

# "Breaking Down Fuel Cells: A Comparative Study of PEMFC and DMFC"

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The straight conversion of Methanol to electricity by direct Methanol fuel cells (DEFCs) makes them a hopeful device for the production of renewable energy. They work by decreasing oxygen at the cathode while burning Methanol at the anode, creating electrons and protons.

PEM Fuel cells are characterized as galvanic cells that have a potential to operate on high efficiencies with only exhaust as water. PEMFC is also flexible with fuel as apart from hydrogen it can take formic acid, methanol as input.

**Anode Components**  
The best catalyst for triggering methanol oxidation reaction (MOR) at the Direct Methanol Fuel Cell (DMFC) anode remains to be noble metal catalysts based on platinum (Pt). However, intermediate species such as CO and CHO can slow down the kinetics of methanol oxidation on Pt, preventing the MOR from being fully achieved. To reduce this impact, Pt is typically alloyed with second metals like Ru, Sn, Mo, Co, Ni, etc.

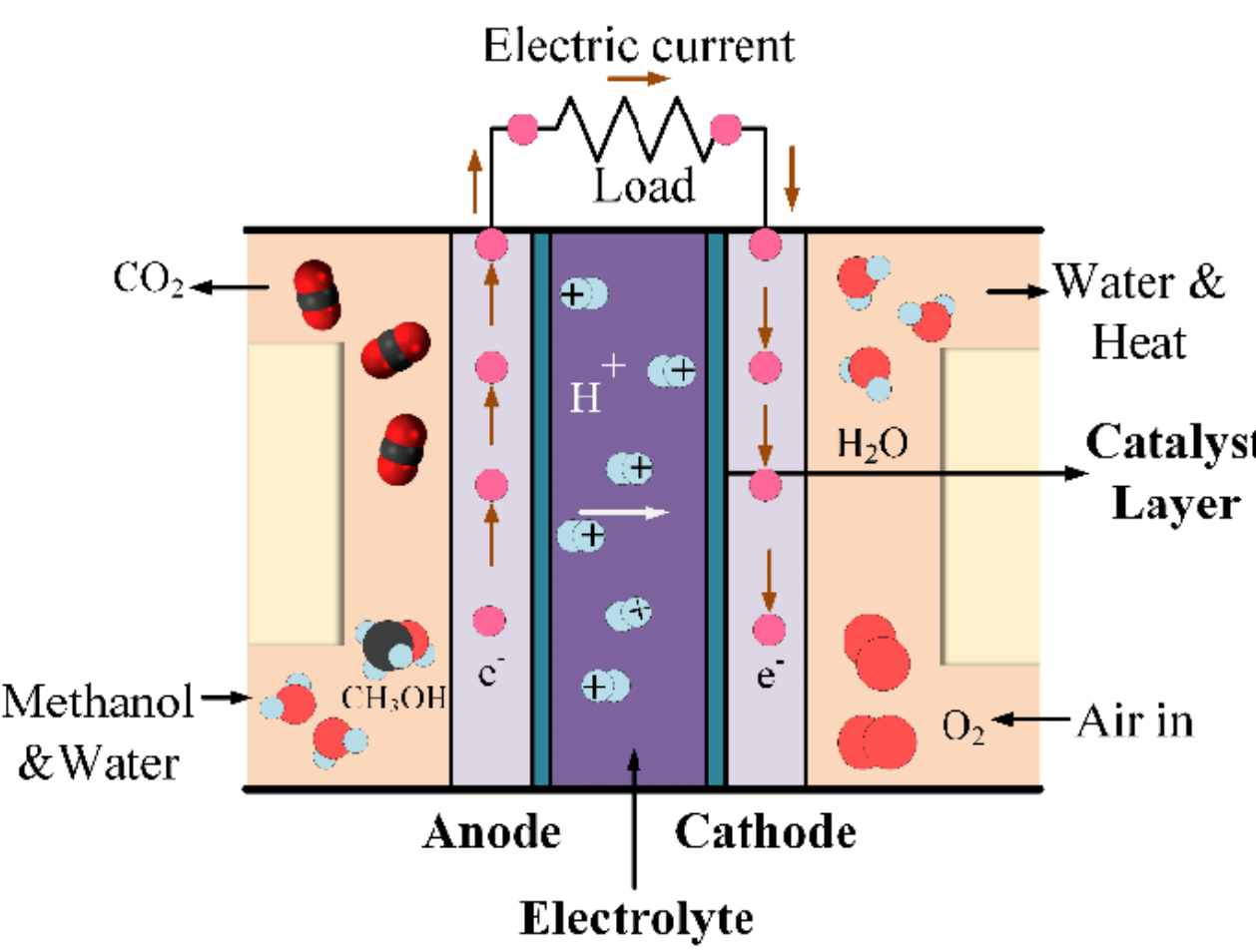
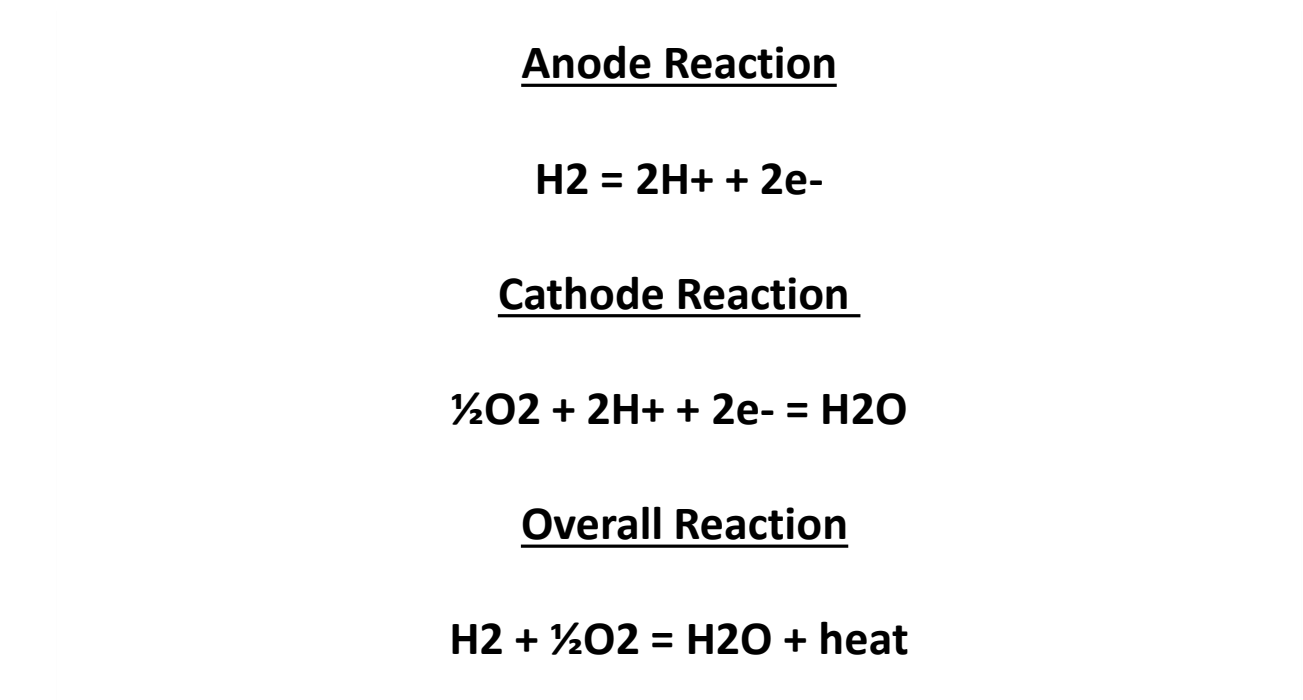


