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Hydrogen Technology Market in Japan

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1 Executive Summary

Traditionally, hydrogen has been used primarily to refine oil and for the production of ammonia. Hydrogen, however, has long been considered as a clean alternative to gasoline. Since the 1970s, there have been discussions about a hydrogen-based economy versus hydrocarbon economy. By simply combining hydrogen and oxygen, a fuel cell can produce electricity including heat and water. Applied to cars, including buses, trucks and forklifts, it could significantly reduce carbon dioxide (CO2) emissions.

However, in spite of this potential, there were many hurdles in the past for transforming to a hydrogen economy. One major hurdle, for instance, were the high development costs of fuel cells.

Although hydrogen is the simplest and most abundant element on Earth, it does not occur as a gas as it is always combined with other elements. It has therefore taking several decades before practical applications were ready.

The major markets in fuel cell development are Japan and the U.S., followed by China and Europe. Japan has taken the leading position in small-scale residential power generation and development of hydrogen-powered cars.

According to a forecast by Navigant Research, the global stationary fuel cell market is expected to grow from USD 1.4 billion in 2014 to USD 40 billion in 2022 [1]. Fuji Keizai Marketing Research & Consulting Group has estimated the corresponding market to be JPY 32.9 billion in 2013, constituting about 30 percent of the global market [2].

In order to cut carbon oxide emissions, Prime Minister Abe has vowed to make Japan a “hydrogen society” as described in a roadmap presented in 2014. From around 2040, the government is planning to supply CO2-free hydrogen by combining CCS (Carbon Capture and Storage) and renewable energy [3]. Tokyo that will host the 2020 Olympics plans to use the games to showcase the advantages of clean hydrogen power.

Since the commercialisation in 2009, Japan has been able to jumpstart the market for home-use stationary power generation as the result of extensive government funding over the last 10-15 years. Under the *ENE-FARM* (“energy farm”) scheme with hydrogen being extracted from natural gas, accumulatively 150,000 micro-CHP (Combined Heating and Power) units have been installed [4].

With several starts and stops over the last 10-15 years, hydrogen fuel cell vehicles (FCVs) are finally hitting the roads. In Japan, the government is subsidising FCVs with the aim of repeating a bet that paid off with the most popular hybrid model. In December 2014, Toyota launched the world’s first mass-produced fuel cell car but for the market to grow, it is necessary to build out the hydrogen infrastructure. In addition to government initiatives, Toyota, Honda and Nissan have partnered with the aim to financially support the hydrogen refuelling network.

One major challenge is the cost of fuel cells. Compared to combustion engines and batteries, fuel cells have been the target of less investment and therefore are a much less mature technology. But the development of fuel cells is continuing and manufacturers are, for instance, reducing the quantity of platinum needed in PEM (proton exchange membrane) fuel cells [5]. In the future, the cost of fuel cells are expected to be further reduced that will contribute the expansion of the market.

Business opportunities for European companies exist in market sub-segments, such as fuel cell systems including components and materials, and hydrogen refuelling station technologies. The hydrogen production technology segment can also offer business opportunities.

Superlight materials are a subfield of strategic importance with business opportunities for European companies that can offer products with features that differentiate from their Japanese competitors.

Much R&D is focused on catalysts. Proton exchange membrane fuel cells (PEMFCs) use platinum as catalyst material. Platinum, however, is quite expensive contributing to the high cost of fuel cells. Many Japanese producers are therefore looking for alternative materials instead of platinum. This is a subfield that could open up opportunities for European companies with attractive products.

The non-stationary application segment could bring opportunities for European players with attractive micro-application solutions for portable devices. This is a sub-segment where there are few Japanese players.

European companies that can deliver attractive technologies for hydrogen refuelling stations could be interesting for Japanese hydrogen station developers looking for solutions tailored to their needs.

It is important to choose the right mode for entry into the Japanese market. Some of the main modes are own subsidiary, local distributor, licensing or joint venture. Joint development is also a possible way to enter. One example of joint development is Nisshinbo's, a Japanese energy company, collaboration with Ballard Power Systems, a world leader in PEM fuel cell development, to develop a new catalyst [6].

When evaluating entering the Japanese market, it is necessary to study the market in detail. As Japanese customers are very demanding, it is important to offer an extensive after-sales service system. The full understanding of top management in Europe is equally important as relationships in Japan are long-term. Adapting the products to the local needs is usually a prerequisite for success.

2 Scope of the Report

This report is the result of extensive secondary research into the current status of hydrogen technology in Japan. It presents an industry overview and provides insights into the market trends, market size, market drivers and challenges that affect the growth of the market. Information on key players and the market size as well as new product developments including R&D activities will also be covered.

Secondary sources referred to for this study include magazines, journals, company financials, press releases, databases, annual reports, company websites as well as government sources.

2.1 Definition of Hydrogen and Fuel Cell Technologies

Hydrogen is the simplest element on earth—it consists of only one proton and one electron—and it is an energy carrier. Hydrogen can store and deliver energy, but it does not exist by itself in nature and must be produced from compounds that contain it.

Fuel cells generate electricity by combining oxygen and hydrogen (or a hydrogen-rich fuel source) in a chemical reaction.

Fuel cells can be utilised in a variety of applications, such as stationary power generation, power for transportation and portable power generation. This report will primarily focus on stationary power applications and use of hydrogen in FCVs.

2.2 List of Abbreviations

AIST	National Institute of Advanced Industrial Science and Technology
CCS	Carbon Capture and Storage
CHP	Combined Heating and Power
FCA	Fuel Cell Association
FCCJ	Fuel Cell Commercialization Conference in Japan
FC-Cubic TRA	Fuel Cell Cutting-Edge Research Center Technology Research Association
FCV	Fuel cell vehicle
FCDIC	Fuel Cell Development Information Center
FY	Fiscal year (from April to March the following year)
HFC technologies	Hydrogen & Fuel Cell technologies
HySUT	The Research Association of Hydrogen/Utilization Technology
IAE	The Institute of Applied Energy
ICT	Ministry of Internal Affairs and Communications
JMA	Japan Management Association
JV	Joint Venture
METI	Ministry of Economy, Trade and Industry
MEXT	Ministry of Education, Culture, Sports, Science and Technology
PAFC	Phosphoric acid fuel cell
PEM	Proton exchange membrane
PEMFC	Proton exchange membrane fuel cell
SOEC	Solid oxide electrolysis cell

SOFC	Solid oxide fuel cell
NEDO	New Energy and Industrial Technology Development Organization
RIKEN	*Ri*kagaku *Ken*kyujo (Institute of Physical and Chemical Research)

3 Global Overview

This section provides some brief information on the global market for hydrogen and fuel cell technologies.

According to the U.S. Department of Energy, hydrogen fuel cells are a reliable, clean and efficient source of energy. While gasoline and diesel vehicles emit hydrocarbons, which are a major source of pollution, hydrogen-powered fuel cell vehicles emit none of these harmful substances. Their only emission is water and warm air [7].

3.1 Global Hydrogen Technology Market Outlook

There is a well-established hydrogen production market, but 96 percent of all hydrogen produced is derived from fossil fuels, the feedstocks being natural gas, liquid hydrocarbons and coal [8]. The global hydrogen generation market is expected to reach USD 152 billion by 2021 [9].

