Fuels of the future

The world needs energy more than ever. This means we need a sustainable system to meet these growing needs while addressing CO_2 emissions and overall environmental impact.

Hydrogen is the solution that can provide the world with sustainable, efficient, and affordable energy. scale. However, the shipping fee is expensive.

Hydrogen

Hydrogen is not only the most important element in the universe. It can also play an important role in the energy mix of the future, from cars to trains, from trucks to ships, to electricity generation and to heating gardens. This is because it is a clean, clean fuel that only releases water when burned or oxidized.

Currently, about half of the world's hydrogen production comes from gas (methane) used in the fertilizers, metals and aerospace industries. But the process of removing hydrogen from carbon monoxide also produces about 10 tons of carbon dioxide for every ton of hydrogen produced. That's why we need to find a more sustainable way.

Blue hydrogen: a key element of the circular carbon economy

For more than a decade, we have been investigating potential technologies for producing high-purity hydrogen from hydrocarbons, including thermal neutral conversion (TNR) and diesel-to-hydrogen catalysts. Our ultimate goal is to create "blue" hydrogen that captures valuable fuel while capturing all CO2 emissions.

Burning methane produces hydrogen and carbon dioxide, but the difference with blue hydrogen is that we capture and reuse, eliminate or reuse the carbon dioxide emissions. All this is part of our vision of a circular economy.

We are now able to extract about 80-85% of energy from hydrocarbons into hydrogen gas and then use the captured CO2 using two new technologies. The first involves injecting one of our oil fields to improve oil production, while the second involves turning waste carbon dioxide into chemicals like methanol that can be used. Additional carbon dioxide can also be safely stored deep underground.

Reducing the cost of transportation

Making hydrogen blue is only half the solution. The next problem we have to tackle is how to store the reserve fuel and get it to where it's needed.

Hydrogen is a very light molecule. It may be liquid, but it must be stored at -254 °C, making it difficult and expensive to transport, especially over long distances. The solution is to convert hydrogen into a substance already commercially available worldwide: ammonia.

Compared to hydrogen, the transportation of liquid ammonia is more convenient, efficient and effective in terms of temperature and temperature.

When blue ammonia reaches its target, it can be converted to blue hydrogen or used directly as fuel in gas turbines for clean electricity generation.

The world's first blue ammonia shipment

In 2020, we completed one of our most ambitious trials to date, an integrated demonstration covering all hydrocarbon resources in collaboration with SABIC and the Japan Energy Industry Institute (IEEJ).

We will be able to reap the fruits of this special collaboration in August 2020, when we will send 40 tons of high-quality blue ammonia to Japan.

The blue ammonia itself is shipped to our home in Japan; here, 20% of the ammonia is processed in existing coal-fired and gas-fired power plants. According to the IEEJ, the pilot project is one of many that will help Japan reach its ultimate goal of becoming a decarbonized society, where up to 10 percent of its electricity can be produced from blue ammonia per day.

Synthetic fuels

Hydrogen and fuel cell technologies also have potential for the future of transportation.

In 2019, Aramco established its first hydrogen filling station in Saudi Arabia, while countries such as Japan, China and South Korea are investing in hydrogen filling stations and infrastructure. The growing demand for hydrogen helps justify the importance of our ability to transport hydrogen around the world at low cost.

Catalyzing new pathways to cleaner fuels

Many challenges will continue in the future, such as working with our international partners to develop ways to convert most of the hydrocarbon energy into hydrogen and to improve the overall production process of electric and hydrogen cars and chains.

But it's clear that turning natural gas into blue hydrogen could be the key to producing affordable, reliable and sustainable clean energy for everyone.

Hydrogen is the simplest substance. A hydrogen atom has only one proton and one electron. Still the most important thing in the universe. Despite its simplicity and abundance, hydrogen does not occur as a gas on Earth; it is always combined with other elements. For example, water is a mixture of hydrogen and oxygen (H2O).

Hydrogen is also found in many organic compounds, especially the hydrocarbons that make up most of our fuels, such as gasoline, natural gas, methanol, and propane. Hydrogen can be separated from hydrocarbons by heating in a process called reforming. Currently, most hydrogen is produced from natural gas. The current can also be used to split water into oxygen and hydrogen. This process is called electrolysis. Some algae and bacteria use sunlight as energy and even release hydrogen gas under certain conditions.

The energy of hydrogen is high and the engine burning hydrogen does not cause pollution. NASA has been using liquid hydrogen to propel the Space Shuttle and other rockets into orbit since the 1970s. Hydrogen fuel cells power the shuttle's electrical system and turn it into a clean product (pure water) that the crew can drink.

Hydrogen Fuel Cells

The gases combine hydrogen and oxygen to produce electricity, heat and water. Fuel cells are often compared to batteries. Both convert energy from chemical reactions into usable electricity. However, when the fuel cell (hydrogen) is powered, the fuel cell produces electricity and does not lose its value.

Fuel cells are useful tools that can be used to heat buildings and provide power, as well as generators of electrical energy to run cars. Fuel cells work best with pure hydrogen. But fuels like natural gas, methanol and even gasoline can be converted into the hydrogen needed for fuel cells. Some fuel cells can also run directly on methanol without the use of a converter.

In the future, hydrogen may become the main energy along with electricity. Electrical equipment transmits electricity in usable form and delivers it to consumers. Renewable energies such as solar and wind cannot always produce power. But they can produce electricity and hydrogen that can be stored until needed. Hydrogen can also be transported (like electricity) wherever it is needed.

Understanding Fuel Cells and Their Role in the Green Energy Revolution

The support and energy of the future should be designed to meet the challenges of society such as climate change, the need for more energy and mobility. The energy needs of the world population are developing. Oil can be an important part of the competition.

As hydrogen becomes a storage medium at all energies, the potential of fuel cell technology is complex. Strong arguments for the use and distribution of these devices are reliability, efficiency and the ability to use renewable energy.

Thanks to their modular design, gas turbines can be easily adjusted to suit the product needed, and their low maintenance and operating costs also make them attractive. In addition, fuel cell technology is ready for commercialization and suitable for commercial use. The fast-growing industry presents huge growth opportunities for zero-emission fuel cell technology.

How Fuel Cells Work

A gas engine works differently from an internal combustion engine. They convert fossil fuels directly into electricity that can be used to generate more electricity. This conversion is more efficient than internal combustion engines because the intermediate thermomechanical requirements of the conventional heat exchanger (heater) are eliminated.

The best thing happens when fuel hydrogen can be regenerated, as it allows both pollution and climate change pollution to be reduced to zero. In this way, fuel cells have the potential to be an important technology in terms of decarbonized propulsion and energy.

Cryogenic Proton Exchange Membrane Fuel Cells or PEMs (sometimes called Polymer Electrolyte Membrane Fuel Cells) currently represent the most suitable technology for developing and growing the Rolls-Royce powertrain portfolio. The low temperature cell has a high energy density, which allows the equipment to be upgraded from even a small device.