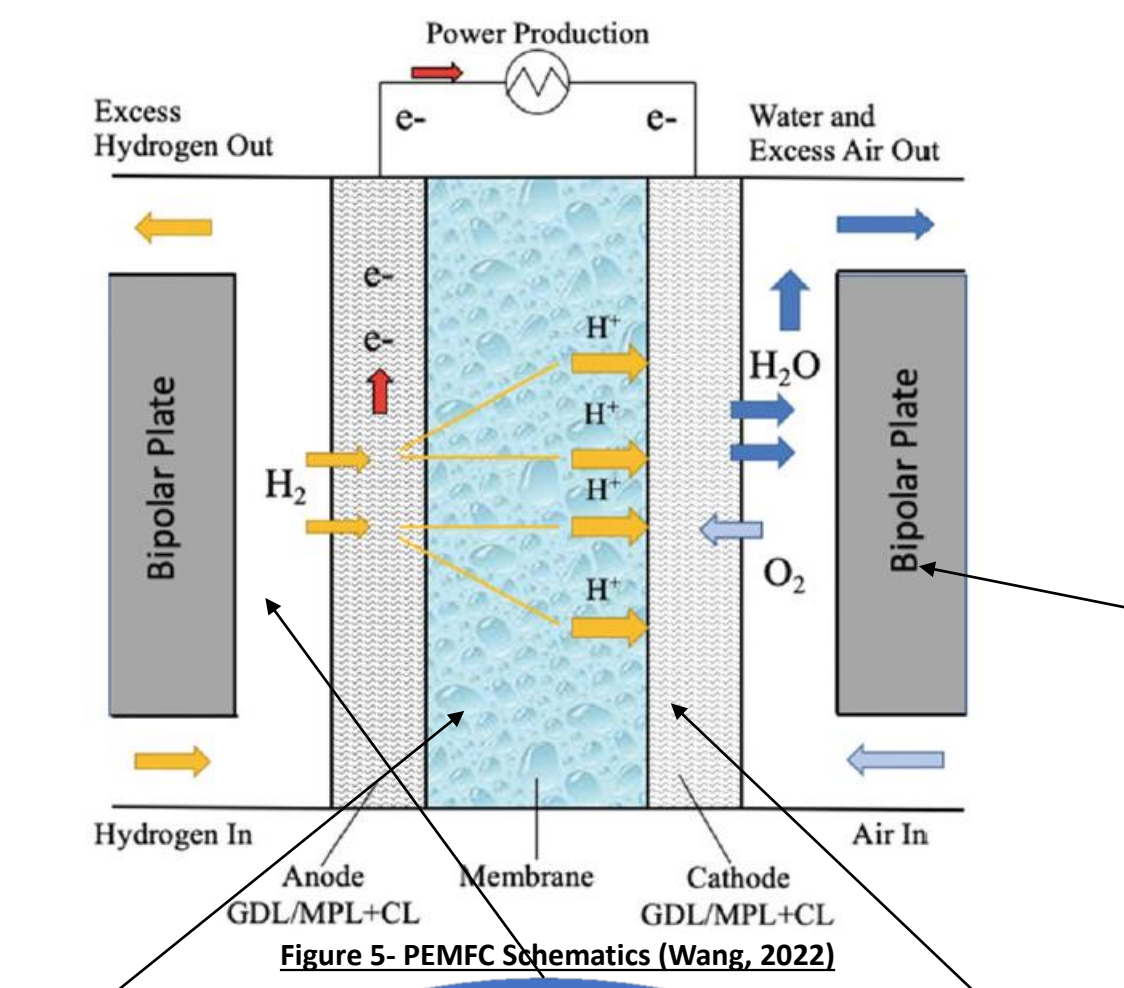
Figure1 Representation of DMFC (Petrovic, 2020)

