substations and electric cables for existing electric locomotives, and prevent accidents.**

* Power infrastructure construction costs: KRW 24.3 billion/km, with KRW 500 million/km in annual maintenance costs

** Railway electrocution incidents: 7 in 2014, 7 in 2015, and 4 in 2016

3. Hydrogen Drones: Long Distance, Long Flight Time, and Remote Flight Capability

	Present	**2022**	**2025**	**2030**
Technology Goals	▶ Secure flight safety and reliability	▶ Enter promising service market through demonstrations	▶ Commercialize drone services for logistics and disaster response efforts	▶ Vitalize the hydrogen fuel cell market

□ Necessity: Hydrogen fuel cell drones can be put on the market as commercial drones, which need to be capable of long flight times for purposes such as agriculture, because they can stay in the air longer than lithium-ion battery drones.

* Flight times: lithium-ion battery drones (30 minutes) and hydrogen fuel cell drones (1 to 2 hours)

○ However, due to the high price of fuel cell drones,* the production period must be shortened by creating an initial market.

* Lithium-ion battery drones (KRW 25 million) vs. hydrogen fuel cell drones (KRW 50 million)

□ Status of technology: completed development of hydrogen drones based on a combination of fuel cells designed for drones and drone platforms of domestic SMBs (2016 to 2018).

* Major countries, including China and the United Kingdom, are developing hydrogen fuel cell drones mainly with drone and hydrogen fuel cell companies, but most of them are still in the R&D stage.

□ Direction of development: After achieving stability and reliability by conducting demonstrations in the public sector, including an assessment of power facilities in 2019, Korea plans to launch hydrogen drones by the end of 2019. After 2020, 100 hydrogen drones will be produced annually.

○ Due to their relatively short flight times, existing drones have limited capabilities in areas such as logistics delivery, leaving the door open for hydrogen drones to dominate such markets.

- **Agriculture/forestry: prediction of crop harvests and pest inspections** over broad areas (after 2020)

- Logistics: offers easy access to island and mountain areas and reduces delivery times and costs (from 2021)

- Safety: commercialize drones for promptly locating people in the event of a disaster (from 2022)

4. Construction Machinery: Small Machines for Warehouses and Underground Work

		Present	2022	2025	2030
Technology Goals	**Excavators**	Power pack R&D	▶ Commercialize small excavator power pack	▶ Test technologies and improve performance through demonstrations	▶ Expand supply
	Forklifts	Standard certification	▶ Introduce small logistics base (in-house hydrogen fueling infrastructure)	▶ Introduce small logistics base (public hydrogen fueling infrastructure)	▶ Expand models and applications

□ Necessity: Hydrogen drones can be used for large-scale construction and logistics work requiring long-term eco-friendly work, such as food warehouse logistics and underground construction.

□ Status of technology: The commercialization of forklifts and excavators* is currently underway. Due to the certification, standardization, and restriction of hydrogen infrastructure, the supply plan has not yet been completed.

* Developed technology for the commercialization of fuel cell power packs for indoor logistics vehicles (November 2012 to 2016)

** Developing a fuel cell power pack for heavy-duty, two-ton, electric, heavy construction equipment (2016 to 2019)

□ Development direction: commercialize fuel cell pack for forklifts and small construction equipment, develop certification and standards, and increase durability and reliability.

○ Forklift: charging/fueling time (six hours → five minutes), operation time (more than two times), and operating cost (down 10 percent, 10 years of use)

○ Excavator: Hydrogen excavators are ideal for work in underground spaces or urban settings, as they do not emit exhaust or produce loud noise.

2. Energy

1 Hydrogen Fuel Cells: Eco-friendly Distributed Power Sources

Goals and Necessity of Disseminating Hydrogen Fuel Cells

1 Dissemination of fuel cells for power generation and homes/buildings (cumulative)

Expected to achieve parity with small/medium gas turbines in 2025 ↓

* ( ): domestic demand

Classification	Present		2022		2040
For Power Generation	307.6MW	➡	1.5GW (1GW)	➡	15GW (8GW)
For Buildings	7MW	➡	50MW	➡	2.1GW

2 Major Projects

○ Expand installation of fuel cells to greatly reduce the installation/power generation costs to the level of small/medium gas turbines.

- Create industrial ecosystem by achieving complete localization of parts, in conjunction with expansion of installation.

○ Eliminate investment uncertainty and support economic efficiency by introducing gas tariffs for fuel cells and REC* preferential treatment for green hydrogen.

* Renewable energy certificate: a certificate proving that electricity is produced and supplied using renewable energy facilities

- Design a support system that takes advantage of distributed power.

○ Establish long-term commercialization plans based on the development of technologies for hydrogen gas turbine power generation by 2030.

1. Hydrogen Fuel Cells for Power Generation

◈ Domestic Supply (cumulative) : 1GW by 2022 → 8GW by 2040
◈ Support the expansion of supply to improve the economic efficiency of fuel cells for power generation

◇ Economy of scale for fuel cells ⇨ Enhance global competitiveness

○ If the cumulative 1GW is realized by 2022, cost savings will be achieved through economies of scale. By 2040, it is expected that installation costs will be reduced by 65 percent and power generation costs reduced by 50 percent.

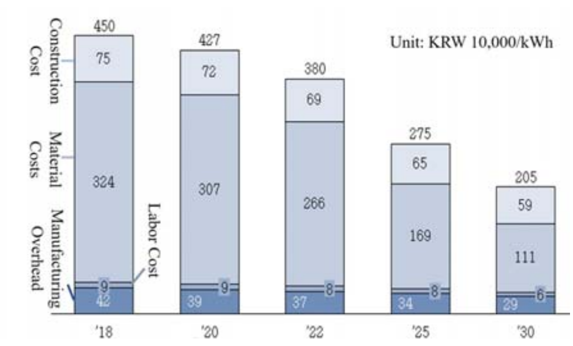
* Installation: KRW 450,000/kW in 2018→KRW 3.8MM/kW by 2022→1.57MM/kW by 2040 / Power generation unit price: KRW 250/kWh in 2018 → KRW 224/kWh by 2022 → KRW 131/kWh by 2040

- In particular, by 2025, the price will reach the level of small- and medium-sized gas turbines.

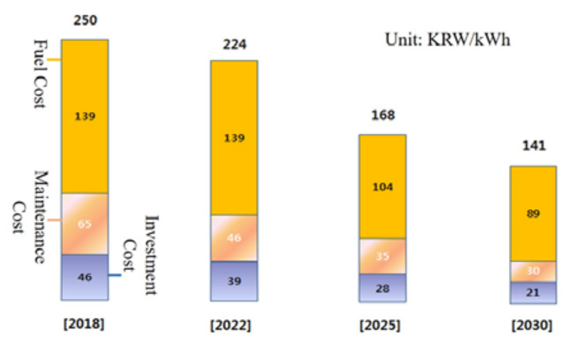
* Current unit price of power generation by small- and medium-sized gas turbines: from KRW 190/kWh to KRW200/kWh

< Fuel Cell Installation and Power Generation Cost Reduction Scenarios >

Fuel Cell Installation Cost Scenario



Fuel Cell Power Generation Scenario



○ Promote large-scale domestic and overseas projects, including the Saemangeum area (100MW, 2022) and secure 1,000 partner companies by 2030.

* Number of Partners: 224 in 2018 → 400 by 2022 → 600 by 2025 → 1,000 by 2030

○ In addition, supply fuel cells to facilities with high rates of electricity consumption, such as industrial complexes.

◇ Ensure economic efficiency of fuel cells

○ Establish LNG price exclusively for fuel cells and maintain fuel cell REC for a certain period of time to eliminate investment uncertainty.

○ The added value of RECs will be additionally preferred in the case of power generation that utilizes green hydrogen.

* Hydrogen with zero GHG emissions, including hydrogen produced using renewable energy (P2H), hydrogen produced overseas, etc.

<Exclusive LNG price for Fuel Cells (Plan)>

▶ Background: gas rate for cogeneration is currently applied to fuel cells

▶ Content: establish separate rate system that cuts fuel cell gas rates

▶ Plan: Korea Gas Corporation will revise Natural Gas Supply Regulations (by March 2019) → new rate to be applied (by May 2019)

○ To promote the stability of the fuel cell industry, the introduction of a long-term (20-year), fixed-price contract system (currently applied to solar → extensively covering fuel cells) will be reviewed.