Cryogenic fuel cells operate up to 100°C with little danger to equipment and personnel, while hot fuel cells reach temperatures between 250°C and 1.000°C. Compared to other types, PEMs have excellent performance characteristics, allowing them to respond to changes in energy demand within seconds. One of the advantages of

PEM fuel is its excellent electrical properties, especially in a part. They mostly use hydrogen fuel; however, they can operate with a variety of fuels such as methanol, diesel or natural gas. This is done by converting the gas into hydrogen using an efficient reforming process. This provides many applications for proton exchange membrane fuel cells.

Proton exchange membrane fuel cell is the first cell to electrochemically react fuel and oxidant (usually air) to produce electricity and fuel. It works silently without too much vibration. Like batteries, fuel cells produce DC voltage. But unlike batteries, fuel cells constantly require fuel and oxidant.

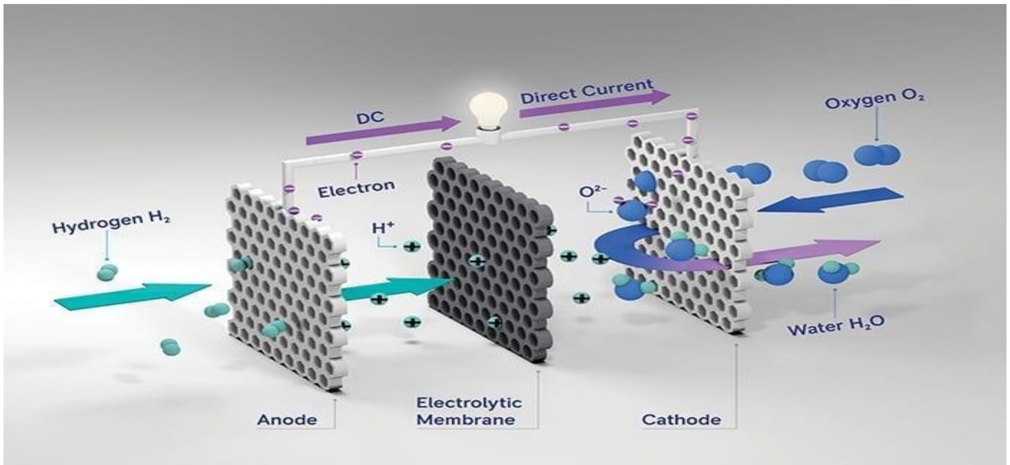

Figure 1: The electrical components of the electronic device include the anode, cathode and electrolyte membrane.

When using a PEM fuel cell, chemical processing takes place between the electrodes (anode and cathode) and good ions (protons) move from the anode to the cathode, electrons are produced from the outside of the anode towards the cathode through the electrical conductor. The product of this process is electricity, which can be extracted and used. The electrodes are coated with a platinum or palladium catalyst and separated by an electrolyte. Without a catalyst, hydrogen and oxygen do not react and produce heat and electricity. An electrolyte has an ion-conducting membrane that is essentially permeable to protons and impermeable to electrons.

Improving Upon Well Established Technology

The name "Polymer Electrolyte Membrane Fuel Cell" means that the membrane is the main part of the fuel cell. It is usually made of plastic, similar to Teflon. The water-saturated polymer membrane acts as an electrolyte that allows only the protons of the positively charged hydrogen nuclei to pass from the anode to the cathode. The water content in the membrane required for conducting ions limits the operating temperature to a maximum of 100 °C. In recent years, the price of important metals such as platinum, which needs catalysts, has fallen. This has significantly reduced costs and is also the focus of development.

PEM fuel cells are ideal for Rolls-Royce powertrain applications due to their energy efficiency, high scalability, modular design and ease of manufacture. For example, fuel cells can be built directly into batteries that use electricity or electricity. The battery achieves high electrical efficiency (approx. 50%) and high current, and is also highly efficient. This situation requires not only the use of fixed electricity (e.g. emergency generator or no electricity), but also the fulfillment of all mobile phone needs.

To increase power, today's gas engines are sometimes equipped with air compressors or even electric turbochargers. Like an internal combustion engine, a compressor or turbocharger pumps air into the engine at a pressure of 2 to 3 bar. The voltage of many people can be increased by connecting the choke in series to form a group. The group can also be connected to a scale for better performance. This increases the value of the current product to several times the amount generated by the link.

Rolls-Royce Power Systems draws on years of expertise and experience in the development and application of fuel cell technology. Between 1999 and 2011, 26 high-temperature Molten Carbonate Fuel Cells (MCFC) systems were installed and successfully applied in various applications. The combination of electricity and high power is widely used in many industrial and sanitary processes. The system was run for an average of approximately 22,000 hours and all performance data and results were recorded and analyzed. While the market and general process of the time did not support all products, now all lights are starting to mass sell PEM fuel cells as an additional source of power propulsion.

Fuel Cell Applications

Their properties mean that PEM fuel cells are well suited for many applications that run internal combustion engines today. Fuel cells can play an important role in zero-carbon information, demand response and ship propulsion, among others.

Data Centers

It is part of a globally oriented infrastructure focused on security, including centers, hospitals, airports and telecommunications centers. Many data centers use diesel generators for emergency power. Combustion of fossil fuels (diesel) inevitably leads to gaseous emissions. If the fuel cell is used as a backup source, the only output will be heat and exhaust gases. Mechanical stress is reduced because there are no moving parts in the fuel cell system.

Fuel cells are also more efficient than electric motors. Another advantage is that fuel cell systems can be easily expanded. More modules means more power, and the power grid can be easily added later and grows with the data center.

Demand Response

Renewable energy requires high flexibility. Where there is too much wind or solar power, the electricity can be used to produce hydrogen by electrolysis and store it without limiting production. If necessary, this energy can be returned in the form of electricity using gas for a short time. Load management or “demand response” operation using smart grids can be an important factor in converting energy to sustainable production methods.

The solution using PEM fuel cells with batteries is the best in terms of grid stability and smoothing power peaks. Customers can use the system to meet their needs even when renewable energy production is low. PEM fuel cell generators can be connected to local generators or microgrids.

Boat propulsion. Alternative propulsion systems are attractive and suitable not only for cars and trucks, but also for ships. The shipping industry accounts for 2-3% of global carbon dioxide emissions and this share is expected to increase by 2050 as global trade grows. On-board fuel cell systems have many advantages. Marine fuel cell propulsion systems are valued not only for their safety and environmental friendliness, but also for their high passenger capacity and high modularity. They are quiet, odorless and vibration free. This emission-free propulsion system allows the boat to be used in oceans, lakes and water areas where some other systems are questioned due to its environmental impact.

An electric motor consists of many parts. The heart of the body is a fuel cell that converts hydrogen into electricity. This electricity is sent from the ship's electricity to small consumers "at home" as well as large consumers such as generators powering generators and cranes. Onboard power distribution systems also often contain electronic devices such as lithium-ion batteries for temporary energy storage. Such batteries enable working hours for energy production and utilization and open the operating hours of individual products to maximum performance. This requires intelligent energy management to manage individual properties.

Fuel Cell Outlook

The gas engine is receiving more and more attention due to pollution emissions and air pollution. Fuel cells, low-cost, zero-carbon energy production and the use of renewable energy for heating purposes are more efficient than other systems, making them attractive for many applications. Even today, fuel cells are used to provide mobile power to land vehicles and ships, as well as to generate sufficient power in stand-alone devices. One of the advantages of hydrogen-powered fuel cells is that CO2 emissions from ships and power plants are reduced to zero when using green hydrogen.

