

The background of the entire page is a decorative image. It features a blue grid pattern, possibly a fuel cell component, with numerous water droplets of varying sizes scattered across it. The lighting creates a bokeh effect with the droplets.

# **FUEL CELL INDUSTRY ANALYSIS REPORT**

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01/01/2015





## BAMBU, THE TEAM

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**Benoit Serot**

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## Part 1

### 1. INTRODUCTION

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#### 1.1 Intentions

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## 1.2 History of fuel cells

## 1.3 Fuel cell as an alternative

## 1.4 Short industry overview

# FUEL CELL

## Part 2

### 2. PRODUCT DESCRIPTION

In this second part, we will provide the reader with an explanation on the way a fuel cell works. A listing of the different technologies available today will also be made according to their characteristics. These define the application perspectives for the product. Eventually, we will dedicate a whole part to the infrastructure necessary to the production and the distribution of hydrogen.

The aim of the section is to give the reader the keys to understand the results of the market analysis that will be led farther in this report with a product view.

#### 2.1 Introduction

The basic principle underlying in the fuel cell technology is to combine oxygen and hydrogen to produce electricity and water. As well as a battery, it provides electricity out of a chemical reaction. The main difference lies in the fact that a fuel cell uses an external sources of hydrogen and oxygen to keep running. The hydrogen source will later be referred to as the fuel.

The structure of the product is meant to enable such a chemical reaction. It consists of an electrolyte and 2 electrodes. The electrolyte is the element that sets the temperature of operation. The range of temperature then

***A fuel cell combines oxygen and hydrogen to produce electricity and water.***

#### Chemical representations:

- Oxygen (O)
- Hydrogen (H)
- Water (H<sub>2</sub>O)

**Electrode** : An electrical conductor used to make contact with a nonmetallic part of a circuit. (Wikipedia contributors 2015a)

**Electrolyte** : A substance that ionizes when dissolved in suitable solvents such as water. (Wikipedia contributors 2015b)

**Reduction** : Chemical reaction during which an element gains electrons.

**Oxydation** : Chemical reaction during which an elements gives electrons away.





determines what catalyst is to be used in order to accelerate the reaction and what fuel can be used. What with the electrodes, they are of two types: the anode where the fuel is being oxidized, and the cathode where oxygen gets reduced. As a result, the voltage of a fuel cell circuit has an order of magnitude of 1 V. Higher values can be reached by assembling several fuel cells in stacks.

## 2.2 Technologies

Research has led today to the development of different fuel cell types. They vary in terms of electrolyte, catalyst, but also in their operating temperature window. Another characteristic that defines them is their tolerance to impurities in the fuel. Indeed, even though hydrogen represents the most abundant chemical element in the universe, it is the most volatile as well. As a consequence, it combines with other elements to form more complex molecules that cannot directly be used as fuels. Eventually, each fuel cell type has its proper power output range, power density, and efficiency, which are determinant in their application perspectives.

In this paragraph, we will give these details about the six most common fuel cell types: PEMFC, AFC, PAFC, SOFC, MCFC, and DMFC<sup>1 2</sup>. They all have already been developed in a commercial context, which testifies of the reliability of their characteristic.

### 2.2.1 PEMFC

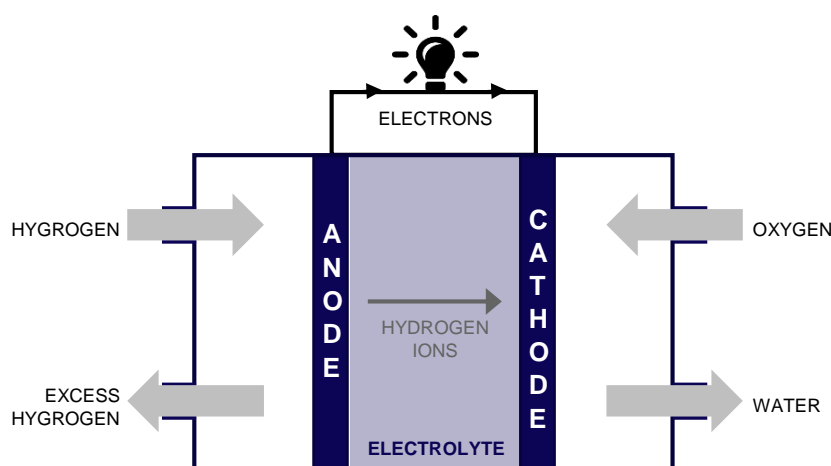


Figure 1: Schematic representation of the structure of a PEMFC

The Proton Exchange Membrane Fuel Cell is made of with polymer electrolyte. According to the basic component of it, it can operate at low or high temperatures.

#### Fuel Cell Abbreviations :

- PEMFC : Proton Exchange Membrane Fuel Cell.
- AFC : Alkaline Fuel Cell.
- PAFC : Phosphoric Acid Fuel Cell.
- SOFC : Solid Oxide Fuel Cell.
- MCFC : Molten Carbonate Fuel Cell.
- DMFC : Direct Methanol Fuel Cell.
- LT : Low Temperature
- HT : High Temperature

**Polymer** : A polymer is a kind of chemical molecule. It is a large molecule in which subgroups of elements are repeated sequentially. The basic subgroup defines the type of polymer.

<sup>1</sup> nedstack

<sup>2</sup> FuelCellToday





Low temperature PEMFC have a water-based electrolyte. They can operate from 40 to 90 °C. This gives them the advantage of handling cold start. However, this temperature range combined with the fact that their electrodes are platinum-based (a noble metal) gives them only little tolerance to impurities in the fuel. Consequently, they have to be run with pure hydrogen. They are appropriate to deliver dynamic supply which gives them all the characteristics for transport uses.

The typical output range for LT PEMFC is between 1 mW and 100 kW and the power density around 0.7 W.cm<sup>2</sup>.

PEMFC can also operate at high temperatures. In such a case, the electrolyte is replaced by a mineral acid-based polymer and the acceptance of impurities in the fuel is improved.

### 2.2.2 DMFC

The Direct Methanol Fuel Cell is made of the same kind of membrane polymer electrolyte as the PEMFC. It therefore works at similar temperature. The main difference between the two comes from the catalyst which permits the transformation of methanol into carbon dioxide and hydrogen ions at the anode of the device. Methanol is a cheap fuel and easy to store and transport compared to hydrogen. However, the reaction involved rejects carbon dioxide.

DMFC are usually used for low power applications such as in mobile devices. Its output can indeed only reach 1 kW. The power density of DMFC can go up to 0.25 W.cm<sup>2</sup>.

### 2.2.3 AFC

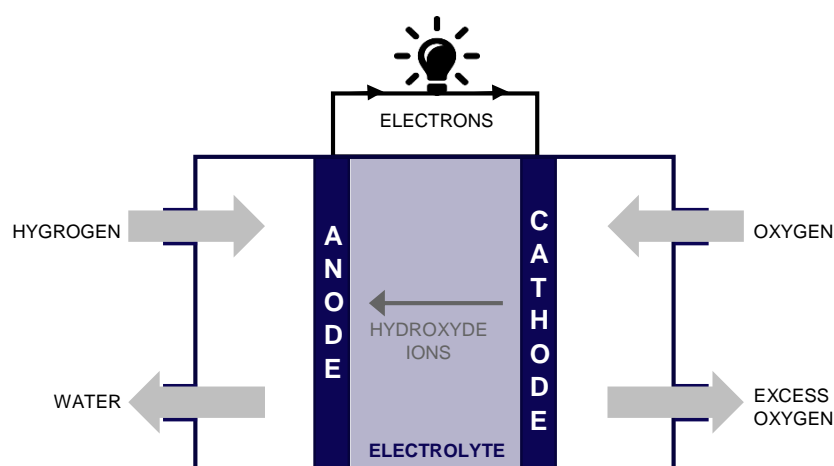


Figure 2: Schematic representation of the structure of an AFC

Alkaline Fuel Cell is a name that comes from the fact that the electrolyte consists of an alkaline. The most common one is potassium hydroxide. Thanks to it, the temperature window is large, from 40 to 200°C. In addition

**Alkali :** A basic, ionic salt of an alkali metal or alkaline earth metal chemical element. (Wikipedia 2015a)

**Alkaline elements :** Elements part of the second of the periodic table of elements.





to this, the electrodes of the AFC do not have to be made of noble-metals. However, its spread is limited because of the complete intolerance to impurities in hydrogen.

The power output can be expected to be between 1 and 5 kW and the power density between 0.1 and 0.3 W.cm<sup>-2</sup>.