The market for hydrogen and fuel cell technologies is expected to continuously be impacted by growing government funding and a strong technological base. Major markets are the U.S., Europe, Japan and China.

According to Lux Research, a research company, hydrogen demand from fuel cells will total 140 million kg in 2030, which corresponds to just 0.56 percent of the global merchant hydrogen demand across all industries [10].

In 2014, private investment in fuel cells and hydrogen technologies including IPOs exceeded USD 1 billion [11].

The fuel cell industry grew by almost USD 1 billion in 2014, reaching USD 2.2 billion, up from USD 1.3 billion in 2013. Major increases were seen in the U.S. and Asia Pacific revenues, boosted by shipments of fuel cells for materials handling (U.S.) and large-scale stationary sales by U.S. companies as well as residential fuel cells in Japan [12].

The research firm MarketsandMarkets forecasts a USD 5.2 billion industry by 2019, with a compound annual growth rate of 14.7 percent from 2014 to 2019 [13].

The global fuel cell market in the automotive industry is dominated by Asia Pacific, accounting for more than 70 percent of the total shipments in 2014 [14].

According to a 2014 report from Navigant Research, the global revenue for stationary fuel cells will grow from USD 1.4 billion in 2013 to USD 40 billion in 2022. WinterGreen Research forecasts this market to increase to USD 14.3 billion in 2020 [15].

In stationary power applications, unit numbers are dominated by Japan due to strong sales under the *ENE-FARM* scheme.

When it comes to hydrogen refuelling station development, 2015 marked the best year during the last five years. After declining from USD 49 million for three years, and reaching a bottom at USD 16 million in 2014, worldwide hydrogen refuelling station Infrastructure jumped to USD 113 million in 2015 [16].

It is expected that it will take many years before hydrogen refuelling becomes a sustainable business due to the complexity of matching the FCV roll-out and the build-up of the hydrogen infrastructure.

IHS Automotive, an auto industry analysis firm, is predicting FCV sales to total 4,500 in 2016, but jump to 11,500 by 2022. Currently, the waiting list in Japan for Toyota's *Mirai* FCV is said to be about three years, the result of the company's limited initial production.

3.2 Global Market Trends, Drivers and Challenges

Trends

China begins to position itself as a serious player [17]. In 2016, the new 5-year plan will increasingly focus on clean energy.

Asia Pacific region is dominating the global fuel cell market.

The governments in Japan and South Korea are continuing their strong support of fuel cell technology and hydrogen energy technologies.

In 2015, the fuel cell industry saw the formation of strategic alliances, business reorganizations and expansions including successful capital raising efforts, and more fuel cell companies going public.

In 2016, we will likely see the continuation of release of plans to produce high-volume hydrogen in regions, such as Australia [18].

In Europe, industrial gas giant Air Liquide has started supplying hydrogen using natural gas pipelines [19].

Drivers

Boosted by various government initiatives, the increasing demand for hydrogen as a transportation fuel will push the market in the years to come.

Other drivers are new emerging technologies in hydrogen storage and higher energy density compared to batteries.

Stricter government regulations to minimise carbon emissions are also impacting the market positively.

Challenges

The paradigm shift towards hydrogen will bring about challenges across multiple sectors of the economy.

One major challenge is related to hydrogen storage. Hydrogen is the lightest element, meaning it must be heavily compressed to fit into practical containers.

Another challenge is that the transition period to a hydrogen fuel system is likely to be long. Particularly, when it comes to hydrogen generation from renewable energy such as wind or solar power.

Technical challenges include inadequate fuel cell stack durability and system design life.

3.3 Global Players

Major global players include Ballard Power Systems, Fuel Cell Energy, Air Liquide and Air Products.

Information on Japanese players is given in section 8. Air Liquide and Air Products are presented in section 9 that includes information on foreign players that are present in the Japanese market.

Ballard Power Systems

Ballard Power Systems is a Canadian company headquartered in Burnaby near Vancouver. The company manufactures stationary power systems, motive modules and fuel cell stacks. The sales in 2015 were USD 56.5 million and the number of employees is 420.

Ballard Power Systems is a world leader in proton exchange membrane fuel cell development and commercialisation.

The company's strengths in particular lie in its technical capability for small- to medium-sized fuel cell batteries.

FuelCell Energy

FuelCell Energy is a leading fuel cell company that designs, manufacturers, installs and services stationary fuel cell power plants. The sales in 2015 amounted to USD 163.1 million and the number of employees is 596 (October, 2015).

The company is working towards commercialization of solid oxide fuel cell technology to target sub-megawatt commercial applications. Customers in Asia are served by the company's partner, Posco Energy, located in South Korea.

4 Japan Hydrogen and Fuel Cell Technology Industry

Hydrogen and fuel cell (HFC) technology utilises fuel cells to convert the stored chemical energy in hydrogen into electrical energy. Fuel cells are very useful as power sources and are utilised in various applications.

In case renewable energy, for instance wind or solar power, is used for hydrogen production, the power-generation is completely carbon-free.

Prime Minister Abe has called hydrogen the "energy of the future" and wants to turn Japan into a hydrogen society to reduce reliance on imported oil and find an alternative energy source to nuclear power.

There are four main reasons for the creation of a hydrogen society – energy-saving, (the) environment, energy security and industrial competitiveness [20]. Additionally, it can help in coping with natural disasters as fuel cell cars would be able to serve as movable generators

Tokyo wants cars and buildings to be powered by the green energy and has made a plan for a "hydrogen highway" with refuelling stations in time for the Tokyo Olympics in 2020 [21].

4.1 Industrial Overview

Background

In December 2013, the Ministry of Economy, Trade and Industry (METI) set up a *Council for a Strategy for Hydrogen and Fuel Cells* with the aim to study approaches to the future utilisation of hydrogen energy through collaboration between industry, academia and the government.

In April 2014, the government approved the fourth Strategic Energy Plan that clearly spells out the use of hydrogen and the need to formulate a roadmap towards the realisation of the hydrogen society.

Two months later, in June 2014, the Council compiled the *Strategic Roadmap for Hydrogen and Fuel Cells* that outlines an integrated approach to hydrogen production, storage, transportation and applications.

The roadmap consists of three phases:

- *Phase 1*: Increase the number of residential fuel cell units to 1.4 million in 2020, and 5.3 million in 2030. Expand the number of hydrogen refuelling stations for FCVs to 100 in FY 2015 and commercialise FCVs in 2015. Introduce commercial/industrial fuel cell systems utilising SOFCs (solid oxide fuel cell) in 2017.
- *Phase 2*: 2025-2030. Introduce hydrogen-based power generation on a full scale and establish large-scale hydrogen supply systems
- *Phase 3*: 2040 and beyond. Full-scale production, transportation and storage of hydrogen without emission of CO2 utilising Carbon Capture and Storage technology (CCS).

On March 22, 2016, the Council issued a revised version of the above roadmap [22]. Highlights of the revision are:

(1) The future price targets for home use fuel cells were clarified

- PEMFC (proton exchange membrane fuel cells): JPY 800, 000 by 2019 from a current subsidised price of JPY 1.42 million
- SOFC (solid oxide fuel cells): JPY 1 million by 2021 from JPY 1.77 million today

(2) Targets for expansion of FCVs

- About 40,000 FCVs by 2020; 200,000 by 2025; and about 800,000 by 2030.