Fuel Cell Technology

The development of brain fuel dates back to the early 1800s, with Sir William Grove being named an explorer in 1839. In the past century, scientists have attempted to develop brain fuel from a variety of fuels and electrolytes. Further work in the first half of the 20th century eventually laid the groundwork for the machine's use in the Gemini and Apollo space flights. However, it was not until 1959 that Francis T. Bacon successfully worked on the first fuel cell.

Proton exchange membrane fuel cells were first used by NASA in the 1960s as part of the Gemini program and were used on seven missions. Fuel cells that use pure oxygen and hydrogen as reaction gases are small, expensive and non-commercial. NASA's interest led to further developments such as electric power in 1973. Fuel cell research has continued since then, and fuel cells have been successfully used in a variety of applications.

Fig. 2: Various PEMFC stacks

Advantages of Fuel Cells

Fuel cell systems are often compared to internal combustion engines and batteries and have both advantages and disadvantages.

Fuel cell systems have the following advantages:

- Fuel cell systems work with pure hydrogen without creating pollution, the only source being clean water and heat. Running on a mixture of hydrogen-rich alternative fuels produces some harmful emissions, although less than emissions from traditional fossil fuel combustion engines. To be fair, an internal combustion engine burning a mixture of hydrogen and air will produce very little pollution, mostly from the breakdown of lubricating oil.
- Fuel cell systems operate with more energy than thermal systems. Heating systems such as internal combustion engines and turbines convert chemical energy into heat by mixing and using the heat to do work. The ideal (or "Carnot") thermodynamic efficiency of a heat engine is called:

$$Efficiency_{MAX} = 1 - \frac{T_2}{T_1}$$

Electric (cold) gas expands more (in 0R or K) and hot oil has a higher temperature.

Since the outlet temperature cannot theoretically be lower than the temperature, the temperature can be increased by any amount to achieve the desired result.

However, in real heating systems, the maximum temperature is limited by the material. Additionally, for internal combustion engines, the inlet temperature is the operating temperature of the engine at the ignition temperature.

Since the fuel cell does not use combustion, its efficiency is independent of the maximum operating temperature. Thus, the efficiency of the heat transfer step (the actual combustion reaction rather than the actual combustion reaction) can be greatly improved. The efficiency of an electrochemical reaction is not the same as the overall efficiency of the system. The performance characteristics of fuel cells compared to other power generation systems are shown in Figure 3.

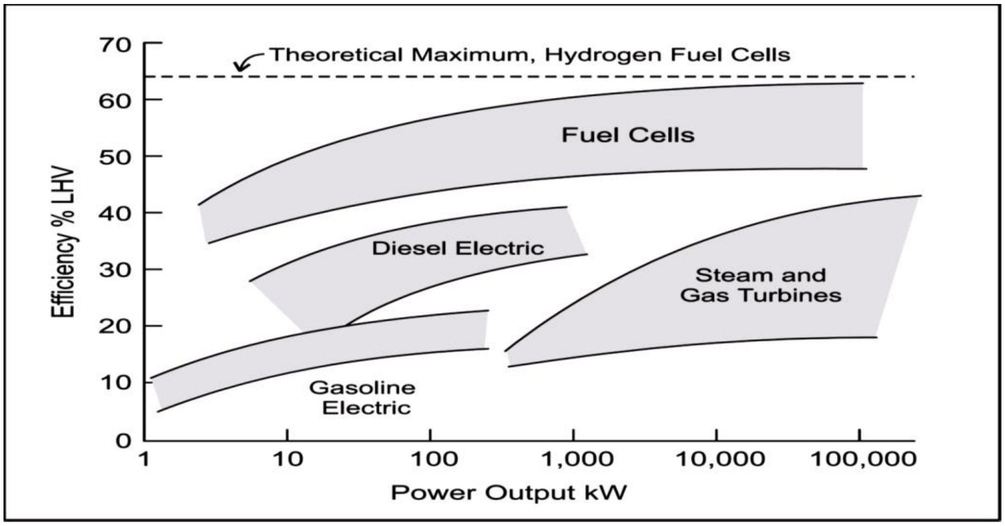

Figure 3: Comparison of Energy Production Efficiency

- In addition to the special thermal efficiency of fuel cells, batteries are higher than heating systems, efficiency does not decrease. The heating system works best at the design speed and shows a reduction in the operating speed of the load.

Fuel cells, like batteries, perform better at part load than at full load and have less variability in overall operation. Fuel cells have a modular structure and have the same functionality regardless of size. But the modifiers work less efficiently on the payload, so when combined with the fuel cells, the overall hull performance suffers.

- Fuel cells have the following advantages. Fuel cells, like batteries, are semiconductor devices that respond quickly to changes in load. But gas turbines are mostly mechanical devices and each has its own time to respond to changes in demand

Nevertheless, gas engines will have a perfect response to pure hydrogen. However, the gas engine running on both the mod and the card can run slowly, especially when using a mechanical modification.

- When used as a source of electricity generation, fuel cells require less energy than heating systems. Fossil fuels, when used as an energy-generating material, require the same conversion time, even though their specific conversions are different.

Fuel cell systems have the following disadvantages:

- Ironically, hydrogen is very beneficial for the environment when used in fuel cells, but its biggest disadvantage is that it is difficult to produce and store. The current production process is expensive and laborious and often results in the use of fossil fuels. An efficient hydrogen system has not yet been developed.

Hydrogen gas storage systems are large and heavy to accommodate the low volumetric energy density of hydrogen. Liquid hydrogen storage systems are smaller and lighter, but must operate at high temperatures. Alternatively, storage and simple solutions at the expense of some environmental benefits if the hydrogen is stored as a hydrocarbon or alcohol and released by on-demand plate reorganization.

- Fuel cells need clean, non-polluting fuel. These pollutants include sulfur and carbon compounds, as well as residual fuel (depending on the type of fuel cell), which can affect the fuel cell's catalyst and reduce its efficiency. None of these pollutants prevent combustion in an internal combustion engine.
- Fuel cells for automotive use often require the use of platinum catalysts to facilitate the energy generation reaction. Platinum is a rare and expensive metal.
- There should be no ice in the fuel cell. Fuel cells produce pure water during the electrical reaction, and fuel cells are generally suitable for use in vehicles using wet fuel. Water remaining in the fuel can cause irreversible swelling damage if allowed to freeze. The gas generator generates enough electricity to prevent freezing at high temperatures during operation, but when shut down in cold weather, the gas must be kept warm or residual water removed before it freezes. This often requires driving the car into a heated area or using local heating.
- Fuel cells using proton exchange products should not be dried during use and should be kept moist during storage. Attempting to start or operate the fuel cell in a dry environment may damage the diaphragm.
- Fuel cells need support and control systems. Fuel cells themselves are state-of-the-art equipment, but not the machinery needed to support their operation. Be aware of the need for compressed air; this requires high-speed compressors that put a lot of strain on the entire system. The complexity of the system is greatly increased when the gas generator works with the on-board rectifier.
- Fuel cell systems are very heavy. The fuel cell itself is not very heavy, but the weight, support and fuel tank of the fuel cell are now more compared to the hybrid generator. More serious is the inclusion process of the replacement of the board of directors. Although battery-powered systems require less support equipment, gas-powered systems are generally lighter than their battery-powered counterparts. As the technology is used, the weight of the system will tend to decrease. Despite the heavy weight, the models with the available fuel system showed that the system can be installed in the vehicle.
- The fuel cell is a new technology. As with any new technology, the key engineering goals remain to reduce cost, weight and size while ensuring reliability and longevity.

