HYDROGEN ECONOMY

Roadmap of Korea

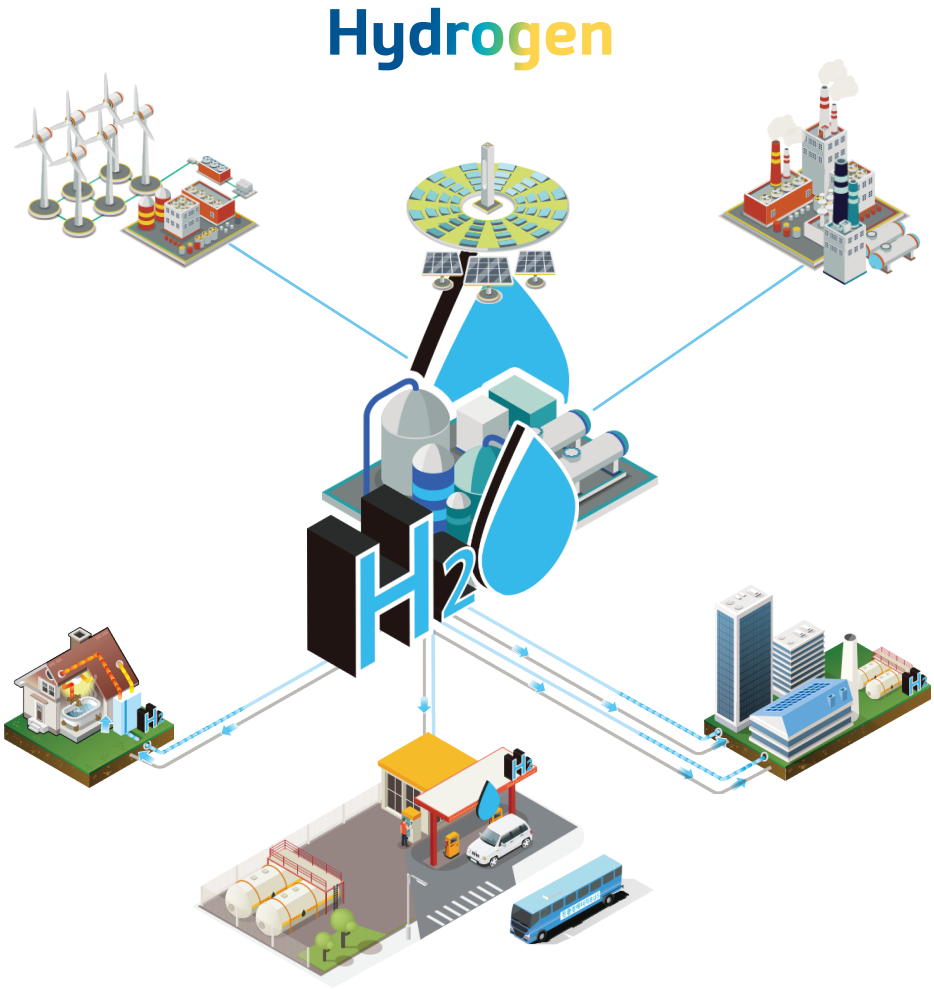
Ministry of Trade,
Industry and Energy

CHAPTER

The Meaning of "Hydrogen Economy"

"Hydrogen economy" refers to an economy where hydrogen is an important environmentally-friendly energy source, brings out radical changes to the national economy and society as a whole, and is a driving force behind economic growth.

As hydrogen is not only a driver of innovative growth but also a means of using energy in a more eco-friendly way, a hydrogen economy refers to the pursuit of a society that realizes the unlimited potential of hydrogen.



Fostering of future industries and solution of eco-friendly energy

CHAPTER

Significance & Expected Benefits of the Hydrogen Economy in Economic Terms

From an economic point of view, new future industries that utilize hydrogen can be developed in a variety of sectors, from hydrogen fuel cell electric vehicles (hydrogen fuel cell EVs) in the transport sector, to electricity and heat in the energy sector.

Apart from hydrogen fuel cell electric vehicles, hydrogen can be used in all forms of vehicle, such as commercial transport, trains, ships, construction machinery, and drones, thereby creating a new industrial ecosystem.

If only 10% of the vehicles manufactured in the USD 2 trillion global automobile market (as of 2017) were converted into hydrogen fuel cell EVs, this would increase the hydrogen industry to about 1.5 times the size of the display market (USD 130 billion) and about half the size of the semiconductor market (USD 420 billion).

