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## **The Future of Fuel Cell Vehicles (FCV)**

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### **Abstract**

Cars have contributed to the development of society by providing freedom and access to markets, healthcare, education, work and leisure for many decades. The sheer number of cars, however, created negative environmental impacts that have the potential to significantly reduce or even offset the benefits. Decarbonizing transport is one of those challenges and Toyota has defined clear targets 2050. When it comes to decarbonizing transport, there are essentially two pathways: electricity and hydrogen. This article describes specifically the advantages of hydrogen and shows the technical and economical progress of Fuel Cell Vehicles leading to the market introduction of the Toyota Mirai. However, that does not mean that Battery Electric Vehicles will become obsolete - the contrary. We will see in future a co-existence of FCV and BEV corresponding to the individual customer mobility requirements.

We consider that FCV product power (price, variation, etc.), H2 station expansion, and the price of hydrogen will further enhance the uptake of fuel cell vehicles.

The market introduction of Toyota's FCV is only the first step towards achieving a hydrogen society (a future where renewable energy and CO2 free hydrogen enable people to live in symbiosis with nature).

We believe in mankind's wisdom and will continue to collaborate with many stakeholders on different levels in order to progressively realise a hydrogen society.

### **Introduction**

Cars became more popular during the 20<sup>th</sup> century mainly due to significant improvements in vehicle technology including internal combustion engines, production technology (enabling mass production), road network, and the wide availability of affordable petrol. By providing freedom and convenience for people and goods, automobiles have largely contributed to the economic, societal and cultural development. However, as we entered into the 21<sup>st</sup> century, a variety of challenges, among which are rise in CO2 emissions (global warming), and increase in air pollution, are becoming more and more urgent.

## Toyota challenge 2050

In order to respond to the various challenges, Toyota has defined the "Toyota Environmental Challenge 2050". This includes the challenge to reduce CO<sub>2</sub> emissions by 90% between today and 2050 – resulting in focusing on Hybrids, Plug in Hybrids, Battery Electric Vehicles and Fuel Cell Vehicles (FIGURE 1).