**Cathode components**  
In a Direct Methanol Fuel Cell (DMFC), as in a Proton Exchange Membrane Fuel Cell (PEMFC), Pt metal makes the finest catalytic substance for the cathode. Though Pt loses nearly 400 mV due to slow electrochemical rates of the oxygen reduction reaction and mixed potential brought on by methanol crossing. Different carbon-supported Pt-based alloys Pt-M like Fe, Au, Pd, Cr, and W2C, have been created to enhance the Oxidation reduction reaction kinetics and tolerability against methanol crossing. Carbon-supported Pt is used in commercial DMFC devices to reduce costs.



**Operating Conditions of PEMFC**

Temperature:	60-80 °C
Pressure:	1-3 atm
Cell Humidity:	80-100%
Coolant Conductivity:	1.8-2.2 μS/cm
Fuel Composition:	99.97% Hydrogen Purity
Current Density	2-5 A/cm <sup>2</sup>
Efficiency	60-80%



**Bipolar Plates**  
These metallic plates separate two fuel cells in a stack. Its function is to provide the reactants to the gas diffusion layer and to provide mechanical support for the electrodes. It is also used for electron transfer and for cooling of the fuel cells through cooling channels. Material used is graphite.

**Catalyst**  
Work of a catalyst is to boost the reactions at the electrodes in a fuel cell. Platinum is deposited on carbon black to work as a catalyst in a PEM fuel cell.

**Membrane**  
Membrane in PEM insulates the cathode side from the anode side. The function of the membrane is to provide ionic conductivity to the ions to reach cathode from anode. It should also be able to bear the harsh environment changes at the electrodes. Material used is Nafion. Electrodes: They are electrical carbon supported conductors where the reaction takes place. It is made up of Teflon binder, Nafion ionomer and Pt particles.

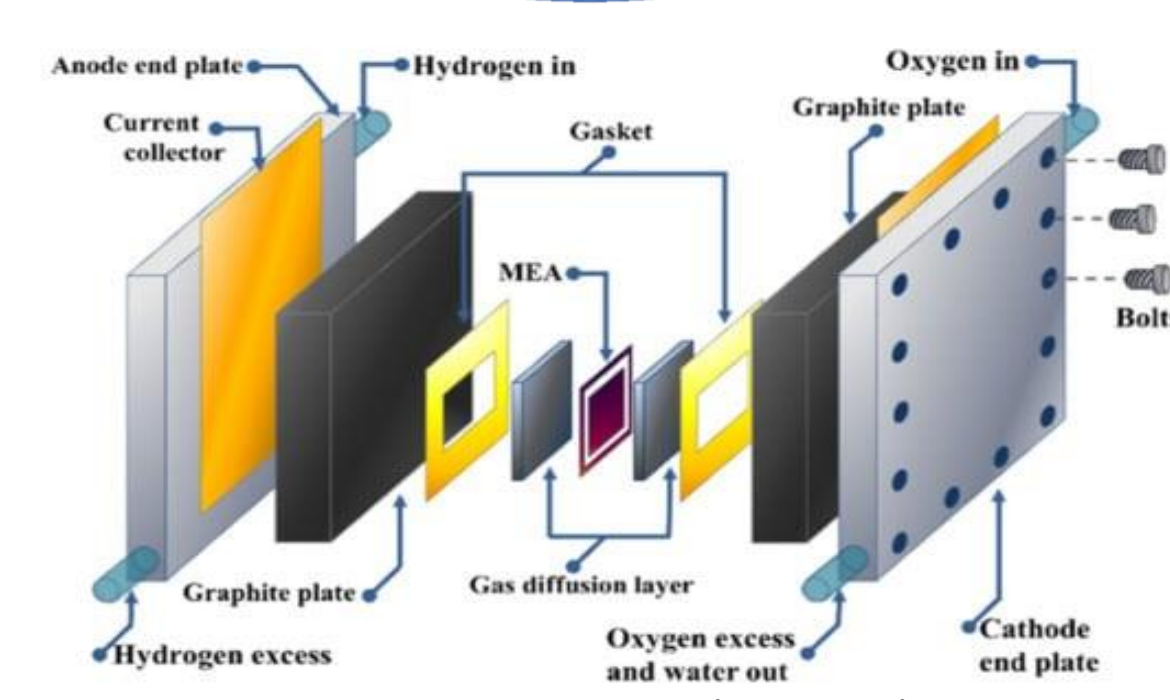
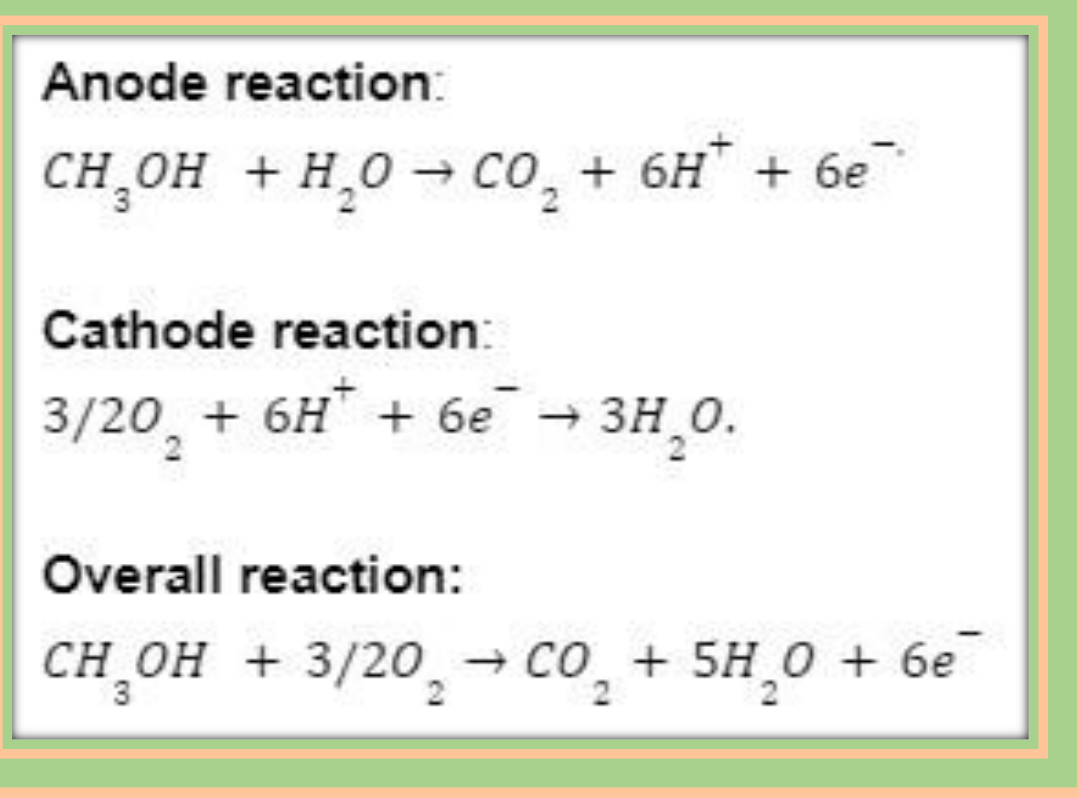