◇ Complete localization of parts

○ Localize all parts except imported materials such as catalysts (platinum, by 2022) → long-term development of technology for imported materials (catalysts, electrodes, and separator plates)

○ Establish standards for fuel cell components to secure economies of scale among suppliers through the common use of parts by manufacturers.

2. Fuel cells for Households and Buildings

◈ Domestic supply (cumulative) : 50MW by 2022 → 2.1GW by 2040

◈ Expand private sector-centered, self-sustaining hydrogen fueling stations

◇ Expansion of distributed power supply to homes and buildings

○ Expand the government's supply projects by gradually increasing the budget.*

* Support the supply of new and renewable energy (KRW 12.6 billion, 2019): KRW 23.4 million/kW for homes and KRW 22.4 million/kW for buildings

○ Emergency power sources (diesel, gasoline, and other fossil fuel generators) used by hospitals and data centers will be replaced with fuel cells for buildings and ESS systems.*

* In response to the continuous decrease in battery efficiency of ESSs for emergency power supply (Hydrogen can be stored in a storage vessel for a long period of time.)

○ Discover new business opportunities, including fuel cell rental* and fuel cell heat and electricity brokerage businesses.**

* Install and manage installation of equipment in homes → Return on investment through rent and incentive income.

** Intermediary companies secure the heat and electric power produced by fuel cells, and then sell it to customers.

◇ Introduction of incentives and mandatory-use system

○ Establish various incentives, such as an LNG-exclusive tariff system and special electricity tariff system, to relieve the burden on the power system (by 2022).

○ Promote mandatory fuel cell system of gas cooling* of public institutions, mandatory fuel cells, referring to mandatory gas cooling system for public institutions.

* City gas is used to satisfy 60 percent of the demand for air-conditioning in new and existing buildings with areas of 1,000m2 or more.

◇ Development of customized models

- ○ Various models are available for different types of installation sites and usage types.

  * Household: 1kW → 700W, light-weight model / Building: 10kW → 25kW, modular, high-capacity

- ○ Develop smart devices that remotely and automatically manage and improve fuel consumption and generate electricity and heat in connection with IoT technology.

2 Hydrogen gas turbines: Commercialization by 2030

		Present	2022	2025	Since 2030
Technology Goals	H_2 Mixed Combustion	-	▶ Develop design change and operating technologies for combustors using mixed fuels of up to 30 percent hydrogen	▶ Modify and apply combustors using hydrogen mixed fuels	▶ Promote commercial application
				▶ Establish basic design for large hydrogen turbine combustors (mixed/mono)	▶ Demonstrate large hydrogen turbine combustor (mixed/mono)
	H_2 Turbine (mono combustion)		▶ Develop hydrogen turbine combustion technologies	▶ Develop 1MW turbines	▶ Promote commercial application

□ Necessity: utilize a gas turbine with excellent response to the grid as a means of solving intermittency and instability issues associated with the expansion of renewable energy supply.

□ Status of technology: establish plan to promote the development of hydrogen mixed- or mono-gas turbine combustion technology by 2020.

* Develop hydrogen combustion technology for large gas turbines and design change technology for combustors.

** Develop 1MW-class future microgrid featuring hydrogen mixed/mono combustion.

□ Direction of development: establish technological development direction for hydrogen mixed (large-scale) and hydrogen mono (small-scale) combustion separately and related infrastructure for both at the same time.

○ Mixed combustion: Develop combustor design technology and operation technology for hydrogen mixed combustion (2022) → Verify technology through the demonstration of prototypes (2024) → Expand application to large gas turbines (2026)

* Apply to combustors remodeled for use with F-class (power generation capacity of 150 MW) gas turbines in operation in Korea.

○ Mono combustion: GT combustion diagnosis demonstration technology (2022) → Combustion device design and production technology (2024) → Joint development and demonstration of 1MW hydrogen gas turbine manufacturing company (2026) → Commercialization (2028)

○ Infrastructure: After verifying the technology based on domestic gas turbine demonstration combustion equipment, the application of hydrogen mixed combustion technology will be extended through power plant demonstration.

- Establish supply chain through microgrid-linked small (1MW) hydrogen turbine demonstration and technology transfers of SMBs.

2 Expansion of a Stable and Universal Hydrogen Supply System

1. Hydrogen Supply

◇ By-product hydrogen and natural gas extraction (SRM)
⇨ Water electrolysis using renewable energy and hydrogen produced overseas

Hydrogen Production Goals and Major Tasks

◈ Strive to become renewable energy-based hydrogen-producing country by 2030.

1 Composition of hydrogen production and supply goals

		Present	2022	2030	2040
Configuration		①By-product hydrogen ② Hydrogen extraction (LNG extraction)	① By-product hydrogen ② Hydrogen extraction ③ Water electrolysis	① By-product hydrogen ② Hydrogen extraction ③ Water electrolysis ④ Overseas production ※ ①+③+④: 50%, ②: 50%	① By-product hydrogen ② Hydrogen extraction ③ Water electrolysis ④ Overseas production ※ ①+③+④: 70%, ②: 30%
		-	Mass production near metropolitan area	Use of hydrogen produced overseas	Mass introduction of CO_2-free hydrogen
Supply		130,000 tons/year	470,000 tons/year	1.94 million tons/year	5.36 million tons/year+α

2 Major Projects

○ **By-product hydrogen**: utilize hydrogen generated as a by-product of **petrochemical processes.**

- In 2017, the amount of hydrogen used for petrochemical processes (as feedstock) was 1.64 million tons, with a spare production capacity of about 50,000 tons (equivalent to 250,000 Hydrogen vehicles(FCEV))

○ **Hydrogen extraction**: establish large-scale hydrogen production base near areas with hydrogen demand.

- Establish **hydrogen production bases nationwide based on the national LNG supply system.**
- **Establish a dispersed hydrogen production base** near areas with hydrogen demand by utilizing urban **LPG and CNG fueling stations or CNG bus garages.**

○ **Hydrogen produced overseas: hydrogen produced overseas** using **renewable energy and imported**

○ **Overseas hydrogen production: produce hydrogen overseas using renewable energy, brown coal, etc. and transport it to Korea** (by 2030).

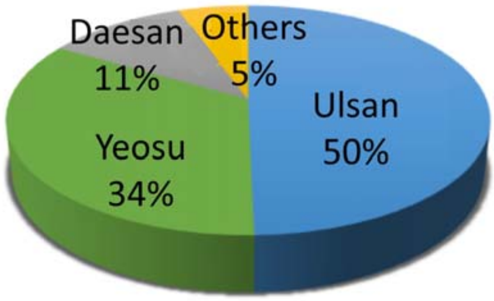
1. By-product Hydrogen

◇ Production centered on petrochemical complex: Toward establishing a hydrogen economy

○ (Current Status) By-product hydrogen is being produced mainly in petrochemical complexes, such as those in Ulsan, Yeosu, and Daesan. The establishment of large-scale infrastructure will make it possible to secure economies of scale.

* Domestic hydrogen production in 2017: 1.92 million tons (Ulsan 50%, Yeosu 34%, Daesan 11%, and others 5%)

Region	Production (tons/year)
Ulsan	949,677
Yeosu	645,626
Daesan	210,222
Others	106,764
Total	**1,912,289**



[**Share of Production by Region**]

- Actual production (2017): approx. 1.64 million tons (domestic utilization: 1.41 million tons + external utilization: 0.23 million tons)

○ Production capacity: approx. 50,000 tons (equivalent to about 250,000 H2 cars)

* Considering the characteristics of by-product hydrogen associated with the utilization rate of the petrochemical process, the production capacity of hydrogen is assumed to remain stable in the long term

- Expecting that it will be able to utilize the external circulation (about 230,000 tons) in the long term

○ Hydrogen supply system: hydrogen pipeline and tube trailers

* Most of the hydrogen used in industry is supplied by pipeline, with only some being supplied by tube trailers.