(3) Targets for the construction of hydrogen refuelling stations

- The target is to construct 160 stations by 2020 and 320 stations by 2025

Before the announcement to make Japan a hydrogen society in 2014, Japan has already taken various actions to promote use of hydrogen for power generation, in particular use of household fuel cells (stationary power generation).

Stationary Power Generation

Japan leads the world in the introduction of fuel cells for home-use power generation that are capable of producing electricity and hot water.

In 2009, Japan was the first country in the world to make PEMFCs available for household use. In 2011, SOFCs were also introduced into the market for home use. The fuel cell extracts hydrogen from natural gas and combines it together with oxygen to generate electrical power. Simultaneously, captured residual heat is used to heat up water.

The government of Japan estimates that the use of a fuel cell in a Japanese household would result in an energy saving of approximately 23 percent. It has also stated that this technology will be used by about 1.4 million households in 2020 and 5.3 million households by 2030.

As of June 2016, accumulatively 173, 653 home use fuel cells have been installed, a large increase from 2,550 units installed in 2009 [23].

Japan's interest in residential fuel cells dates back to 1999. A large-scale demonstration program (3,300 units) started in 2005 and was successful to justify a commercial launch in 2009, supported by a large government subsidy [24]. In 2009, the government agreed to pay JPY 1.4 million per unit and made a multi-year commitment with a declining subsidy per unit, but an increasing overall budget. In FY 2016, the subsidy amounts to JPY 150,000 in case of a PEMFC and JPY 190,000 for a SOFC unit [25].

Transport/FCVs

According to the roadmap for a hydrogen society, increasing the presence of FCVs is an important step.

The world's first mass-produced FCV, *Mirai,* was released in December 2014 by Toyota. *Mirai* combines fuel cell technology with hybrid technology. The price was JPY 7.24 million. Domestic consumers are given a government subsidy of about JPY 2 million if they purchase a *Mirai* which means "future" in Japanese. Japan will make FCVs the official car of its ministries and other government offices.

At the end of March 2016, only about 500 FVCs have been sold in Japan. The government's target of 40,000 by 2020 seems somewhat optimistic as it is common practice for the government to set very ambitious targets. Toyota is planning to release a mass-production model priced at between JPY 5.5 million and JPY 6 million in 2019. This may boost the sales of fuel cell vehicles together with Honda's *Clarity* FCV that hit the market in March 2016.

Hino Motors will commercialise its fuel cell bus during 2016, aiming at deploying 100 units in Japan in time for the Tokyo Olympics in 2020.

Suzuki Motor plans to commercialise a hydrogen-driven fuel cell motorcycle and will start testing on public roads in 2016.

4.2 Hydrogen and Fuel Cell Technology Overview

In order to realize the hydrogen society, it is necessary to develop efficient hydrogen technologies for production, transportation, storage and applications.

For FY 2016, METI asked for a boost in its funding on hydrogen-related deployment (fuel cells and hydrogen refuelling stations) and research from FY 2015's JPY 11.9 billion to JPY 37.1 billion [26].

The Ministry of Environment has launched a JPY 3 billion power-to-fuel project to convert excess renewables into hydrogen, via electrolysis, for use in transport. The aim is to utilize renewable-derived hydrogen as a means to achieve CO2-free hydrogen on a large scale from about 2040.

Including hydrogen production, Japan has at various occasions implemented the "technology-forcing" policy as its *modus operandi*, i.e. pick a technology, develop a local industrial base and help to subsidise its initial market development. Earlier, the government successfully subsidised the market introduction of residential fuel cells showing that public-private partnerships can push new technology into the marketplace.

From around 2005, the New Energy and Industrial Technology Development Organization (NEDO) has conducted R&D on fuel cell and hydrogen technologies.

Fuel Cell Technologies

(1) *Residential market (micro-CHP fuel cell systems)*

- PEMFC (proton exchange membrane fuel cells).
  Market share: about 90 percent.
  Main suppliers: Panasonic and Toshiba (mainly 0.7 – 0.75 kW units)
- SOFC (solid oxide fuel cells).
  Market share: about 10 percent.
  Main supplier: Aishin Seiki (0.7 – 0.75 kW)
  The government's roadmap aims for widespread commercialisation of SOFCs from 2015 to 2020 [27].

Recent developments in both PEMFCs and SOFCs by Japanese manufacturers have improved fuel cell stack lifetimes. The leading residential systems are now expected to operate for 60-80,000 hours for PEMFCs and up to 90,000 hours for SOFCs. Panasonic claims that its 2015 model achieves a 95 percent combined heat and electrical efficiency compared to between 80 percent and 90 percent for earlier models.

Distribution channels to market are mostly through Japan's gas suppliers such as Tokyo Gas and Osaka Gas. Panasonic, for example, is working with 17 of these entities.

Aishin Seiki is using Kyocera fuel cells and entered the SOFC market in 2014 through Osaka Gas.

Toshiba and Panasonic have continuously improved the performance of their products. In 2015, Panasonic reconfigured the stack, simplified the system and reduced the number of components by 15 percent and implemented a 20 percent reduction in platinum usage [28].

Japanese PEM technology is also being used in Europe in the micro-CHP sector.

(2) *Transport market*

- PEMFC (proton exchange membrane fuel cells).
  Market share: 100 percent.
  Main suppliers: Panasonic and Toshiba

In 2020, Nissan is planning to begin selling an electric car using bio-ethanol as the on-board hydrogen source. Nissan's new e-Bio fuel cell system uses a reformer to convert bio-ethanol into hydrogen. This is the world's first solid-oxide fuel cell stack for automobiles [29]. The technology has so far been used in stationary fuel cells for households and businesses.

Transportation and Production of Hydrogen

Chiyoda, an industrial plant engineering company, has developed technology to convert hydrogen into toluene, a colorless liquid, which can be transported commercially using ordinary tankers, and then transform it back to hydrogen. The company hopes to put the technology into practical use in 2020 [30].

Chiyoda has also developed a floating facility with *Mitsubishi Heavy Industrie*s to produce hydrogen from petroleum gas contained in undersea oil fields.

Kawasaki Heavy Industries (KHI) has built a plant that turns hydrogen into liquid fuel with one-800th the volume of hydrogen gas, with the capability of producing about five tons of liquid hydrogen a day [31]. In two years, KHI will begin sales of the plant to operators of steel factories that generate hydrogen as a byproduct. The company also intends to establish a mass-production system and long-distance transport system of liquid hydrogen before the 2020 Tokyo Olympic Games.

KHI is testing technology in Australia in which hydrogen will be extracted from low-grade Australian brown coal *(lignite*). In 2017, KHI will begin constructing a pilot plant capable of producing 20 tons of hydrogen a day using CCS. The hydrogen will be transported to Japan by liquefied hydrogen tankers.

In March 2016, KHI partnered with Anglo-Dutch oil major *Royal Dutch Shell* to develop technologies to transport hydrogen by sea.

JX Group Holdings is planning to commercialise technology that will allow hydrogen to be transported as a liquid at ordinary temperatures and pressures [32]. The company is also working on usage of special membranes to extract hydrogen from oil or natural gas in order to improve the recovery rate from 70 percent to about 90 percent.

Hydrogen Infrastructure

Without an extensive hydrogen infrastructure, in particular refuelling stations, the market uptake of FCVs will be a slow process.