Figure 6- PEMFC Components (Miriam, 2021)

**Water Management**  
The membrane of the fuel cell requires certain humidification to avoid drying or flooding of the membrane. Therefore, a humidifier is required along with a water tank and water separator unit.

**Hydrogen Reforming unit**  
If hydrogen entering the fuel cell contains impurities such as carbon monoxide, the catalyst of the cell can get damaged. The purpose of this unit is to check the purity of the hydrogen that enters the fuel cell. However, hydrogen can also be provided directly in pressurized form.



Operating conditions	Range/value
Temperature	60-90°C
Pressure	1-2 atm (Fuel and oxidant)
Fuel concentration	1-3 M
Fuel flow rate	50-200 ml/min (fuel and oxidant)
Current density	10mA/cm <sup>2</sup> -500mA/cm <sup>2</sup>

Table 1: Operating conditions (Kulkovskiy, A.A. (2007))

**Cell Degradation**

- Membrane : mechanical stress due to non uniform pressing, thermal stress, membrane drying, contamination .
- Catalyst layer: mechanical stress, contamination dealloying of electrocatalyst.
- Gas diffusion layer : Degradation of backing material, corrosion because of poor water management control
- Sealing gasket : due to corrosion and mechanical stress

**Electrolyte Materials**  
In a DMFC application, a PEM should have the following characteristics:  
i) I stable high temperature (80-90 °C) operation capability;  
ii) low methanol crossover or low membrane diffusion coefficient;  
iii) high ionic conductivity;  
iv) high chemical and mechanical durability, particularly at T > 80 °C;  
v) low ruthenium crossover; and  
vi) low cost. The Dupont Nafion membrane is the most widely used cation exchange membrane (CEM) in DMFCs.

**Efficiency**  
Efficiency is referred to as the percentage of methanol's chemical energy that is transformed into power. Efficiency can be defined based on either lower heating value or higher heating value,  $U_{LHV} = 1.10$  V for the lower heating value and  $U_{HHV} = 1.25$  V for the higher heating value are the cell voltages for 100% voltage effectiveness.  
**Efficiency**  $\eta_{HHV} = \eta_{LHV} \times 1.10/1.25$ , or  $\eta_G = \eta_{LHV} \times 1.10/1.21$ , where  $\eta_G$  is the efficiency based on Gibbs free energy. Typical efficiency range of DMFC is around 20%-40% depending on the DMFC design and operating conditions.  
**Reasons:**  
• Methanol cross over, where the fuel passes through the membrane and reacts with oxygen on the cathode side.  
• Lower operating temperature leads to lower efficiency as they affect the rate of reaction  
• Catalyst used are expensive like Pt based alloys and the durability of the catalyst is important and if they degrade or become poisoned the efficiency is reduced .  
• Fuel cell makers can increase the efficiency of their fuel cells, lower expenses, and lengthen the life of the fuel cell by optimizing the catalyst.

