Infrastructure for Next-Generation Vehicles

Seiichiro Kimura and Hiroshige Matsumoto

Abstract During and after the intense growth period of the economy in Japan around the 1960s, the number of fuel filling stations increased with the rapid spread of automobiles. However, two oil crises in the 1970s triggered the introduction of "next-generation vehicles." Examples include battery electric vehicles (BEVs), compressed natural gas vehicles (CNGVs), and hydrogen fuel cell electric vehicles (FCEVs). After the 1990s, CNGVs began to be introduced, and the development of BEVs and FCEVs accelerated. However, penetration of these next-generation vehicles was not fully successful, owing to their inferior performance (range, acceleration, durability, economic efficiency, and other factors) compared with conventional internal combustion engine vehicles (ICEVs) and a lack of infrastructure, e.g., insufficient CNG stations for CNGVs.

Since around 2010, the introduction of next-generation vehicles has progressed gradually. The higher price and shorter cruising range relative to ICEVs has been improved, and their infrastructure has expanded. FCEVs are scheduled to be on the market in 2015, and their hydrogen infrastructure is also being developed. This study discusses next-generation vehicles' fuel supply infrastructure, particularly its technical goals, challenges, and risks, and surveys Japan's past approaches and efforts and future prospects.

Keywords Fuel cell vehicle • Hydrogen station • Battery electric vehicle • Charger • Refueling station

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S. Kimura (✉)
The Matsushita Institute of Government and Management, Kanagawa, Japan
e-mail: s-kimura@mskj.or.jp

H. Matsumoto
Kyushu University, Fukuoka, Japan
e-mail: matsumoto@i2cner.kyushu-u.ac.jp

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1 Introduction

In 1886, Gottlieb Daimler and Karl Benz invented gasoline-fueled cars. After the Ford Motor Company produced the Model T in the USA, car prices began to decline, and ICEVs become one of the major transportation means. In Japan, motoring accelerated from the 1960s, and around 1980, the number of automobiles nearly equaled the number of households [1, 2]. The increase in the number of automobiles was rapid, which caused them to consume the most energy in transportation.

Japan's primary energy consumption in 2012 was 19.2 EJ through which various services including heat and transportation were facilitated. The transportation sector consumed approximately 17 % of this or 3.28 EJ. Eighty-nine percent of all energy consumed in this sector went to automobiles. Figure 1 shows the breakdown of energy consumption by vehicle type. Approximately 60 % of total vehicle energy consumption was for passenger cars, whereas taxis and buses consumed 2 % each. Nearly all buses use diesel fuel, and most taxis are operated by LPG fuel.

Ten percent of freight trucks have Otto engines, and 98 % of those run on gasoline. The energy consumption of diesel-fueled freight trucks constitutes 28 % of that of total vehicles, which is the second greatest after passenger cars. The number of registered passenger cars in Japan as of 31 March 2013 was 59.36 million, and the number of registered freight trucks was 14.85 million [1]. Energy consumption of freight trucks is one and a half times that of passenger cars.

Figures 2 and 3 show trends in primary energy consumption from 2000 to 2012. A consistent decrease of consumption in the transportation sector is clear in both figures. A decrease in passenger cars is particularly evident in Fig. 2. A closer look also reveals a drastic decrease of freight vehicles with diesel engines. Reasons for this are fuel efficiency improvement and a decline in the number of registered freight trucks. The fuel efficiency improvement was affected by the introduction of

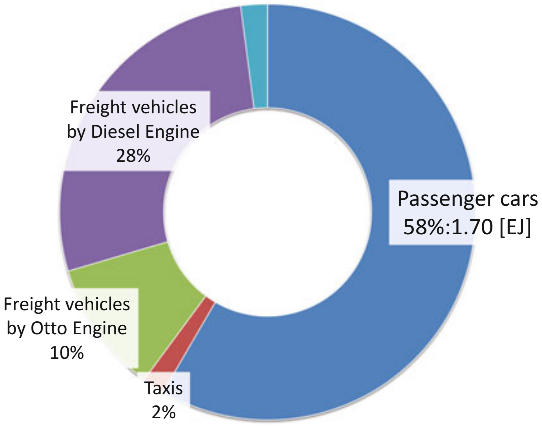


Fig. 1 Overall energy consumption in transportation sector during 2012 [3]

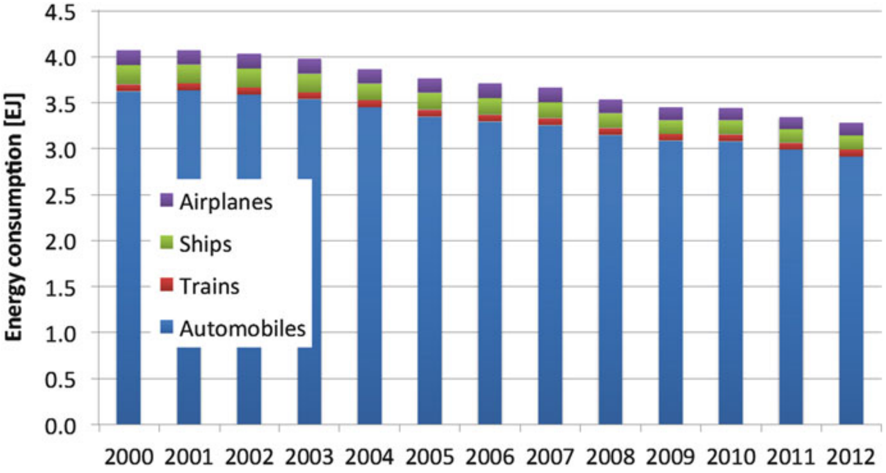


Fig. 2 Trend of primary energy consumption in transportation sector [3]