In addition, considering the global fuel cell market's average annual growth rate of 22% or higher, hydrogen's economic value in fuel cells must not be neglected, as it can be used to produce electricity and heat in an eco-friendly, highly efficient way with the technology and facilities for optimal energy conversion of distributed power supply.

Another advantage of hydrogen-utilizing industries is the substantial production of added value and job creation through affiliation with other industries across value chains from hydrogen production to storage, transportation and utilization.

Companies manufacturing hydrogen fuel cell EVs and their cell parts suppliers are mostly small and medium-sized enterprises. As utilization increases, so will the growth of cooperating companies and the number of jobs. The construction of infrastructure such as hydrogen production, transportation, storage will lead to more investment in related industries such as facilities, and to the expansion of market and employment.

If South Korea's hydrogen economy grows, the volume of added value it creates by 2040 will exceed KRW 43 trillion, equivalent to 2.5% of the nation's 2017 GDP. It will create an estimated 420,000 jobs, or 75% of the entire 2018 workforce in the automobile industry.

CHAPTER

Significance & Expected Benefits of the Hydrogen Economy in Environmental Terms

In addition, if hydrogen is utilized as energy, this will contribute to reducing greenhouse gases (GHGs) and fine dust, accelerating the country into creating a clean and safe society.

The decarbonization of energy consumption can contribute greatly to reduction of GHGs, and reduce fine dust in a variety of sectors such as transportation and power generation, and thereby reduce the related social costs.

If South Korea's hydrogen economy continues to grow, the amount of energy consumption replaced by hydrogen is expected to be about 10.4 million TOEs in 2040 – equal to 5% of total expected energy consumption or total LNG consumption by domestic households in 2016.

Hydrogen ratio of gross energy

5%
2040

Greenhous gas reduction

27 million tons
2040

Also, a reduction of 27.28 million tons of CO_2 is expected (equivalent to the emissions from nine 500MW coal-fired power generators) by 2040, and 23.73 million tons of fine dust (equivalent to 6.1% of all fine dust emissions on Korean roads in 2015).

CHAPTER 4

South Korea's Hydrogen Economy : Potential & Limitations

Sufficient conditions are already in place to promote the hydrogen economy, which drives social value in South Korea.

South Korea has the potential to lead the hydrogen economy

01 World-leading technology including hydrogen vehicles and fuel cells

02 Petrochemical plant infrastructure and rich experience

03 Potential for existing LNG supply network to deliver hydrogen across

Most importantly, South Korea's well-established physical infrastructure can effectively promote development of the hydrogen economy.

Currently, large-scale petrochemical complexes (in Ulsan, Yeosu and Daesan) have a hydrogen pipeline and high purity production technology, producing, circulating and utilizing about 1.64 million tons of hydrogen annually.

If the existing petrochemical and plant infrastructure and experience are sufficient to efficiently meet hydrogen demand, byproduct hydrogen can be supplied large-scale through facility expansion and conversion production processes.

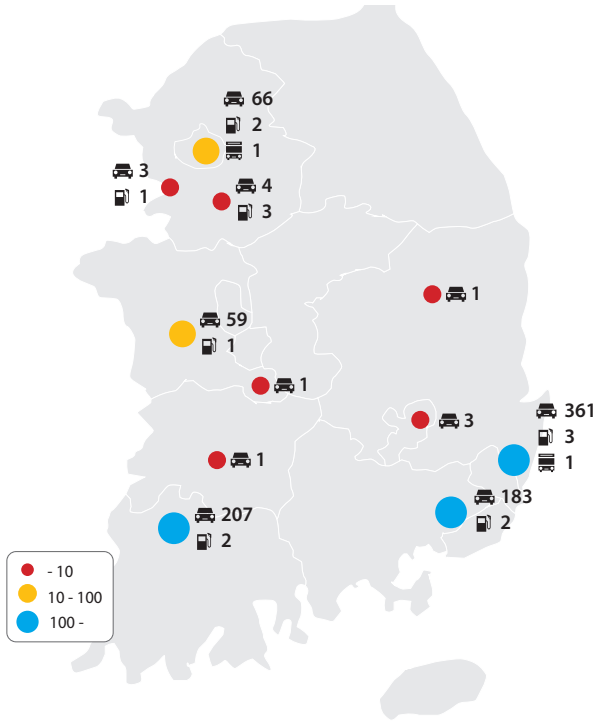
Moreover, the existing LNG supply network can make it possible to establish a nationwide hydrogen production and supply system in an easy, stable, and economically-viable way without additional investment in infrastructure.