Toyota, Honda and Nissan have partnered to develop hydrogen station infrastructure in Japan. They will together spend around JPY 5 billion to JPY 6 billion over the next 5 years to help build hydrogen stations. They also plan to provide support to infrastructure companies for the creation of a refueling network for the owners of FCVs [33].

Toyota, Honda and Nissan are also part of an agreement between 10 Japanese gas companies to jointly develop a "hydrogen highway".

As of March 2016, there were 80 hydrogen refuelling stations, short of the target of 100 stations. The government aims to quadruple the number of hydrogen refuelling stations to 320 by 2025 to get more FCVs on the market.

Iwatani and *JX Nippon Oil & Energy Corporation* are the two main developers of hydrogen refuelling stations in Japan. Iwatani plans to increase the number of hydrogen stations to roughly 30 by March 2017, from 17 stations today and will focus on smaller cities in the future.

Iwatani sells hydrogen for JPY 1,100 per kilogram, a price in par with the fuel cost of a high-end hybrid car. This price, however, is said to be unprofitable.

A hydrogen station costs JPY 400 million to JPY 500 million to build, compared with about JPY 100 million for a conventional gasoline station. Constructing hydrogen stations is two to three times more expensive in Japan than in Europe and the U.S. [34].

Since the end of 2015, a hydrogen refuelling station is operating at a sewage treatment plant in Fukuoka in southern Japan. Hydrogen is created from biogas. Japan's government has invested USD 12 million in this project in which Mitsubishi, Toyota and Kyushu University have been taking part [35].

METI will offer subsidies for efforts as technological development to lower construction and operating costs for the stations. The cost to operate a hydrogen refuelling station amounts to more than JPY 40 million a year.

Air Products, a U.S. industrial gas company, has teamed up with *Nippon Steel & Sumikin Pipeline & Engineering* to develop the hydrogen refuelling market in Japan [36]. Recently, the first station under the collaboration was opened that uses Air Products' *SmartFuel* hydrogen refuelling station technology and fueling protocol license.

Air Liquide Japan, a subsidiary of Air Liquide (France), completed the construction of a hydrogen station in Saga city in March, 2016. The construction was subsidised from METI and from the Saga Prefectural Government [37].

Industrial-Scale Power Systems

Phase 2 of the *Strategic Roadmap for Hydrogen and Fuel Cells* envisions the construction of large-scale hydrogen-based systems such as industrial power stations. Several power-plant manufacturers have experienced with hydrogen-powered turbines, but no commercial models have so far been launched. Phase 2 may prove technically challenging and, currently, only Kawasaki Heavy Industries and Mitsubishi Hitachi Power Systems are actively pursuing the technology [38].

New Alkaline Water Electrolysis Hydrogen Production System by Toshiba

On July 14, 2016, *Toshiba* announced Japan's largest alkaline water electrolysis hydrogen production system. The company has developed the system with a next-generation *Solid Oxide Electrolysis Cell* (SOEC). By using an alkaline solution at the electrolyte in the hydrogen producing chemical reaction, there is no need for expensive metals in the system's electrodes. This will create a cheaper output capacity [39].

4.3 Key Industry Drivers

The key driver of the hydrogen and fuel cell technology market is the government's commitment to make Japan a hydrogen society. The government has been funding a range of fuel cell and hydrogen R&D and demonstration project activities.

As part of the hydrogen push, Japan has been promoting home-use fuel cells and the development of FCVs by offering subsidies. The government plans to support clean transportation more aggressively in the future ("*hydrogen highway*"), as Japan seeks a full-fledged introduction of hydrogen by 2030.

The planned development of a comprehensive hydrogen infrastructure is also expected to contribute to the commercialisation of the hydrogen concept.

In January 2015, Toyota announced that it will make more than 5,600 of its hydrogen fuel-cell technologies patents free including patents for fuel stack technology and patents for software to control hydrogen fueling systems [40].

Toyota hopes that the release of the patents would open "the door to the hydrogen future" and boost the transition to a zero-emission future.

Tokyo Metropolitan Government is actively promoting the use of hydrogen including the creation of a JPY 40 billion fund for setting up hydrogen refuelling stations and other infrastructure.

4.4 Current Trends

Japanese automakers continue to set the pace in the development of FCVs.

A growing number of companies are entering the market, in particular the hydrogen station segment in which many foreign companies are present in collaboration with Japanese companies.

Japanese companies are teaming up with foreign firms to develop the market for fuel cell components.

On September 7, 2016, the government announced that it intends to enable large-scale production of hydrogen in Fukushima Prefecture [41]. According to the plan "Fukushima plan for a new energy society", the prefecture will become a model district utilising renewable energy such as wind power. METI has requested JPY 75.4 billion in the FY 2017 budget to carry out the project. The government intends to supply hydrogen from Fukushima Prefecture to Tokyo for use during the Tokyo Olympics in 2020.

The hydrogen fuel supply will be further diversified through the establishment of a hydrogen import terminal in Kobe to open in 2020 [42]. Iwatani, an energy supplier, and Kawasaki Heavy Industries will construct the hub on the island housing Kobe Airport.

The trend to carry out demonstration projects including testing is continuing. Starting this fall, a public-private partnership will evaluate an end-to-end low-carbon hydrogen supply chain which will use hydrogen produced from renewable energy to power forklifts in Yokohama [43].

Recently, hydrogen production from domestic renewable energy is drawing much attention.

4.5 Challenges

One major challenge is the high cost for construction of hydrogen refuelling stations and the immature hydrogen infrastructure

Another challenge is the high price tag for fuel cell vehicles that is hindering wider adoption. Cost has long been the main obstacle to the widespread commercialisation of fuel cells. Most PEM fuel cells need platinum, an expensive and rare metal.

Ensuring support from the general public for the drive towards the hydrogen society is also an important issue. The safety of hydrogen power must be clearly demonstrated. A widespread refuelling infrastructure is essential to gain customer acceptance.

5 Japan Hydrogen and Fuel Cell Technology Market

5.1 Market Overview

Japan's stationary market continues to develop with more than 173, 000 residential fuel cell units sold cumulatively by the end of June, 2016. FCVs have hit Japan's streets but the number of such vehicles is still quite limited (about 500 as of March 2016).

The government is continuously pushing the hydrogen concept and private players are getting active in various segments of the overall market.

The first municipal hydrogen power plant in Japan will start production in Kobe in 2018. *Kawasaki Heavy Industries* and *Obayashi*, a construction firm, will work together with *Kansai Electric Power* to provide electricity to a 25-hectare area housing hotels and other buildings. The electricity generated would be sufficient to power offices holding around 10,000 workers. The plant will use as much hydrogen in a year as is consumed by about 20,000 FCVs [44].

A 1,000 kW-class turbine with a mix of 80 percent natural gas and 20 percent hydrogen will be used as fuel. As hydrogen releases no carbon dioxide when burned, the plant will emit 20 percent less carbon than current models.

5.2 Main Application Areas

The main application areas are:

(1) *Stationary sector*

- Residential CHP (Combined Heating and Power)
- Backup power (including indoor and outdoor power for telecoms)

(2) *Transport sector*

- Cars
- Buses
- Forklifts

(3) *Portable sector*

- Compact, portable fuel cell systems can be used to recharge batteries or directly power consumer electronics (such as laptops and smartphones)

5.3 Market Potential

According to NEDO, it is estimated that the combined market for fuel cells and hydrogen technology, including hydrogen-powered cars, could reach JPY 1 trillion by 2030, and JPY 8 trillion by 2050 [45].