#### 2.2.4 PAFC

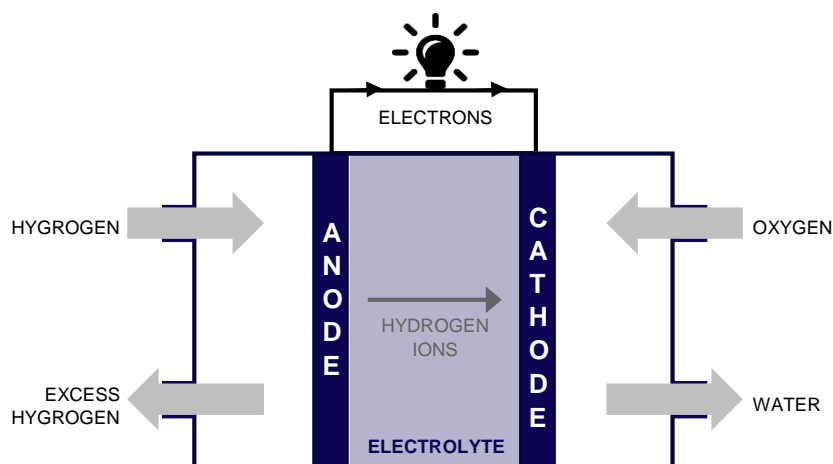


Figure 3: Schematic representation of the structure of a PAFC

#### Combined Heat & Power System :

System that uses a heat engine or power station to generate electricity and useful heat at the same time. (Wikipedia 2015b)

The Phosphoric Acid Fuel, as opposed to alkaline ones, can accept carbon monoxide in their fuel up to 2 %. Their electrolyte is made of phosphoric acid and the electrodes with platinum. The resulting operating temperature is around 200 °C. This type of fuel cell has a low efficiency in itself (55 %), but can be integrated into combined heat and power structures in order to reach an 80 % system ratio.

Its typical output range is higher than the previously mentioned fuel cells with an upper limit of circa 200 kW, which encourages its integration into industrial or commercial heat and power systems. The power density of such cell lies around 0.14 W.cm<sup>-2</sup>.



## 2.2.5 SOFC

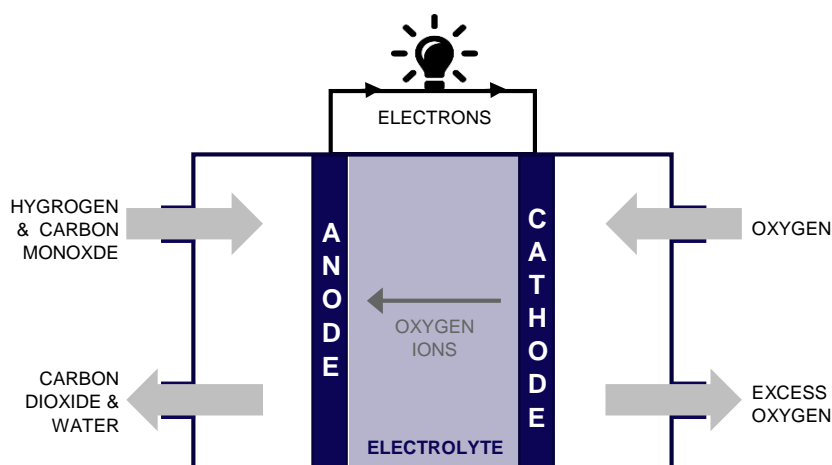


Figure 4: Schematic representation of the structure of a SOFC

Another HT operating fuel cell is the Solid Oxide Fuel Cell. It can be run between 600 and 950 °C. This is due to the solid ceramic electrolyte of the cell (mostly yttrium stabilized zirconia). It provides a great resistance to impurities, as natural gas or even hydrocarbons can be used as fuels. In addition to this, the heat facilitates chemical reactions, and no catalyst is hence needed. The efficiency of SOFC is higher than the one of PAFC, but it remains interesting to use them as combined heat and power units. This is one of their main applications for domestic use. However, their power output range being very wide, from 1 mW to 5 MW, they can also found an application as small electronic charger. Their power density is between 0.15 and 0.7 W.cm<sup>-2</sup>.

**Yttrium-stabilized zirconia** : YSZ is a ceramic combining oxides to stabilize its structure.

## 2.2.6 MCFC

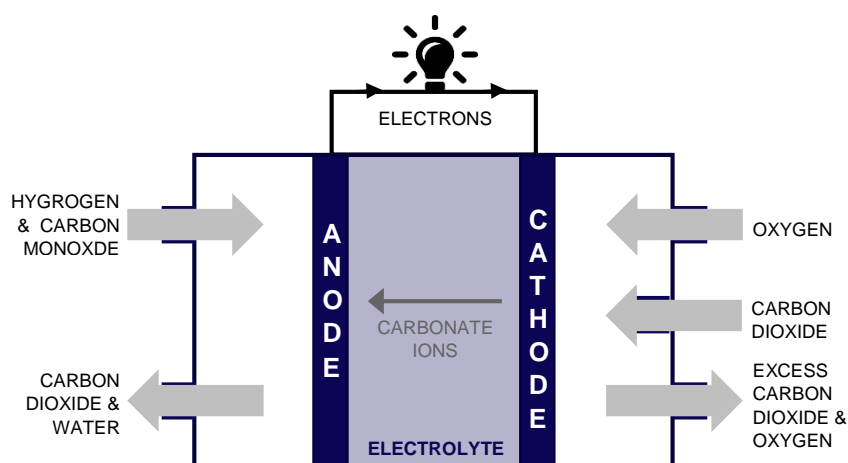


Figure 5: Schematic representation of the structure of an MCFC

Eventually, the Molten Carbonate Fuel Cell can also deliver a high power output (up to 5MW). It consequently is typically used in large heat and power plants. Its temperature window indeed is around 650 °C, which again





In order to understand what fuel cell technology is through an explanative video and to have an introduction about the following parts, you can visit the U.S. Department of Energy's YouTube account and watch:

#### Energy 101: Fuel Cell Technology



improves its tolerance in terms of fuel. Its electrolyte consists of a molten carbonate salt, made of components such as lithium, sodium and carbonate potassium. Carbon dioxide has to be injected on the side of the cathode in order to form the carbonate ions that will circulate in it. Once again, its high operating temperature only allows a slow start. It has a low power density, between 0.1 and 0.12 W.cm<sup>-2</sup>.

### 2.2.7 Conclusion

Among the six types of fuel cells presented above, various output power ranges and operating conditions are available. According to the fuel that is to be used, the output expected (power only or combined power and heat), the profile of the energy demand (stable or not) and the size of the cell, these products already provide a wide range of options, which makes various applications conceivable.

The following table is storing the characteristics mentioned previously in a normalized way.

Table 1: Summary of the different fuel cells and their operating conditions

Type of FC	Electrolyte	Fuel	Operating Temp. (°C)	Output Range	Cell Efficiency (%)	Power Density (W.cm <sup>-2</sup> )
LT PEMFC	Polymer (Water Base)	H <sub>2</sub>	[40, 90]	1 mW – 100 kW	[50, 70]	0.7
HT PEMFC	Polymer (Mineral Acid Base)	H <sub>2</sub> (/CO)	[125, 220]	100 W – 10 kW	[50, 70]	0.7
DMFC	Polymer	Methanol	[60, 130]	1 mW – 1 kW	[20, 30]	0.25
AFC	KOH	H <sub>2</sub>	[40, 200]	1 kW – 5 kW	[60, 70]	[0.1, 0.3]
PAFC	Phosphoric Acid	H <sub>2</sub> (/CO)	200	25 kW – 200 kW	55	0.14
SOFC	Solid Oxide	CH <sub>4</sub> , H <sub>2</sub> , CO	[600, 950]	1 mW – 5 MW	[60, 65]	[0.15, 0.7]
MCFC	Molten Carbonate	CH <sub>4</sub> , H <sub>2</sub> , CO	650	50 kW – 5 MW	55	[0.1, 0.12]

Electrodes: ☒ Noble metal ☐ Noble or non-noble meta ☐ Non-noble metal



## 2.3 Applications

The second paragraph of this part was setting the emphasis on the characteristics of six specific fuel cell products. In doing so, it followed the conventions already used by other informative organisms such as FuelCellToday which defines itself as *the leading authority on fuel cells*. This paragraph being dedicated to the different applications of fuel cells, it will remain consistent with these norms in order to help them become references for the whole fuel cell industry. They differentiate three different range of applications according to the use that is made of the fuel cell corresponding to the following contexts<sup>3 4</sup>:

- **Transport:** Units providing propulsive power to a vehicle.
- **Stationary:** Units providing power (and sometimes heat) but are not meant to be mobile.
- **Portable:** Units integrating systems designed to be moved.