Principle of Operation

When the fuel chemically reacts with the oxygen in the air, energy is released. In an internal combustion engine, the reaction proceeds violently and energy is released as heat; some of them can be used to good work pushing pistons. In a fuel cell, the reaction takes place electrochemically and energy is released as a combination of low-voltage direct current and heat. When lost as heat or used for other purposes, electricity can be directly used to perform important tasks.

Electrochemical reactions in galvanic batteries form the basis of the conversion of chemical energy into electrical energy. All types of electricity are main cells and batteries. In an electrolytic cell, on the other hand, electrical energy is converted into chemical energy, for example by electrolysis or electroplating.

Fuel Cells

An important feature of a fuel cell is that the current charge determines the amount of hydrogen and oxygen. In the process of use, the oil can be used for various electrical products. In a fuel cell, fuel and oxidizing gases form the anode and cathode. The physical structure of the electric fuel is therefore one in which the fuel is carried to both sides of the electrolyte by the water stream. The electrolyte is the difference between the different types of fuel cells. Different electrolytes form different ions.

Electrolytes can be liquid or solid; some work at low temperatures. Low-burning fuels usually require a high-quality electrode (usually platinum) to support the electrode reaction, while high-burning fuels do not. Most fuel cells suitable for use in vehicles use low-energy materials that produce hydrogen ions, as shown in Figure 4.

In principle, fuel cells can work with different types of fuels and oxidants. Hydrogen has long been considered the most efficient fuel for power generation due to its higher electrical conductivity than other fuels such as hydrocarbons or alcohol. Even fuel cells that run directly on non-hydrogen fuels tend to produce hydrogen and other products before the reaction takes place. Oxygen is an obvious choice of oxidant due to its high reactivity and abundance in the atmosphere.

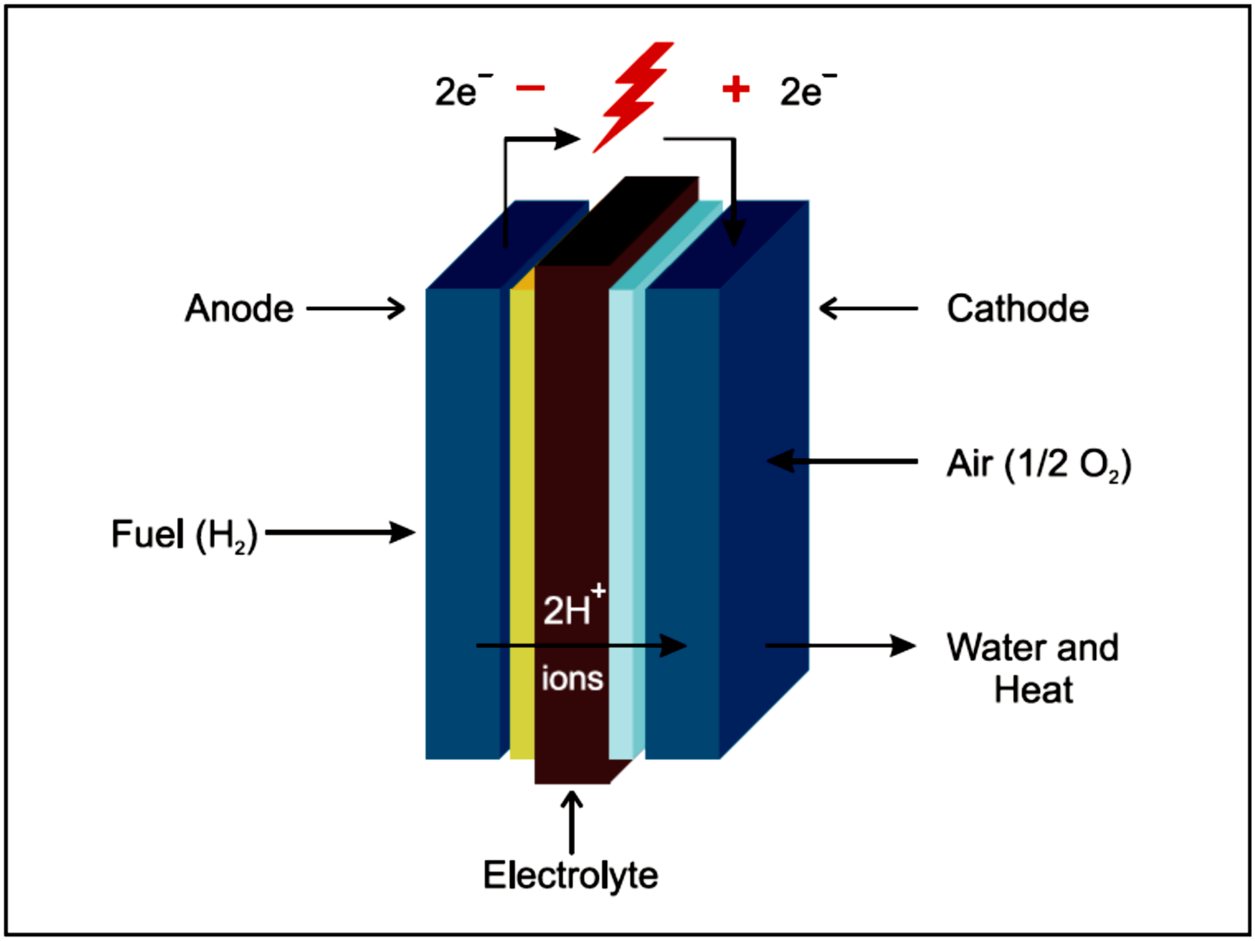

Figure 4: Low Temperature Electrolyte Produces Hydrogen Ions

Types of Fuel Cells

The types of fuel cells differ depending on the type of electrolyte used. The type of electrolyte determines the operating temperature, and the operating temperature of different types is very different.

High temperature fuel cells operate at temperatures above 600°C (1100°F). This heat enables the conversion of light hydrocarbon fuels, such as the conversion of methane to hydrogen and carbon in the presence of water. This reaction always takes place at the anode of the nickel catalyst if there is enough heat. This is the main part of the conversion process.

Internal modifications eliminate the need for a separate oil system and allow the use of oils other than pure water. These significant benefits lead to a 15% increase in overall performance. In the second electrochemical reaction, the fuel uses the chemical energy released by the reaction of hydrogen and oxygen to produce water and to produce carbon dioxide using carbon monoxide and oxygen.

High-temperature fuel cells also produce high-energy products that can be used to combine heat and power in low-cost processes.