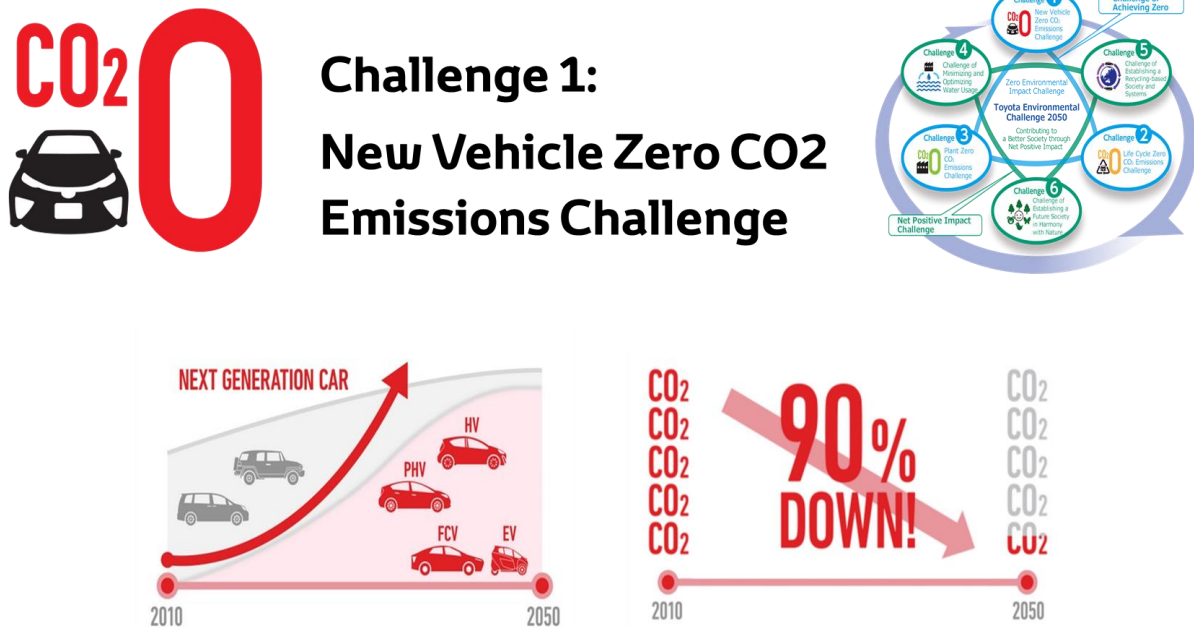


FIGURE 1: Toyota Environmental Challenge 2050

Today the automotive industry is mainly concentrating its efforts in improving exhaust emissions and fuel consumption (energy conservation) of traditional internal combustion engines by using various innovations including hybrid technology. At the same time, the industry is also preparing for a diversification of fuels. As each substitute for petrol has its own merits and demerits, it is an evident not to focus on one single type of fuel or technology. Massive CO<sub>2</sub> emissions' reductions are only possible by utilising "electricity" and "hydrogen" as these energy carriers are considered to be prospective petrol substitutes with little concerns related to supply volume (FIGURE 2).

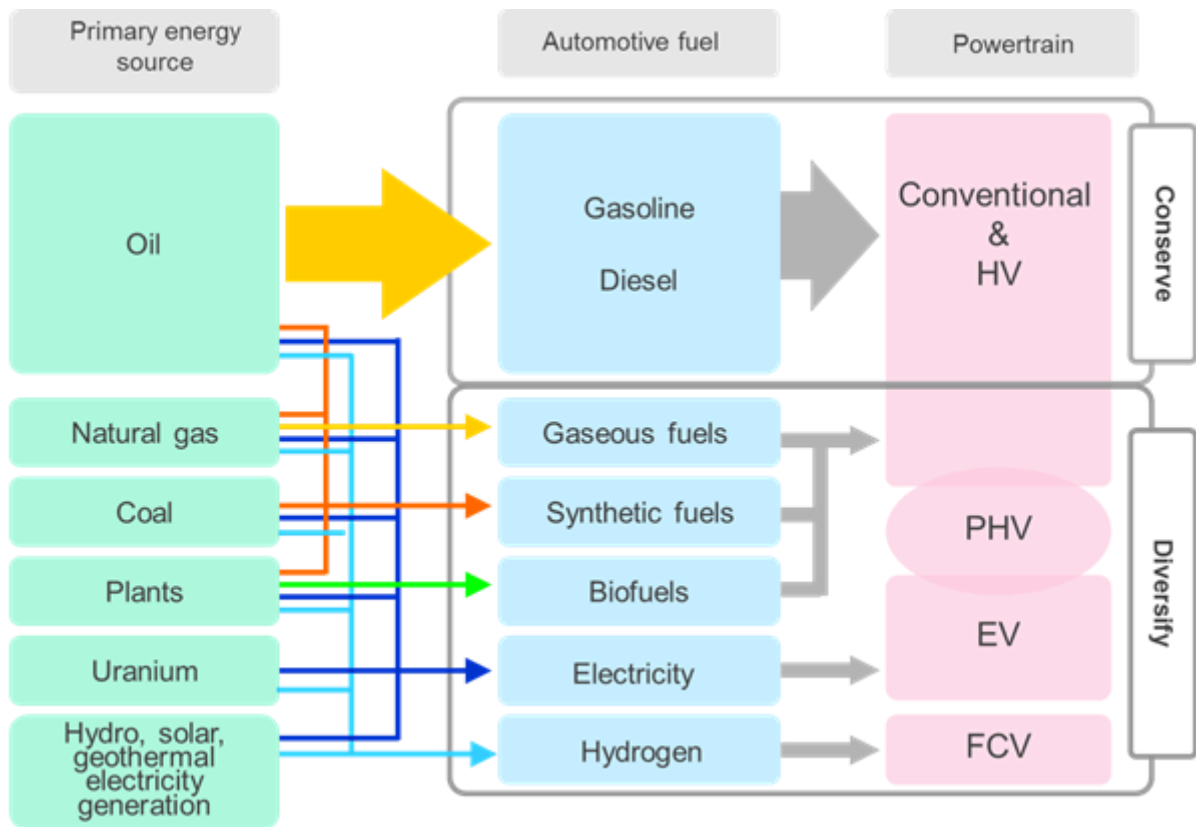


FIGURE 2. Diversification of fuels and powertrain

Aiming for sustainable mobility, the journey to electrify the transport sector has begun in all regions of the world.