### 2.3.1 Transport

“Units providing propulsive power to a vehicle.”

This definition matches with the most advertised fuel cell application: hydrogen cars. However, fuel cell power can also be used for other vehicles. As an example, boats or even submarines can work with hydrogen. In addition to reduce polluting gas emission, it presents the advantage of being silent.

Boeing's project to build a completely hydrogen powered unmanned aircraft is advertised on YouTube:

Boeing's fuel cell technology is making sustainable flight closer to reality



Figure 6: A hydrogen powered bus in London



<sup>3</sup> FuelCellToday

<sup>4</sup> Hart et al. 2014





Some light aircrafts are also fuel cell powered, with companies such as Boeing showing their interest for the technology. Other applications in the professional world are light-duty vehicles, forklifts or trucks.

### 2.3.2 Stationary

“Units providing power (and sometimes heat) but are not meant to be mobile.”

In UPS, fuel cells are often installed as backup supply units that would be able to keep running and provide electricity even in case of a failure from the grid. As an example, it can be used for servers or other IT products.

These applications represent a particularly high ratio in the hydrogen power. The main reason is that they include large power plants. Those can be built in remote places where electricity is hard to “ship” in order to improve the reliability for users by implementing off-line supplies. As an examples, they might be useful for some factories or villages that are hardly reachable. The fact that a fuel cell can work off-line makes it have an advantage towards Uninterruptible Power Systems (UPS).

A stationary application can also be of smaller scale, for simple residential use. It corresponds to the context in which a power and heat combination can be fully exploited and is all the more advantageous for the user. Those units are spreading in Asian countries such as Japan and South Korea thanks to government incentives.



Figure 7: SOFC installation by Bloom Energy at a NASA center

### 2.3.3 Portable

“Units integrating systems designed to be moved.”

Portable units are designed to charge or be part of portable devices. Auxiliary power units (APU) that can be used to charge electronic devices are therefore part of them. They can also integrate portable systems such as a torch, a music player, or even a personal computer. Thereupon they represent a field of investigation for military laboratories. Indeed, a fuel cell powered device discharges more slowly recharges more quickly than one running a conventional battery, which increases reliability. In addition to this, it operates silently weighs little, and can work off-grid.

If you are curious about how to charge your phone with hydrogen, you can visit this YouTube page:

**Fuel-cell phone charger makes its own electricity**



Figure 8: A fuel cell charger designed by Brunton. It uses small hydrogen reservoirs to refuel.

### 2.3.4 Conclusion

Table 2: Summary of the different applications for fuel cells

Category	Power Range	FC Type	Applications
Transport	1 kW to 100 kW	<ul style="list-style-type: none"> <li>• PEMFC</li> <li>• AFC</li> </ul>	<ul style="list-style-type: none"> <li>• Personal Vehicles (cars; motorcycles; scooters)</li> <li>• Transportation (planes; trains; boats or ferries)</li> <li>• Military use (plane; submarine)</li> <li>• Support to other power supplies</li> </ul>
Stationary	0.5 kW to 5 MW	<ul style="list-style-type: none"> <li>• PEMFC</li> <li>• SOFC</li> <li>• MCFC</li> <li>• PAFC</li> <li>• AFC</li> </ul>	<ul style="list-style-type: none"> <li>• Residential supply (CHP or simply power)</li> <li>• UPS</li> <li>• Primary power units (large or small prime power plants)</li> </ul>
Portable	5 W to 500 kW	<ul style="list-style-type: none"> <li>• PEMFC</li> <li>• DMFC</li> </ul>	<ul style="list-style-type: none"> <li>• APU</li> <li>• Personal electric devices (small or large)</li> <li>• Military use</li> </ul>





## 2.4 Infrastructure

As explained previously, a fuel cell is a product able to produce energy out of a chemical reaction that minimizes polluting emissions compared to traditional gas power engines. This reaction nevertheless is not completely natural in the way that it has to be triggered by some specific conditions such as the temperature, the electrolyse structure, and eventually, the supply in a fuel: hydrogen. Depending on the model, hydrogen can be of more or less pure constitution, but the air we breathe does not have a high enough concentration in it to consist of a fuel. As a consequence, the gas used needs to be processed and stored before it is distributed to the operating units.

These steps are preceding the fuel cell exploitation. As a consequence, the fuel cell and the hydrogen industries are profoundly correlated by justifying each other. Indeed they could not survive separately. This paragraph provides a short introduction to the hydrogen distribution infrastructure, which is essential to be thought of for fuel cells to be adopted by the general public. In a second part, it will address two different hydrogen production modes and their implementation conditions.

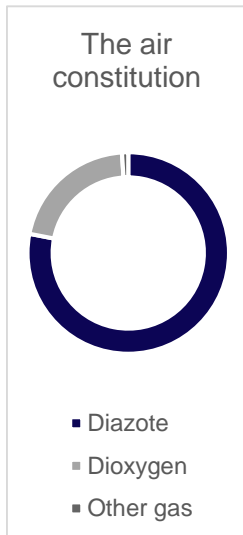


Figure 9 The air present on the surface of Earth is made of 78,08 % of diazote, 20,95 % of dioxygen, and 1 % of other gas. Hydrogen represents only a 0,000072 % fraction of it.

### 2.4.1 Distribution facilities

Hydrogen is the lightest chemical element on earth. In such a normal environment, it has the state of a gas. It therefore is volatile and its volumetric mass is very low. As a consequence, in one given unit of volume, there is less hydrogen than there would be of any other element (8 MJ.L<sup>-1</sup> against 32 MJ.L<sup>-1</sup> for gasoline). And less hydrogen implies less fuel. Hydrogen therefore is a costly fuel to ship.



Figure 10: A hydrogen "plug" on a car



#### 2.4.1.1 Delivery

Today, there are three different ways of transporting hydrogen, in pipelines, or in containers. The first option is particularly expensive in the short term because it requires a complete network and infrastructure to be built in order to adapt to users' needs. It is the best way to transport large quantities of fuel. The second option is adapted to smaller needs, by storing hydrogen into closed containers that can then be shipped by conventional methods (truck, train or boat carriage). Again, there exist two possibilities to do this. The first one is to compress hydrogen and store it into high pressure tubes. The other one is to liquefy the fuel in order to put it into liquid insulated tankers. However, this option remains costly because it requires to bring the gas at its liquefaction temperature,  $-253\text{ }^{\circ}\text{C}$  and then to use adapted refrigerating devices. The advantage of it is that it holds more fuel per volume unit.



Figure 11: Hydrogen high pressure tubes designed by Shijiazhuang Enric Gas Equipment Co.

Eventually, as it is the properties of hydrogen that make it hard to transport, it is also possible to mix it with other elements in order to ship it as ethanol or ammoniac for example. However, the drawback of this method is that a dehydration process has to be carried before use. This last method is referred to as carrier and is still at a development stage.

#### 2.4.1.2 Hydrogen storage

With regards to the previously addressed problems related to hydrogen delivery, storage is also a delicate task, especially when it comes to achieve this in a moving vehicle. Several solutions have been implemented:

#### Hydrogen Transportation:

- Pipeline



- Conventional transportation modes





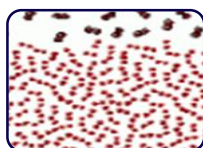


Hydrogen  
production plant in  
Rotterdam



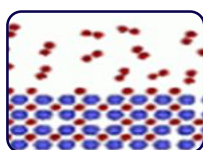
### Compressed gas storage

- Hydrogen is subject to in 5,000 to 10,000 psi in a tank



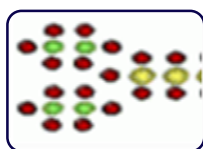
### Cryogenic liquid storage

- The temperature of the tanks has to be maintained under 253 °C



### Material-based storage

- Hydrogen then infiltrates into the structure of solid or liquid materials and can be stored in conditions of temperature and pressure that are closer to normal



### Chemical storage

- Hydrogen is then stored by the medium of the reaction between hydrogen containing components and water

Figure 12 : Illustration of the different storage modes for Hydrogen

## 2.4.2 Hydrogen production

Fuel cell is a promising zero-emission concept. Nevertheless, because it is in addition to delivery and storage a costly process in terms of energy. Whether hydrogen power is green or not then depends on how it is produced. Today, the sources are natural gas, electricity, solar energy and biomass. The second one is all the more interesting with the fact that it can be collected from natural energy such as wind, solar, or biomass power. Solar and biomass energy however can be involved in direct hydrogen production, which differentiates them from conventional electric sources.