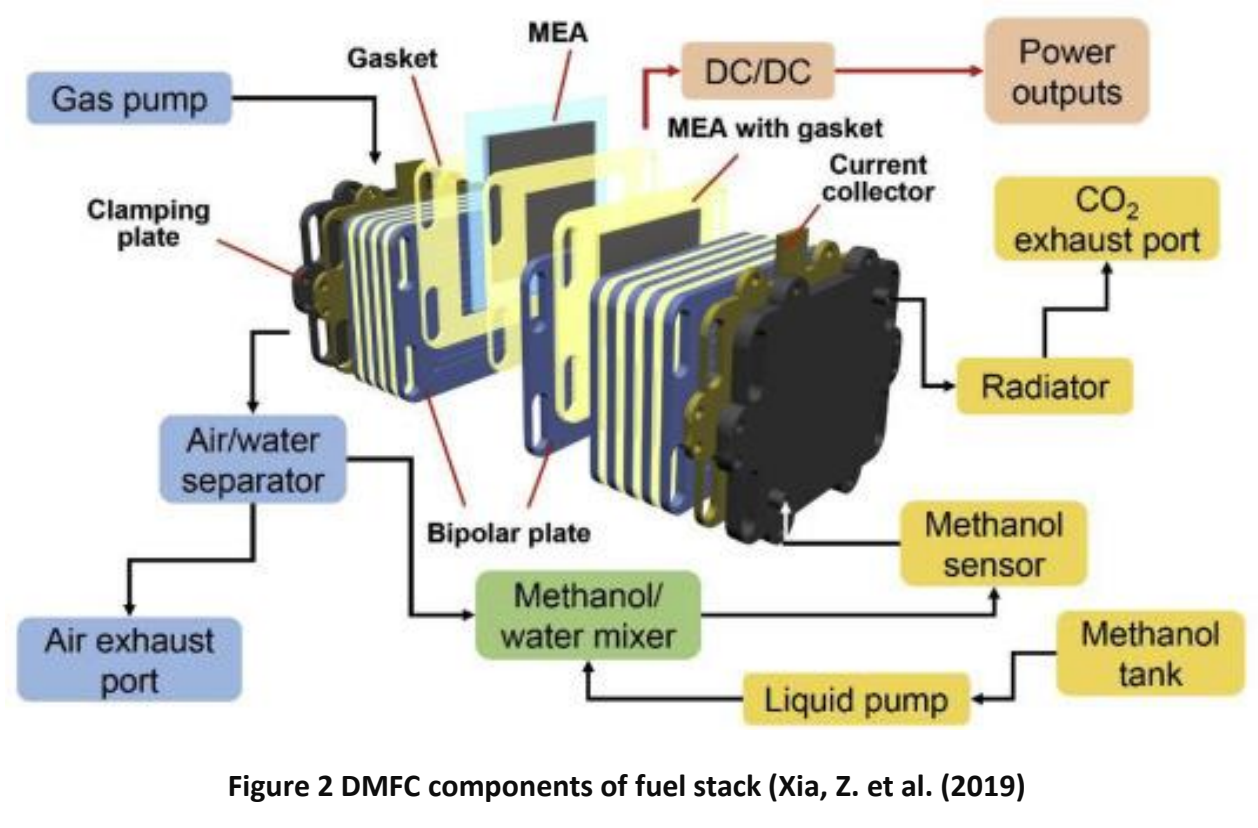


Figure 2 DMFC components of fuel stack (Xia, Z. et al., 2019)