An estimation of Japan's fuel cell market made by JMA (Japan Management Association) Research Institute in 2011, projects the market size to grow from USD 450 million in 2011 to USD 5.2 billion in 2020, and to USD 29 billion in 2030 [46].

Fuji Keizai Marketing Research & Consulting Group estimates the market size for fuel cells in Japan, primarily stationary power applications, to be JPY 32.9 billion in 2013.

Japan has a strong fuel cell supply chain network and is the major market in the Asia-Pacific region that deals in fuel cells. Due to the strong demand for home-use micro-CHP systems, the market will further grow.

A rough calculation of the domestic market size of residential fuel cells and FCVs in 2015, gives a market value of approximately JPY 35 billion, of which JPY 2.2 billion would be the sales value of 300 sold Toyota *Mirai* FCVs (calculated at the actual, non-subsidised sales price: JPY 7.24 million). The share of sold FCVs would just be about 6 percent of the estimated market value.

5.4 New Product Developments

Japan's manufacturers will soon start marketing large-scale hydrogen fuel cells for offices and other commercial facilities. Several companies are developing large solid oxide (SOFC) units and such systems are able to produce electricity that is 30 - 40 percent more efficient than PEMFCs [47].

The prices are relatively high and fuel-cell buyers would need more than 10 years to recoup the cost for purchase and installation. The manufacturers, however, are aiming to reduce the prices by about two-thirds by exploiting cost cuts from large-scale production as the technology further develops.

Mitsubishi Hitachi Power Systems plans to introduce a SOFC 250kW fuel cell in 2017 that can supply facilities such as shopping centers with more than half their power need. Models generating 1,000 kW or more may be released in 2018 with factories as potential customers.

*Kyocera i*s planning to introduce a SOFC 3 kW fuel cell in FY 2017.

Fuji Electric will begin selling a medium-scale 50 kW model (SOFC) in FY 2018 targeting supermarkets and hospitals with a price of about JPY 50 million.

Miura, Japan's largest boiler manufacturer is planning to release a small 5 kW fuel cell in FY 2017 partnering with Tokyo Gas and Osaka Gas. The company is targeting restaurants and smaller-scale enterprises.

6 Regulatory Framework

Until recently, hydrogen has been used almost exclusively by industrial sectors. Regulations have not been adapted to hydrogen-based power generation applications.

Related authorities have discussed ways to lower the cost of hydrogen refuelling stations that constitutes a major challenge for the realisation of the hydrogen society.

On November 20, 2014, METI announced the revision of the technical standards for compressed hydrogen refuelling stations [48]. The new standards have been designed to make it easier and less costly for companies to install hydrogen stations.

METI has revised the *General High Pressure Gas Safety Ordinance*, the *Industrial Complex Safety Ordinance*, and other regulations.

The highlights of the revision are:

(1) For the first time in Japan, it will be possible to use composite hydrogen storage tanks, allowing the use of materials like carbon fibre-reinforced plastics.

(2) The temperature range that steel-based tanks can operate in has been expanded. This will make them less costly and easier to install and maintain.

(3) The concept of hydrogen pre-cooling has been introduced in the regulations. This will enable a faster filling time.

(4) Under the new regulations, the operators are allowed to transport and store liquefied hydrogen as a raw material. This will make it easier to transport hydrogen fuel since the liquid itself takes less space than the gas.

(5) The new regulations lessen the distance requirement of being 6 meters away from public spaces provided the supplier has followed all necessary safety precautions. The exact distance is not specified but it is assumed to be somewhere around the four-meter separation requirement for gasoline filling stations [49].

From May 2014, METI allows hydrogen tanks to be filled to a maximum of 875 atmospheres from 700 atmospheres. This will extend FCV range by about 20 percent without refuelling.

Many Hurdles for Honda's Compact Hydrogen Refuelling Station

Together with Iwatani, Japan's largest hydrogen supplier, Honda has developed the "*Smart Hydrogen Station*" to boost hydrogen supply outside of major cities. The compact station only needs 7.8 sq. meters of space. Currently, two stations are open for testing: one in Saitama City north of Tokyo and one in southern Japan.

Honda's technology utilises solar energy to electrolyse water to generate hydrogen.

Criteria set by METI on what materials can be used to make hydrogen storage tanks have only applied to larger facilities. Although many years of deliberations by regulators, METI has still not set the rules related to smaller refuelling facilities which makes it difficult for Honda and Iwatani to promote this compact station concept [50].

7 R&D

METI's revised plan announced in March 2016, calls for the promotion of R&D to reduce the cost of fuel cells to price levels of FCVs which consumers can afford to buy. This should be possible by reducing the use of expensive cell materials, standardisation and sharing of cell components.

The Japanese government plans to increase R&D for clean energy technology to around JPY 90 billion by FY 2021 [51]. One area of emphasis will include producing hydrogen energy that does not emit carbon dioxide, and developing superlight materials that can reduce vehicle weights by half.

Japan currently spends about JPY 350 billion yen annually on energy-related R&D. This corresponds to 0.07 percent of GDP that is one of the highest among industrialised nations.

Some examples of research by industry, universities and national laboratories are listed below.

7.1 Research at Universities

Kyoto University, Department of Energy and Hydrocarbon Chemistry. Professor Koichi Eguchi is conducting research on materials and systems related to fuel cells and hydrogen production [52].

Kwansei Gakuin University. Professor Hirohisa Tanaka is researching new functional materials of nanoscale structures related to fuel cells.

Yamanashi University. Basic materials research for high-performance fuel cells.

Kyushu University. Professor Ogo Seiji and his research group have successfully developed a nickel-iron catalyst. They have found that iron could activate hydrogen at normal pressure and temperature. This technique could make it possible to develop a metal-free fuel cell catalyst [53].

University of Electro-Communications. Has developed a highly functional and durable catalyst for cathodes of PEMFCs. The catalyst exhibits five to eight times more catalytic reaction in mass than conventional platinum catalysts, and over double of that of platinum cobalt catalysts.

7.2 Research at Public Research Institutes

New Energy and Industrial Technology Development Organization (NEDO). Various hydrogen energy-related R&D activities. The budget for such R&D was USD 100 million in FY 2015.

7.3 Collaboration between Companies and Universities/Research Institutes

Yokohama Rubber and *Kyushu University* are conducting joint research on a low-cost hydrogen refuelling hose including a standard for evaluation the robustness of hoses [54].

Mitsubishi Kakoki and *Kyushu University* are collaborating with Fukuoka city to establish a means of generating hydrogen from sewage sludge and supply it for FCVs [55].

7.4 Corporate Research

Kobe Steel is developing lightweight composite materials to be used in FCVs that will protect hydrogen tanks in case of collisions [56].

Chiyoda is continuing to optimise the technology to convert hydrogen into toluene for transportation by ordinary tankers.

8 Competitive Landscape: Japanese Players

This section gives information on multiple players in relation to the hydrogen and fuel cell technology market. There are five broad groups of main players, such as (1) automakers: *Toyota*, *Honda* and *Nissan*, (2) fuel cell manufacturers: *Panasonic*, *Toshiba*, *Aishin Seiki* and *Fuji Electric*, (3) developers of hydrogen refuelling stations: *Iwatani* and *JX Group Holdings*, (4) hydrogen supply chain providers: *Kawasaki Heavy Industries*, and (5) distributors: *Tokyo Gas* and *Osaka Gas*.