High-temperature fuel cells can be produced easily and efficiently without expensive metal catalysts such as platinum. On the other hand, the energy released by the electrochemical reaction decreases with increasing reaction temperature.

High temperature fuel cells face serious problems. Few materials can work for a long time without deterioration in a hot chemical environment. Also, hot work is not suitable for extensive work and situations that need to be started quickly. Therefore, the current application of high-temperature fuel cells is mainly focused on power plants, where internal conditioning and compression efficiency are more important than low-end product and slow start-up.

The most famous fuel cells are:

- Molten carbonate
- Solid oxide

Low temperature fuels generally operate below 250 ºC (480 ºF). These low temperatures do not allow for internal reforming, so an external source of hydrogen is needed.

On the other hand, they start quickly, have fewer equipment problems and are easier to solve vehicle handling problems.

The most important low-temperature fuel cells are:

- Alkaline
- Phosphoric acid
- Proton exchange membrane (or solid polymer)

PEM Fuel Cell Performance

Figure 5: PEM fuel cell

Efficiency

The performance of fuel cells is often considered one of the key advantages of this technology. While this is true in principle, it is important to distinguish between fuel cell system efficiency and fuel cell system efficiency.

Fuel Cell Stack Efficiency

The efficiency of the fuel cell charge is mainly related to the accuracy of the electrochemical reaction. This performance can be given as follows. According to

The reaction $H_2 + \frac{1}{2}O_2$ H_2O, the energy released when hydrogen and oxygen combine to form water is called the "enthalpy of reaction" ($\Delta H0$). This value is measured experimentally and depends on whether the water is gaseous or liquid. For gas cells where water is formed in the gaseous state, the reaction enthalpy is called:

$$\Delta H^0_{(gas)} = -230 \frac{BTU}{mole_{Water}} = -242 \frac{kJ}{mole_{Water}}$$

Where molar water = 6.023 x 1023 water molecules, the energy released during the reaction is not absorbed.

The enthalpy of this reaction is definitely only 77 ºF (25 ºC) and 1 air pressure. The effect of temperature is greater than that of altitude and performance decreases with temperature. The change in energy efficiency only changes by a few percent with heat. Therefore, high temperature fuel is less efficient than low temperature fuel.

Unfortunately, not all of the enthalpy of a reaction can be used to do important work. Part of the enthalpy in the form of entropy causes the world to be disordered and disappears; the remainder is called the "Gibbs free energy" (ΔG0). For gaseous water (77 ºF / 25 ºC and 1 air) it is known:

$$\Delta G^0_{(gas)} = -217 \frac{BTU}{mole_{Water}} = -229 \frac{kJ}{mole_{Water}}$$

The cell voltage ($\mathcal{E}$Cell) is related to the Gibbs free energy according to the following equation:

$$\mathcal{E}_{Cell} = -\frac{\Delta G^0}{n\mathcal{F}}$$

Where n = number Number of electrons involved in the Reaction. The simplest expression is "moles of electrons", $\boldsymbol{\mathcal{F}}$ = Faraday's constant.

Turn the results into equations (using British units):

$$\mathcal{E}_{Cell} = \frac{-217\ \cancel{BTU}}{\cancel{mole_{Water}}}\ x\ \frac{1055.7\ J}{\cancel{BTU}}\ x\ \frac{\cancel{mole_{Water}}}{2\ \cancel{mole\ e^-}}\ x\ \frac{\cancel{mole\ e^-}}{95{,}500\ coul}$$

$$= \frac{1.187\ J}{coul} = 1.187\ V$$

Therefore, each cell can produce a maximum theoretical voltage of 1.187 V (at 77 ºF / 25 °C and 1 air). Fuel cell efficiency is therefore the ratio of the actual voltage produced by the cell to the theoretical maximum:

$$Efficiency\mathcal{E}_{Cell} = \frac{V_{Actual}}{\mathcal{E}_{Cell}} \cong \frac{V_{Actual}}{1.2\ V}$$

For a true fuel cell, typical voltages at normal operating other loads are between 0.5 and 0.6 V and can reach 1.1 of normal operating loads. . V open state. Therefore, the electrochemical efficiency is usually around 40% to 50%, up to 90% under open circuit conditions.

Fuel Cell System Efficiency

The efficiency of the fuel cell system is related to the overall efficiency of the fuel cell power plant.

The fuel cell assembly can only function if it is supplied with compressed air and hydrogen and flushed with cold water. Diesel-fired power plants require additional equipment to control oil and fluid flow, lubrication, service operations, control electrical equipment, and provide process control. Some machines contain oil conditioning modifiers. All of these devices create losses and reduce the body's optimal performance.

In order to make a good comparison between fuel cells and other generators, all generators must be defined in the same way.

When we compare gas generators to internal generators for automotive use, they can be easily defined as devices that access gas and air and provide electricity to the device to power the driver. In both cases, oil is withdrawn from reservoirs in gaseous or liquid form and stored after refining or other processing.

Two air compressors; Internal combustion engines use pistons only, while fuel cell engines use an external combustion engine. An internal combustion engine supplies electricity directly to the engine, while an internal combustion engine uses an electric motor and an electric motor. Both systems use coolant pumps, electric motors and other thermal management systems to dissipate heat to the environment. Both machines share the same load.

The overall efficiency of an internal combustion engine is usually between 15% and 25%. These values represent the power of the car's wheels; Flywheel performance is typically between 30% and 35% efficiency and more for diesel engines.

For a pure hydrogen fuel cell power plant, the flywheel power efficiency comparison is approximately as follows:

Fuel cell efficiency: 40 - 50%

Air compression: 85% (when using 15%) % of total power

Converter efficiency: 95%

Engine efficiency: 97%

Multiplying each of these values yields a full system efficiency of approximately 31 to 39%.

For fuel cells operating with a modifier, these efficiencies decrease further from 65% to 75% for all processes, from around 20% to 29% (depending on the type of modifier).

The effect of total weight is more difficult to measure. Fuel cell systems (including fuel storage) are heavier than hybrid generators of the same power and range and therefore use more electricity.

An electrochemical battery is better compared to a fuel cell. While a battery does not need air compression, refrigeration or inverters when used as an electric motor in a car, it does need generators and generators. Although energy storage batteries are heavier than fuel cells, this is somewhat offset by the removal of additional components.

Taking a step back, fuel products have become an integral part of the overall operation.

For internal combustion engines, this often involves refining hydrocarbon fuels. For fuel cells, this includes the production of hydrogen from fossil fuels or the electrolysis of water, or the production of fuels such as methanol for reformers. For battery systems, this includes the energy used for charging.

These conditions are difficult to analyze and depend on the location of the oil, the method of operation, handling and shipping difficulties, and other factors such as the energy required to compress or liquefy the oil. Ultimately, these conditions reduce the overall price of oil; however, these costs cannot include costs associated with long-term environmental damage.

Polarization Characteristics

Ideally, the theoretically optimal fuel cell voltage of 1.2 V is achieved at all operating currents. Fuel cells reach their maximum output voltage under open circuit (no load) conditions and current is drawn as the voltage drops. This is called polarization and is represented by the polarization curve as shown in Figure 6.