In this paragraph, the emphasis will lie on two specific hydrogen production modes, gas reforming and electrolysis. The first one is already well adopted in the hydrogen industry. As an example, it is responsible for 95% of the hydrogen production in the United States<sup>5</sup>. The second works thanks to electricity. It therefore is adaptable to various sources of power and can easily integrate existing electrical grids.

### 2.4.2.1 Gas Reforming

It is today the main hydrogen production mode because the process is mature and can respond to large needs of the users. It relies on chemical reactions involving methane ( $\text{CH}_4$ ):

- Partial Oxidation

<sup>5</sup> EERE 2015





- Steam Reforming

Gas reforming is criticized because of its greenhouse gas emissions. It nevertheless remains lower than what results of the use of gasoline power engines.

#### 2.4.2.2 *Electrolysis*

The idea behind the electrolysis is to reverse the fuel cell process, i.e.: use electricity to split water into oxygen and hydrogen.

The technology required therefore is similar to the one of fuel cells, proton exchange membrane, alkaline and solid oxide electrolyzers being preferred in practice.

Electrolysis units can easily integrate power systems. They can be of various size just as well as fuel cell and hence can be used in residential or industrial contexts. This is particularly interesting because it raises the question of centralized or distributed production. Indeed, the previous paragraph about Distribution Facilities mentioned some of the difficulties storage and delivery have to overpass. Decentralizing the production of hydrogen could help reduce delivery-related problems. What with storage, its resort could be minimized with dynamic production units, available thanks to the PEM technology (cf. 2.2.1. PEMFC).





## Part 3

### 3. MARKET PERSPECTIVE

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#### 3.1 Introduction

In general, fuel cells are devices capable of combining hydrogen and oxygen thus, obtaining electricity, water and heat in the process. And it differs from batteries because of the fact that it would continually produce electricity as long as hydrogen is being provided to the cells, it also differs from the conventional energy sources due to it does not burn fuel, thus it holds few advantages :

- 1) The generation process is quiet
- 2) The process is pollution-free
- 3) It's two to three times more efficient than combustion<sup>6</sup>

The markets for fuel cells can be classified into:

- 1) stationary power: applications where the fuel cells are working at a stationary or fixed location mostly for primary power, CHP or backup power sources;
- 2) transportation power: applications where fuel cells are used in transportation vehicles like passenger cars, buses and other FCEVs ;
- 3) and portable power: applications where fuel cells are in portable electronic devices like MP3 players, laptops, mobile phones.

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<sup>6</sup> US Department of Energy



### 3.2 Investment Cost Reduction

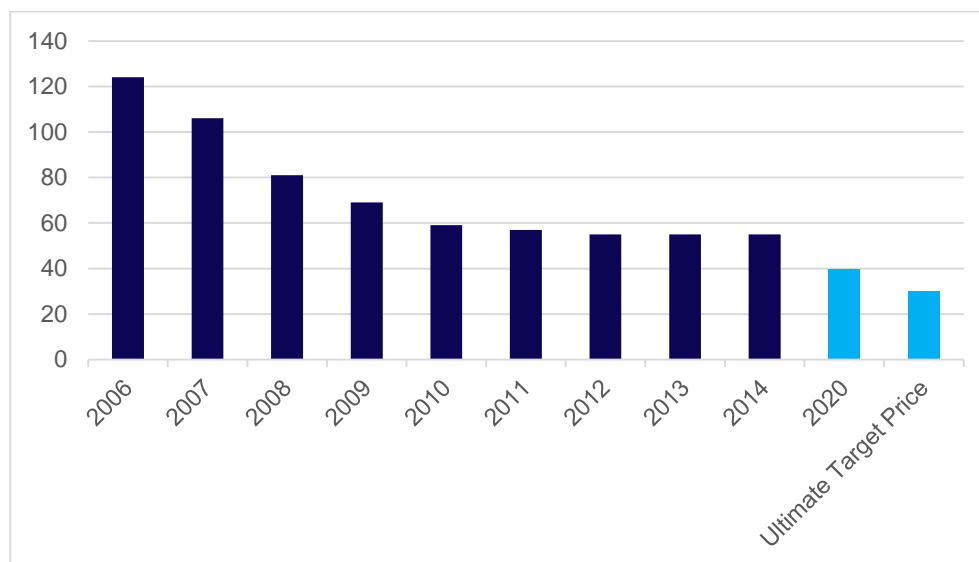


Figure 13 : FC Investment Cost Reduction <sup>7</sup>

In the last decade, the cost of fuel cells continued to decline significantly in terms of the average capital needed in order to generate a unit kilowatt of energy using fuel cells, as it is pointed out in the figure above that the cost of fuel cells decreased by fifty percent in a period of five years mainly because R&D departments of many companies attempted and succeeded to some extents in making the fuel cell prices comparable with conventional energy sources. At the same time, it was discovered that durability of the cells has increased by two times in general.<sup>8</sup> The fuel cells cost have then been quite stable for three years till now. However, experts projected that the investment cost will again decrease further in the year 2020, due to fuel cells will be actively used in public transportation.<sup>9</sup>

### 3.3 Intellectual Property

The data in this section is referred from the Clean Energy Patent Growth Index report which keeps tracks of clean energy patents and covered many sectors involved, including fuel cells.<sup>10</sup>

In brief, automakers took most control. Toyota Corporation has once again been receiving most fuel cell patents since it did so in 2012, now with 89 patents. While General Motors Corporation with 89 patents comes as the second highest. Samsung and Honda are in the third and fourth places

<sup>7</sup> [http://www.hydrogen.energy.gov/pdfs/14014\\_fuel\\_cell\\_system\\_cost\\_2014.pdf](http://www.hydrogen.energy.gov/pdfs/14014_fuel_cell_system_cost_2014.pdf)

<sup>8</sup> [http://www.hydrogen.energy.gov/pdfs/11003\\_fuel\\_cell\\_stack\\_durability.pdf](http://www.hydrogen.energy.gov/pdfs/11003_fuel_cell_stack_durability.pdf)