8.1 Toyota

Toyota is an automotive manufacturer headquartered in Toyota city, near Nagoya. As of February 2016, Toyota is the 13th-largest company in the world. Consolidated sales in FY 2015 were JPY 27.2 trillion. The number of employees is 344,100.

In December 2014, Toyota launched its fuel cell vehicle *Mirai* in Japan. As of June 2016, *Mirai* is available for retail sales in the U.S, the U.K., Germany, Belgium and Norway.

Mirai uses Toyota's proprietary, small, light-weight fuel cell stack and two 70 MPa high-pressure hydrogen tanks placed beneath the specially designed body.

Toyota has a partnership with German automaker BMW related to fuel cell vehicles.

8.2 Honda

Honda is a multinational corporation, headquartered in Tokyo that manufactures automobiles, motorbikes and power equipment. Honda has been the world's largest motorbike manufacturer since 1959. In FY 2015, the sales amounted to JPY 13.3 trillion. The number of employees is 204,700.

In March 2016, Honda began sales in Japan of its all-new fuel cell vehicle – the Clarity Fuel Cell, priced at JPY 7.6 million. It is the world's first five-passenger sedan type FCV. The on-board 70 MPa high-pressure hydrogen storage tank provides a cruising range of approximately 750 km.

For the first year of the launch in Japan, Honda will focus on lease sales mainly to local government bodies. Honda is planning to introduce the Clarity Fuel Cell to Europe and the U.S. before the end of 2016. In Japan, Honda is targeting sales of 200 units during 2016.

Honda is testing the feasibility of using FCVs to supply electricity to homes. A full tank with hydrogen can generate 60 kilowatt-hours of electricity, enough to supply an average household for 6 days [57].

Honda has a partnership with General Motors working to develop a next-generation fuel cell system.

8.3 Nissan

Nissan is a multinational automobile manufacturer headquartered in Yokohama. Since 1999, Nissan has been part of the Nissan-Renault Alliance, a partnership between Nissan and French automaker Renault. The consolidated sales in FY 2015 were JPY 12.2 trillion and it employs 149,000 people worldwide.

In June 2016, Nissan announced that it is researching and developing a SOFC-powered system utilising bio-ethanol as the on-board hydrogen source. The company is planning to commercialise the technology in 2020. Solid oxide fuel cells have been of interest for transportation applications because of their fuel-flexibility, i.e. no need for a dedicated hydrogen production and refuelling infrastructure.

Nissan believes that the system's operating costs will be JPY 3.1 per km, roughly equivalent to the JPY 2.9 for current electric vehicles. Nissan aims to price its first SOFC vehicle about the same as conventional electric vehicles to achieve good sales.

Nissan has tied up with Daimler and Ford Motor in the development of hydrogen-based fuel cell vehicle technology.

In August 2016, Nissan will launch a new minivan featuring self-driving technology. The technology is called *Propilot*, which monitors road conditions using a camera.

8.4 Panasonic

Panasonic is a multinational electronics company headquartered in Kadoma, Osaka. The company was founded in 1918 and has grown to become one of the largest Japanese electronics producers along with Sony and Hitachi. The consolidated sales in FY 2015 were JPY 7.7 trillion and the total number of employees is 254,000.

Panasonic is active in the PEM residential fuel cell segment and are supplying fuel cells through 17 of Japan's gas corporations. The recommended retail price of the 2016 model is about JPY 300,000 lower than that of the 2013 model for the same functionality and an approximately 17 percent longer operating time [58].

8.5 Toshiba

Toshiba is a multinational conglomerate headquartered in Tokyo. Its products include information technology and communications equipment, electronic components, power systems, consumer electronics and household appliances. The number of employees is 199,000. The sales in FY 2015 were JPY 6.6 trillion.

Toshiba Fuel Cell Power Systems Corporation focuses on PEMFCs for the Japanese market, both for stationary power applications and for use in FCVs.

In April 2015, Toshiba started operating its H2One product in Kawasaki City's port area. Under the H2One system, solar photovoltaics, batteries, an electrolyser, hydrogen and a fuel cell are combined to provide emergency autonomous power, heat and water [59].

8.6 Aishin Seiki

Aishin Seiki, a member of the Toyota Group, is a specialist in the creation and production of components and systems for the automotive industry. It also is engaged in the fuel cell business. Consolidated sales in FY 2015 were JPY 2.96 trillion and the number of employees is 89,390.

Since 2012, Aishin Seiki markets residential fuel cell systems equipped with solid oxide fuel cells for efficient power generation performance. Starting from 2014, Bosch is purchasing SOFC technology from Aishin Seiki for integration into its power-generating heating system.

8.7 Fuji Electric

Fuji Electric is an electrical equipment company that manufactures thermal power generation systems, solar power systems and fuel cells. Total consolidated sales in FY 2015 were JPY 850 billion. The total number of employees is 25,500.

Fuji Electric entered the fuel cell business in 2009 and has commercialised a 100 kW phosphoric acid fuel cell (ACFC) for industrial use. The company has delivered fuel-cell packages to many office buildings and hospitals in Japan. Fuji Electric has also delivered products for power generation to South Korea and Europe with nearly JPY 1 billion in annual sales. In 2016, Fuji Electric has acquired N2telligence, a German firm engaged in the fuel cell business. The company has recently won a significant order from South Africa [60].

8.8 Iwatani

Iwatani is Japan's largest manufacturer of hydrogen gas with 70 percent of the domestic market. The consolidated sales in FY 2015 were JPY 616.2 billion. The total number of employees is 8,700.

Iwatani is a developer of hydrogen infrastructure. Since 2014, the company has been advancing the development of hydrogen refuelling stations, primarily focused around Japan's four major metropolitan areas. The company is planning to expand its network of hydrogen stations to roughly 30 by March 2017 [61].

8.9 JX Group Holdings

JX Group Holdings was established in 2010 through the management integration of Nippon Oil Corporation and Nippon Mining Holdings. The Group engages in the integrated development, production, and sale of petroleum, natural gas, and non-ferrous metals. Consolidated sales in FY 2015 were JPY 8.7 trillion and the number of employees is 14,560 (March 2016).

JX group Holdings is engaged in developing hydrogen supply systems for fuel cell vehicles through its subsidiary JX Nippon Oil & Energy Corp. The company is planning to develop a network of about 40 hydrogen stations.

8.10 Kawasaki Heavy Industries

Kawasaki Heavy Industries (KHI) is a multinational corporation, primarily known as a manufacturer of motorcycles, heavy equipment and aerospace equipment. Total consolidated sales in FY 2015 were JPY 1.54 trillion and the number of employees is 34,000.

Kawasaki Heavy industries is promoting a hydrogen supply chain between Japan and Australia through gasification of brown coal in Australia.

KHI is developing a hydrogen gas turbine and combustion technology for mixed combustion of natural gas and hydrogen.

KHI is also working to develop special tankers to transport liquefied hydrogen by sea.

8.11 Tokyo Gas

Tokyo Gas, founded in 1885, is the largest natural gas utility in Japan. Sales in FY 2015 were JPY 1.8 trillion. The total number of employees is 7,973.