Supply Methods	Hydrogen Pipeline		Hydrogen Tube Trailers	
	Volume (tons/year)	Share (%)	Volume (tons/year)	Share (%)
Volume	214,655	92.7	16,967	7.3

2. Hydrogen Extraction

◇ Basis for mass supply of hydrogen: Key to early implementation of hydrogen economy

○ Medium- and large-sized hydrogen production base: Hydrogen extractors with a capacity of 300 to 1,000 Nm3/h or more* will be built in the natural gas supply chain* near high-demand areas to implement the mass production of hydrogen.

- Proposed production places: 142 governor stations of the Korea Gas Corporation
- Establishment of hydrogen production base (cumulative): to be built in 2019 and expanded annually in consideration of hydrogen demand

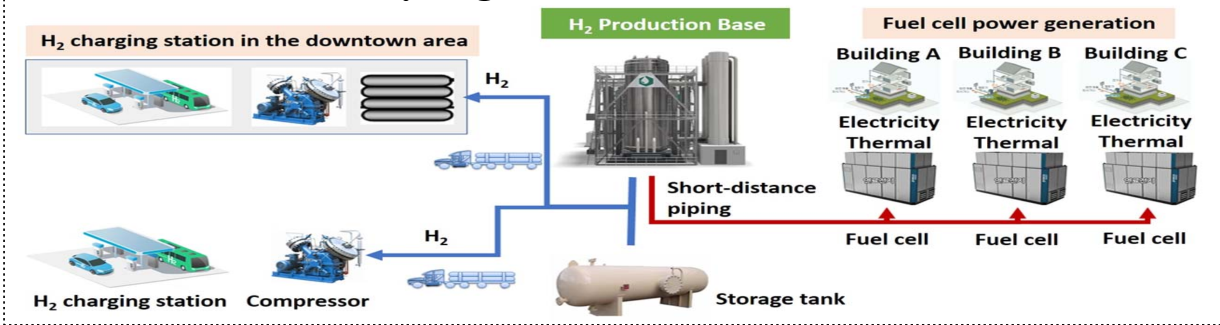
* At present, no other facilities other than gas supply facilities can be installed in governor stations. Therefore, it is necessary to revise the city gas legislation after completing an empirical evaluation.

○ Distributed hydrogen production base: install hydrogen extractors of 300N㎥/h* scale at LPG and CNG stations in urban centers or CNG bus garages

* Hydrogen production: 500kg/day (equivalent to 20 hydrogen buses and 90 to 100 Hydrogen vehicles(FCEV))

- Utilizing city gas piping to produce extracted hydrogen and operating nearby hydrogen fueling and Mother stations
- Establishment of hydrogen production base: three units in 2019 (KRW 15 billion in total) → expand annually in connection with increase in Hydrogen vehicles(FCEV) supply and installation of fueling stations

<Hydrogen Production Base >



◇ Localize and increase efficiency of hydrogen extractors

○ Secure high-efficiency, large-scale extraction technologies and reduce the costs of building hydrogen production bases by localizing hydrogen extractors.

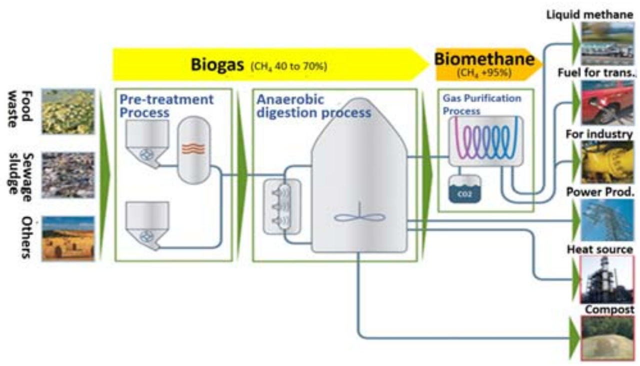
○ Secure steam extraction system technology (25kg/h or more, by 2022) and large-scale extraction technology (1,000kg/h or more) with an efficiency of at least 75 percent (by 2030).

◇ Diversify LNG and hydrogen extraction methods

○ Develop hydrogen production technology based on biomass, such as sewage sludge and municipal waste.

* Conduct research on the production of syngas using municipal waste and sewage sludge from research centers, such as the Institute of Energy Technology.

< Measures for Utilizing Biomass and Municipal Waste >

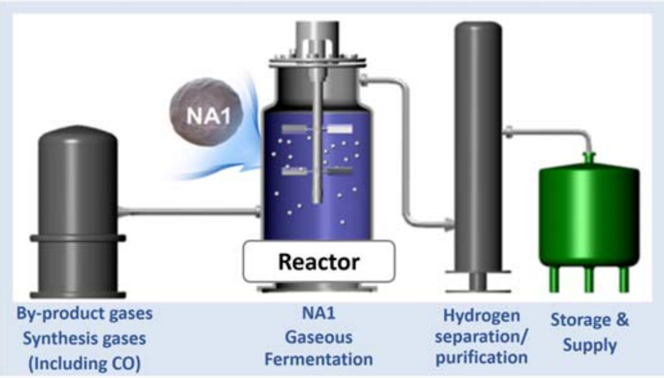


Utilization of Biomass

Utilization of Municipal waste

○ Produce hydrogen using oceanic microorganisms (NA1) as a catalyst and carbon monoxide and sea water as raw materials.

< Marine Bio-Hydrogen Production >



- Develop bio-hydrogen production technologies
- $CO + H_2O \rightarrow H_2 + CO_2$
- Patents for all processes have been secured.

3. Water Electrolysis: Utilization of Renewable Energy Surplus Power

◇ The commercialization of water electrolysis linked to renewable energy is a milestone in the effort to implement a hydrogen economy, including ❶**the production and supply of CO_2-free green Hydrogen and expasion of renewable energy use.**

◇ Develop large-scale, high-efficiency water electrolysis

○ Develop MW-class, renewable energy-linked water electrolysis design technology by 2022 and demonstrate 100MW-class renewable energy-linked technology.

<P2G: Renewable Energy Surplus Power → Hydrogen Production (Water Electrolysis)>

Classification	Phase 1: R&D (2019-21)		Phase 2: Demonstration (2022-23)
P2G	· Develop control technologies for water electrolysis · Electricity and gas connected to grid	☞	· Build and operate MW-class demonstration plant (1,000 hours or more)

○ Develop high-capacity and long-term storage technologies for water electrolysis (MWh-class at least, by 2025).

< Major Tasks >

- By 2022: perform basic and demonstration studies on liquid and solid storage.
- By 2025: secure MWh-class liquid and solid storage technologies and demonstrate fuel cell connection technologies.
- From 2025: commercialize high-capacity power storage based on liquid and solid storage technologies

○ Increase efficiency of water electrolysis (55→70%, by 2022) and secure economy.

< Major Tasks >

- By 2022: secure high-capacity alkaline water electrolysis technology (over 15kg-H2/h in single stack) and demonstrate polyelectrolyte water electrolysis technology (over 15kg-H2/h based on single stack).
- By 2030: achieve less than 50kWh/kg-H2 for power consumption of water electrolysis system and commercialize and localize water electrolysis-based hydrogen production plant.
- From 2030: achieve 43kWh/kg for power consumption of water electrolysis system.

◇ Renewable energy power plant complex-linked measures

○ Mass produce hydrogen in large-scale renewable energy (including offshore wind power) generation complexes.

* Ex: Siemens participated in a P2G demonstration plant using wind power generation.

○ Install solar panels on abandoned/upper roads and at landfill/reclamation sites and discover sites for "Solar PV + P2H," which produces hydrogen using a distributed method.

4. Utilization of Overseas Hydrogen: Introduced in 2030

◇ The production of hydrogen overseas contributes to ❶stabilizing hydrogen supply and demand, ❷reducing domestic GHG emissions, ❸developing related industries such as hydrogen transportation vessels.

○ Based on the prospect of future demand for hydrogen,* it is necessary to establish stable and eco-friendly supply plans.

- Contribute to stabilization of domestic hydrogen price by supplying large volumes of hydrogen.

- Import and transport hydrogen: no infrastructure required for hydrogen production.

○ Reduce GHG emissions by replacing fossil fuel-based hydrogen with imported CO2-free hydrogen.