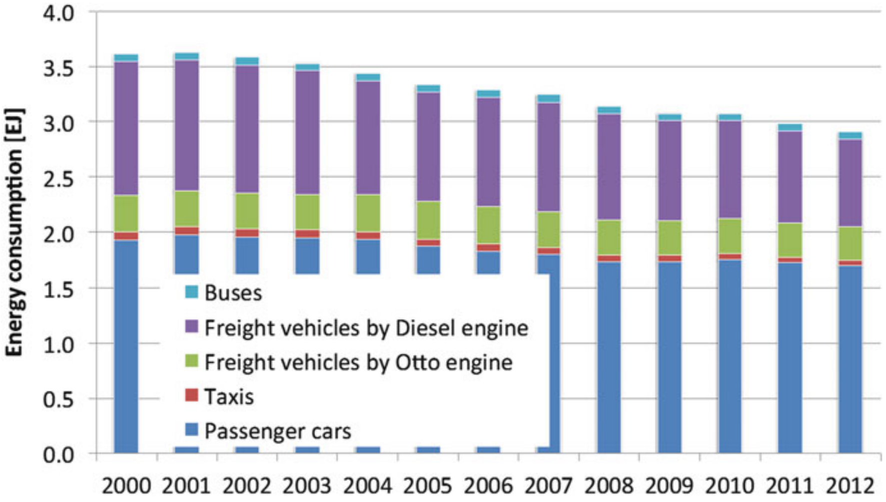


Fig. 3 Trend of primary energy consumption on type of automobile [3]

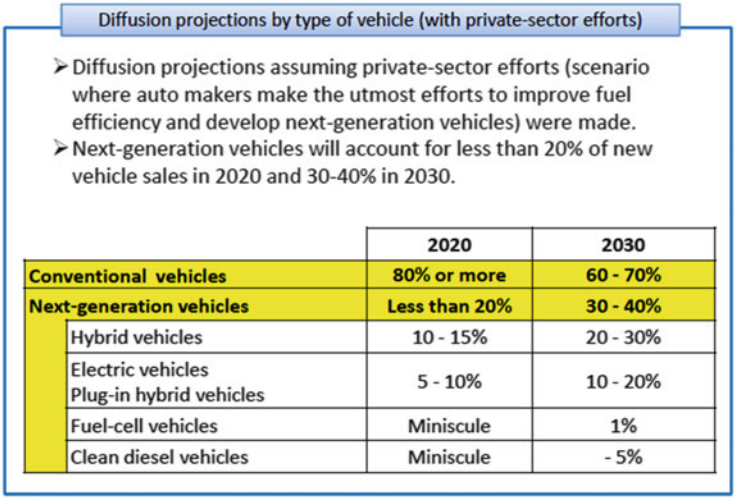
fuel-efficient vehicles such as hybrid electric vehicles (HEVs). However, these fuel-efficient vehicles still used conventional gasoline refueling stations. The number of registered freight vehicles peaked in 1991 at 21.15 million and then declined.

Taking such situations into consideration, in 2010, the Ministry of Economy, Trade and Industry (METI) specified trends and market needs of new-generation vehicles and developed a strategy in the *Next-Generation Vehicle Strategy 2010*. This strategy was planned by considering not only that next-generation vehicles are efficient in mitigating climate change caused by greenhouse gas (GHG) emissions but also the following three items:

1. Medium- to long-term energy restrictions such as continued high prices of crude oil
2. Maintaining Japanese companies' leading role in merger and acquisition activities in the field of environmental technology for automobiles
3. Economic development by industry related to next-generation vehicles

Next-Generation Vehicle Strategy 2010 also includes a concrete action plan and targets. Figure 4a shows diffusion projections with utmost private-sector efforts, and Fig. 4b shows government targets. Government goals are that total vehicle sales in 2020 should include 20–30 % HEVs, 15–20 % battery electric vehicles (BEVs)/ plug-in HEVs (PHEVs), less than 1 % FCEVs, and less than 5 % clean diesel vehicles. Targets for 2030 were set at 20–30 % for BEVs/PHEVs and ~3 % for FCEVs.

For the required infrastructure deployment, the targets are 2 million normal charging stations and 5000 quick charging stations for BEVs/PHEVs [4]. To achieve these targets, the Japanese government provided 100.5 billion JPY under its 2012 supplemental budget for charging infrastructure deployment. Based on the targets and action plan in this strategy and allocated budget, charging infrastructure for BEVs/PHEVs is rapidly progressing, as shown in the following chapter. In addition, preparation for hydrogen station deployment for FCEVs began in 2013 [5]. Preparation for the diffusion of next-generation vehicles is also in progress, but many challenges remain. The following chapter describes the market and infrastructure situations of already-introduced next-generation vehicles and related law and regulation updates.

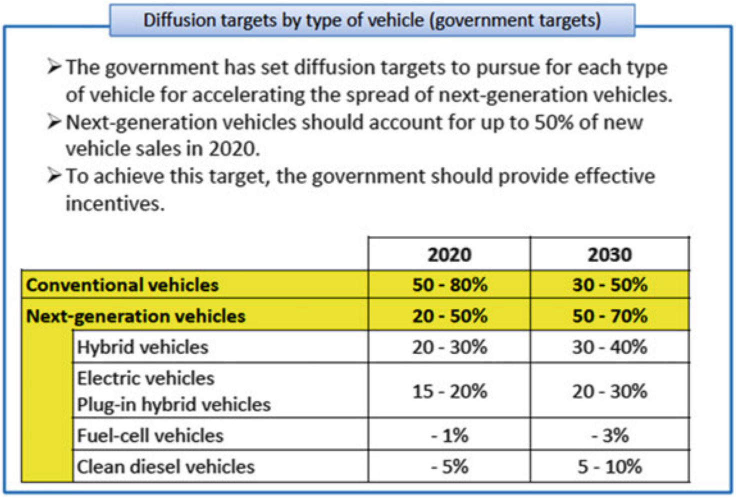


Diffusion projections by type of vehicle (with private-sector efforts)

- Diffusion projections assuming private-sector efforts (scenario where auto makers make the utmost efforts to improve fuel efficiency and develop next-generation vehicles) were made.
- Next-generation vehicles will account for less than 20% of new vehicle sales in 2020 and 30-40% in 2030.