Tokyo Gas started sales of *ENE-FARM, the residential-use fuel cell,* for detached dwellings in 2009. In 2014, Tokyo Gas launched the world's first *ENE-FARM* home-fuel system for condominiums jointly developed together with Panasonic. In comparison to detached houses, condominiums have more restrictions on the conditions for installations.

Tokyo Gas opened its first hydrogen refuelling station in December 2014 when Toyota launched its *Mirai* FCV. The hydrogen station was built on the site of an existing station that sells compressed natural gas. Like regular gasoline stations, the station is called an "off-site station" as it does not make its own hydrogen. Another planned station will be "on-site".

8.12 Osaka Gas

Osaka Gas is a gas company headquartered in Osaka. The company owns oil and gas assets in Norway and Australia. Total sales in FY 2015 were JPY 1.32 trillion and the number of employees is 20,100.

Osaka Gas is offering residential PEM fuel cells manufactured by Toshiba. A reformer, fuel processing system, produces hydrogen for the fuel cell by steam reforming of natural gas from the existing gas pipeline infrastructure. The company has also developed equipment that uses liquefied petroleum gas (LP gas) to produce hydrogen

Osaka Gas' residential fuel cell co-generation systems are using both PEMFCs and SOFCs.

Osaka Gas has built one hydrogen refuelling station with plans for a second one.

9 Foreign Players in the Japanese Market

9.1 Bloom Energy

Bloom Energy is an American solid oxide fuel cell technology provider founded in 2001 and headquartered in Sunnyvale, California.

In 2013, Bloom Energy completed its first international installation (SOFC) at SoftBank's M-Tower in Fukuoka, Japan. Bloom Energy's equipment runs on natural gas and requires a reformer.

Bloom Energy Japan was established in 2013. The sales in 2014 were JPY 249 million.

9.2 Air Liquide

Air Liquide is a French multinational which supplies industrial gas to various companies. The sales in 2015 amounted to 16.3 billion euro. The number of employees is about 68,000 worldwide.

Air Liquide has partnered with Toyota Tsusho for hydrogen refuelling station deployment in Japan. In May 2016, the company completed its fourth and fifth hydrogen filling stations in Japan.

Air Liquide Japan was founded in 1930. It has 2,000 employees and has a Research and Technology Center in Tsukuba. Japan serves as a technology & research base for Air Liquide in Asia.

9.3 Linde Group

The Linde Group is a multinational industrial gas and engineering company founded in Germany in 1879. It is the world's largest industrial gas company by market share. Consolidated sales in 2015 were 17.9 billion euro. The number of employees is 64,538.

In 2014, Linde finalized a deal with Iwatani for the delivery of 28 hydrogen refuelling stations with ionic compressors. The first of these units is operating since 2014 in Amagasaki near Osaka, Japan [62].

9.4 H2 Logic

H2 Logic is a leading Norwegian manufacturer of hydrogen refuelling stations. The company is part of NEL ASA, a listed company on the Oslo Stock Exchange.

In 2015, H2 Logic signed a technology licensing agreement with Mitsubishi Kakoki that has been involved in the construction of 14 refuelling stations in Japan. The collaboration with H2 Logic will strengthen Mitsubishi Kakoki's position as a provider of hydrogen refuelling stations. H2 Logic will assist in adapting the design for use in Japan [63].

9.5 Ceres Power

Ceres Power is a U.K. next-generation household fuel cell manufacturer that was established in 2001. In 2014, the company set up a representative office in Osaka. The company has developed a new type of steel fuel cell (SOFC) using ceria as the electrolyte material to provide efficient heat and power for homes and businesses.

Ceres Power has signed an agreement with Honda to jointly develop its technology for a range of energy applications [64].

Ceres Power has recently (June 2016) partnered with Nissan. The two firms will work together to develop a compact, on-board solid oxide fuel cells (SOFC) that improves the distance electric cars can travel without needing to recharge, one of the limiting factors currently.

9.6 Air Products

Air Products is an American corporation selling gas and chemicals for industrial uses. The company is headquartered in Allentown, Pennsylvania. Consolidated sales in 2015 were USD 9.8 billion and the number of employees is 19,700.

In 2015, Air Products signed an alliance agreement with Suzuki Shokan, an industrial gas company based in Tokyo, to work together on the design, construction and operation of hydrogen refuelling stations for the materials handling equipment market in Japan.

Both companies will utilise Air Products' hydrogen refuelling technology and jointly make necessary infrastructure modifications to meet Japanese laws and regulations [65].

10 SWOT Analysis

A SWOT analysis of Japan's hydrogen and fuel cell technology industry is presented below.

Strengths:

- Existing government promotions (massive funding including subsidies) for the creation of the hydrogen society
- Drive for clean technologies
- Strong emphasis on demonstration projects

Weaknesses:

- High construction cost of hydrogen refuelling stations
- Limited capacity of hydrogen supply in Japan
- High cost of fuel cell vehicles
- Immature hydrogen infrastructure
- Insufficient awareness of stationary fuel cells among the public
- Limited government support for hydrogen production from CO2-free renewable energy
- Transportation of hydrogen by pipeline not yet commercialised. Need for large infrastructure investment

Opportunities:

- Fuel cell economics will improve with volume, components and materials technology advancements
- International expansion
- Use of cheaper metals
- International partnering to develop technologies
- Flexibility and variety of fuel cell technology
- New regulations for large facilities will make it easier to operate hydrogen stations

Threats:

- Low acceptance level due to safety concerns among consumers
- Lack of regulations for compact hydrogen refuelling stations
- Emergence of "new players" – China, South Korea and India

Comments

International expansion. The policy to encourage local deployment of fuel cells, have enabled Japanese companies to break out of the home market and start to develop overseas. Fuji Electric, for instance, is selling fuel cells in South Africa and Germany. Panasonic has set up a residential fuel cell development base in the U.K.

Lack of regulations for compact hydrogen stations. The slowness of the regulation review by METI for compact hydrogen stations seems to hold up many local governments from ordering Honda's *Smart Hydrogen Station*.

Emergence of "new players". South Korea has emerged as a leader in several market segments. Hyundai was the first automaker to offer a FCV for lease on commercial terms (2013). Posco Power is strong in the large-scale fuel cell power generation segment and runs the world's largest fuel cell installation at 58.8 megawatts.

11 Associations, Organisations and Forums

Fuel Cell Association (FCA). The aim of FCA is to promote the diffusion of fuel cells and contribute to the reduction of CO2 emissions in order to lessen the environmental impact in Japan. FCA was established in 2008 and is composed of 9 regular members and 21 associate members.

Fuel Cell Commercialization Conference in Japan (FCCJ). FCCJ aims to examine specific issues affecting the commercialisation and diffusion of fuel cells and incorporate the findings into policy recommendations to the Japanese government. Through this, FCCJ is able to make an important contribution to the growth of Japan's fuel cell industry. The FCCJ was established in 2001 and, as of April 2016, the number of members is 112 companies and organisations [66].

Fuel Cell Cutting-Edge Research Center Technology Research Association (FC-Cubic TRA). FC-Cubic TRA was established in 2010 with the support of fuel cell power-related companies, universities and National Institute of Advanced Industrial Science and Technology (AIST). The aim of the association is to support fundamental technology research of fuel cells and its systems in industry. FC-Cubic TRA consists of 7 corporate members, 6 universities and one national research institute.