< Introduction of Overseas Hydrogen Production >

Overseas Production		**Import** (Transportation)		**Mass Supply**
Construction of Hydrogen production bases	→	Production of hydrogen for import	→	Construction of domestic receiving bases for supply

○ Develop infrastructure and technology related to hydrogen liquefaction and liquid technology, hydrogen transportation vessels, and liquefaction plants and build hydrogen production bases for overseas production (from 2022).

- Promote use of liquefied hydrogen first and actively utilize Open Innovation to secure core technology based on the technology and experience gained from building LNG receiving terminal bases.

< Major Tasks >

▸ 2022: Decompose ammonia.
Establish basis for storage and extraction of liquid hydrogen.

▸ 2025: Secure and demonstrate commercial ammonia decomposition, liquid organic hydrogen storage, and extraction technologies.
Commercialize and localize liquefied hydrogen transportation vessels.

▸ 2025: Decompose ammonia.
Commercialize liquid organic hydrogen storage and extraction.
Completely localize core equipment for hydrogen import.
Develop high-capacity tanks for transport of imported hydrogen.

○ Import hydrogen produced overseas (by 2025) and build “renewable energy + hydrogen production” bases

* Ex: cooperation on and demonstration of transportation of liquid hydrogen extracted from lignite, liquid hydrogen extracted from oil, and ammonia-derived hydrogen extracted from LNG

Complete development and demonstration by 2030, in accordance with introduction of hydrogen produced overseas

◈ Completing the development and demonstration by 2030 in accordance with overseas H_2 introduction

	Present	2022	2025	2030
GOALS	Beginning development of technology for baggage racks	▶ Design baggage racks ▶ Secure technologies for insulating, unloading, and BOG treatment	▶ Build a demonstration ship	▶ Ship operation test and commercialization

☐ **(Necessity)** To cope with long-term consumption of large volumes of hydrogen, **hydrogen produced overseas should be stored in the form of a liquid or liquefied** (organic compound) for mass-transport by ship.

* Liquefaction: insulation technology for cryogenic (-253℃) storage is crucial, most hydrogen storage and transportation possible Liquid: It is possible to store hydrogen by chemically bonding it to compounds (such as ammonia) as well as to use existing vessels.

☐ **(Status of Technology)** Started developing technologies for liquid hydrogen storage warehouse in 2016 and currently developing design technology, cryogenic insulation technology, safety evaluations, etc.

* Three shipbuilding companies and universities are participating in the technology development activities under the supervision of the Korean Register of Shipping (2016 to 2020, KRW 2.6 billion).

☐ **(Development Direction) Intensively support the core technologies of liquid Hydrogen carriers*** and conduct long-term basic research on liquid-phase (organic compound) carriers.

* Top three Core Technologies : ❶ Cryogenic insulation technology, ❷Unloading technology, ❸ BOG processing technology

○ Establish an industrial ecosystem that leads core technology development and promotes cooperation with equipment companies.

2. Hydrogen Storage and Transportation

◇ Increase Economical Efficiency of Hydrogen Distribution

Main Goals of Hydrogen Storage and Transportation

	Present	2022	2030
Tube Trailers	500	Large-scale gas storage and transportation	Liquefaction and liquid and solid hydrogen storage and transportation
Pipeline	200km	Establish hydrogen pipelines near sources of by-product hydrogen production (Ulsan, Yeosu, and Daesan)	Consider the construction of high-pressure hydrogen pipelines nationwide
Core Issues	-	Establish base of supply centered on demand	Establish supply infrastructure nationwide

1. Diversification and advancement of hydrogen storage methods

◇ (Gas) Develop high-pressure storage and expand capabilities

○ Technology for high-pressure storage containers (tube trailers) rated for 500 bar or more is already available. However, efficiency needs to be improved through deregulation related to pressure standards.

◇ (Liquefaction) Localize core technologies and establish mass storage/supply of hydrogen

○ Liquid hydrogen is more advantageous than gaseous hydrogen in terms of both safety and economy.

* Safety: Gaseous hydrogen is stored at a high pressure of 200 bar or more, while liquid hydrogen is stored at atmospheric pressure.
Economy: Additional cost (KRW 1,680/kg) is required, but the volume is 1/800 and transportation cost is only 1/10 those of to gas.

○ The United States, Europe, and Japan are operating on the commercialization of hydrogen liquefaction plants, but no such plant has yet been built in Korea. ⇨ Localization of core technologies

< **Major Tasks** >

▶ Localize technologies for liquefaction plants, liquefaction tanks, pumps, valves etc. (by 2030). * Level of domestic technology (rankings among 100 top technologies): compressor 53 / plant design, construction, and operation 55-59, etc.

◇ (Liquid/Solid) Safe and stable supply/demand: Expansion of technical support

○ Liquid: When hydrogen is bound to an organic compound, such as toluene or ammonia, it can be safely stored and transported in large quantities and at a normal temperatures and pressures.

- Expand the development of some foundational technologies that are currently being promoted and continue supporting them.

○ Solid: Hydrogen can be safely and efficiently stored and transported in solid form using the interior or surface of solid materials, such as alloys for hydrogen storage alloys.

* Solid storage is the safest way of storing hydrogen. → It is also used in specific fields, such as submarines.

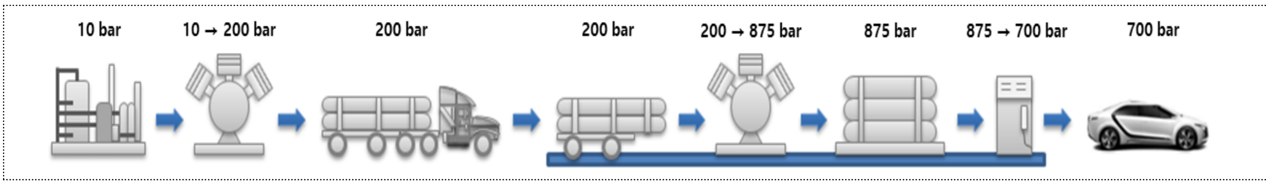
- As this technology is still in the early stages globally, support should be expanded for its development in the long term.

< **Major Task** >

▶ Demonstrate and commercialize liquid and solid storage technologies at the commercial level (27kg-H2/h) by 2030.

2. Efficient hydrogen transportation system

◇ (Tube trailers) From high-pressure gas to liquid/liquefaction transportation



< Hydrogen Storage and Transportation Process>

○ **Reduce transportation costs and expand areas to which hydrogen can be supplied by increasing the storage and transport capacity of high-pressure gas and lightweight tube trailers* (by 2022).**

* Currently, the tube trailers weigh 40 tons each, which limits their use on some bridges in Seoul. → Reduce to 20 tons.

- At the same time, to secure the economic efficiency of hydrogen fueling stations, it is necessary to expand the utilization of tube trucks of 700 bar or more that are capable of transporting one ton* of hydrogen each.

* A single trailer is enough to meet the demand of bus garages in small- and medium-sized cities, saving up to 63 percent on shipping costs.

< Global Trends of Tube Trailers >

	Main Content
United States	‣ Commercializing 500-bar tube trailers → Demonstrating 700-bar tube trailers currently in development ‣ Because vessels are not limited in terms of storage capacity, it is possible to transport large volumes of hydrogen by increasing vessel capacity.
Japan	‣ Commercializing 450-bar tube trailers ‣ Capacity limitation (350L) → 400kg/trip, cannot be used for high-capacity fueling stations (ex: buses)
Korea	‣ Commercializing 200-bar tube trailers → 340kg/trip ‣ Limited vessel capacity (150L)

○ In the long term, it is possible to improve transportation efficiency based on liquid/liquefaction transportation (tank lorry, by 2030).

◇ (Pipelines) Expand pipelines to serve high-demand areas nationwide

○ In Korea, a 200km-long hydrogen pipeline has been installed. To increase the supply pressure* and lifespan, measures such as material development are necessary.

* Develop materials for hydrogen-exclusive pipelines (over 50 bar, to overcome fragility).

** Current supply pressure is about 20 bar → Need to increase pressure to 100 bar or more, which is the U.S. DOE target pressure

○ Prioritize installation of pipelines in high-demand areas and establish main pipelines connected to the large-scale supply network of LNG production bases and hydrogen-receiving bases in the medium to long term.