		2020	2030
Conventional vehicles		**80% or more**	**60 - 70%**
Next-generation vehicles		**Less than 20%**	**30 - 40%**
	Hybrid vehicles	10 - 15%	20 - 30%
	Electric vehicles Plug-in hybrid vehicles	5 - 10%	10 - 20%
	Fuel-cell vehicles	Miniscule	1%
	Clean diesel vehicles	Miniscule	- 5%

Fig. 4a METI next-generation vehicle plan 2010 with private-sector effort only [4]



Diffusion targets by type of vehicle (government targets)

- ➢ The government has set diffusion targets to pursue for each type of vehicle for accelerating the spread of next-generation vehicles.
- ➢ Next-generation vehicles should account for up to 50% of new vehicle sales in 2020.
- ➢ To achieve this target, the government should provide effective incentives.

	2020	2030
Conventional vehicles	**50 - 80%**	**30 - 50%**
Next-generation vehicles	**20 - 50%**	**50 - 70%**
Hybrid vehicles	20 - 30%	30 - 40%
Electric vehicles Plug-in hybrid vehicles	15 - 20%	20 - 30%
Fuel-cell vehicles	- 1%	- 3%
Clean diesel vehicles	- 5%	5 - 10%

Fig. 4b Government target on METI next-generation vehicle plan 2010 [4]

2 Present Status

To address the present status of infrastructure deployment for next-generation vehicles such as BEVs/PHEVs and FCEVs in the introduction phase, the current status of conventional ICEVs and gasoline refueling stations is first examined.

Figure 5 shows the number of vehicles and gasoline refueling stations in Japan after 1991. Vehicles here include those with more than three wheels, such as passenger cars and light and heavy duty vehicles, excluding two-wheeled vehicles. The figure shows that the number of gasoline refueling stations declined after a peak in 1993. In 2013, there were ~35,000 gasoline refueling stations, and the annual number of such stations closed was more than 1000.

The increase in the number of vehicles slowed temporarily after the Lehman Brothers bankruptcy in 2009 and Great East Japan Earthquake in 2011. The increase began again after 2012. Figure 6 shows that the number of HEVs owned has rapidly increased since 2009. Conventional gasoline refueling stations can also be used to fuel HEVs, and because they have a fuel efficiency double that of conventional ICEVs, HEVs have a longer range per liter so they need fewer visits to fuel stations. Considering that fuel efficiency of conventional ICEVs is improving and high-efficient vehicle also increases, the number of gasoline refueling stations is likely to continually decline in the future.

CNGVs were considered the potential winner among next-generation vehicles in the early 1990s, before HEVs were developed for the market. This is because CNGVs can use existing auto cycle engines, so their technical hurdles are not substantial. Moreover, CNGVs are more environmentally friendly because they emit less SOx, particulate matter, and CO_2. The numbers of CNGVs and CNG stations in Japan are shown in Fig. 7. Since around 1991, pilot CNG stations began

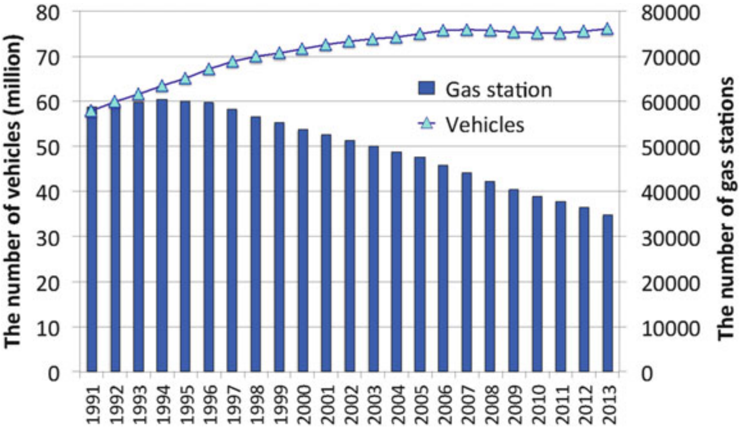


Fig. 5 Number of gasoline refueling stations and vehicles [1, 6]

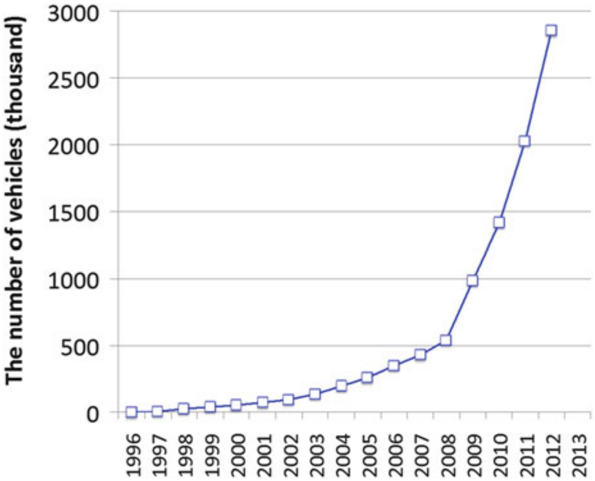


Fig. 6 Number of hybrid vehicles [7]

to be installed inside gas companies, and CNGVs were on the road for testing. CNGVs entered the market in 1996, and since then, the numbers of CNGVs and CNG stations have increased rapidly. In 2008, there were 344 CNG stations in the country. However, after the dissolution of “The Japan Eco-Service Stations Promotion Association” in 2007 [8, 9], CNG stations began to decrease, and the total number at the end of 2013 was less than 300. CNGVs, on the other hand, were adopted by cost-competitive delivery service providers and environmentally conscious transport companies. These vehicles reached 40,000 in 2010 and have slowly increased in number.