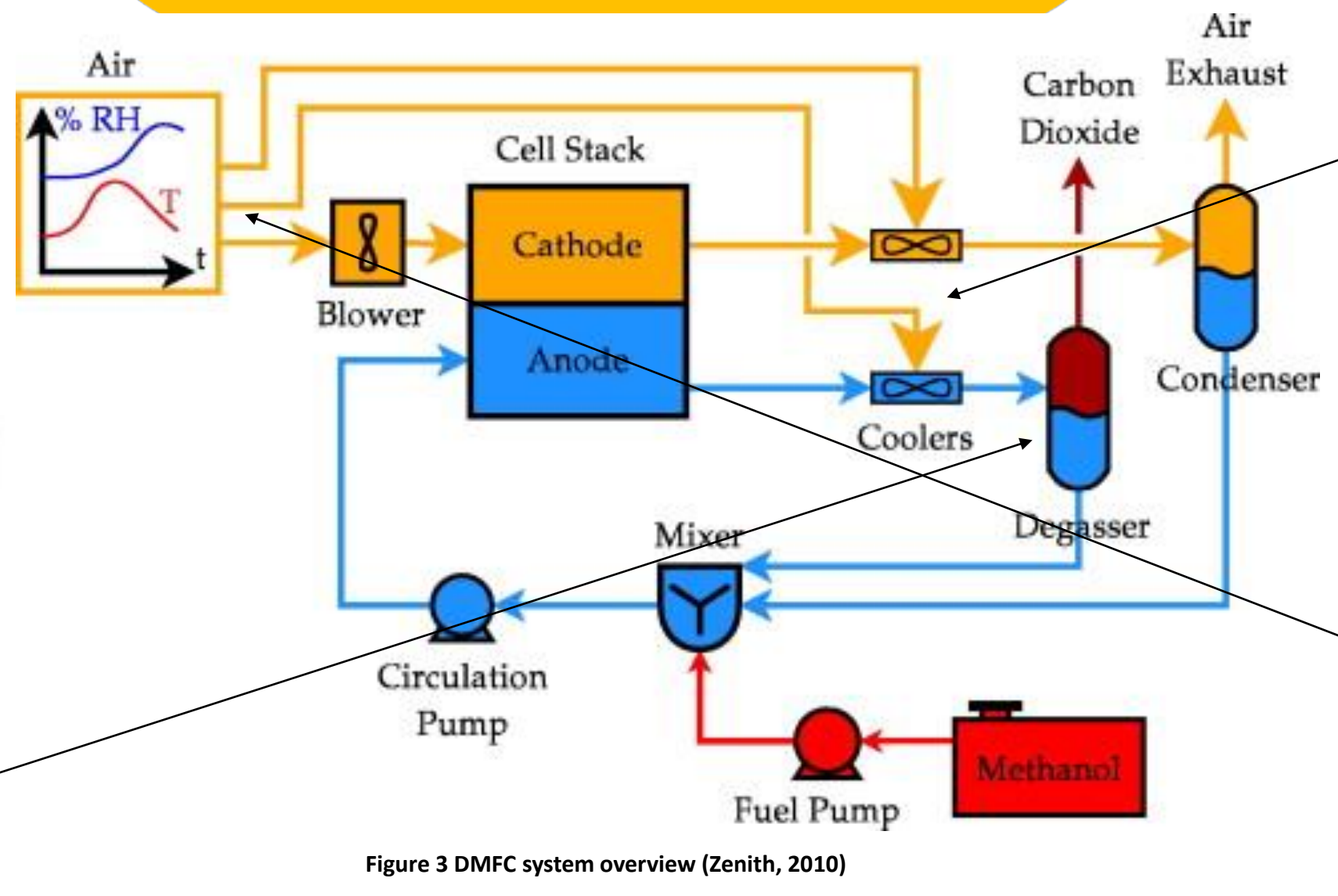


Figure 3 DMFC system overview (Zenith, 2010)

**Thermal Management**  
To keep the stack of fuel cells in optimum temperature region, an active or passive cooling system is needed.

**Air Supply Unit**  
The cathode in FC requires oxygen at a specific pressure and flow rate, for effective working. Therefore, we need a motor compressor unit for this purpose.

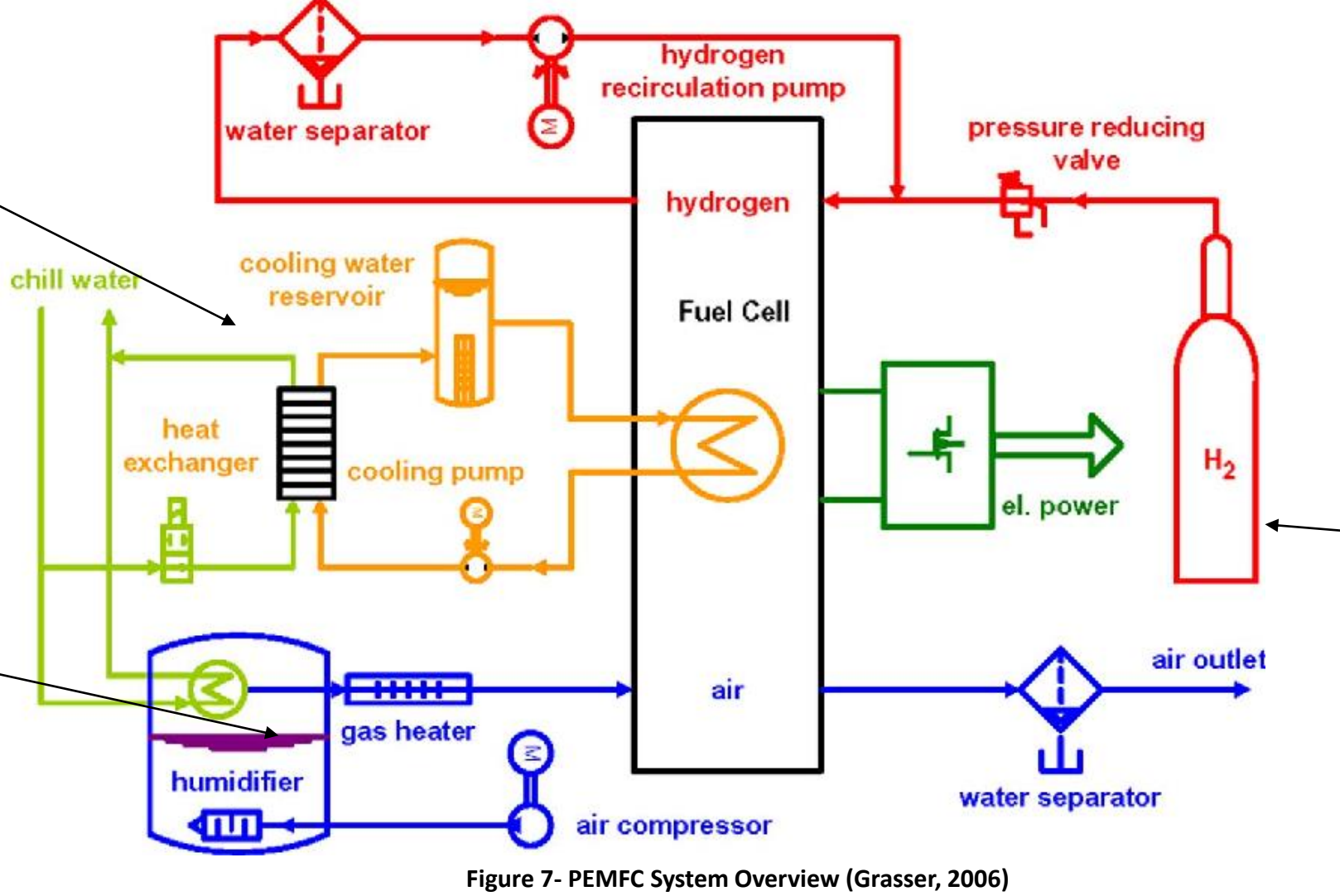


Figure 7- PEMFC System Overview (Grasser, 2006)