* It costs about KRW 400 million to install 1km of hydrogen-only pipeline.

- Establish private-sector pipelines in cities with high hydrogen demand (by 2022).

- Supply large amounts of hydrogen to adjacent areas by installing pipelines at import bases (by 2025).

- In the long term, and in accordance with the growing demand for hydrogen, main hydrogen pipelines will be installed to connect the Hydrogen Distribution Center with the entire country (by 2030).

3 Creation of the Industrial Ecosystem of the Hydrogen Economy

1. Improvement of Technical Competitiveness: Establishment and Promotion of Cross-ministerial Technology Roadmap

□ Prepare detailed roadmap for future leading technologies through collaboration between the Ministry of Industry, Ministry of Science and Technology, Ministry of Land, and Ministry of Water Resources ⇨ Launch cross-ministerial preliminary feasibility study for hydrogen (2021 to 2030, KRW 200 billion)

❶ Localize core technologies to maintain the global leadership of domestic companies in the field of Hydrogen vehicles(FCEV) and fuel cells.

- Derive areas with high economic and technological ripple effects based on industry feedback.

	Localization
Hydrogen vehicles (FCEV)	Membrane electrode assembly, gas diffusion layer, carbon material for high-pressure vessel, etc.
Fuel Cells	For power generation: cell electrode and catalyst and fuel converter catalyst / For households and buildings: membrane electrode assembly

❷ Upstream fields as a base and source → Connect with R&D throughout the entire cycle, from demonstration to commercialization.

- Promote flexible technology acquisition strategies through Open-Innovation to ensure that foundational technologies, such as liquefaction and liquid technologies, are secure where needed most urgently.

Sector		Basic/Original (MSIT)	Parts/Products (MOTIE)	Support for Diffusion (MOLIT & MOF)
Production		Alkaline, PAM water electrolysis technology, etc.	P2H technology development and demonstration	Site provision (abandoned roads, etc.)
STO·TRANS	**Lique-faction**	Ultra-vacuum liquid hydrogen storage, etc.	Liquefaction tank lorry and fueling technology	Mass demonstration in central urban areas
	Liquid	Hydrogen → organic compound (ammonia) conversion	Transport technology for liquid organic compounds	
Shipping	**Propul-sion**	Electrode/catalyst materials	Ship fuel cell manufacturing	Establishing infrastructure to supply and store H_2 in port
	TRANS	Cryogenic insulation, unloading technology, etc.	Basic designs for storage vessels, etc.	

❸ Build a large-scale demonstration platform offering next-generation technologies and services.

Sector	Expected Effects	Main Content
Hydrogen Fusion & Convergence Complex (MOTIE)	**Increased industrial competitiveness**	▪ For hydrogen companies, research institutes, and other areas where infrastructure is concentrated ▪ Establish infrastructure, designate specialized companies, train professional personnel, etc.
Specialized Demonstration	**Securing of leading technologies**	▪ Demonstrate the production of hydrogen from biomass such as municipal waste

❹ Ensure safety throughout the entire value chain to ensure the reliability and stability of the hydrogen economy.

	Major Content
Fuel Cells & Parts of Hydrogen vehicles(FCEV) (MOTIE)	Prepare safety test and certification standards for fuel cell products for power generation Improve the safety of vehicle parts and fueling systems, such as storage vessels
Hydrogen Trains and Ships	Establish safety verification and technical standards for the commercialization of hydrogen trains

Hydrogen Technology Roadmap (Plan)

			Main Tasks	Tech. Development→Commercialization (year)											
				19	20	21	22	23	24	25	26	27	28	29	30-
Production	Reform		Localize hydrogen extraction using natural gas and improve efficiency	■	■	■	■	■							
	Water electrolysis	Alkali	Secure high-capacity alkaline electrolysis technology	■	■	■	■								
			Localize and standardize alkaline electrolytic parts				■	■	■	■	■	■			
		PEM	Secure high-capacity polymer/water electrolytic technolog	■	■	■	■								
			Localize and standardize polymer/water electrolytic parts				■	■	■	■	■	■			
			Water electrolytic integration system technology linked with renewable energy				■	■	■	■					
			Improve lifespan and power consumption of water electrolytic syste						■	■	■	■	■	■	
			Commercialize water electrolyte-based hydrogen production						■	■	■	■	■	■	■
	Other		Secure hydrogen production technology utilizing biomass such as waste	■	■										
Storage	Gas		Demonstrate large-scale hydrogen gas storage and transportation (450 bar)	■	■	■									
			Develop high-pressure complex vessel for hydrogen fueling (900 bar↑)		■	■	■								
	Liquef.		Develop designs related to hydrogen storage and transportation and core parts			■	■	■	■	■	■				
	Solid		Develop solid hydrogen storage (tank lorry) technology for transportation	■	■	■	■	■							
			Develop high-pressure gas-solid/liquid-solid hybrid storage technology				■	■	■	■	■	■			
	Liquid		Develop liquid compound materials and storage/transportation technolog	■	■	■	■	■	■	■					
			Demonstrate liquid compound storage and transportation technology								■	■	■	■	■
Transportation	Pipeline		Establish short-distance piping infrastructure (within 10 km)		■	■	■								
			Demonstrate hydrogen using piping for transportation			■	■	■	■	■					
			Construct hydrogen supply piping (acquisition base-consumers)										■	■	■
	TT		Develop ultra-high-pressure tube trailers (450, 900 bar)	■	■	■	■	■							
	Tank lorry		Develop transportation (tank lorry) low-pressure liquid hydrogen (3 bar) and fueling technology				■	■	■	■	■	■			
	Ships		Construct liquid hydrogen storage/acquisition base							■	■	■	■	■	■
			Develop liquid Hydrogen carrier (utilizing LNG carrier building technology)								■	■	■	■	■
Applications	Hydrogen vehicles(FCEV)		R&D to improve safety related to collisions, rollovers, and fires		■	■	■								
			Secure high-pressure hydrogen vessel and high-voltage converter technology for buses		■	■	■								
			Analyze and improve the durability of parts by demonstrating hydrogen taxis	■	■	■	■								
			Develop 5- to 10-ton hydrogen trucks	■	■	■	■	■							
			Develop technology for localizing electric parts (inverters and converters)	■	■	■									
			Localize core parts (compression high-pressure valve, storage container, etc.) and fueling technology	■	■	■	■								
			Mass-produce parts and reduce core part prices (stack, platinum catalyst, H2 tank, etc.)		■	■	■								
			Develop safety evaluation method for fueling stations and parts	■	■	■	■								
			Improve hydrogen storage density (wt%) and minimize safety incidents		■	■	■								
			Develop metropolitan hydrogen bus (charter bus) technology (design, motor, H2 vessel, etc.)				■	■	■	■	■				
	Fueling stations		Develop 1- to 2-ton hydrogen fueling technology per day			■	■	■	■						
			Develop liquid hydrogen fueling station technology							■	■	■	■	■	
			Develop high-pressure complex vessel for hydrogen fueling stations (900 bar↑)		■	■	■								
	Other trans		Develop and demonstrate core technology of hydrogen, fuel cells, and shops	■	■	■	■	■							
			Improve hydrogen train efficiency and verify safet	■	■	■	■								
	Fuel cells		Develop technology for high-power fuel cells	■	■	■	■	■	■						
			Localize all parts of fuel cells for power generation and standardize	■	■	■	■	■							
			Commercialize hydrogen generation using by-product hydrogen		■	■									
			Improve lifespan and efficiency of parts for homes and buildings	■	■	■	■	■	■						
			Develop IoT-linked products to maximize fuel and heat utilization		■	■									
			Develop and localize hydrogen gas turbine technology			■	■	■	■	■	■	■	■	■	■
			Develop fuel cell manufacturing auto. technology for power generation		■	■	■	■							

2. Training of Specialists: In Response to the Expansion of the New Hydrogen Market

◇ Training of safety manpower: Establishment and operation of training programs

○ Establish a national professional qualification (hydrogen safety manager (tentative title) who effectively manages the safety of hydrogen across all processes, including hydrogen production, transportation, and supply.

* Promote content on the provision of a specialized qualification examination for the Hydrogen Safety Law.