BEV diffusion was not successful in Japan until 2008, owing to their higher prices and shorter cruising ranges compared with ICEVs. Under the influence of the California state’s Zero Emission Vehicle (ZEV) program, there were ~2500 BEVs

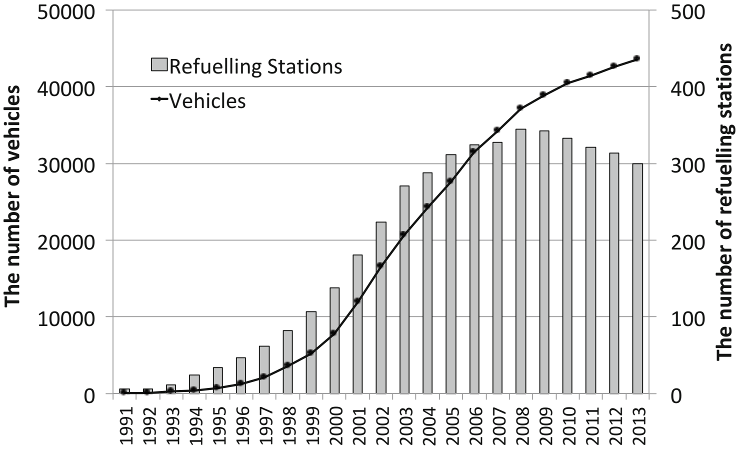


Fig. 7 Number of CNG stations and CNGVs [10, 11]

in 1996, but this decreased to 387 in 2008 [11]. After 2009, when development of the lithium-ion battery made great progress [12], automobile manufacturers began to bring BEVs and PHEVs to the market. Quick and normal charging stations have also been in development. Figure 8 (left, middle) shows quick charging station including TESLA supercharger, and Fig. 8 (right) shows a normal 200-V charger installed in a parking lot. Full charging takes about 30 min[1] for a BEV with a 24-kWh battery and CHAdeMO 50-kW quick charger (QC), whereas a 200-V normal charger takes 6–8 h. The total number of BEVs and PHEVs at the end of March 2012 was slightly less than 60,000 (Fig. 9).

FCEVs driven by fuel cells were introduced in 1994. DaimlerChrysler AG (currently Daimler AG) in Germany developed the New Electric Car (NECAR) with compressed hydrogen and a polymer electrolyte fuel cell (PEFC) for producing electricity onboard. Later, Toyota, Honda, GM, Ford, Nissan, and Matsuda followed with fuel cell development. Initially, gasoline or methanol was considered an FCEV fuel to generate hydrogen onboard because the early development stage of FCEVs was based on using existing gasoline refueling stations. Methanol was also considered for sale at modified gasoline refueling stations. However, because FCEVs with a gasoline/methanol reformer require at least several tens of seconds to start and additional fuel consumption by the reformer, FCEV development shifted to store pure hydrogen onboard [11].

The FCEV hydrogen storage method includes high pressure, metal hydride, and liquefied hydrogen, all of which were tested for verification. According to the results, 70-MPa compressed hydrogen gas has become mainstream for every automobile manufacturer [11]. It is pointed out, however, that quick filling at 70 MPa is costly in terms of pressure to added mass ratio. Therefore, cost reduction

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[1] Using CHAdeMO, power 50 KW – for 24 kWh BEV.

Fig. 8 Examples of charging equipment for BEVs/PHEVs (*left*: TESLA supercharger, *middle*: quick charger, *Right*: 200-V normal charger)

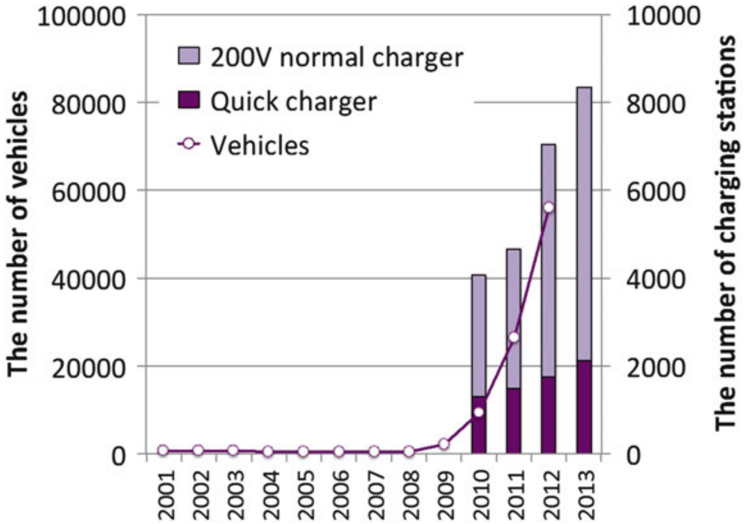
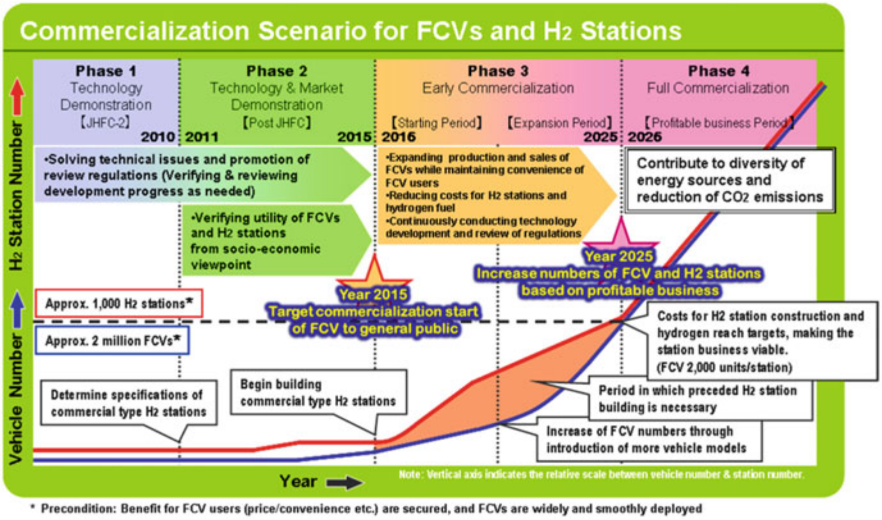


Fig. 9 Number of charging stations and BEVs/PHEVs [11, 13]

is necessary with the aid of technological development and revision of regulations [14].