In the following chapters we will focus on one specific fuel, hydrogen, and show why we think that hydrogen is a viable option to solve the challenges ahead.

### The necessity to realise a Hydrogen Society

Our company is convinced that fuel cell vehicles are suitable to respond to these future challenges and that it is inevitable that FCV contribute to society. In December 2014, stemming from our conviction that FCV will become "the vehicle for the next 100 years", we have launched the "MIRAI".

We believe that hydrogen will become a powerful energy for our future because of the following reasons:

- (1) Depending on how hydrogen is produced, FCVs have the potential to emit **net zero CO<sub>2</sub>**.
- (2) Along with the fact that H<sub>2</sub> can be produced from a wide variety of primary energy sources, it is excellent in terms of **energy security** because of little concern that it will deplete like fossil fuels.
- (3) H<sub>2</sub> is suited for **local production**. In other words, it can reduce dependence on acquiring energy sources from other countries or other regions.

- (4) Today about 30% of global primary energy supply is traded across borders<sup>4</sup>. Shipped, piped, or trucked, hydrogen is a means to **redistributing energy effectively** among cities and regions.
- (5) Hydrogen will provide the **storage and back-up generation capacity** to balance supply and demand of more variable renewable electricity in the power sector.
- (6) Today about 15% of the world's total annual energy demand is stored<sup>4</sup> which helps to **absorb supply chain shocks and to provide strategic reserves**. The storability of Hydrogen has the potential to balance external supply and demand shocks as well.
- (7) Hydrogen **offers a viable solution** for sectors where technological or economical obstacles prevent the direct use electrification, such as heavy duty transport or overseas transport.
- (8) By building a society that merges the electric grid with the hydrogen grid, it is possible to create an even **lower carbon society** (FIGURE 3)