○ Train hydrogen fueling station managers responsible for station design, operation, and safety management.

* Establish the "Hydrogen Fueling Station Manager" course (tentative title) and offer it at educational institutions or commission it to the Gas Safety Corporation.

○ Establish and operate a training course focused on conducting safety inspections in the parts (storage vessels) design and production stages.

* Establish and offer commissioned education or specialized courses on containers and special facilities.

◇ Train core technology development personnel: Operate support program for personnel with MA/PhD degrees

○ Support the dispatch and recruitment of the specialized personnel needed to upgrade the technology of SMBs.

* Currently, the Technological Innovation Small & Medium Business Researcher Support Project is supporting companies by dispatching the research personnel of public research institutes to SMBs (once per company for up to three years) and supporting SMBs in their efforts to recruit research staff (1 to 2 researchers per company for up to three years).

❶ Production: Water electrolysis technology (KIER, KIST-SMBs [EMS, Elkemteg, etc.])
❷ Storage: Advanced liquefaction/liquid technology (KIST, KIMM-SMBs [MetaVIsta, Hylium, etc.)

○ **Establish education programs on the design, production, and maintenance** of hydrogen fuel cells to stabilize the supply and demand of personnel in the hydrogen industry

❶ (Hydrogen vehicles(FCEV)) Operate education programs based on partnership between manufacturing companies and polytechnics (including Meister high schools). ❷ (Fuel Cells) Operate cooperative internship programs between manufacturing companies and universities.

3. Preceding International Standards: Leading of the Global Market

◇ Proposal of international standards: Increase of 13 cases by 2030 (20 percent)

* ISO/TC197 (hydrogen technology), IEC/TC105 (fuel cells), GTR (Global Technical Regulation), etc.

○ **Hydrogen Technology**: Propose two cases by 2022 → more than five in total by 2030

Main Content	Hydrogen Manufacturing
	❶ Evaluation of the performance and safety of large-scale extractors (300m^3/hour) (by 2022) ❷ Evaluation of the performance and safety of high-efficiency electricity/thermal/hydrogen-production system based on fuel cells (by 2030)
	Storage Vessel
	❸ Evaluation of Type 3 and 4 storage vessels* of fueling stations (by 2030) * Type 3: vessels wrapped with carbon fiber in metal Type 4: vessels wrapped with carbon fiber in non-metallic material
	Fueling System
	❹ Evaluation of the comprehensive performance and safety of hydrogen fueling system (by 2022) ❺ Evaluation of the performance and safety of portable hydrogen fueling stations (by 2025)

○ **Fuel Cells**: Propose three cases by 2022 → more than 10 in total by 2030

Main Content	For Construction Equipment
	Three cases, including the general requirements and performance evaluation of the power system of fuel cells for construction equipment, such as excavators and trucks (by 2022)
	For Transportation
	Four cases, including general requirements and performance/safety evaluation of (portable) fuel cells for transportation, such as drones, ships, and trains (by 2030)
	Next-generation Technology
	Three cases, including next-generation, high-efficiency performance evaluation required for the revision of international standards for fixed/micro-type fuel cells (by 2030)

◇ Leading of International Standardization

○ Promote strategic international standardization by reviewing and proposing international standards and **developing a roadmap to support industries through the operation of departments* at the Hydrogen Economy Standard Forum** (launched in December 2018).

* Policies, hydrogen technology (manufacturing, storage, and fueling), and fuel cells (for power generation and transportation)

- Link with R&D projects related to the establishment of the hydrogen economy and support industrial responses to international standardization.

○ **Expand industrial participation** through international seminars and forums and **establish a standard system for cooperation among Korea, China, and Japan.**

* In accordance with the terms of the international standard proposal, more than five countries must agree to participate in the working group.

4. Establishment of Basis for Hydrogen Economy: Promotion System and Support Organization

◇ Cross-ministerial promotion system for the hydrogen economy

○ **(Constitution)** Establish and operate the **cross-ministerial Hydrogen Economy Promotion Committee* as a general policy/coordination institution** linked to hydrogen economy-related laws.

* Chairman: Prime Minister / Commissioners: Ministers and private experts

○ **(Necessity)** : To implement a roadmap for various government ministries at an early stage and achieve results, it is **necessary to have a system for promoting cooperation between ministries and agencies.**

- Discuss and coordinate **the direction of the hydrogen economy implementation policy, roles and cooperation plans among ministries, implementation targets** (technology development, infrastructure, industrial ecosystem, etc.) and **deregulation.**

○ **(Support System) : It will be launched within the Ministry of Industry first, and its expansion to a cross-ministerial system will be reviewed in consultation with other relevant authorities,** considering the future demand for policy.

* Enact or revise laws and regulations, relax regulation, secure support budget, expand applications in terms of transportation and energy use, build infrastructure (such as hydrogen production, storage, transportation, and fueling stations), and conduct technology development and demonstrations.

- A review will also be conducted to establish a specialized agency dedicated to fostering the hydrogen economy in the mid to long term.

* The Hydrogen Convergence Alliance, a public-private consultation body, was established in 2016, but its activities are currently limited. Some other institutions, such as the Korea Energy Agency and Energy Technology Institute, are sharing the responsibility for management functions.

※ **Consider establishing the Hydrogen Distribution Center as well**

‣ (Purpose) Establish a fair and efficient distribution system by ensuring the stable supply and demand of hydrogen.

‣ (Main functions) ❶manage hydrogen supply and demand, logistics, and ❷ information and provide information on supply and demand trends and price difference by region of hydrogen available for sale.

◇ Creation of hydrogen industrial cluster (2021)

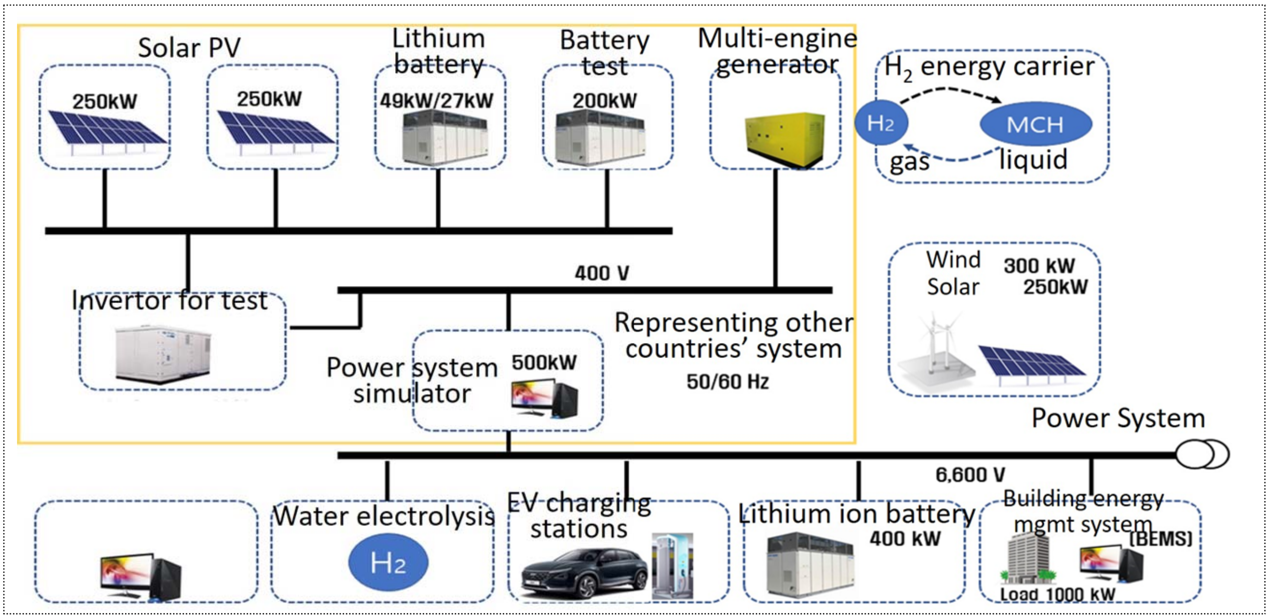
○ (Purpose) Establish clusters, companies, and research institutes related to all parts of the value chain, including hydrogen production, storage, transportation, and utilization.