The deployment of hydrogen refueling stations has also been discussed. In 2008, the Fuel Cell Commercialization Conference of Japan (FCCJ) presented a hydrogen station deployment scenario for 2015. The following year, the Council on Competitiveness-Nippon (COCN) released a proposal for FCEVs and hydrogen supply infrastructure deployment, in which hydrogen stations were to be deployed mainly in four metropolitan areas, Tokyo, Nagoya, Osaka, and Fukuoka. Later, the



* Precondition: Benefit for FCV users (price/convenience etc.) are secured, and FCVs are widely and smoothly deployed

Fig. 10 Commercialization scenario for FCEVs and hydrogen stations [15]

FCCJ updated its scenario, which shows 1000 hydrogen stations by 2025 for two million FCEVs on the road (Fig. 10).

There are currently two types of hydrogen station, on-site and off-site. At an on-site station, hydrogen is generated on-site and compressed and supplied to FCEVs. It is common at such stations to generate hydrogen by natural gas or LPG reforming (Fig. 11). At an off-site hydrogen station, hydrogen is produced outside the station and delivered by trailer or pipelines and then supplied to FCEVs after compression (Fig. 12). An off-site station has less construction cost but has a hydrogen transportation cost.

The construction cost (excluding land) for one commercial on-site hydrogen station in Japan was estimated at ~500–600 million JPY [14], whereas that of an off-site station was ~400–500 million JPY [14]. This cost is greater than in Europe or the USA because of differences in materials of storage tanks and criteria and standards in the design and regulation of station construction, such as offset distance [16]. Discussions on deregulation for cost reduction are ongoing in the Japanese government. Issues under consideration include the introduction of liquid-hydrogen stations, installation of compound vessels for stations, increases in fueling pressure of hydrogen transportation trailers, and others [17]. Subsidies from METI to introduce hydrogen stations were 4.6 billion JPY in 2013 and 7.2 billion JPY in 2014, equivalent to 280 million JPY paid by the government per station [18]. Table 1 shows the distribution of 42 hydrogen stations, including those under construction. There are more than 50 stations expected by the end of 2015.

Companies have presented challenges for hydrogen station cost reduction. On 18 September 2014, Honda Motor Corporation and Iwatani Corporation announced the completion of a 20-ft container-sized “mini-hydrogen station” in the city of

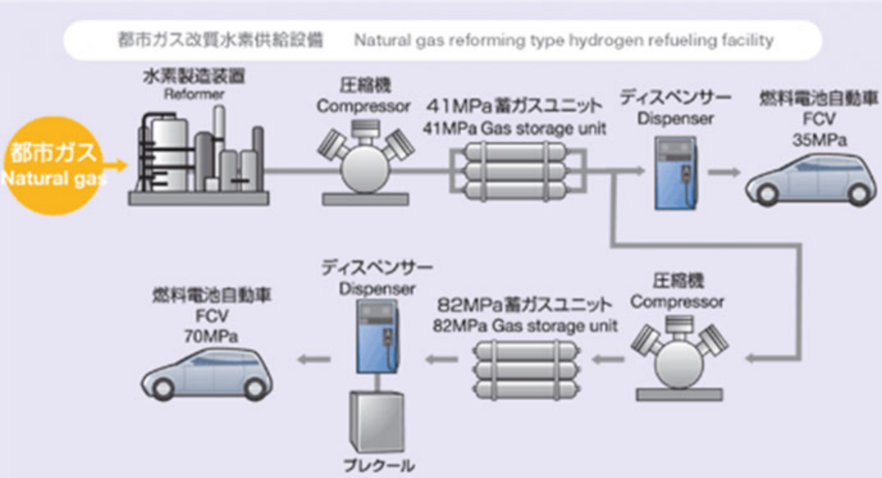


Fig. 11 On-site (natural gas reforming type) hydrogen station [14]

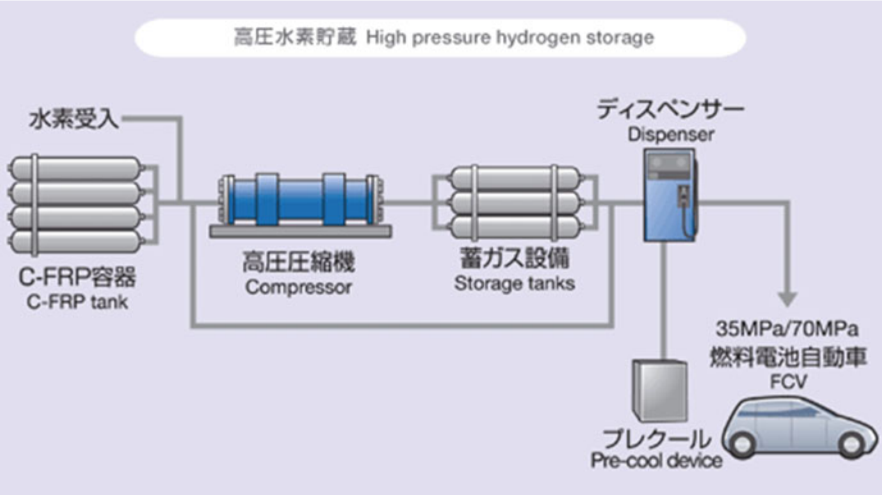


Fig. 12 Off-site hydrogen station [14]

Saitama that can produce 17-Nm^3 hydrogen per day and store 200 Nm^3 [20, 21] (Fig. 13). Figure 14 shows that via a high-pressure electrolyzer, a compressor is unnecessary at such mini-hydrogen stations. The mini-hydrogen station can be installed in 1 day, and the construction cost is much less than that of existing commercial hydrogen stations. The technology is considered appropriate in the early penetration phase with limited demand. However, because the technology did not see widespread use before October 2014, the High Pressure Gas Safety Act requires special approval by the minister of METI for its use. Therefore, legal

Table 1 Number of deployed hydrogen stations [18, 19]