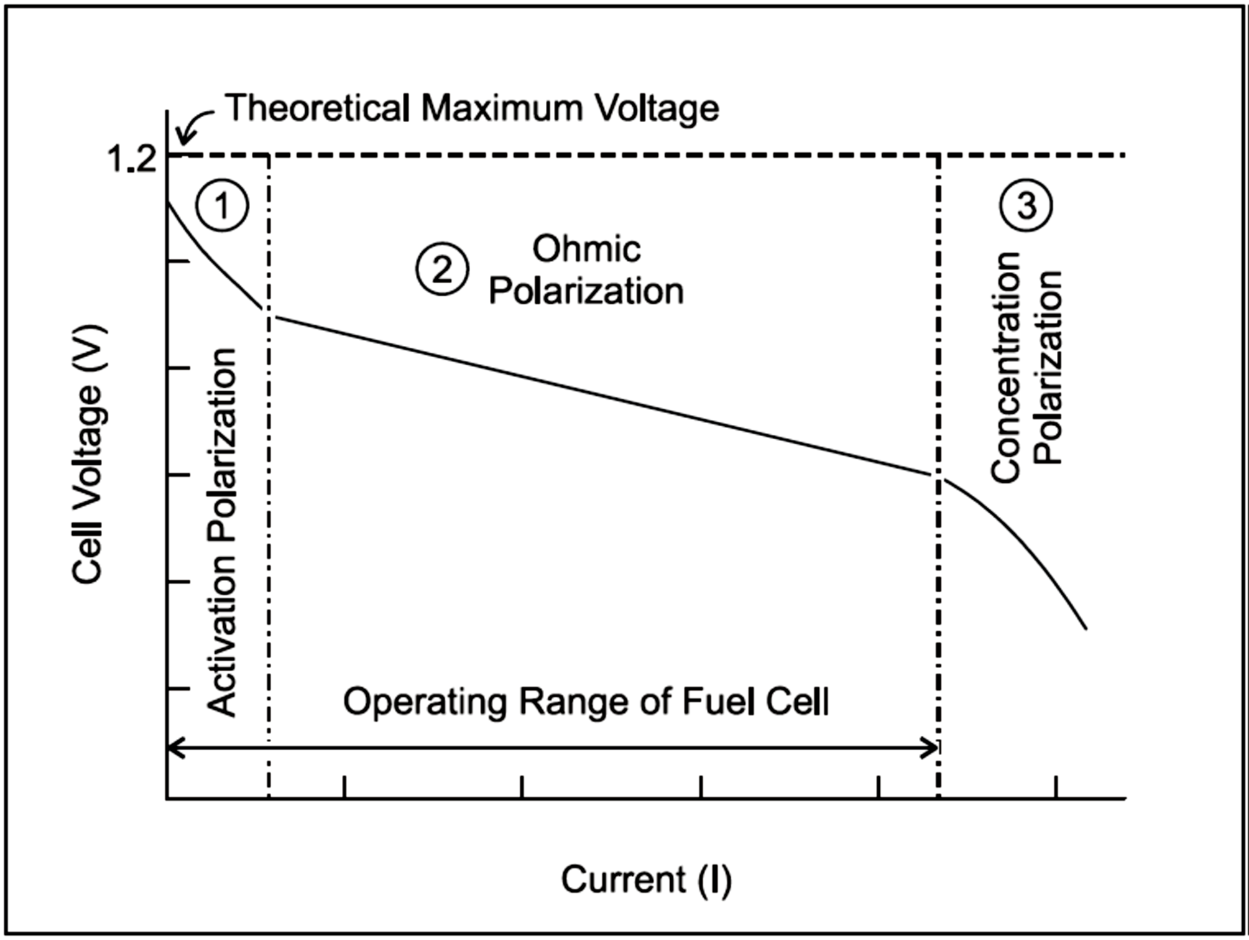

Fig. 6: Typical PEM fuel cell polarization curve

The polarization curve shows that the hand of the cell is defined as the current work. Now it depends on the size of the electric charge of the fuel cell or More importantly, the polarization curve shows the electrochemical efficiency of the fuel cell at its operating current, since efficiency is the ratio of the actual cell voltage divided by the theoretical maximum of 1.2 V.

The polarization curve of a battery is similar to this. from the fuel cell. Both batteries and fuel cells perform best because the voltage increases as the load decreases.

In contrast, internal combustion engines operate efficiently at full load and quickly lose efficiency at part load.

Polarization is the result of chemical and physical effects on many aspects of a fuel cell.

These conditions limit the chemical reaction process when current flows. Three main factors affecting the Earth's polarization:

- Increased polarization
- Ohmic polarization (or resistive polarization)
- Concentration polarization

The difference in cell potential from positive behavior is the result of a number of these factors that directly affect the total charge.

Activation Polarization

Polarization refers to the energy barrier that must be overcome to initiate a chemical reaction of reactants. When the current consumption is lower, the electricity rate gradually changes and some electricity is lost to compensate for the insufficient electrocatalytic activity.

Ohmic Polarization

Ohmic polarization (or "resistive polarization") occurs as a result of low battery voltage. These losses occur in the electrolyte (ions), the electrodes (electrons and ions) and the terminals (electrons) in the battery. Since the stacked plate and electrolyte obey Ohm's law ($V = IR$), the magnitude of the field voltage drop varies by region.

Concentration Polarization

Concentration polarization occurs when the reaction electrode is affected by a mass change. In this region, reactants are consumed faster than they are given, while products accumulate faster than they are removed. Eventually these effects inhibit all other reactions and the cell voltage drops to zero.

Power Characteristics

Electricity is the product of voltage and current ($P = VI$). Since the fuel cell polarization curve shows the relationship between voltage and current under all operating conditions, it can be used to create a power curve. The current at any point on the curve is shown as a rectangle tangent to the curve. Figure 7 shows the performance curve.

The maximum output occurs between 0.5 and 0.6 V, which corresponds to a very high current. At its peak, the internal resistance of the battery equals the resistance of the external circuit. However, there is a trade-off between high power and high efficiency, as efficiency decreases with increasing voltage. Electric power generators must choose the required power based on whether efficiency or power is important to the application. He never wanted to go over the declining performance curve.