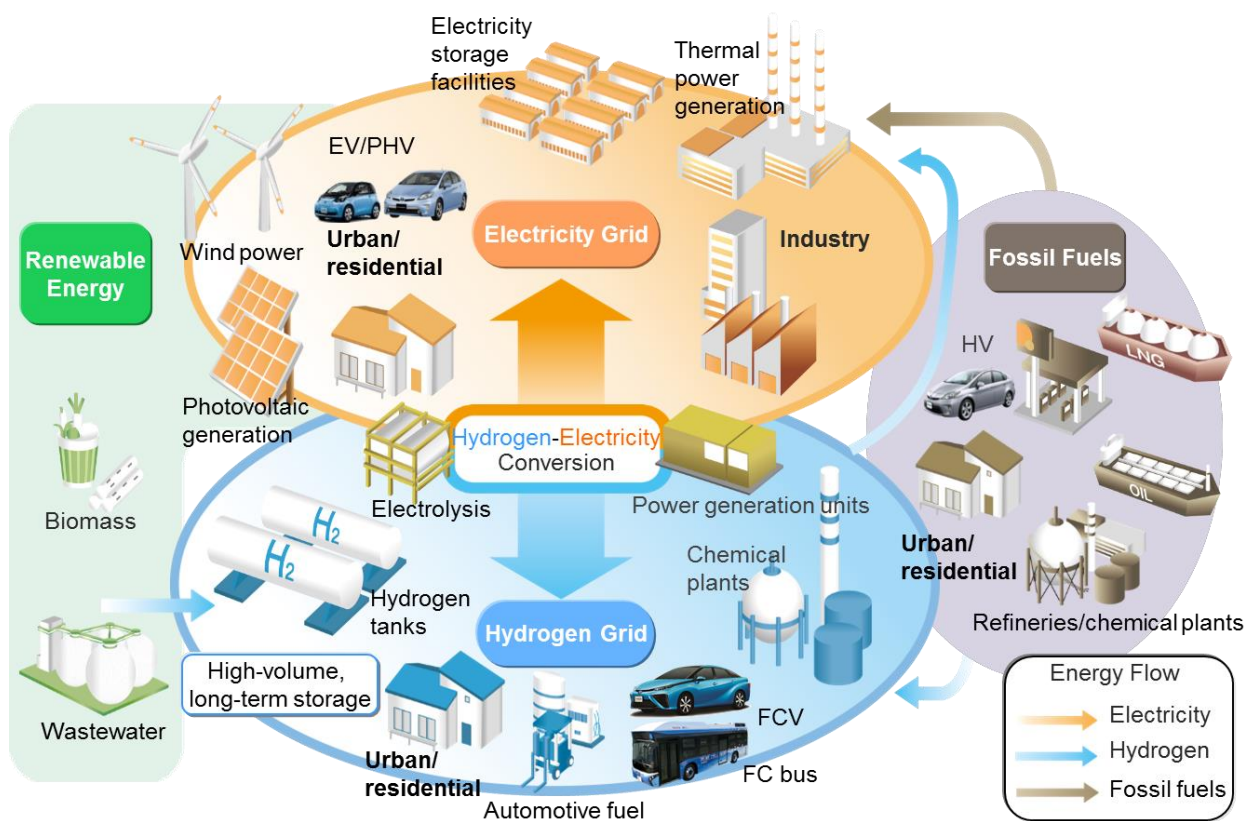


FIGURE 3. Image of a hydrogen society

### What is a fuel cell vehicle (FCV)?

FCV is a vehicle powered by an electric motor that runs on the chemical reaction of hydrogen with oxygen from air. In addition to deliver zero-emission, a possible path to energy diversification and fun to drive, FCV is also very convenient to use like a gasoline car. Furthermore, with its high generation capacity, it has a big potential to become an "emergency power supply" as well.

The Mirai is using a hybrid system (similar to that of the Prius), recuperating energy from braking, and it switches to battery power when the efficiency of the FC system is low. In this sense, we can say that hybrid

technology is a core technology for PHV, EV but also FCV.

The fuel cell is a highly efficient power generator that uses hydrogen and emits only water. The voltage generated by a single cell is 1~0. It is around 6V and arranged in series of several hundred cells that form a FC stack (FIGURE 4).