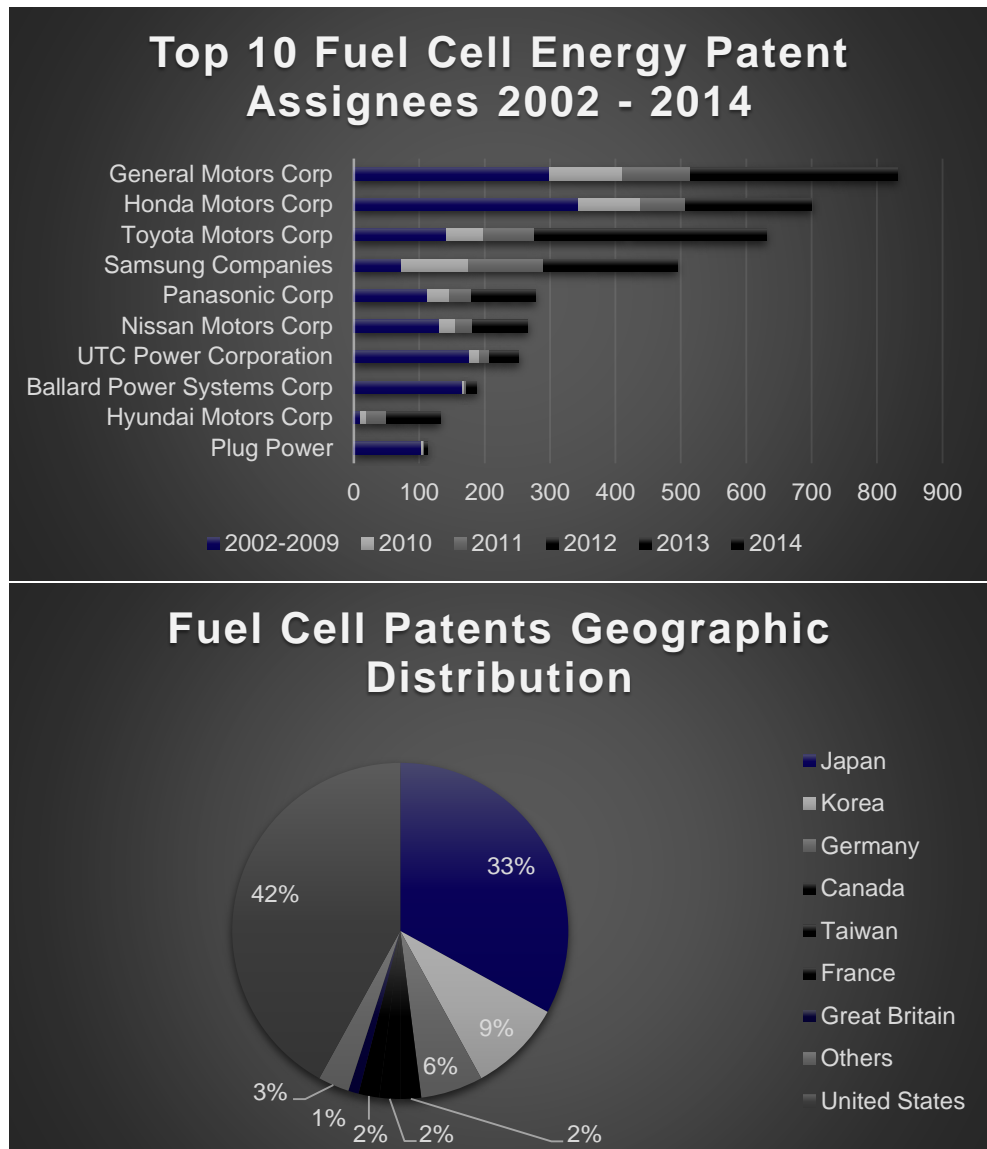
<sup>9</sup> E4tech

<sup>10</sup> <http://www.cepgi.com/2015/04/2014-year-end.html>



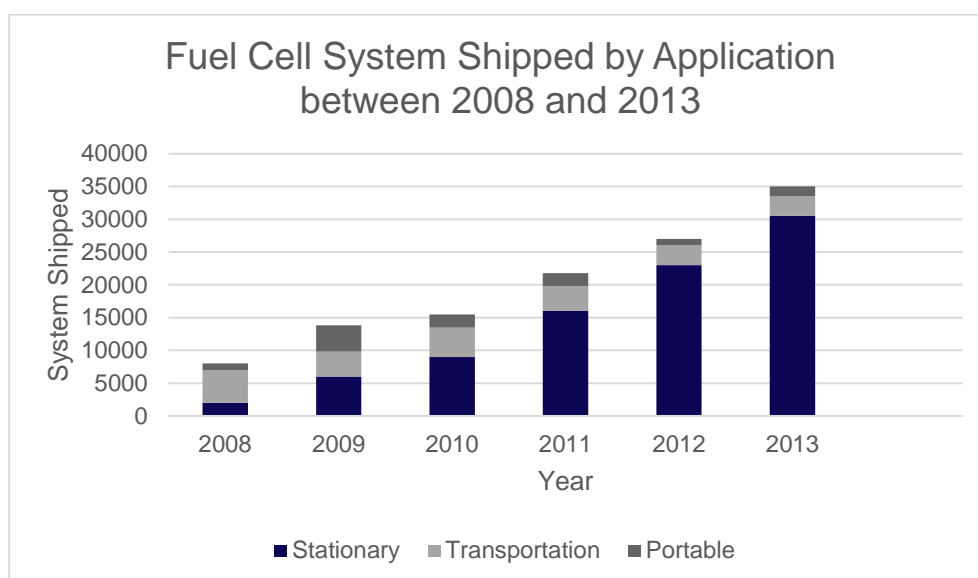


respectively. The approximate number of patent entities granted is 300. The figures below show the distribution between the top ten assignees and how the patents are distributed geographically.



### 3.4 Quantity of Fuel Cells shipped

The shipments of the fuel cell systems shipped in terms of individual systems shipped divided in terms of applications namely: stationary power, transportation power and portable power. Transportation power used to be the majority of the shipped system in 2008. However, with the introduction of the CHP units in the market, residential units of CHP were continuously deployed in Japan. And in the year 2013 alone, more than 26,000 units have been shipped to Japan. The shipments of transportation and portable FC have been quite stable and experts forecast that it will remain so at least for a couple of years.



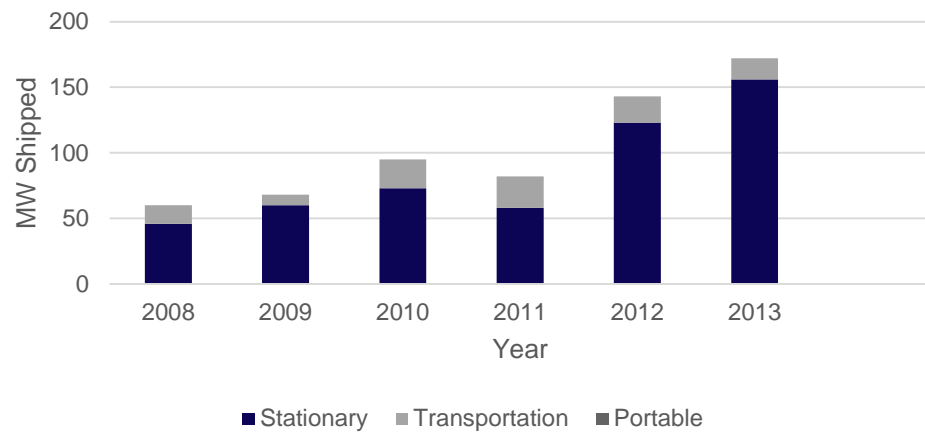
Form the figure above, we may notice that portable shipments are not visible in the graph this is due to the quantitative value of MW shipped less than 1 MW each year for portable power FC. Majority of stationary FC displayed in this graph is contributed from CHP and telecommunication backup power which require decent amount of power to maintain its operation.



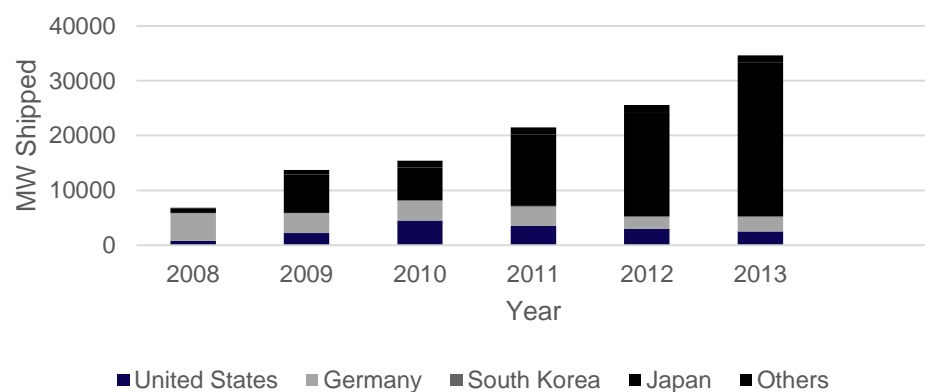


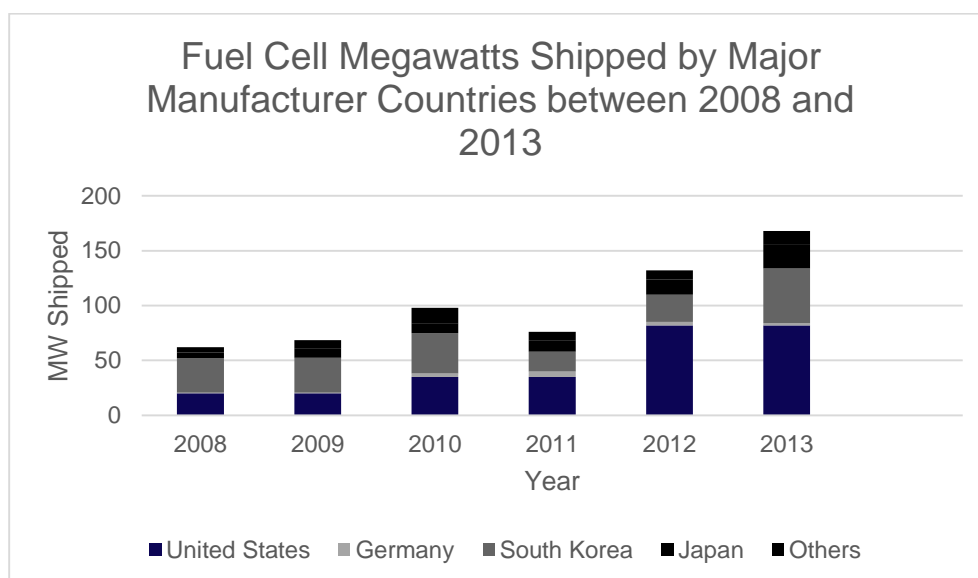


Fuel Cell Magawatts Shipped by Applications  
between 2008 and 2013



Fuel Cell System Shipped by Major  
Manufacturer Countries between 2008 and  
2013