In addition to this physical infrastructure, hydrogen utilizing industries have already secured world-class technology.

South Korea became the first country to successfully mass produce hydrogen fuel cell EVs in 2013, releasing a commercial car model with the world's longest driving range in 2018. In terms of fuel cells, the country has secured top-level technology through alliances and M&A with domestic and foreign companies holding source technology.

Despite such mature conditions and advanced technology, the hydrogen fuel cell EV industry currently faces many problems including high costs, the difficulties of application to public transportation, and an insufficient charging infrastructure, while the fuel cell industry is facing high installation and fuel costs. Given the current situation, development levels are too low to call this a "market".

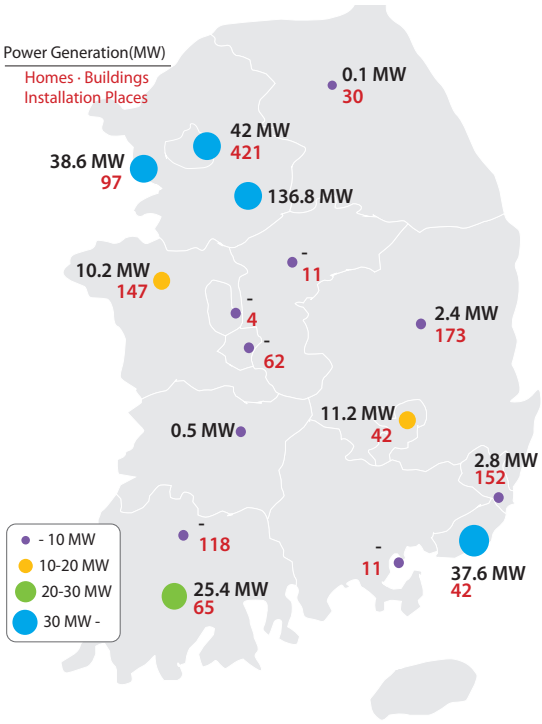
Hydrogen vehicle and charging station status



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

(as of December 2018)

Fuel Cell Status



Sector	MW	Places
Power gen.	307.6	41
Homes/Buildings	7.05	3,167

(as of December 2018)

To overcome these issues, efforts are needed to actively create demand and expand supply to secure economic efficiency and to accelerate the self-proliferation of technology.

There is also a lack of core source technology in and commercialization of extracting hydrogen from natural gas and electrolysis, and of demonstration for commercialization. And although it is possible to store and transport high pressure gas, hydrogen liquefaction and storage technology for long-distance bulk transportation still remains in the development stage, and greater technological competitiveness is needed as soon as possible.

From a policy viewpoint, there is partial support, including for the development and supply of hydrogen vehicles, charging stations, and fuel cells. However, the grim reality is the lack of a comprehensive strategy and legal support system to promote the hydrogen economy.

In the end, the "Hydrogen Economy Roadmap" of the South Korean government has been materialized in reflection of such demands of the times.

Hydrogen Economy

Refers to an economy where hydrogen is an important environmentally-friendly energy source,brings out radical changes to the national economy and society as a whole, and is a driving force behind economic growth.

CHAPTER 5

South Korea's Hydrogen Economy : Vision & Strategy

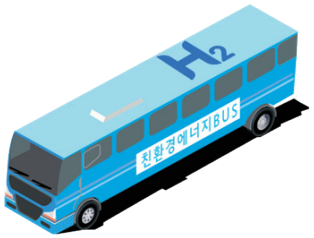
South Korea's hydrogen economy roadmap places top priority on market creation and developing hydrogen-utilizing industries towards achieving the world's largest market share in hydrogen fuel cell EVs and fuel cells.

Of course, hydrogen utilizing products can be used in a variety of fields including ships, trains and drones, in addition to hydrogen fuel cell EVs and fuel cells for power generation or home consumption. However, in terms of technology maturity at this point, commercialization has already been achieved. The fostering of three sectors which can visibly realize market creation will be prioritized, and support given to further improve technology maturity. Once this maturity has reached a sufficient level, the government plans to expand the application of hydrogen to ships, trains, drones and other areas.