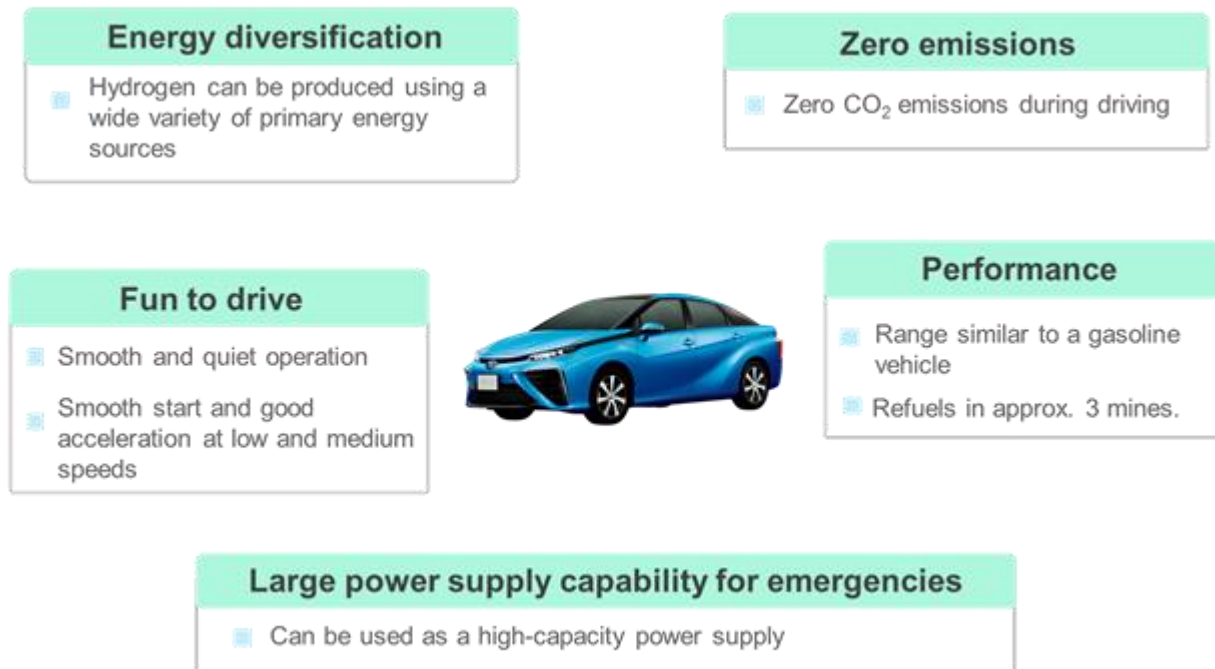


FIGURE 4: Merits of a Fuel Cell Vehicle

In addition, Fuel Cells are also available on the market for applications beyond mobility, such as energy farms. Vehicle FC stacks for cars need to be compact. In the case of the Mirai, we were able to reduce the size significantly and at the same time increase the performance up to 3.1KW/l. That allowed to install it under the body floor.

We were able to reduce the cost of the Mirai's FC system by more than 95% compared to the 2008 FCHV-adv model (FIGURE 5).

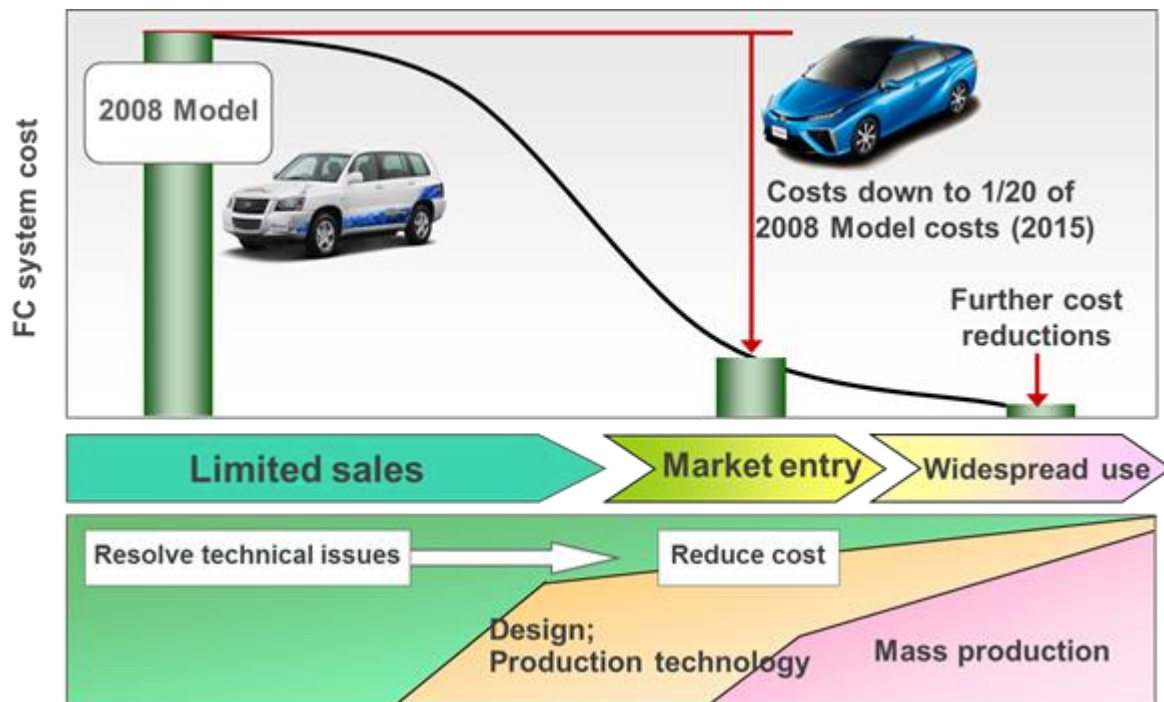


FIGURE 5: Cost reduction efforts of Mirai

Despite these efforts, FC technology is still more expensive than a hybrid and therefore we will further challenge cost reduction for the full-scale deployment planned after 2020. Recent studies expect cost parity with a medium to large passenger car (from a TCO perspective) by 2025<sup>4</sup>.