* Ex: renewable energy, water electrolysis, next-generation fuel cells (for households/buildings and power generation), Hydrogen vehicles(FCEV) and drones, railroads, etc.

○ (Main function) Develop technology throughout entire hydrogen industry and operate large-scale demonstration test bed.

- Establish hydrogen production and storage/transportation infrastructure in the cluster and perform R&D and large-scale demonstrations.

* From planning to R&D on demonstration complex design (total budget: KRW 2 billion / March 2019 to August 2020)



◇ Hydrogen City composition: three pilot cities (by 2022)

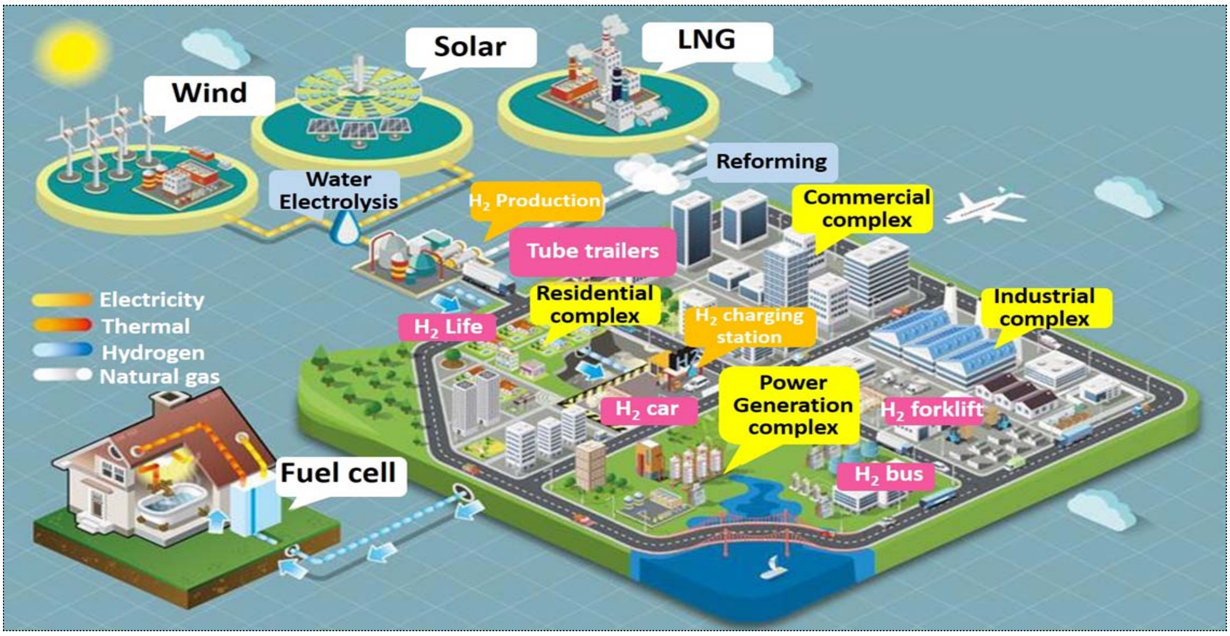
○ (Purpose) create hydrogen cities by establishing distributed heat-electricity networks using hydrogen.

- Minimize the construction of backbone networks in urban areas by installing a distributed heat and power network based on hydrogen and achieve heat and electricity supply and demand stability by complementing intermittency.

○ (Construction strategy) After the pilot city project is completed, cities will be transformed to allow them to utilize hydrogen in all possible areas, such as residential, industrial, and traffic.

- Expanding hydrogen production, storage, transportation, and utilization of Hydrogen vehicles(FCEV), fuel cells, and hydrogen mega stations to the actual city.

- Designing Hydrogen pilot cities (June 2019) → Review the condition of hydrogen production/supply and acceptability by end of 2019 → Selected the 1st pilot city (end of 2019) → will select the 2nd pilot city (2020)



5. Enact Laws: Institutional Base for Systematic Hydrogen Industry

○ The Hydrogen Economy Act will be enacted in the second half of 2019.

 * A number of bills related to the hydrogen economy have been passed recently.

○ Reflect the overall regulations of the hydrogen industry, including the establishment of basic plans for the hydrogen economy, provision of support for hydrogen companies,* and improvement of regulations and safety management standards.

 * Leading hydrogen-related SMBs and middle-standing companies → Provide multilateral support for R&D, commercialization, human resources, taxation, financing, etc.

< Main Content of Hydrogen Economy Act (Plan) >

- Establish five-year basic and annual plans for transition to a hydrogen economy-based society.
- Recommend improvement of relevant laws.
  (Ministry of Industry → heads of central agencies)
- Support hydrogen companies (subsidies, taxation, etc.), designate specialized complexes, promote fueling station installation, train personnel, etc.
- Establish safety management regulations for hydrogen-related products and facilities, safety registration, and licensing standards for operators.

6. Leading of Global Hydrogen Economy: Strategic International Cooperation

◇ Establishment of global hydrogen economic cooperation network

○ Enhance partnerships with global companies by actively participating in international cooperation organizations, such as the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) and the Hydrogen Council.

○ Secure leadership of global hydrogen economy by strengthening cooperation between interested countries.

* Strengthen exchange and cooperation among the certification bodies of the three countries and establish an international standardization response system.

◇ Strengthening of cooperation for establishment of overseas hydrogen import base

○ Produce hydrogen overseas by utilizing overseas resources such as solar power and wind power in the Middle East, and Central and South America and transport the hydrogen to the domestic market.

* Korea-Australia Resource Collaboration (ministerial-level) will work to establish a channel of cooperation for hydrogen projects and coordinate agendas.
(Co-develop water electrolysis technology → Demonstrate at large-scale renewable energy complex)

◇ Expansion of technical cooperation by sector and value chain of hydrogen economy

○ **Production, storage, and transportation:** Develop water electrolysis technology, carbon capture technology for LNG extraction-type hydrogen production base, and medium- and large-scale liquid hydrogen production plant technology.

○ **Hydrogen utilization:** Implement technical cooperation to global market, develop/demonstrate hydrogen gas turbine technology, etc.

7. Establishment of Infrastructure for Export Industrialization: Hydrogen Korea

◇ Public and private Hydrogen vehicles(FCEV) export capacity

○ Support exports by developing optimal package models for Hydrogen vehicles(FCEV) (buses, trucks, and taxis) and hydrogen infrastructure (production, transportation, and fueling) in emerging countries.

* Support the acquisition of international funds, such as the AIDB, in order to secure the funds needed to develop such package models.

○ Expand the case of patent sharing among automobile companies.

◇ Overseas advancement of fuel cells and parts materials

○ Advance into overseas power generation markets in cooperation with public development corporations with low-cost fuels such as by-product hydrogen (small/medium) and flare gas.

○ **Promote projects to secure the Track-Record,** which guarantees the reliability of domestic fuel cells, in connection with overseas technology development and demonstration projects and **export products.**

* Domestic: Support the joint equipment development and evaluation center for testing, demonstrating, and evaluating fuel cell components and systems → Track Record (domestic and overseas) → export (overseas)

○ Develop contract guarantee financial products by government and public institution (financial institutions, etc.) to enhance the stability of large-scale overseas projects.

8. Improvement of the Ecosystem of the Hydrogen Industry

◇ Fostering of SMBs and middle-standing companies: Parts and materials

❶ Support the growth of parts and materials manufacturing companies through **R&D linked to purchase conditions.**

○ Large companies manufacturing Hydrogen vehicles(FCEV) and fuel cells are required **to provide the specifications of all necessary parts and materials.**

- As Hydrogen vehicles(FCEV) will drive the initial growth of the industry, it is important to propose concrete technical specifications for demand companies and eliminate any uncertainties that the parts and materials producers have regarding the initial investment.

- Fuel cells are situated according to type (MCFC, PAFC, SOFC, PEMFC, etc.), but they can be expanded by sharing technologies for the production of common parts.

○ Complete a virtuous cycle structure comprised of: government R&D → demonstrations by demand companies → commitment to procurement

- When government R&D is announced, it is necessary to design the tasks so that the joint R&D results generated through cooperation between the demand companies and parts and materials companies can be linked to demonstration tests and the purchasing of demand companies (from 2019).