HYDROGEN FUEL CELL EV SECTOR

To create a market for hydrogen fuel cell EVs, specific measures are planned to establish and expand a mass production system of hydrogen-powered vehicles, to convert public transportation to hydrogen taxis or buses, and utilize hydrogen trucks in the public sector.

Buses



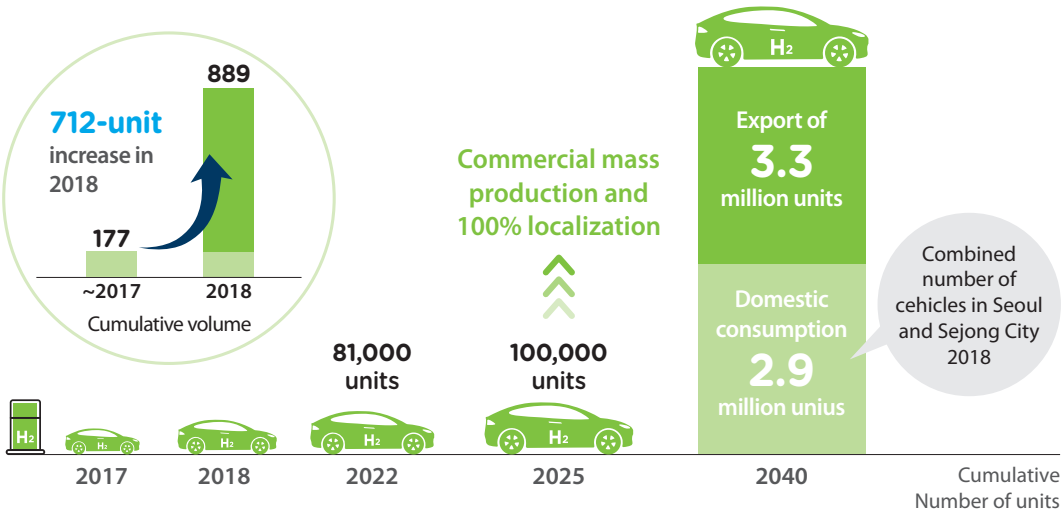
*Replace 819 all poilce buses with hydrogen buses

Taxis

Trucks

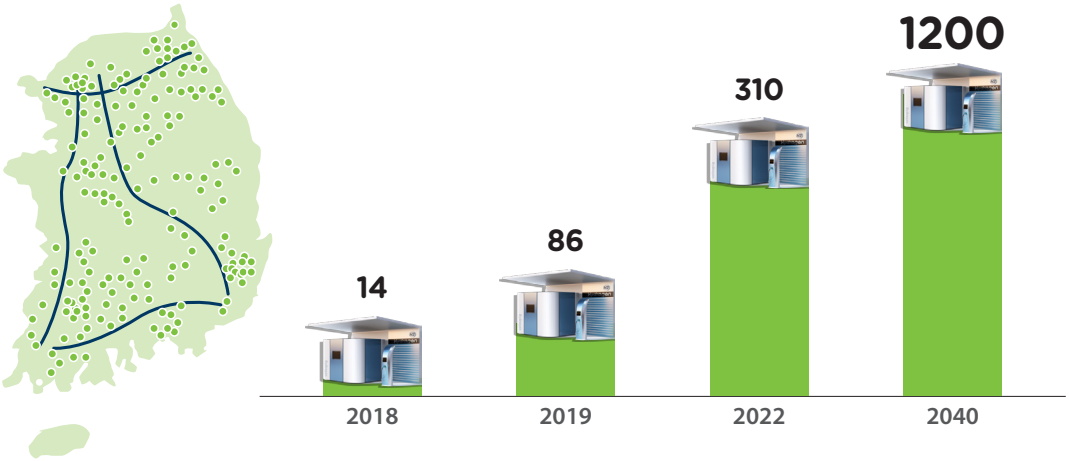
Through this, the market size of hydrogen fuel cell EVs is expected to expand from about 1,800 units in 2018 to 80,000 in 2022, and 6.2 million in 2040.

Hydrogen Car Supply Expansion



Of course, hydrogen fuel cell EVs cannot operate without the infrastructure to supply hydrogen for recharging. There is particular need for expansion of the hydrogen filling station network. To this end, charging stations will increase from 14 locations in 2018 to 310 locations by 2022, and 1,200 locations in 2040.