Prefecture	Already deployed	Under construction
Saitama	0	5
Tokyo	4	4
Kanagawa	1	12
Chiba	1	3
Yamanashi	0	1
Aichi	3	10
Shiga	0	1
Osaka	2	2
Hyogo	0	1
Yamaguchi	0	1
Fukuoka	2	3
Saga	1	0
Total	14	42

Fig. 13 On-site mini-hydrogen station [20, 21]

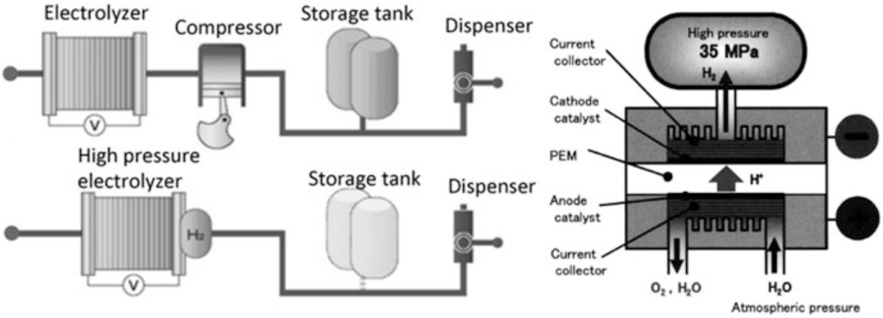


Fig. 14 Mechanism of direct-type, high-pressure water electrolysis [21]

deregulation is necessary for further cost reduction if this type of hydrogen station is introduced to facilitate FCEV market penetration [17].

3 Technology Road Map

Considering past diffusion trends of next-generation vehicles, BEVs/PHEVs and FCEVs are expected to be candidates for next-generation vehicles in the future, as described in the previous section. This section provides the technology road map of infrastructure for these vehicles as shown by Fig. 15.

There are five major challenges to be addressed in infrastructure deployment for the vehicles:

1. Appropriate locations for hydrogen and charging stations are limited, as are required spaces for station installation.
2. Lack of hydrogen demand because of the slow penetration of FCEVs.
3. Various energy supplies and coordination with energy storage systems.
4. Existing infrastructure replacement and necessity of introducing new infrastructure.
5. Cooperation of society and energy systems.

Efforts to tackle these challenges are described as follows. For charging stations, installation of public chargers for PEBs/PHEVs is in progress with active support from the government. The government target is 5000 quick chargers and 2 million 200-V normal chargers by 2020 [16]. Toyota, Honda, Nissan, and Mitsubishi motor corporations provide charging services at their local dealers and cover expenses for charging station installation. Their charging services and cost burden for installing these stations will continue for another 7 years, which is the depreciation and payout period [22].

It is expected that charging station deployment will be completed to a certain extent and that charging infrastructure will then play a different role, from mere charging to absorbing fluctuating supply energies from renewables. In other words, future charging stations may be used as a means of demand and response. It is also anticipated that BEVs/PHEVs will play a role in energy storage, including charging and discharging.

Supplier challenges include improvement of the quick charger when technology development makes it possible for BEVs/PHEVs to extend the driving range. Greater power demand is more likely in the future because of increased BEV/PHEV diffusion, so it is expected that power suppliers will respond accordingly, such as with the promotion of power system reform. To address this issue, the cooperation of three parties, BEV/PHEV users, charging station suppliers, and power suppliers, is important.

A major challenge for hydrogen stations is low usage of a station in the early introduction phase, caused by weak hydrogen demand. Building hydrogen supply chains deeply tied to a region is considered effective in solving this problem, which