In terms of countries, the US FC shipments remains quite stationary and the growth is stagnant mainly due to the end of federal American Recovery and Reinvestment Act or (ARRA) which leads to the decline in Fuel Cell shipments but the decline is expected to be reversed in the few years. When the act will be re-enacted and this will encourage a number of companies to deploy fuel cells at their warehouses.<sup>11</sup> For fuel cell electric vehicles, the global shipments remains quite low this is because of the major auto manufacturers planned to release their commercial fuel cell electric vehicles starting in the year 2017. The notable company that took initiative in shipping commercial fuel cell vehicles is Hyundai who started the shipment to European Region in the year 2013.<sup>12</sup>

<sup>11</sup> <http://www.recovery.gov/arra/Pages/default.aspx>

<sup>12</sup> <http://www.hyundai.co.uk/about-us/environment/hydrogen-fuel-cell>





### 3.5 Company Profiles

Currently the fuel cell market is flourished with many companies developing a variety of different products ranging from small hand held fuel cell mp3 players to big substations used to power backup for vital communications. Our group decided to give introduction to all the aspects of fuel cells, therefore introduction to fuel cell companies from all corners of the world are covered in this chapter. Notice that this is not the complete list of all the manufacturers, since there are many public and private companies in existence but the profiles provided in this chapter should prove significant to give insight to the entire fuel cell industry.

Here is the list of companies included in this IAR in alphabetical order:

- Bloom Energy
- Horizon Fuel Cell Technologies
- Intelligent Energy
- Nedstack
- Panasonic
- Plug Power
- SFC Energy
- Toshiba



### 3.5.1 Bloom Energy

Fuel Cells

The company was founded in the year 2001 and is headquartered in Sunnyvale, California. Its first customer was the University of Tennessee, which ordered the company a SOFC product for educational purposes in 2006. Many other university across the United States similarly ordered the same product to conduct field trials. But it wasn't until July of 2008 that the first commercial version of Bloom Energy's products were shipped to Google. The company proved to be one of the highest ranked SOFC producers since then some notable customers of this firm includes Adobe, Bank of America, Coca-Cola, eBay, Google, Kaiser Permanente, and Walmart. The Company claimed that their products have already generated more than 100 million kilowatt-hours of clean energy for its customers.<sup>13</sup>

Headquarters	California, USA
Fuel Cell Type	SOFC
Market	Stationary (Large-Scale)
Application	Buildings(commercial, universities, arenas) data centers



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<sup>13</sup> <http://www.bloomenergy.com>

<sup>14</sup> <http://www.teqarazzi.com/bloom-box-energy-server-hands-on-literally-with-video/>





### 3.5.2 Horizon Fuel Cell Technologies

Horizon is currently the largest micro fuel cell producer and the largest producer of PEM fuel cell stacks below 1,000 W. Today, the firm produces compact, lightweight PEM fuel cells at various performance levels, and also delivers hydrogen storage and on-site hydrogen generation solutions for multiple applications. The company was founded in 2003 and it currently own five subsidiaries around the globe.<sup>15</sup>

Headquarters	Singapore
Fuel Cell Type	PEM
Market	Portable, Stationary(backup)
Application	Educational, consumer electronics, military, aerospace

**PEM:**

Proton Ex  
Membran

<sup>15</sup> <http://www.horizonfuelcell.com>





### 3.5.3 Intelligent Energy



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Intelligent Energy was founded in Loughborough, United Kingdom 2001. Its main focuses are Proton Exchange Membrane type fuel cells. The firm partners with global companies that research on automotive, stationary power, and consumer electronics markets. Very notable accomplishments include collaborating with Suzuki Motor Corporation and built “Burgman” the first fuel cell scooter to achieve European Whole Vehicle Type Approval, and supplying fuel cells to Boeing who used it for the first fuel cell aircraft.<sup>17</sup>

<b>Headquarters</b>	<b>Loughborough, United Kingdoms</b>
Fuel Cell Type	PEM
Market	Portable, Stationary(backup)
Application	Aerospace, defense, generation portable power, automotive



<sup>16</sup> <http://ec.europa.eu/energy/intelligent/>

<sup>17</sup> <http://www.intelligent-energy.com/>





### 3.5.4 Nedstack



Nedstack is a PEM fuel cell stack provider for system integrators who delivers energy systems to the telecom, rail, and utilities industries. The company was founded in 1998 when seven engineers took over AkzoNobel's PEM activities. Right now, over 1,000 Nedstack fuel cells are in operation world-wide mostly as backup power sources.<sup>18</sup>

Headquarters	Amhem, The Netherlands
Fuel Cell Type	PEM
Market	Transportation, Stationary(backup)
Application	Stationary power, telecommunication backup, buses



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<sup>18</sup> <http://www.nedstack.com/>

<sup>19</sup> <http://www.engineersonline.nl>



### 3.5.5 Panasonic

# Panasonic

## ideas for life

The firm was founded in the year 1918, at the moment it was known as Matsushita Electronics, the company now comprises of more than 500 sub companies. The company was the first to manufacture a DMFC laptop which was capable for operating continually on battery for 20 hours and displayed it publicly at the International Consumer Electronics Show, 2006'. The firm is also one of the largest global manufacturers for residential CHP, and in recent years, the company managed to miniature and simplify fuel cell's structures.<sup>2021</sup>

Headquarters	Osaka, Japan
Fuel Cell Type	DMFC, PEM
Market	Stationary, Portable
Application	CHP units, Consumer Electronics, DMFC



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<sup>20</sup> <http://panasonic.net>

<sup>21</sup> [http://www.theregister.co.uk/2008/10/20/panasonic\\_dmfc\\_demo/](http://www.theregister.co.uk/2008/10/20/panasonic_dmfc_demo/)

<sup>22</sup> <http://kythuatso.net/the-gioi-so/Panasonic-trien-lam-laptop-pin-nhien-lieu-9ff.html>





### 3.5.6 Plug Power



Plug Power is a major player in the PEM fuel cell material handling equipment market. The company was incorporated the year 1997 as a joint venture between Edison Development Corporation and Mechanical Technology Inc. Right now, the company mainly focuses on GenDrive®, a PEMFC designed for industrial vehicles especially material handling equipment and distribution facilities. The company has deployed over 3,000 GenDrive® units with run times exceeding 8.5 million hours.<sup>23</sup>

Headquarters	Latham, New York
Fuel Cell Type	PEM
Market	Stationary, Transportation
Application	Material Handling Equipment



24

<sup>23</sup> <http://www.plugpower.com/>

<sup>24</sup> <http://www.fleetsandfuels.com/wp-content/uploads/PlugPowerSeries1000.jpg>



### 3.5.7 SFC Energy



The firm produces power generator for mobile homes, yachts and vacation cabins. SFC Energy ally itself with other big companies in different industries and had already shipped more than 30,000 commercial products. The company's facilities are located mainly in the Netherlands and Romania, its fuel cartridges are manufactured in Germany near Munich where its R&D department is located. SFC Energy also manufactures DMFC for mobile and off-grid power serving leisure, industrial and defense market.<sup>25</sup>

<b>Headquarters</b>	<b>Brunnthal, Germany</b>
Fuel Cell Type	DMFC
Market	Stationary
Application	Leisure, industrial and defense



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<sup>25</sup> <http://www.sfc.com/>

<sup>26</sup> <http://www.sfc-defense.com/>





### 3.5.8 Toshiba

# TOSHIBA

## Leading Innovation >>>

In the year 1984, Toshiba operated an experimental 50 kW fuel cell power plant, the first power plant in Japan. The company actively research on DMFC and PEM technologies for the Japanese market. Among the main products are residential PEM fuel cells and PAFC developed since 1990s. The company also demonstrates its DMFC-powered cell phones and MP3 players at the CEATEC conference which can operate for 320 hours using fuel cell and methanol fuel.<sup>27</sup>

Headquarters	Tokyo, Japan
Fuel Cell Type	DMFC, PEM
Market	Stationary, Portable
Application	Consumer Electronics, Residential



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<sup>27</sup> <http://www.toshiba.co.jp>

<sup>28</sup> <http://www.informationweek.com/toshibas-mp3-player-rocks-on-with-alcohol/d-d-id/1036125?>

**CEATEC:**

Combined  
Advanced  
an annual  
Japan.