Increasing The Number of Hydrogen Fueling Stations



In the beginning, the government will certainly bear some of the burden for establishment and operation of hydrogen filling stations, which will be built at major transportation bases within city centers, at points along highways such as rest stops, and at bus and taxi garages in affiliation with hydrogen vehicle distribution programs at the city and province level, by providing different amounts of installation and operation assistance depending on filling station type.

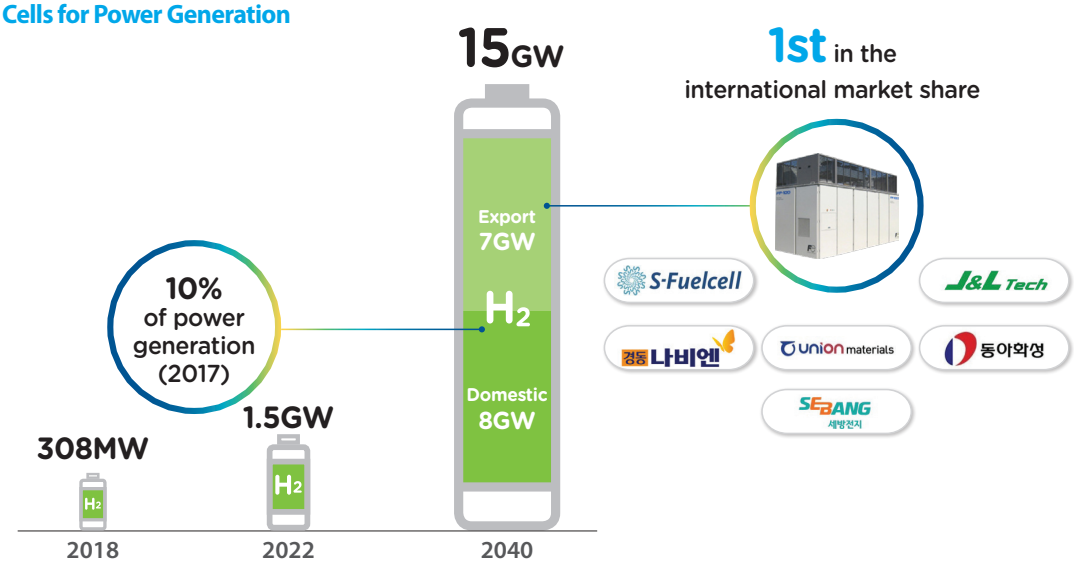
However, once the goal for distribution of hydrogen fuel cell EVs is achieved, the project will change from government-led to private sector-led to expand the number of privately-operated hydrogen filling stations. Efforts for greater economic efficiency will include converting LPG and CNG filling stations into hybrid filling stations capable of providing hydrogen.

FUEL CELL SECTOR

Next, in terms of fuel cells for power generation, an LNG billing system for fuel cells will be introduced, and weighted renewable supply certificates (RECs) for fuel cells will be maintained for a certain period to encourage the installation of fuel cells for power generation, thereby eliminating the uncertainty of investment and promoting economic efficiency.

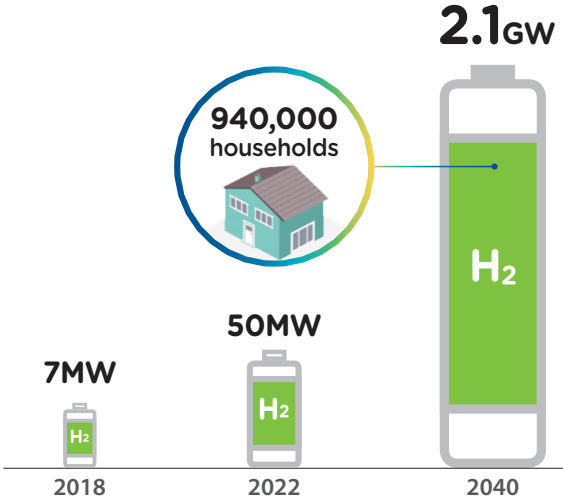
This will expand the current capacity from 307.6MW to 1.5GW by 2022, significantly. The mass production is expected to reduce installation and power generation costs by 2025 to a level required by a small- or medium-sized gas turbine. Thus, the combined production volume for exports and domestic consumption is expected to expand to at least 15GW by 2040.