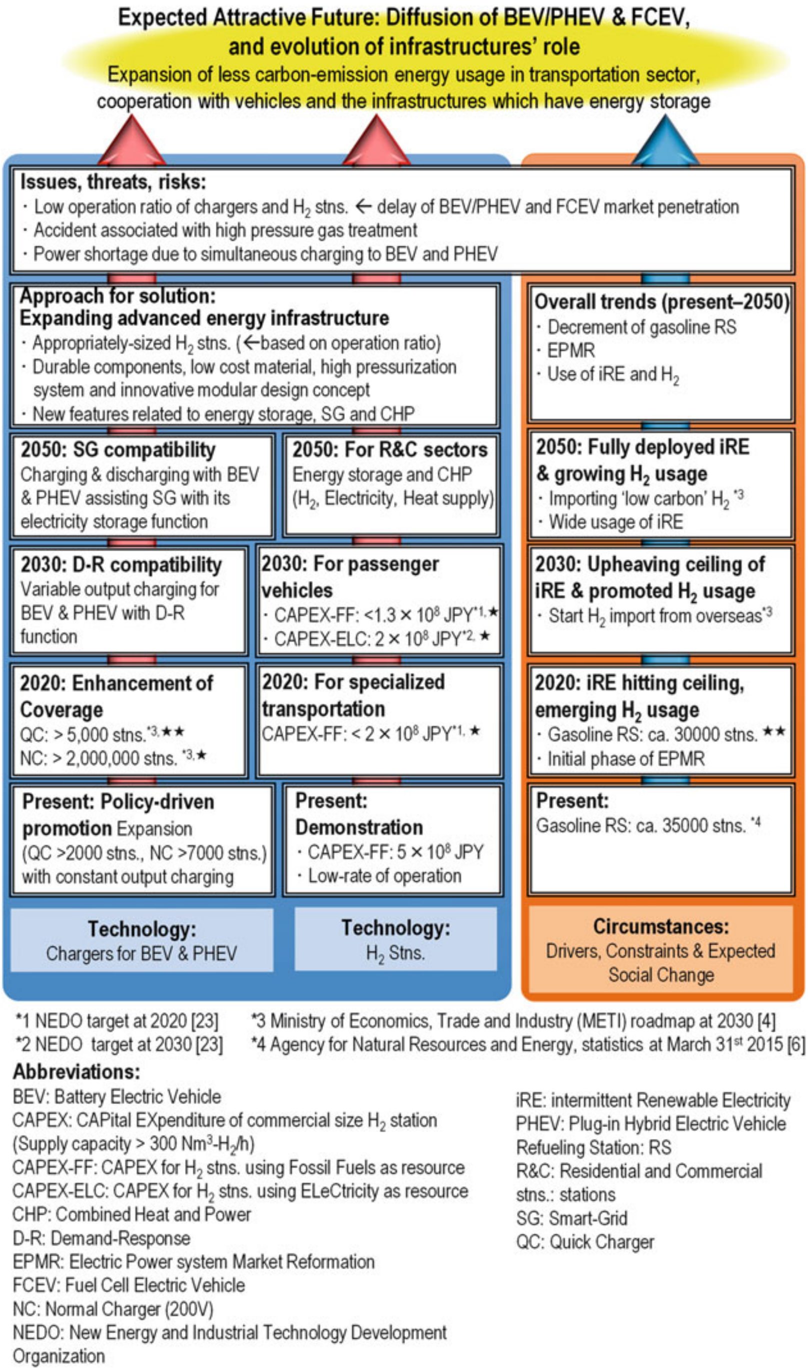


Fig. 15 Road map of infrastructures for FCEV and BEV/PHEV

involves the introduction of hydrogen-fueled official cars, buses, and forklifts by local governments, local companies, and public transportation service providers [16]. The state is also expected to be actively involved in this activity by 2020 or thereabouts. Further, creating more demand by expanding FCEV uses is considered essential. The FCEV power supply capability is five times greater than an EV [16]. This feature is expected to be valuable in times of disaster and has great potential when applied to special-use vehicles such as power-source vehicles at construction sites.

Cost reduction of commercial-sized hydrogen stations capable of greater than 300-Nm^3/h supply is also a challenge. In particular, compressor, accumulator, and dispenser cost are currently estimated at 250 million JPY [11], which needs to be reduced by deregulation, mass production, and standardization of specifications.

It is expected that around 2020, there will be ~200 hydrogen stations and 30,000 gasoline refueling stations and that most on-road vehicles will be ICEVs and HEVs. The construction cost of a commercial hydrogen station will slightly decrease by that time, to ~300 million JPY, the same level as in foreign countries. In addition, legal deregulation of mini-hydrogen stations is required as described in chapter "Roadmap of Energy Technologies for Envisioning Future Energy Systems," for easier installation and consequent diffusion of FCEVs. At a current small-sized hydrogen station, daily hydrogen generation is 17 Nm^3. For further cost reduction at designated full depreciation, deregulation and technology development are crucial for increasing this hydrogen production.

Gasoline refueling stations are forecast to decline by 2030, and hydrogen stations are expected to be installed at their abandoned station sites. There would be no foundation cost or ancillary facilities for such new hydrogen stations, so this would facilitate their installation at less initial cost. The cost target of a commercial-sized hydrogen station whose resource is electricity in 2030 is less than 200 million JPY [23]. In addition, importing H_2 from overseas is likely, considering the trend of more aggressive targets for CO_2 emission cuts and that the hydrogen price from overseas hydrogen plants is expected to be 30 JPY/m^3 [6]. This will accelerate hydrogen station deployment, but it is expected to take time to supply hydrogen to wider areas. Therefore, there will be a need for mini-stations and mobile hydrogen stations, for which cooperation from both FCEV users and hydrogen suppliers is critical.

Around 2050, it is expected that construction costs of commercial hydrogen stations will be similar to those of conventional gasoline refueling stations in 2013. It is also projected that around 2050, CO_2-free imported hydrogen will be supplied, accelerating FCEV market penetration. The future vision also includes a network in which hydrogen stations supply hydrogen to homes and industrial buildings such as community gas businesses. Energy storage plus power and heat energy supplies using hydrogen as a medium are foreseen in this network.

Technical goals and challenges for 2050 include reliability improvement of equipment used at hydrogen stations, low-cost material and design applications, and cost reduction for hydrogen production.

If the infrastructure for BEVs, PHEVs, and FCEVs is not developed as described in the road map, both hydrogen and electric charging stations face the following challenges and risks: securing precious metals such as cobalt and platinum, procuring low-cost CO_2-free hydrogen and electricity, continued high prices for vehicles, and developing competitive technology such as hybrid vehicles. Hydrogen stations may have additional challenges and risks, such as social acceptance of hydrogen energy and stations and limited site conditions for the stations in the early stage of FCEV diffusion until ~2030. For electric charging stations, failure to secure sites on expressways could be one of the hurdles to infrastructure deployment.

4 Benefits and Attractive Future Vision

The benefits of infrastructure deployment for next-generation vehicles in Japan are listed as follows:

1. Contribution to the diffusion of next-generation vehicles, followed by reductions of energy consumption, GHG emissions, and energy procurement costs
2. Function and role as regional energy supply and load-change absorption facilities, such as smart grids
3. Ensuring international competitiveness in the area of infrastructure for next-generation vehicles
4. Enhancing social acceptance of hydrogen

Each benefit is detailed below.

4.1 Contribution to the Diffusion of Next-Generation Vehicles

Currently there are waiting times for BEVs/PHEVs at certain high-demand charging stations, such as those on expressways. Charging infrastructure is expected to progress with the aid of charging infrastructure deployment described in the preceding chapter. Therefore, BEVs and PHEVs will spread. Assuming BEV penetration, the benefit can be calculated as follows [11].

Table 2 shows the results based on the assumption of ten million BEVs and FCEVs. Ten million BEVs would be able to reduce 1.5 % (0.29 EJ) energy consumption in Japan (compared with 2010; the same comparison applies to the following). This may instead increase by ~0.5 % (0.09 EJ), depending on the means of electricity generation. Regarding CO_2 emission, electricity is supplied from natural gas, and as much as 1.4 % (18 million tons) of CO_2 can be reduced by BEVs. If electricity is supplied from renewables, 1.8 % (22 million tons) of CO_2 can

Table 2 Reductions in energy consumption, CO_2 emission, and procurement cost by introducing BEVs and FCEVs

	Energy consumption	CO_2 emission	Procurement cost
BEVs	−1.5 % to +0.5 %	−1.8 % to −0.1 %	−500 billion JPY[a]
FCEVs	−1.3 % to +0.7 %	−1.8 % to +0.1 %	−500 billion JPY[a]

[a] Based on the assumption that the average crude oil procurement cost is 1.8 JPY/MJ (2008 figure)

be reduced by BEVs. The energy self-sufficiency rate is related to prices of domestic electricity, imported oil, natural gas, and others. In the diffusion scenarios of BEVs, if fuels are generated only by domestic renewable energy, the annual contribution to energy procurement cost reduction would be 500 billion JPY by BEVs. This projection is based on the assumption of an average crude oil procurement cost of 1.8 JPY/MJ (the 2008 figure). An approximate 1 % increase in energy self-sufficiency rate is estimated from BEVs/PHEVs.