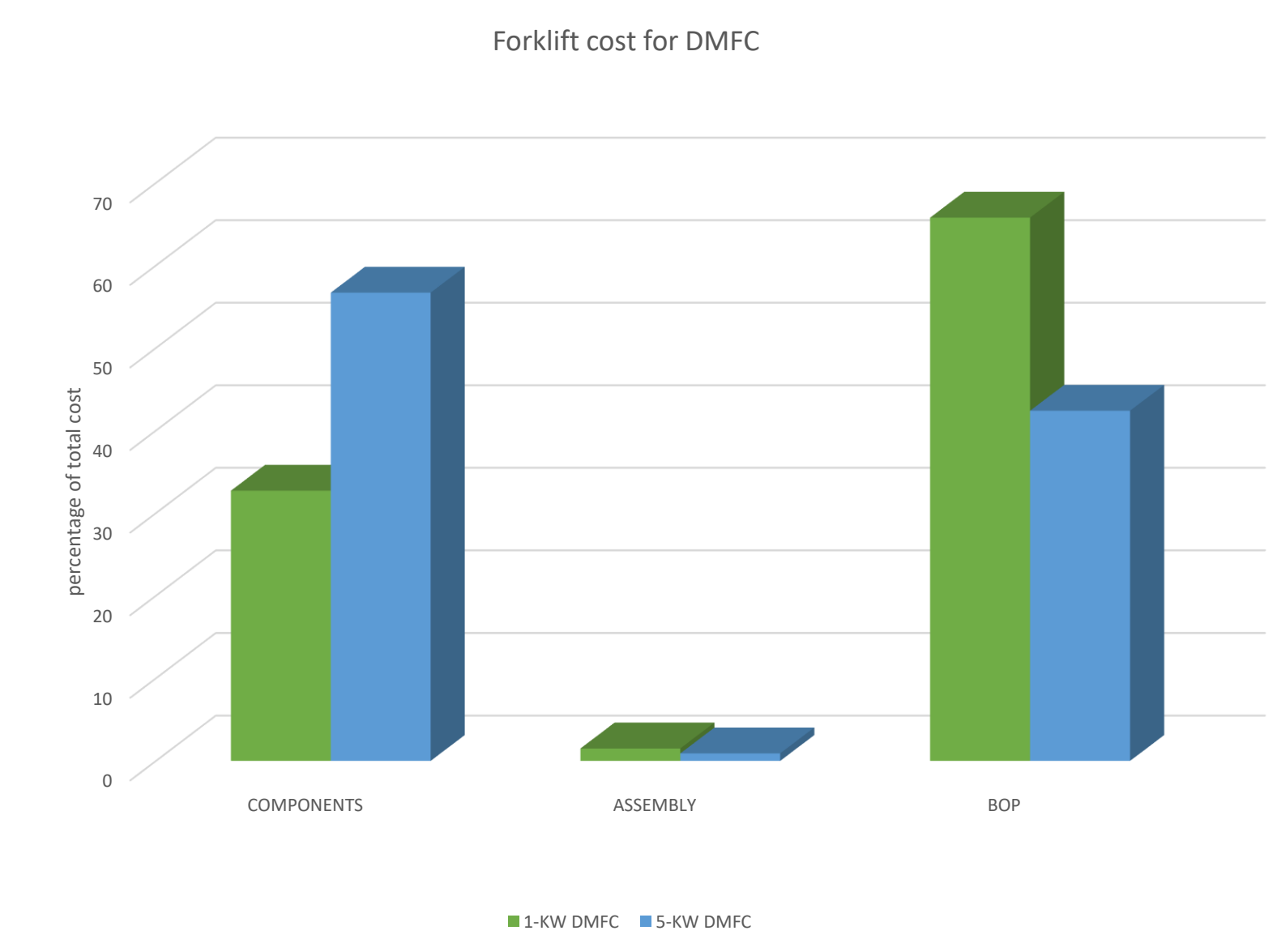


Figure 4- Cost for DMFC for forklift application (based on data from Metzger & Li, 2022)