Hydrogen Fuel Cells for Power Generation



The distribution of home fuel cells will be supported by gradual expansion of government budgets, introduction of an LNG-exclusive billing system, provision of financial incentives such as extension of the electricity tariff specialization system so as to ease the burden on the electrical grid, and mandatory installation of fuel cells at public institutions and new private buildings. Through this, the current distribution of 7MW is expected to expand to 50MW by 2022 and 2.1GW or higher by 2040.

Fuel Cell For Home and Building



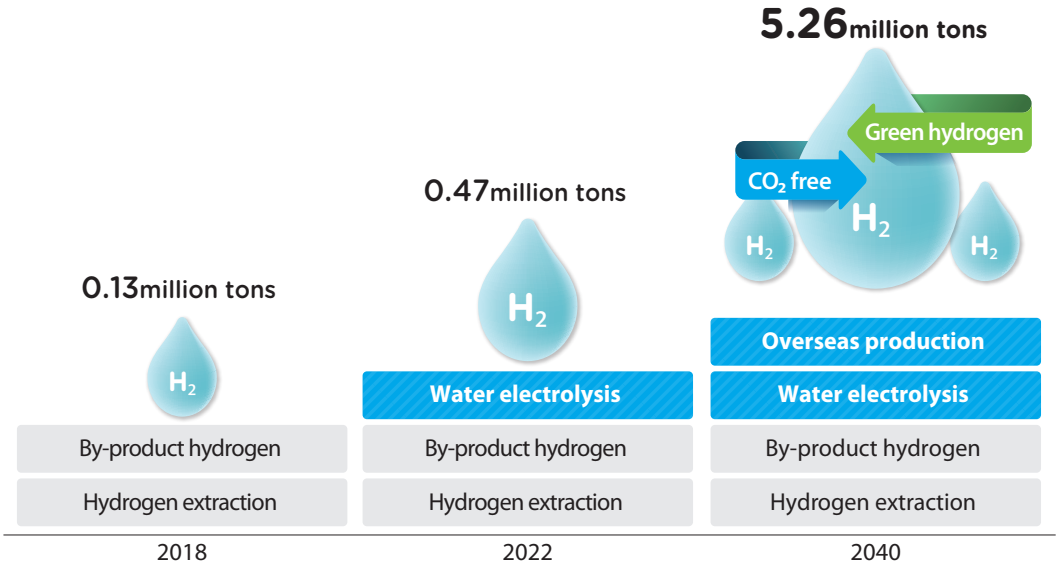
A variety of models have been developed to fit a variety fo installation locations and different uses in consideration of the characteristics of an eco-friendly distributed power generation system

HYDROGEN SUPPLY SECTOR

If the government is to realize its plans to develop and expand hydrogen-utilizing industries, demand for hydrogen itself will need to increase as derivative demand, and the hydrogen market expand with a focus on the energy sector.

Currently, the demand for hydrogen generated from hydrogen-utilizing industries such as those related to hydrogen fuel cell EVs and fuel cells is estimated to be about 130,000 tons per year. However, if such industries grow according to the government road map, the demand for hydrogen will increase from 470,000 tons per year in 2022 to 1.94 million tons in 2030, and to 5.26 million tons in 2040.

Hydrogen Generated from Hydrogen-Utilizing Industries



If demand for hydrogen expands as expected, supply will be increased to meet the growing demand for hydrogen with the least expensive production technology.

Byproduct hydrogen, which is a byproduct of petrochemical processes, is currently used for hydrogen fuel cell EVs, while hydrogen extracted from natural gas has mainly been used for fuel cells.

In an earlier stage when there is insufficient demand for hydrogen, it will be extracted from natural gas for supply and production bases constructed near LNG supply networks and sources of demand.

However, current hydrogen production costs are relatively high. Surplus renewable energy, currently not cost-effective, can be expanded as demand for hydrogen continues to rise, as it is an environmentally friendly method for production. To prepare for this, large-scale R&D on electrolysis and demonstrations using surplus renewable energy (P2G or power-to-gas) will begin by 2022, and hydrogen production planned to be in affiliation with large-scale renewable energy generation complexes, such as those harnessing offshore wind power and solar power.

In consideration of the limited capacity of eco-friendly hydrogen production, overseas hydrogen produced with renewable energy and brown coal in an eco-friendly way will be imported from 2030, with 70% of demand for hydrogen met with eco-friendly, CO_2-free hydrogen by 2040.