Fuel Cell Development Information Center (FCDIC). FCDIC was set up in 1986 to exchange information among its members on fuel cell research development and deployment aiming at the introduction and diffusion of fuel cells. FCDIC consists of 115 general members including major private Japanese companies and national organisations working on fuel cell development, 40 academic individuals and 12 foreign organisations.

The Institute of Applied Energy (IAE). IAE was established in 1978 and is composed of 87 members as of April 1, 2015. The Hydrogen Energy Group of IAE contributes to the formulation of Japan’s energy strategy and also to the development of hydrogen-related industries through assessing viability of hydrogen energy systems. It also conducts research on innovative hydrogen-related technologies including fuel cells.

The Research Association of Hydrogen Supply/Utilization Technology (HySUT). HySUT was founded in 2009 with the aim to build up the hydrogen supply infrastructure and to improve the hydrogen business environment. It consists of 19 members including Toyota, Honda and Nissan. HySUT is conducting R&D on hydrogen utilisation technology to achieve cost reductions of devices and systems in relation to the hydrogen infrastructure. The association is also promoting the diffusion of FCVs and the strengthening of Japan's international competitiveness [67].

12 Trade Fairs

FC Expo Osaka 2016 (1st International Hydrogen & Fuel Cell Expo Osaka). FC Expo Osaka 2016 will take place from September 7 to September 9, 2016, at Intex Venue in Osaka.

FC Expo 2017 (13th International Hydrogen & Fuel Cell Expo). FC Expo 2017 will take place from March 1 to March 3 at Big Site Venue in Tokyo.

13 Challenges and Opportunities for European Companies

13.1 Key Success Factors

Important success factors for market entry to Japan include:

- *Long-term commitment*. There is no easy and quick way to succeed in Japan. It usually takes long time to get a firm foothold in Japan and it is important to have the full understanding of the top management (company-wide commitment).
- *Researching the Japanese market.* There are significant differences between doing business in Japan and in Europe. For instance, Japan presents challenges uniquely distinct from many other markets.
- *Offering an extensive customer support and after-sales system*. High quality and extensive product service expectations in Japan where serving the customer are part of the Japanese business culture.
- *Adapt products to local needs*.
- *Need to develop the right Go-To-Market strategy*

13.2 Challenges for European Companies

Major challenges for European companies are:

- *Choose the right market entry*. Own subsidiary, using a local distributor, licensing or a joint venture are the main alternatives to consider. Long-term the best strategy may be a direct presence through a subsidiary.
- *Expensive after-sales service system.* Japanese companies and customers are very demanding when it comes to the after-sales service. This can be a challenge for European SMEs as it usually will be costlier than in Europe.
- *Cultural differences.* Japan's business culture is quite different compared to Europe.
- *Understanding regulatory requirements.*

13.3 Potential Business Opportunities for European Companies

Japan has a leading position in some of the hydrogen and fuel cell technology segments.

Potential business opportunities for European companies are related to fuel cell systems including components and materials, hydrogen storage including hydrogen refuelling station technologies, and hydrogen production technology.

(1) *Fuel cell systems, components and material*

An emerging trend is the increasing number of large-scale SOFC models for offices and other commercial facilities being developed by Japanese players. This could open up opportunities for European players with capabilities in this segment.

Development of SOFC materials for operation at intermediate temperature ranges could be another potential subfield for European companies that could help Japanese companies to overcome remaining challenges in the fuel cell development.

Main research focus areas in Japan related to fuel cells include membranes, membrane electrode assemblies, electro catalysts and electrode design/architecture, gas diffusion layers and bipolar plates. This could be interesting for European companies with attractive technology solutions in these subfields.

Catalysts, in particular, are a subfield that is gaining the attention of Japanese fuel cell manufacturers. The wide uses of PEMFCs that utilise catalysts make it necessary to find ways to reduce the use of platinum as catalyst material due to cost concerns. This could offer opportunities for European SMEs that can offer solutions, for instance, without use of platinum.

Superlight materials, for instance lightweight composite tanks for high-pressure storage, are a subfield of strategic importance in Japan that could offer opportunities.

In the non-stationary power application segment, micro-applications in portable devices including mobile telephone and consumer electronics such as computers could offer opportunities. Judging from the literature review, there seems not to be much activity or development in Japan.

(2) *Hydrogen storage and distribution*

Much attention is being directed towards technologies for long-distance mass transportation of liquefied hydrogen including loading and unloading of liquefied hydrogen. This could offer opportunities for European companies with relevant capabilities.

Japan needs to build out its network of hydrogen refuelling stations. This is a segment where European technology already has entered Japan through companies such as Linde, Air Liquide and H2 Logic. There could also be opportunities for other European companies with attractive technologies/solutions.

(3) *Hydrogen production technology*

For Japan, the priority is to develop efficient hydrogen production technologies with a focus on renewable and low carbon sources. The ultimate objective is to lower the cost of hydrogen delivery at the point of use. Japan will likely not be able to achieve this alone and this could offer additional opportunities for European companies.

Own subsidiary, using a local distributor, licensing or joint venture are potential entry modes to the Japanese market. Joint development is an additional mode. One example is Nisshinbo, an energy company that is developing a new PEM fuel cell catalyst together with Ballard Power Systems.

14 Summary & Recommendations

Japan aims to materialise a hydrogen society as envisioned by Prime Minister Abe. Besides promoting hydrogen fuel cell vehicles, Japan is also pushing the market expansion of household fuel cells capable of generating electricity. The Japanese government has supported the markets by funding much of the R&D including financing of demonstration projects at levels up to 100 percent.

Japan is a global leader in the field of fuel cell-based stationary power applications, with more than 173,000 units of cumulative sales at the end of June, 2016. Currently, CO2 is emitted when natural gas is passed through the reformer unit to produce hydrogen. In the future, when switching to more pure hydrogen it will possible to more actively cut CO2 emissions.

Most fuel cell systems, however, are not yet cost competitive and massive government subsidies are still required to further develop the market. Utilising pure hydrogen would enable significant cost reductions for fuel cells as there would be no need for reformers and many of the gas purification components. If operated on a piped hydrogen infrastructure, the fuel cells could also be made smaller and cheaper.

Higher production volumes and technological progress are other important factors necessary to bring down hydrogen-related costs. A largely expanded hydrogen infrastructure including a wide network of hydrogen refuelling stations and ample access to hydrogen will facilitate the market uptake of FCVs.

In Japan, the expected wider use of fuel cells in the future will offer business opportunities for European companies. Potential areas are (1) fuel cell systems including components and materials, (2) hydrogen storage and hydrogen refuelling station technologies, and (3) hydrogen production technology.

The stationary segment for large-scale SOFC systems for office buildings and restaurants is expanding and can bring opportunities for European companies with product features that are distinctive enough to differentiate from Japanese products.

Fuel cell components such as membrane electrode assemblies, catalysts and membranes are subfields that could be interesting for European players that can provide components and solutions that the Japanese market wants but does not yet have.

Some European companies with attractive hydrogen refuelling station technologies are already active in this segment in Japan, but it could also be business opportunities for other companies.

Hydrogen production technology is another potential area in which European companies with technology across the entire hydrogen supply chain from production to storage could gain business chances by offering interesting solutions.

As always, visiting trade fairs in Japan will give rich opportunities not only to find out in detail about Japanese products and solutions, but also to meet Japanese companies and discuss business opportunities including partnering.

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