  * Develop core technologies for new and renewable energy and conduct s project to demonstrate the practical applications of hydrogen fuel cell electric vehicle parts.

- As government R&D is linked to purchasing, the R&D conducted by and production investment of parts and materials companies will lead to the specialization and growth of hydrogen-related parts and materials companies.

❷ **Operate technology competence programs** for suppliers of Hydrogen vehicles(FCEV) and fuel cell parts and materials.

○ Specialized technical training courses and new technology exhibits established and operated by Hydrogen vehicles(FCEV) and fuel cell manufacturers through their own win-win cooperation center

* Provide regular, on-site guidance on the development of parts and materials by operating technical support teams for demand companies.

❸ Provide **programs to support key, high-quality personnel** of government-funded research institutes or specialized research enters.

○ Establish cooperative programs to support the transfer of original and demonstrated/commercialized technologies developed by government-funded research institutes and specialized research centers to partner companies.

◇ Financing support for investment in facility operation

○ Support Hydrogen vehicles(FCEV) business partners with long-term, low-interest policy loans and investment expenses.

- In the short term, partners are expected to face a cumulative deficit until mass production is realized. Therefore, a plan has been developed to provide long-term, low-cost policy funds to these companies and support demand companies’ investment in their suppliers.

* Average interest rate of 1.75 percent, five-year grace period, 10-year installment repayment, within 90 percent (by Industrial Bank, etc.)

** Demand companies will provide support for up to KRW 40 billion in investment costs for partners supplying parts for Nexo.

○ Support fuel cell vendors by utilizing the **New Power Industry Fund** (KRW 500 billion).

- Promote financial support for SMBs and middle-standing companies manufacturing fuel cells in order to establish mass production facilities.

◇ Support for the growth of hidden champions

○ Draw up **"Hydrogen Hidden Champions 20"** (tentative name).

- **Foster SMBs and middle-standing companies in the hydrogen downstream industries,** which have certain requirements in terms of exports, technical competence, proportion of R&D investment, etc., **as global companies.**

  * Selection criteria (example): KRW 40 billion to KRW 1 trillion in sales, 30 percent exports (or three percent of R&D investment)

- Starting from 2020, four to five companies will be selected annually. **The number of selected companies will be increased to 20.**

○ Support the selected companies with **R&D-export-finance package.**

- Promote selected companies' capacity for innovation to help them secure competitiveness in the global market.

4 Ensuring hydrogen safety

1. Establishment of a systematic safety management system

□ **Establish a legal basis for safety management in the hydrogen industry to make hydrogen as safe as natural gas,** which citizens currently use with confidence (2019).

* At present, high-pressure hydrogen (10 bar or more) is subject to the High-Pressure Gas Safety Management Act. → It is necessary to establish a separate safety management law that includes low-pressure hydrogen, in consideration of the importance and characteristics of the hydrogen industry.

** Currently, two bills related to hydrogen safety have been initiated.

□ Establish a safe industry ecosystem by establishing an institutional basis for **ensuring safety throughout the entire cycle of the hydrogen industry** (manufacturing, storage, transportation, and use).

<Main contents of legislation>

- Policy measures that enable forecasts of supply and demand conditions for the safe use and transportation of hydrogen
- Safety management regulations for the manufacturing, fueling, storage, sales, and use of hydrogen and other hydrogen-related facilities and products
- License, quality, facility, and technology standards to which hydrogen companies are required to comply

2. Enhancement of hydrogen component and product safety standards

□ **Provide upgraded safety standards to meet global standard, expand hydrogen infrastructure,** and allow people to use hydrogen safely.

Hydrogen fueling Stations	▪ Revise KS standards to ensure that the parts of hydrogen fueling stations can withstand ultra-high pressure (up to 82Mpa). ▪ Develop monitoring and remote control systems for hydrogen fueling stations using IoT technology.
Tube Trailers	▪ Upward adjust the storage vessel pressure standard to the level of Japan and the United States (35 → up to 45Mpa)
Fuel Cells for power Generation	▪ Establish safety test and certification standards for fuel cells (stacks) for power generation, which are expected to undergo large-scale dissemination.

□ Immediately establish safety standards for P2H, expected to be newly applied in Korea, and liquid hydrogen.

P2H	▪ Develop safety evaluation technology for water electrolysis technology that produces hydrogen through water decomposition using surplus renewable energy.
Storage and Transportation of Liquid Hydrogen	▪ Prepare standards for safety test and certification of key components (liquefaction equipment, storage tanks, piping, valves, etc.) for storing and transporting liquefied hydrogen that are currently being developed in Korea. ▪ Establish facility standards for liquid hydrogen tanks for fueling stations, including separation distance from adjacent parking lots (two meters in Japan).

3. Establishment of the 'Hydrogen All-Cycle Safety Center' (2021)

□ **Improve the safety of parts and products involved in the entire cycle of the hydrogen industry, including production, storage/transportation, and fueling,** by supporting the development of relevant technologies and performance evaluations.

○ Evaluate the durability and reliability of materials, parts, equipment, and technology to establish and secure safety in all steps of technology development, certification, and standardization.

□ Support SMBs that manufacture parts in developing safety-related technology and promote the improvement of domestic criteria to bring them in line with the global standard.

○ Promote collaboration with the United States and other countries to prepare the basis for research on hydrogen safety and international standards.

4. Promotion of positive public perception of hydrogen safety

□ Distribute **'hydrogen safety guidebooks'**, and **reflect the guidebooks in school curricula.**

○ Provide accurate information on and address public concerns regarding the safety of hydrogen through guidebooks, and reflect such content in the school safety education program.

□ Designate and hold an exhibit to celebrate 'Hydrogen Day’

○ Declare 'Hydrogen Day', award respectable companies that have made significant contributions (such as building safe fueling stations), discover and promote best practices, and hold web cartoon design contests.

* The United States designated October 8 as the 'Hydrogen Day' (officially declared in 2018)

○ Organize hydrogen safety technology exhibitions, business programs, and programs for experiencing new products, such as hydrogen drones, bicycles, etc.

□ Establish Hydrogen Safety Experience Centers

○ Promote the establishment of Hydrogen Safety Experience Centers as a mechanism of spreading hydrogen safety education and safety culture in major cities in cooperation with the hydrogen industry and local governments.

Ⅴ. Future of the Hydrogen Economy

Individual Lifestyle Based on Hydrogen (Homo Hydrogenus)

√ **Hydrogen becomes a major energy source, replacing the fossil fuels on which we have been dependent for thousands of years.**

2.75 million Hydrogen vehicles(FCEV)	‣ 15 percent of all passenger cars in 2018 (equivalent to total number of cars in Seoul and Sejong)
600MW Fuel Cell for Home	‣ Distributed to a total of 940,000 households (equivalent to 25 percent of all households in Seoul in 2017) (equivalent to all households in Daegu in 2017)

Society Urban clean transportation infrastructure

√ **Clean, CO2-free hydrogen transforms the paradigm of public transportation, eliminating carbon emissions.**

80,000 Hydrogen Taxis	‣ 33 percent of all taxis in 2018 (equivalent to all taxis in Seoul)
40,000 Hydrogen Buses	‣ More than 85 percent of domestic bus routes in 2018
30,000 Hydrogen Trucks	‣ All domestic freight vehicles in 2018
2,373 tons of fine dust annually	‣ 6.1 percent of fine dust from transportation sector (road) in 2015

Industry Economy New energy as well as a source of growth

√ **Hydrogen is a new growth engine that creates value added and jobs as well as a low-cost, eco-friendly energy source.**

Jobs creation: 420,000	‣ 75 percent of all employees in the automobile industry in 2018
Economic effect: KRW 43 trillion	‣ More than 2.5 percent of Korea's GDP in 2017
Hydrogen-derived energy: 10.4 million TOE	‣ Approximately 5% of final energy consumption in 2040 ‣ More than 40% of domestic natural gas final consumption in 2016 (equivalent to natural gas consumption of households)
GHG reduction: 27.28 million tons	‣ Equivalent to GHG emissions produced by nine units of 500MW coal-fired power plants
Power generation: 55,949 GWh	‣ More than 10 percent of total domestic power generation in 2017