### Fuel cell vehicle development and market introduction

Since more than 10 years, many car makers around the world have been working on FCV development. Improvement of technological challenges through demonstration tests in Japan, US and Europe, the establishment of harmonised standards and regulations, the expansion of hydrogen stations and many other activities have made it possible to launch the FCV "Mirai" in December 2014 in Japan. In addition to passenger cars, we have also begun development, demonstration tests, and the market introduction of FC buses, and forklifts (FIGURE 6).



FIGURE 6: Toyota Group’s fuel cell applications

**FC Bus**

Toyota started sales of FC buses under the Toyota brand from early 2017. The Tokyo Metropolitan Government utilizing as fixed-route buses. Toyota aims to engage continuously in the diligent development targeted at the expansion of the introduction of the new FC buses from 2018 (Figure 7).

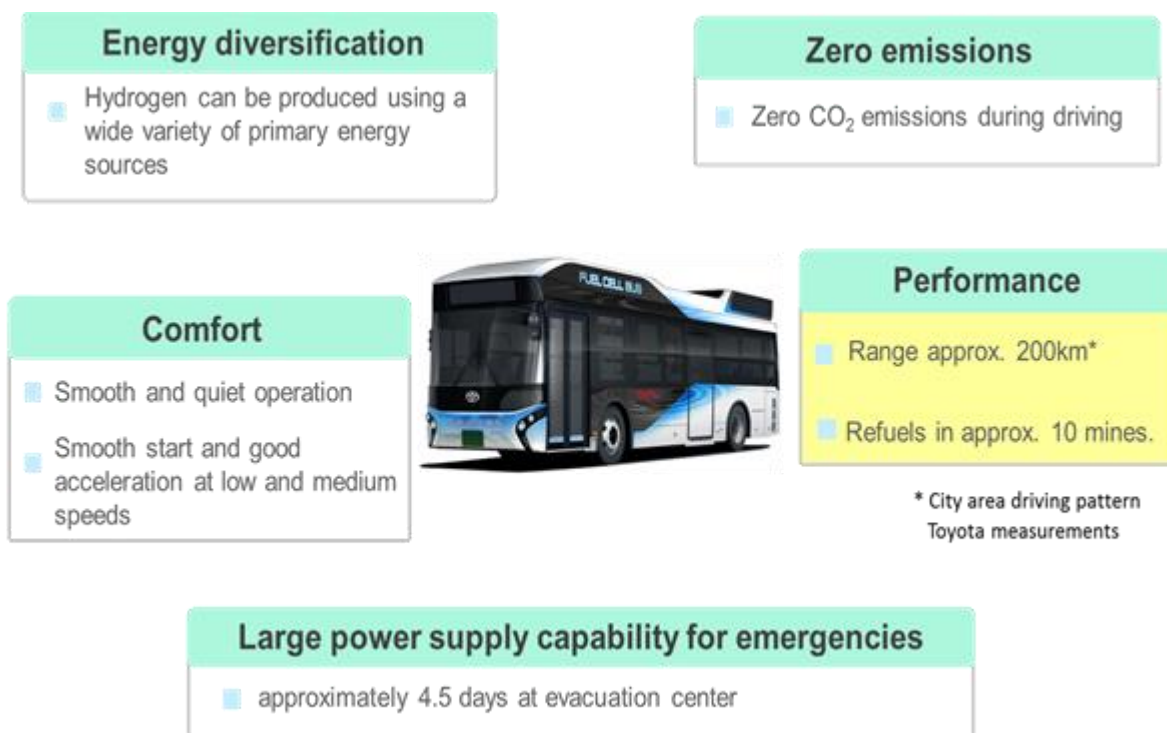


Figure 7; Advantage of Toyota FC Bus

## H2 infrastructure preparation and hydrogen society establishment

Preparing sufficient hydrogen stations is a big challenge. At this moment, several hundred of H2 stations are expected to be built globally until 2020 (FIGURE 8).

