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| FUEL CELL INDUSTRY ANALYSIS REPORT |
| 01/01/2015 |

Bambu, the team

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# Introduction

## Intentions

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## History of fuel cells

## Fuel cell as an alternative

## Short industry overview

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# Product description

**Oxygen :** It can be found the most in the nature under the form of dioxygen (O2). It is part of the three most plentiful elements in the universe.

**Hydrogen :** The most abundant element in the universe is mostly present in the nature under the form of dihydrogen (H2).

**Water :** The water molecule results of the combination of Oxygen and Hydrogen. Its chemical formula is H2O.

**Electrode :**

**Electrolyte :**

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

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

***The basic principle is to combine oxygen and hydrogen to produce electricity.***

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.

## 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. This range of temperature then 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 combining several fuel cells in stacks.

## Technologies

**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 :

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.

### 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.

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/cm².



HYGROGEN

EXCESS HYGROGEN

OXYGEN

WATER

HYDROGEN IONS

ELECTRONS

**ELECTROLYTE**

**CATHODE**

**ANODE**

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.

### AFC

**Alkanline :**

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 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.



HYGROGEN

WATER

OXYGEN

EXCESS OXYGEN

HYDROXYDE IONS

ELECTRONS

**ELECTROLYTE**

**CATHODE**

**ANODE**

The power output can be expected to be between 1 and 5 kW and the power density between 0.1 and 0.3 W/cm².

### PAFC



HYGROGEN

EXCESS HYGROGEN

OXYGEN

WATER

HYDROGEN IONS

ELECTRONS

**ELECTROLYTE**

**CATHODE**

**ANODE**

### SOFC



HYGROGEN & CARBON MONOXDE

CARBON DIOXIDE & WATER

OXYGEN

EXCESS OXYGEN

OXYGEN IONS

ELECTRONS

**ELECTROLYTE**

**CATHODE**

**ANODE**

### MCFC



HYGROGEN & CARBON MONOXDE

CARBON DIOXIDE & WATER

OXYGEN

EXCESS CARBON DIOXIDE & OXYGEN

CARBONATE IONS

ELECTRONS

**ELECTROLYTE**

**CATHODE**

**ANODE**

CARBON DIOXIDE

### DMFC



METHANOL

CARBON DIOXIDE

OXYGEN

WATER

HYDROGEN IONS

ELECTRONS

**ELECTROLYTE**

**CATHODE**

**ANODE**

### Summary

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Type of FC | Electrolyte | Electrodes | Fuel | Operating Temperature (°C) | Output Range | Cell Efficiency (%) | Power Density (W/cm²) | Operating Price ($/W) |
| LT PEMFC | Polymer (Water Based) | Noble Metal | H2 | [40, 90] | 1 mW – 100 kW | [50, 70] | 0.7 | [50, 100] |
| HT PEMFC | Polymer (Mineral Acid Based) | Noble Metal | H2 (/CO) | [125, 220] | 100 W – 10 kW | [50, 70] | 0.7 | [50, 100] |
| AFC | KOH | Noble/ Non-noble Metal | H2 | [40, 200] | 1 kW – 5 kW | [60, 70] | [0.1, 0.3] |  |
| PAFC | Phosphoric Acid | Noble Metal | H2 | 200 | 25 kW – 125 kW | 55 | 0.14 | [4, 4,5] |
| SOFC | Solid Oxide | Non-noble Metal | CH4, H2, CO | [600, 950] | 1 mW – 125 kW | [60, 65] | [0.15, 0.7] |  |
| MCFC | Molten Carbonate | Non-noble Metal | CH4, H2, CO | 650 | 50 kW – 125 kW | 55 | [0.1, 0.12] |  |
| DMFC | Polymer | Noble Metal | Methanol | [60, 130] | 1 mW – 1 kW | [20, 30] | 0.25 | 125 |

## Applications

### Categorisation choices

### Transport

### Portable

### Stationary

## Infrastructure

### Distribution facilities

#### Delivery

#### Hydrogen storage

### Hydrogen production

#### Introduction

#### Electrolysis

#### Steam reforming

#### Summary

# Future perspectives

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## Limitations and risks

## Forecast

# Conclusion

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