HYDROGEN STORAGE & THE RELATED TRANSPORTATION SECTOR

As mentioned above, development of hydrogen-utilizing industries will expand hydrogen production and naturally lead to growth of the storage and related transportation sector in this process.

It will become difficult to accommodate the increasing need for hydrogen-related logistics with the current fleet of 500 low-pressure gas tube trailers and existing 200 km of hydrogen pipelines built near the sources of demand.

To cope with this increasing demand for hydrogen logistics, development of high-pressure (700 bar or more) tubes is planned and will be used to transport the entire daily consumption (1 ton) of a small- to medium-sized city bus filling station in a single delivery.

In the long run, however, the government will support the development of new storage and transportation technologies such as those for liquefied hydrogen, liquid hydrogen and solid hydrogen to replace the compressed hydrogen system and its limited storage density, and is planning to use liquid and liquefied hydrogen tank lorries from 2030 in actual distribution of hydrogen.

In addition, we will develop a pipeline that successfully overcomes the problem of brittleness to transport hydrogen at a high pressure of 50 bar or more, and begin to expand it to include major sources of demand before making it a nationwide network in the mid- to long term.

Overseas eco-friendly hydrogen will be introduced in 2030. To prepare for this, South Korea will start to develop related infrastructure including liquefaction and liquid technology, hydrogen transportation vessel, and liquefaction plants in 2022, as well as the construction of receiving bases for overseas hydrogen. The hydrogen pipeline will be connected to these receiving bases after 2025 as part of a nationwide supply network.

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

CREATION OF ECOSYSTEM FOR HYDROGEN ECONOMY

In the end, growth of the storage and transportation sector will lead to greater efficiency in hydrogen-utilizing industries, creating a virtuous cycle that promotes the growth of these sectors.

Core to the hydrogen economy roadmap is that such market creation and growth will accelerate development of the technology required by the market and establishment of a market-driven innovation system.

To build such a system, the government is planning a roadmap to support all stages of technological development throughout the entire value chain, from development of source technology in hydrogen-powered vehicles, core components of fuel cells, and storage and transportation, to demonstration, commercialization, and improvement of stability.

In addition, the government will establish safety standards for greater stability throughout the entire hydrogen economy and put such standards into law, while it goes all-out to provide legal and institutional support through enactment of a "Hydrogen Economy Act".

The Hydrogen Economy Promotion Committee has been set up by the South Korean government to put the Roadmap for Hydrogen Economy into action and to serve as a pan-government control tower. And the promotion team has been established for standardization, professional training for the needed manpower, development and support of small- & mid-sized companies, and international cooperation in order to create an ecosystem for hydrogen economy.

This is not the first time a hydrogen economy roadmap has been made. In 2005, the government of the time set up a "Master Plan for Implementation of an Environmentally-friendly Hydrogen Economy". However, the roadmap announced in 2019 differs from this previous Master Plan in three ways.

First, their priorities are different. In 2005, when hydrogen-utilizing products (hydrogen-powered vehicles, fuel cells, etc.) were still in the infant stage of development, government support was desperately needed. On the other hand, the more recent roadmap has been established in the face of the need for a strategy to create and develop a market after the same hydrogen-utilizing products have already entered the commercialization stage. This is where government policy comes in.

Second, the scope of the two roadmaps is different. The 2005 master plan was limited to hydrogen-powered cars and fuel cells, while this year's roadmap includes new hydrogen-utilizing technology such as hydrogen ships, trains, drones, and gas turbines.

Lastly, the most important difference is a change in policy environment. In fact, there was no clear energy conversion policy to break away from fossil fuel-based energy supply and demand structures in 2005. As a result, the previous master plan was simply a strategy to develop a new industry, separate from the energy policy framework. However, a clear framework for conversion from fossil fuel to new renewable energy has been established and implemented since 2017. This policy framework has laid down a foundation for the roadmap to invigorate the hydrogen economy. As such, this roadmap is highly-consistent with policy.

The 2019 roadmap will also be reflected in the 3rd Energy Basic Plan and in the 9th Electricity Supply and Demand Plan, also to be established this year, while the actual effectiveness of the roadmap will be strengthened above and beyond the previous master plan. The possibility to repeat the failure of the 2005 master plan is reduced, while the possibility of the roadmap's success is also much higher.

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