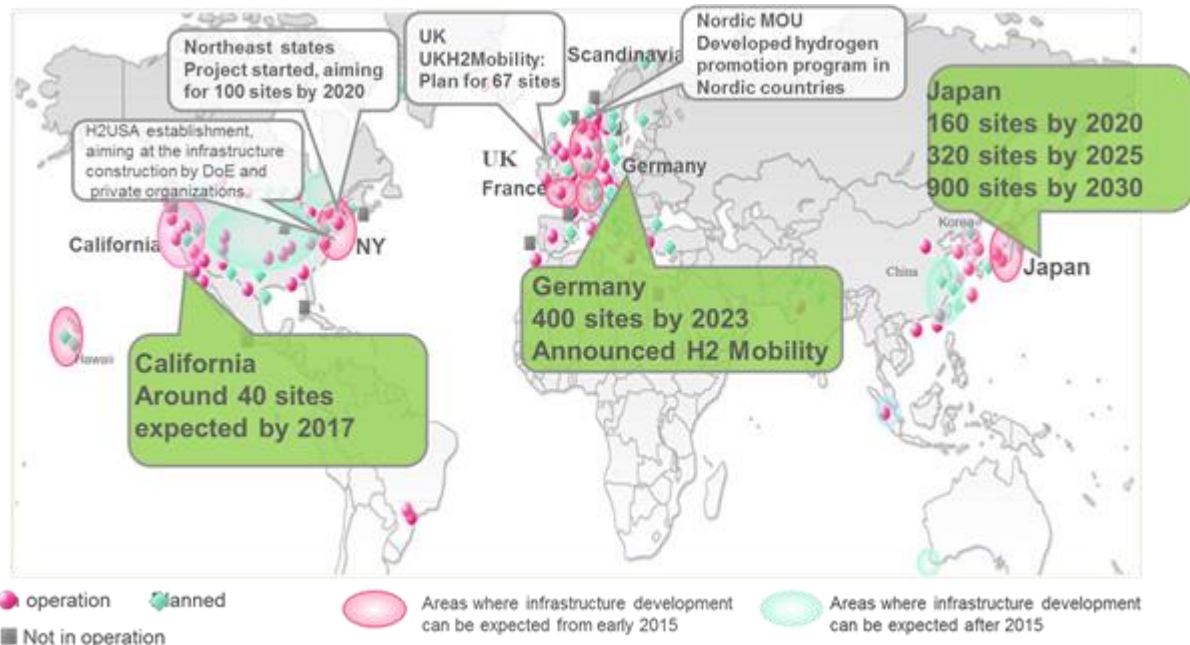


FIGURE 8: Global H2 stations roll-out

In Japan, 13 car makers and infrastructure developers have agreed to proceeding with the set-up a network of about 100 H2 stations. We also aim towards the expansion of CO2 free H2 from renewable sources and expect further technological developments, including the promotion of hydrogen utilization (for energy generation, industrial purposes, civilian purposes), and the formulation of new regulations and standards.

### References

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### Authors



In March 1984, I received a Master's Degree in mechanical and physical engineering from Tokyo Institute of Technology. After earning my degree I joined Toyota Motor Corporation in its Engine Research & Advanced Engineering Department. In January 1995 I was assigned to work at Toyota Technical Center U.S.A. In January 1998 I was returned to Japan, where I have served as Project General Manager in Toyota's Power Train Management Engineering Division. In January 2014 I was assigned to work at Toyota Motor Europe as a Vice President of Technology Trend Analysis, Technical Affair Planning & Advanced Technology Group.