## Part 4

### 4. LAW AND GOVERNMENTAL REGULATIONS

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It is shown that innovations in their early stages need technology specific support, to prevent lock-in effects of earlier technologies from only incentivizing incremental innovations<sup>29</sup>. When developing such innovations new products or entering markets, firms are acting in a network of governmental influence, universities and customer. The actors, which are engaging in this network, can be classified as the role of the government and the interaction between firms and non-firm. This chapter will discuss the different influences of the institutional framework, which influence the development of technologies, by framing policies, opportunities and capabilities<sup>30</sup>.

Support of new technologies may happen through R&D funding, support for demonstration trials, testing etc. Another form of influence can be planning

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<sup>29</sup> Raimund Bleischwitz and Nikolas Bader, "Policies for the transition towards a hydrogen economy: the EU case," *The socio-economic transition towards a hydrogen economy - findings from European research, with regular papers* 38, no. 10 (2010), doi:10.1016/j.enpol.2009.03.041, <http://www.sciencedirect.com/science/article/pii/S0301421509002006>

<sup>30</sup> Gurneeta Vasudeva, "How national institutions influence technology policies and firms' knowledge-building strategies: A study of fuel cell innovation across industrialized countries," *Research Policy* 38, no. 8 (2009), doi:10.1016/j.respol.2009.05.006, <http://www.sciencedirect.com/science/article/pii/S0048733309001152>





incentives on a regional level, for example incentives for the use of fuel cells in new buildings<sup>31</sup>.

The targets of stimulating the fuel cell industry vary from region to region. In the US they are mainly driven by national security issues, in Europe by environmental targets and in Japan economic as well as environmental targets. As shown in part **Erreur ! Source du renvoi introuvable.** there are several technologies, policies may vary from technology to technology depending on which focus is set and therefore create competition between those. Also other technologies compete or complement fuel cell. Incentives can be a high influence on creating the wanted effects<sup>32</sup>. One of the main indicators of political influence are the expenditures for R&D in this area. In the following the situation in the three countries which are ranked highest with regard to expenditures are analyzed<sup>33</sup>. Other possible influences are subsidies or public support.

Although often seen together hydrogen and renewable energies have some distinctions, which influence the policies, as it is unlikely that the same policies will work. Hydrogen is an energy carrier and therefore need infrastructure for production and distribution. Hydrogen has to be made compatible for the existing infrastructure and cannot be blended. The future development is heavily relying on critical issues like storage where technological progress is necessary. Therefore a successful policy has to connect market requirements, climate requirements and the hydrogen technology development.<sup>34</sup>

A study in Germany has shown that the political conditions influence the adoption of FC. There is a difference in the adoption thorough commercial and private users. For commercial user the investment decision is influenced by feed in laws for CHP systems and the oil and energy price. Private consumers are positively affected by a future oriented energy policy and clear law statements. Whereas commercial users deny subventions, because they are unreliable, private users endorse subventions to cover expenses which arouse by the use of FC<sup>35</sup>.

METI : Ministry of  
Economy, Trade,  
and Industry  
(Japan)

JHFC : Japan  
Hydrogen and Fuel  
Cell

FCV : Fuel Cell  
Vehicle

<sup>31</sup> Paul E. Dodds et al., "Hydrogen and fuel cell technologies for heating: A review," *International Journal of Hydrogen Energy* 40, no. 5 (2015), doi:10.1016/j.ijhydene.2014.11.059, <http://www.sciencedirect.com/science/article/pii/S0360319914031383>

<sup>32</sup> Vasudeva

<sup>33</sup> P. Lako and M.E. Ros, "R&D expenditure for H2 and FC as indicator for political will," November 2006

<sup>34</sup> Bleischwitz and Bader

<sup>35</sup> Cornelia R. Karger and Richard Bongartz, "External determinants for the adoption of stationary fuel cells—Infrastructure and policy issues," *Energy Policy* 36, no. 2 (2008), doi:10.1016/j.enpol.2007.10.024, <http://www.sciencedirect.com/science/article/pii/S0301421507004806>



## 4.1 Situation in Japan

Due to the lack of fossil fuel sources Japan's government is heavily investing in fuel cells and their research during the last years through R&D funding<sup>363738</sup>. Already in 1974 the sunshine project was started to examine hydrogen power among other renewable energy sources. Around 1980 the development was pushed by the moonlight project who aimed to develop fuel cells. With the new sunshine project of 1993 the effort on PEMFC was increased. All the efforts culminate in the millennium project from 2000. This is including R&D for PEMFC for use in automobile and residential application. This project is flanked by another program to develop tests and evaluation for safety and reliability standards which is stated to be a critical factor for the adoption of a new technology<sup>39</sup>. As a result of the announcement of Daimler-Benz of their failed plan to commercialize fuel cells, the government developed a strategic plan. According to this a partnership between METI and several Japanese fuel cell companies is established and called JHFC project. The intention of this project was mainly focused on the development of a FCV and surrounding infrastructure like hydrogen production, storage and filling. The development is characterized by a high degree of cooperation between government and industry, which is significant for high corporatist countries. The plan was divided in three phases. The first phase from 2002 to 2005 was intended to develop a hydrogen infrastructure and to determine performance statistics. The aim of the second phase from 2006 to 2010 was to develop standards investigate about policies and reduce costs. Besides this plan there was an agreement of the Japanese car manufacturers to release fuel cell vehicles by 2015<sup>40</sup>. In 2002 the Japanese government announced the target to reach 15 GW produced by stationary fuel cells in 2030. Besides funding, another influence of the government, is the research on the practical use of fuel cells. Japan has a clear focus on creating new markets for fuel cell CHP. The Japanese effort is among the highest<sup>41</sup>.

<sup>36</sup> International Energy Agency Staff, *Energy Policies of Iea Countries Japan: 2008* (Washington, Biggleswade: Organization for Economic Cooperation & Development; Turpin Distribution Services Limited [Distributor], 2008)

<sup>37</sup> James E. Brown, Chris N. Hendry, and Paul Harborne, "An emerging market in fuel cells? Residential combined heat and power in four countries," *Energy Policy* 35, no. 4 (2007), doi:10.1016/j.enpol.2006.07.002, <http://www.sciencedirect.com/science/article/pii/S0301421506002813>

<sup>38</sup> Manoj Pudukudy et al., "Renewable hydrogen economy in Asia – Opportunities and challenges: An overview," *Renewable and Sustainable Energy Reviews* 30, no. 0 (2014), doi:10.1016/j.rser.2013.11.015, <http://www.sciencedirect.com/science/article/pii/S1364032113007648>

<sup>39</sup> Brown, Hendry and Harborne

<sup>40</sup> Gareth E. Haslam, Joni Jupesta, and Govindan Parayil, "Assessing fuel cell vehicle innovation and the role of policy in Japan, Korea, and China," *HYFUSEN Special Issue for the 4th National - 3rd Latin American Conference on Hydrogen and Sustainable Energy Sources (HYFUSEN)*, 6-9 June 2011, Mar Del Plata, Argentina 37, no. 19 (2012), doi:10.1016/j.ijhydene.2012.06.112, <http://www.sciencedirect.com/science/article/pii/S0360319912015315>

<sup>41</sup> Brown, Hendry and Harborne





Using FCV and stationary appliances Japan intends to use 4 billion \$ for hydrogen usage and is expecting that by 2020 all road vehicles are powered by hydrogen fuel cells. In 2000 a funding of 25 billion Y were made for R&D on FC, in 2004 another 31 billion Y were spend. The government is also funding manufacturers and an estimated value of 380 million \$/year is done for research and commercialization of FC.