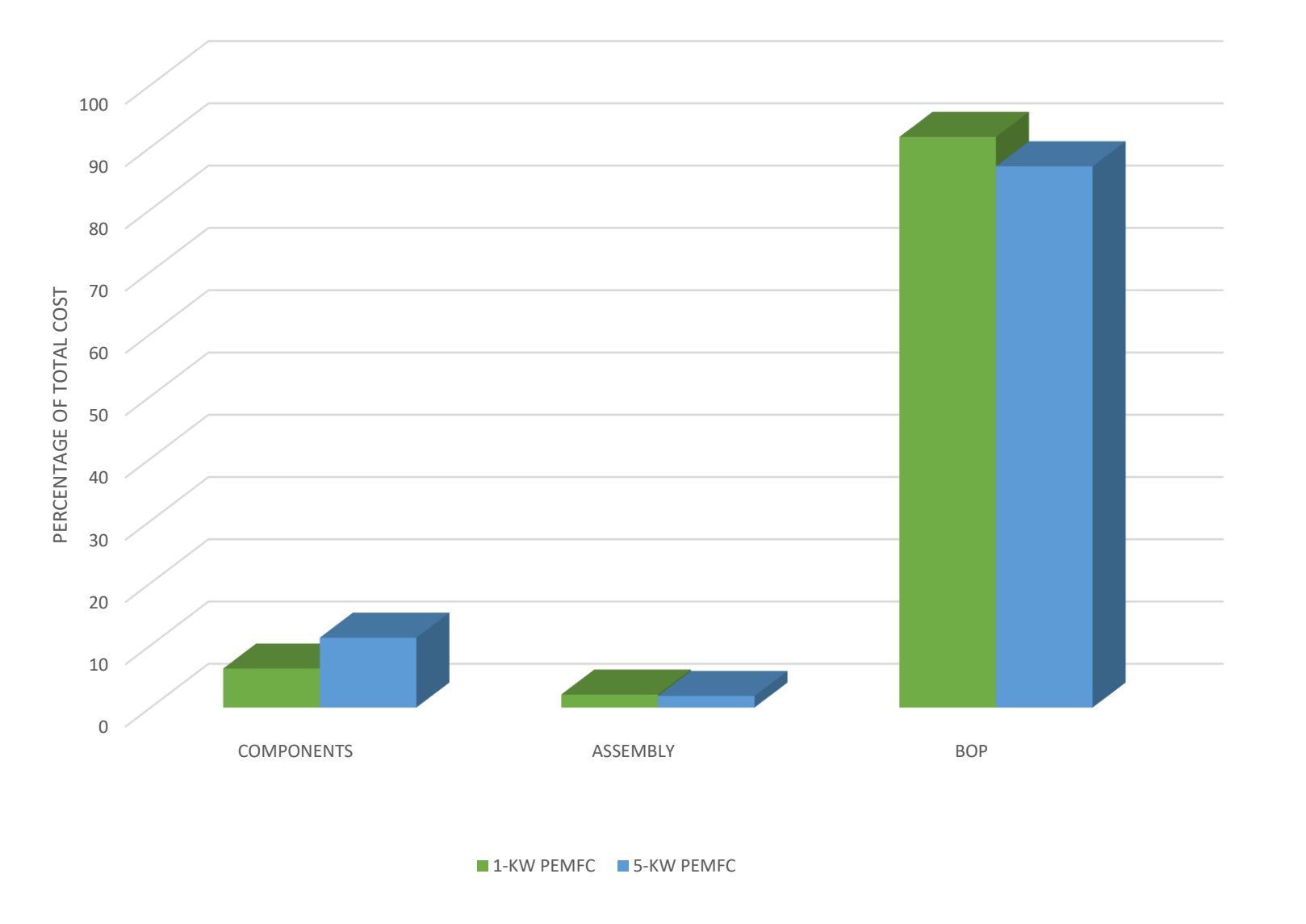


Figure 8- Cost for PEMFC for forklift application (based on data from Metzger & Li, 2022)

**Applications**

- It is mostly used for small portable electronic devices as it can provide small amount of power for long period of time. Currently most of the small electronic devices use rechargeable batteries that have limited capacity and require external electrical energy for charging.
- It also has the potential to replace the generators that run on conventional fossil fuels. DMFC uses a renewable fuel due to which it is more environment friendly than diesel generators.
- It also has the potential to be used in military applications as it has low noise and thermal signature characteristics.
- Some automotive companies are also experimenting with DMFC for future propulsion. Yamaha created the FC06 DMFC-powered motorbike prototype in 2003, with a 500 W output capacity. In 2007, the FC-Dii, an upgraded model of the DMFC-powered two-wheeler, was released with a 1 kW peak capacity.

**Cell Degradation**

The platinum particle grows into a larger particle due its high surface energy. This reduces the active area and hence reduces the efficiency of the fuel cell.

Carbon Oxidation: At high temperature situations, the water content in the carbon carrier in the catalyst can increase. This will lead to carbon oxidation which will lead to damage in the electrode pore structure, will decrease the connectivity of the catalyst and can also lead to reduction in hydrophobicity.

Nafion ionomer degradation Mechanism : The Nafion ionomer is responsible for the water and ion transfer in the catalyst. When the pores of the ionomers start to increase the decay, process begins. Damage in the Nafion ionomer reduces the ion transfer and thus reduces the performance.

**Applications**

- Automotive: The operation of the fuel cell in automobiles is very dynamic and weight/space sensitive. Therefore, the fuel cell used for this application must have low start-up time, compact design, lightweight and high energy density. Emission is a major problem in the automotive industry, so using PEMFC the only exhaust obtained is water. They operate at approximately 40% efficiency.
- Stationary Power Generation: They can be used as systems for emergencies like generators in case of power cut and as a supplemental system to the grid. They can provide 5kW power at 30% efficiency.
- Portable Fuel cell applications: Due to its better energy density than batteries, the fuel cell can replace batteries in cell phones, laptops, power banks etc. The portable fuel cell can provide power up to 5kW.

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