Applying the calculation above to FCEVs, assuming a widespread adoption of ten million, hydrogen stations are estimated at ~5000. This is based on the correlation between existing gasoline cars and gas refueling stations. There are now 35,000 gas stations and ~76 million vehicles (excluding two-wheel) on the road in Japan, indicating that one gasoline refueling station services more than 2000 vehicles.

By-product hydrogen in steel, oil, and other industries is estimated to be adequate to supply more than ten million FCEVs [24]. Assuming ten million of these vehicles on the road, the calculated benefit is 1.3 % (0.26 EJ) of the total energy consumption reduction in Japan [11]. This reduction is projected to increase by only 0.7 % (0.14 EJ), however, if FCEV fuel efficiency is poor and there are other energy consumption sources such as air conditioners during driving, and hydrogen is generated from fossil fuel. Regarding CO_2 emission, if all hydrogen and electricity are supplied from natural gas, as much as 1.4 % (17 million tons) of CO_2 can be reduced by FCEVs. If hydrogen is supplied by renewables, 1.8 % (22 million tons) of CO_2 can be reduced by those vehicles. In the FCEV diffusion scenarios, if fuels are generated only by domestic renewable energy, the contribution to energy cost reduction would be 500 billion JPY annually. This projection is based on the assumption of an average crude oil procurement cost of 1.8 JPY/MJ (the 2008 figure). An approximate 1 % increase in energy self-sufficiency rate by FCEVs is estimated.

There are potential increases in CO_2 emissions if fossil fuel is an energy source for next-generation vehicles, and this also depends on vehicle fuel efficiency. Therefore, it is desirable to use more renewables instead of fossil fuel for reducing CO_2 emissions.

4.2 Function and Role as Regional Energy Supply and Load-Change Absorption Facility

When hydrogen stations and refueling infrastructure are developed regionally, it is anticipated that hydrogen and refueling infrastructures linked to smart grids will function as energy supply and load-change absorption facilities.

There is already an example of a hydrogen station functioning as an energy supply facility. In the city of Kitakyushu, Fukuoka Prefecture, a pipeline and its core refueling station supply hydrogen to the region [25]. This hydrogen is then used for cogeneration at private residences and public facilities using fuel cells, and when the generated electricity supply cannot meet demand, measures such as increasing this supply can be taken according to the situation. Kitakyushu is also active in introducing FCEVs and developing hydrogen infrastructure [26].

Similarly, refueling infrastructure can help stabilize electricity supply by fueling FCEVs and BEVs/PHEVs and using fuels in various ways. An example at a commercial building demonstrates a reduction of peak demand for electricity and electricity costs by connecting the building with FCEVs [27, 28]. More effective use of energy is expected in the future from the merger of such chargers and the energy supply system.

4.3 Ensuring Infrastructure Investment Cost Reduction

In the development and diffusion phases of next-generation vehicles such as FCEVs and BEVs, infrastructure deployment is essential. The diffusion of such vehicles is greatly influenced by this deployment. Indeed, the deployment is inextricably associated with the diffusion of said vehicles. Progress in infrastructure deployment facilitates cost reduction and reliability improvement that will lead to infrastructure development. In the worldwide trend toward decreasing energy consumption and GHG emissions, the call for next-generation vehicles is expected to arise gradually from both developed and developing countries. Ahead of that time, if Japan can succeed in developing the infrastructure for those vehicles, it will ensure their diffusion across the world. Regarding energy storage, in some parts of Europe, surplus power from wind power generation is converted to hydrogen for storage and supply [29, 30]. One of the concerns of hydrogen infrastructure deployment is a lack of investment, owing to the weak demand of hydrogen for FCEVs. Therefore, if Japan succeeds in spreading FCEVs together with capacity-flexible mobile hydrogen stations, that would work even when hydrogen demand is weak. The impact would likely have an effect on Europe.

Japan's initiative for next-generation vehicle infrastructure deployment will therefore contribute to its overseas development in the future and reinforcement of the automobile industry's competitiveness and progress.

4.4 Enhancing Social Acceptance of Hydrogen

Hydrogen, which has not been widely used as an energy medium, is to be used for FCEVs. Generally, in Japan, not only is awareness of the safety of hydrogen energy sources poor but they have less technological reliability compared with gasoline, which has been used widely as vehicle fuel [31]. Therefore, more awareness and reliability of hydrogen is required among the public to introduce hydrogen infrastructure for further diffusion of the FCEV. Measures for this purpose can include advertisements and FCEV demonstration rides. Group interviews in Kitakyushu hydrogen town last year by the authors demonstrated the effectiveness of illustrating the safety of hydrogen stations and pipelines in use, toward broader and deeper understanding of hydrogen [32]. The more the public understands hydrogen, the greater the likelihood of FCEV purchase. FCEV diffusion and infrastructure development will then result in hydrogen's acceptance in society. The key to such acceptance is to introduce hydrogen infrastructure safely and reliably. The acceptance of hydrogen in one area may contribute to that in another area where understanding of hydrogen is more challenging, ultimately achieving acceptance in society as a whole. Each technology broached in this chapter has its own unique and important role. They are significant from a global perspective and can meet international standards. It is necessary to spread them appropriately to avoid specific optimization for domestic market, which is called as the "Galápagos syndrome" in Japan.

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