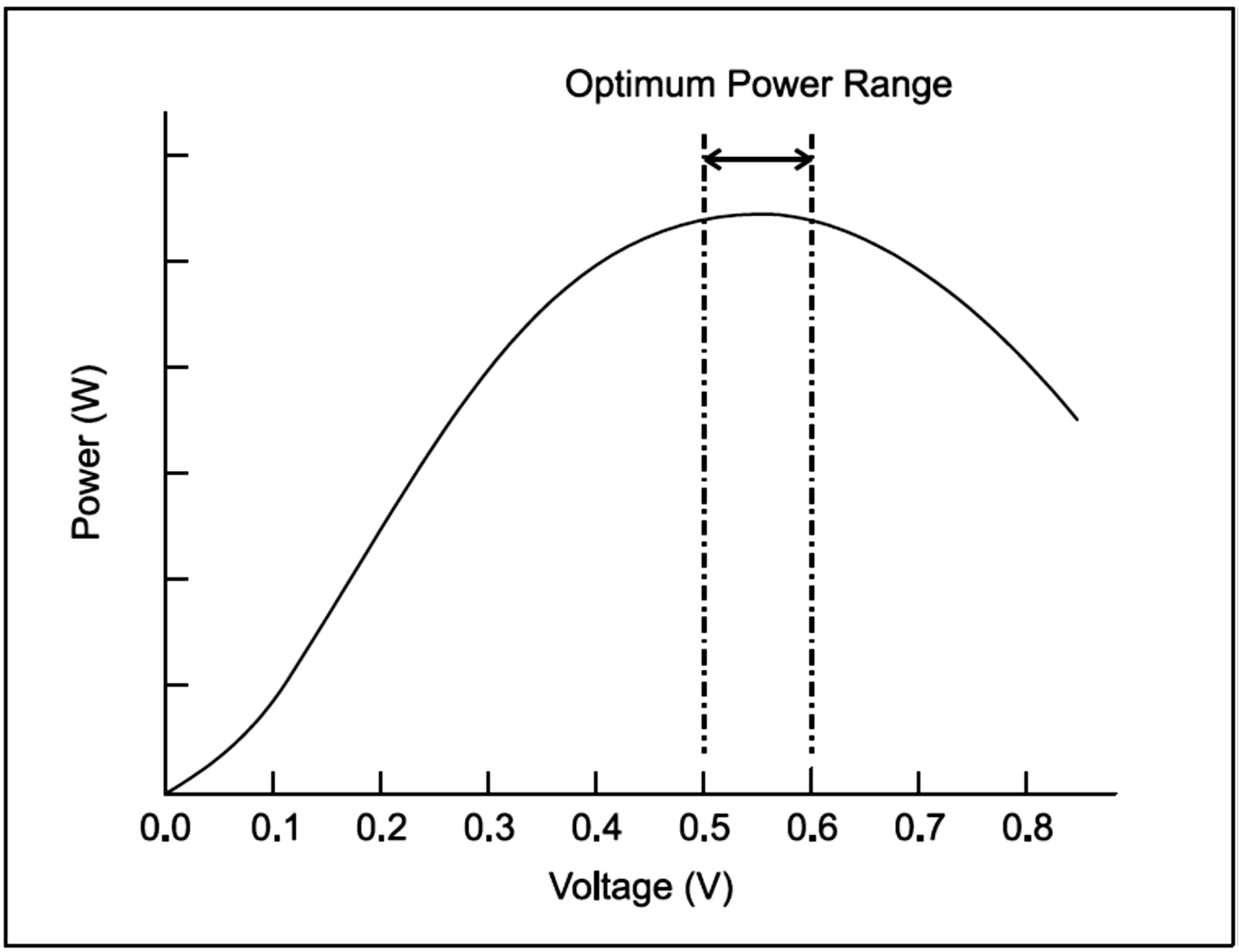

Fig. 7: Typical PEM fuel cell power curve

Temperature and Pressure Effects

The shape of the polarization curve depends on the operating temperature and pressure of the group. In general, a series of polarization curves can be drawn to characterize battery performance over the entire operating range.

Fuel cell designers evaluate the overall performance of a fuel cell assembly in terms of volumetric energy density. It is calculated by dividing the maximum energy in W/L by the body volume. Energy density indicates that a small unit can break a large amount of energy.

PEM fuel cells have a power density of over 1350 W/L; Ten years ago, the power density was about 90 W/L.

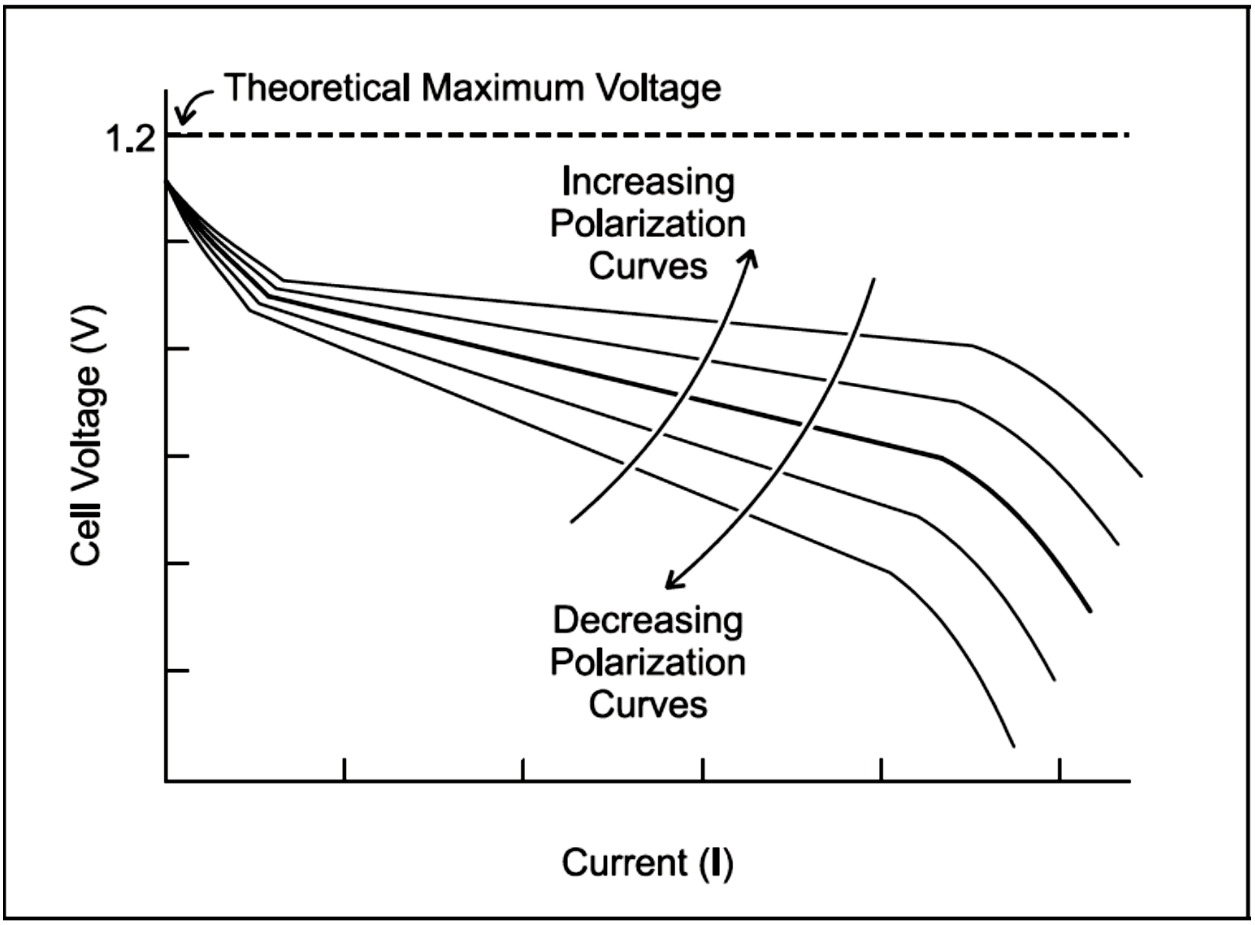

Fig. 8: Polarization curve change

In general, the change is that it becomes more and more powerful. electrochemical efficiency. rear.