**Japan: \$380 million in 2008 for R&D and commercialization<sup>42</sup>**

## 4.2 Situation in the USA

The electricity market in the US is decentralized. In contrast to Germany or Japan there is less support for creating a market for fuel cell CHP. The SECA program which is focusing on SOFC for small stationary use, SOFC may be the best choice for electricity generation but is lacking behind PEMFC. Besides the US Department of Defense is also investigating about residential fuel cells in military related fields.<sup>43</sup>

US department of energy Hydrogen Program. Furthermore there is a direct subsidy support for manufacturing facilities.<sup>44</sup>

**USA: \$640 million annually to 2014 plus; \$3,000/ kW purchase incentive tax credit<sup>45</sup>**

## 4.3 Situation in Germany

As a part of the EU the German policies have also to be seen in the context of the European framework, as the national framework is largely shaped by the European context. The general consent within the EU is that the “further development and market introduction” is desirable, as it can be a carbon neutral substitute for fossil fuels. One of those projects which empower fuel cell is the JTI in which frame 1 billion € will be spend from 2008 to 2017<sup>46</sup> It was shown that Germany is one of the most innovative regions regarding fuel cells<sup>47,48</sup>. The public federal funding amounts 8-10 million every year. For the time 2001-2003 additionally 15 million were added in the “program on investment into the future”. The Helmholtz foundation, which undertakes

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<sup>42</sup> Canadian Hydrogen and Fuel Cell Association, “10 Reasons to Support Hydrogen and Fuel Cell Funding,” accessed May 6, 2015, [http://www.chfca.ca/media/10\\_Reasons\\_Support\\_Funding.pdf](http://www.chfca.ca/media/10_Reasons_Support_Funding.pdf)

<sup>43</sup> Brown, Hendry and Harborne

<sup>44</sup> Dodds et al.

<sup>45</sup> Canadian Hydrogen and Fuel Cell Association

<sup>46</sup> Bleischwitz and Bader

<sup>47</sup> Anne N. Tanner, “Regional Branching Reconsidered: Emergence of the Fuel Cell Industry in European Regions,” *Economic Geography* 90, no. 4 (2014), doi:10.1111/ecge.12055

<sup>48</sup> P. Lako and M.E. Ros



basic research is supported with 15 million annually. In addition in 2006 a program containing another 500 million was announced. Besides financial support, politicians reinforce hydrogen, e.g. by presenting newest technologies<sup>49</sup>. The German government often proved to create new markets for new energy forms, e.g. with the “feed in law” from 1991 which guarantee a specific price for electricity generated by renewable energies. Germany is creating a market for fuel cell CHP within a broader range of technologies. To further develop fuel cells for the residential market there is an extensive ZIP program. Another indicator is how much new technologies are encouraged as this is creating an atmosphere in which firms will experiment more. Japan and the US may have the highest spendings for R&D, but the highest use of renewable energies is reached in Germany. A main reason for this is the feed-in law.<sup>50</sup> Another influence is the taxation, in Germany hydrogen is taxed when used as a motor fuel<sup>51</sup>

Furthermore there is the NOW program. Germany also make use of subsidies for capital cost and give feed in tariffs for fuel cell CHP<sup>52</sup>

**Germany: \$1.1 billion until 2017<sup>53</sup>**

## 4.4 Conclusion

Most of the policies are facing the same problem. On the one hand they have to be broad enough to create new markets and encourage firms to enter, but on the other hand they are focused on specific technologies where there is the greatest chance to success. A proposed solution includes to keep regulatory measures flexible while focusing R&D on special technologies<sup>54</sup>.

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<sup>49</sup> Ibid.

<sup>50</sup> Brown, Hendry and Harborne

<sup>51</sup> Bleischwitz and Bader

<sup>52</sup> Dodds et al.

<sup>53</sup> Canadian Hydrogen and Fuel Cell Association

<sup>54</sup> Brown, Hendry and Harborne





## Part 5

### 5. COMPARISON TO OTHER TECHNOLOGIES

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#### 5.1 Fuel Cells as Off-Grid Power Source<sup>55</sup>

Prior to the London's Olympic Games, the UK government decided that the security level in roads and motorways could still be increased by installing CCTVs on strategically important locations. However, the people involved in the project of providing energy sources for these CCTV realized that connecting these cameras to the grid would cost an absurdly high amount of budget from the government even without considering the maintenance cost of the grid itself. The construction engineers also argued that the construction would take up two years provided that sufficient manpower, materials and budgets are provided.

The government then turned to off-grid power as the ultimate solution to minimize the cost and time spent in installing the CCTVs system. Two fuel cell companies called 'FCS' and 'UPS systems' came into interest of the government. The companies installed stationary fuel cells at remote location in order to supply power for the fuelcells 24/7 the technology is superior to other renewable energy sources like wind energy and solar energy as the energy produced is stable regardless of the changing weather or climate conditions as long as fuel hydrogen is continually supplied. From the client's

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<sup>55</sup> <http://www.fuelcellsystems.co.uk/fcapplications/case-studies/remote-off-grid-power-for-road-network-cctv/>





perspective, the fuel cells are easier to deal with than batteries mainly because of the lighter weight, relatively more compact size and longer unit lifetime. This means that the maintenance team can actually perform maintenance more easily and economically. The fact that the country did not have to consider about the space and equipment for recharging the batteries for the entire highway itself made fuel cells easily became the solution for the UK government.

From our point of view, fuel cells can also be used in similar scenarios where off-grid power systems are need under the fact that weather and climate conditions are unstable. The technology is even more appealing to environmentalists as it produce zero noise and air pollution.

## 5.2 Hydrogen Infrastructure<sup>56</sup>

Before Hydrogen Fuel Cell Vehicles can become a successful commercialization of international scale, then Fuel Cell Industry must actualized certain concept in the near future, below are the vital elements that must be established with the support of government institutions and society: Hydrogen pipeline transport, as the name implies, is the transportation of hydrogen gas through a pipe. Sufficient length, quantity and area coverage of the piping system is mandatory in order to supply sufficeint amount of hydrogen to all the vehicles in the country; Hydrogen refuelling stations, these stations will be used to refuel vehicles with hydrogen thus essentially it functions acts more or less the same as a petrol station, the main difference between the two is simply the fuel type. As for major countries, the USA for example, The National Renewable Energy Laboratory believes that U.S. counties have the potential to produce more renewable hydrogen for fuel cell vehicles than the gasoline they consumed in 2002. Thus, fuel cell maybe a sensible alternative or a potential replacement of conventional fuels.<sup>57</sup>

## 5.3 Technology

In the technology domain, there is one innovation that regards electrodes and therefore is awaited because it offers the possibility to reduce the manufacturing price a lot. Core-Shell electrodes are indeed offering the possibility to keep the properties presented by platinum electrodes at the same time as reduciug the amount of precious metal contained in the component. The idea is to concentrate the platinum at the surface of the electrode so that it remains in small quantity<sup>58</sup>. Such kind of techniques are particularly interesting because they can be applied for existing types of fuel cells which have already been found usage and therefore will not require any change in terms of standards. Other improvements could also be brought by minimizing the cost of the electrolyte or catalysts consisting of the fuel cell.

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<sup>56</sup>

[http://www.researchgate.net/publication/233987484\\_Fuel\\_cell\\_electric\\_vehicles\\_and\\_hydrogen\\_infrastructure\\_status\\_2012](http://www.researchgate.net/publication/233987484_Fuel_cell_electric_vehicles_and_hydrogen_infrastructure_status_2012)

<sup>57</sup> <http://www.nrel.gov/docs/fy07osti/41134.pdf>

<sup>58</sup> Core-Shell Fuel Cell Electrodes - Energy Innovation Portal





Those innovations will have an impact by making the product more accessible to customers. But fuel cells already present quite a few advantages compared to combustion engines. Indeed, because of the little movement pieces are submitted to, it is a system that requires little maintenance. Fuel cells however can fail for mechanical or thermal degradation, or from a loss of efficiency of the different components (catalyst, electrode, and electrolyte) <sup>59</sup> . As a consequence, research and commercialization will also help improve reliability.

These innovations have to be done because of the remaining immaturity of the technology and infrastructure. And indeed in terms of infrastructure, the hydrogen production equipments are rare. A fuel cell is supposed to provide a zero-emission option. To remain consistent, the best hydrogen production modes then are the non-polluting ones. In addition to this, as hydrogen needs to be produced and then used, the process is not efficient in terms of energy spendings. This can be seen as a defect. However, because natural energy sources cannot be controled and therefore are hard to exploit efficiently, making hydrogen out of them is a great opportunity to make good usage of their potential. Nowadays this is done through electrolysis. More efficient options are being developed, including a promising one: direct solar water splitting. It can be done thanks to cells similar to photovoltaic ones where the splitting is powered by the sunlight. Another promising and original possibility is use microorganisms that will produce hydrogen through their



photosynthesis process<sup>60</sup>.

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<sup>59</sup> Wu et al. 2008

<sup>60</sup> Hydrogen Production Processes | Department of Energy





## Part 6

### 6. CONCLUSION

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