Pressure

The polarization curve of fuel cells usually increases with higher power. Conversely, the polarization curve decreases with higher activity.

The speed of the reaction is directly proportional to the partial pressure of hydrogen and oxygen. (All gases in the fuel mixture contribute to a partial pressure equal to the total pressure.) Therefore, the result of maximum pressure increase is expressed when using either a diluted oxidizer (eg air) or a diluted oil (eg modified). .

The higher pressure basically helps the hydrogen and oxygen to come into contact with the electrolyte. Pressure sensitivity is greater at high and low tides.

Although increasing the pressure promotes the electrochemical reaction, it also brings other problems. Fuel cell volumetric flow fields perform better at low pressure because they exhibit less shock. Fuel cell seals operate under increased pressure. There must be more air compression that takes all the power. Other processes need to be reinvented; For this reason, some products need to be increased in size and price.

Ultimately, the high pressure restores the low pressure relative to the performance of the group and the overall effect of the body. Because of these factors, PEM fuel cells generally operate at altitudes of no more than a few atmospheres.

Temperature

The polarization curve of fuel cells increases with increasing operating temperature. Conversely, the polarization curve decreases as the operating temperature decreases.

High temperature improves mass transfer in the gas and causes depletion in the cell (electron conductivity in metal decreases with increasing temperature, but ionic conductivity in electrolytes increases). Together, these effects increase the response.

Accumulation of water in the oxidizer stream effectively limits the operating temperature below 212ºF (100ºC). Water boils hot and cold, and the resulting steam reduces some of the oxygen. This greatly reduces battery performance due to lack of oxygen. This can damage the fuel cell and shorten its life.

Because the connection increases the temperature of the water, higher temperatures can be achieved by operating at partially higher altitudes. However, this effect is small in the highly efficient operation of PEM fuel cells.

As a result, the electric current of the gas increases with temperature until the temperature reaches that of hot water, while the electric current begins to decrease. The optimum temperature is around 175°F (80°C), where both effects are equal, as shown in Figure 9. The operating temperature is 70 to 90°C (158 to 194°F).

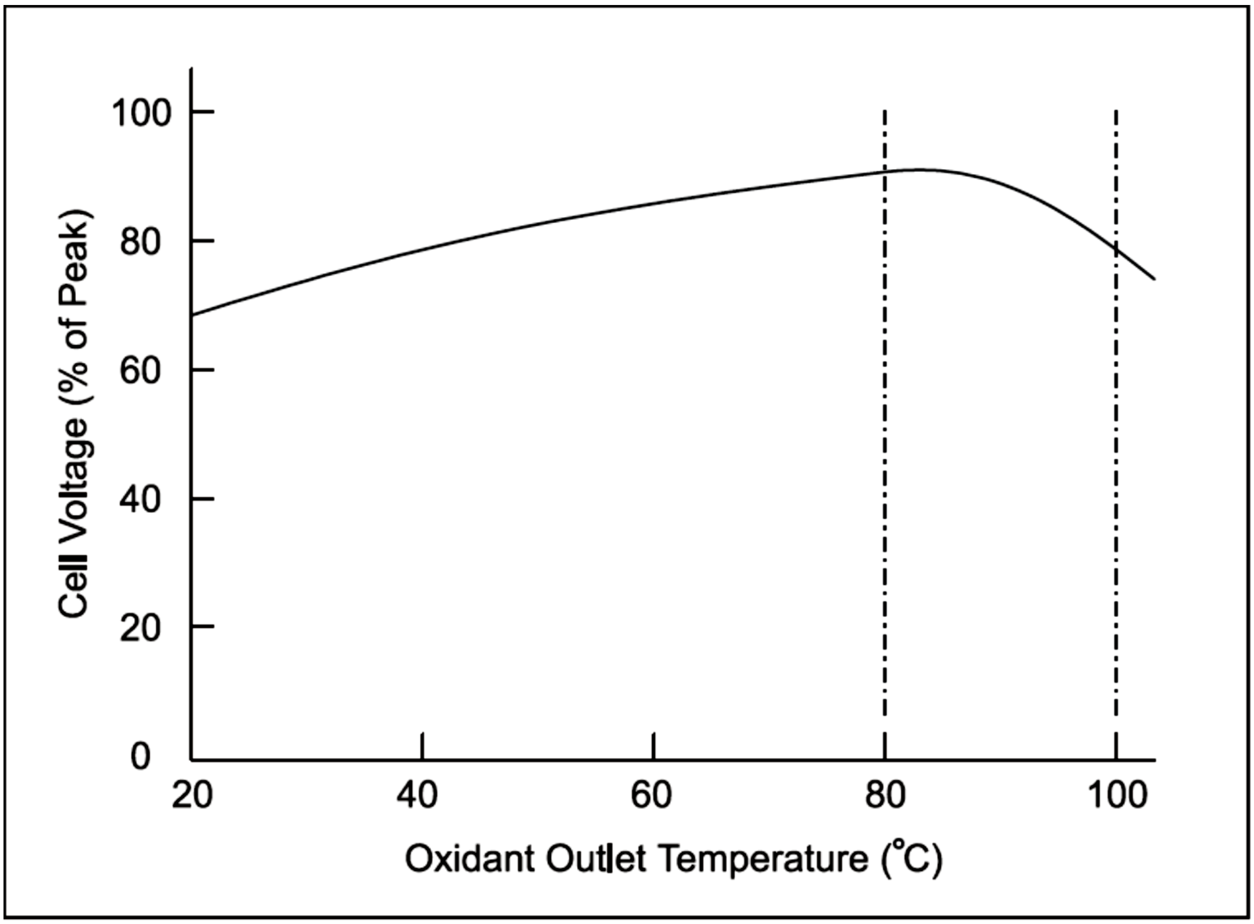

Figure 9: Effect of temperature on fuel cell voltage

According to high voltage operation, high temperature operation affects all components in the system, some need to be adjusted accordingly.

Stoichiometry Effects

Polarization curves of fuel cells Increasing gas stoichiometry with reagents. On the contrary, the polarization curves decrease with decreasing stoichiometry of the reaction gas.

This is because greater stoichiometry causes more hydrogen and oxygen molecules to interact with the electrolyte. Insufficient stoichiometry can cause the fuel cell to lose (or "starve") enough nutrients and cause permanent damage.

Stoichiometry is the ratio of the gas available to the gas required to complete the reaction. This is similar to the concept of gravity, where density corresponds to the material used. Therefore, a stoichiometric ratio of 1.0 indicates the exact number of gas molecules needed for the reaction to theoretically occur. A stoichiometric ratio greater than 1.0 gives too much fuel, while a stoichiometric ratio less than 1.0 gives not enough fuel. A stoichiometric ratio of 2.0 gives twice the number of gas molecules needed.

As the gas flow stoichiometric ratio increases, the resulting fuel gas temperature will gradually reach the terminal voltage as shown in Figure 10. Product electrical power generators generally operate with a hydrogen stoichiometry of 1.4 and an air stoichiometry of 2.0 at rated load; added oil provides little added benefit. A greater stoichiometric ratio is required for low power operation.

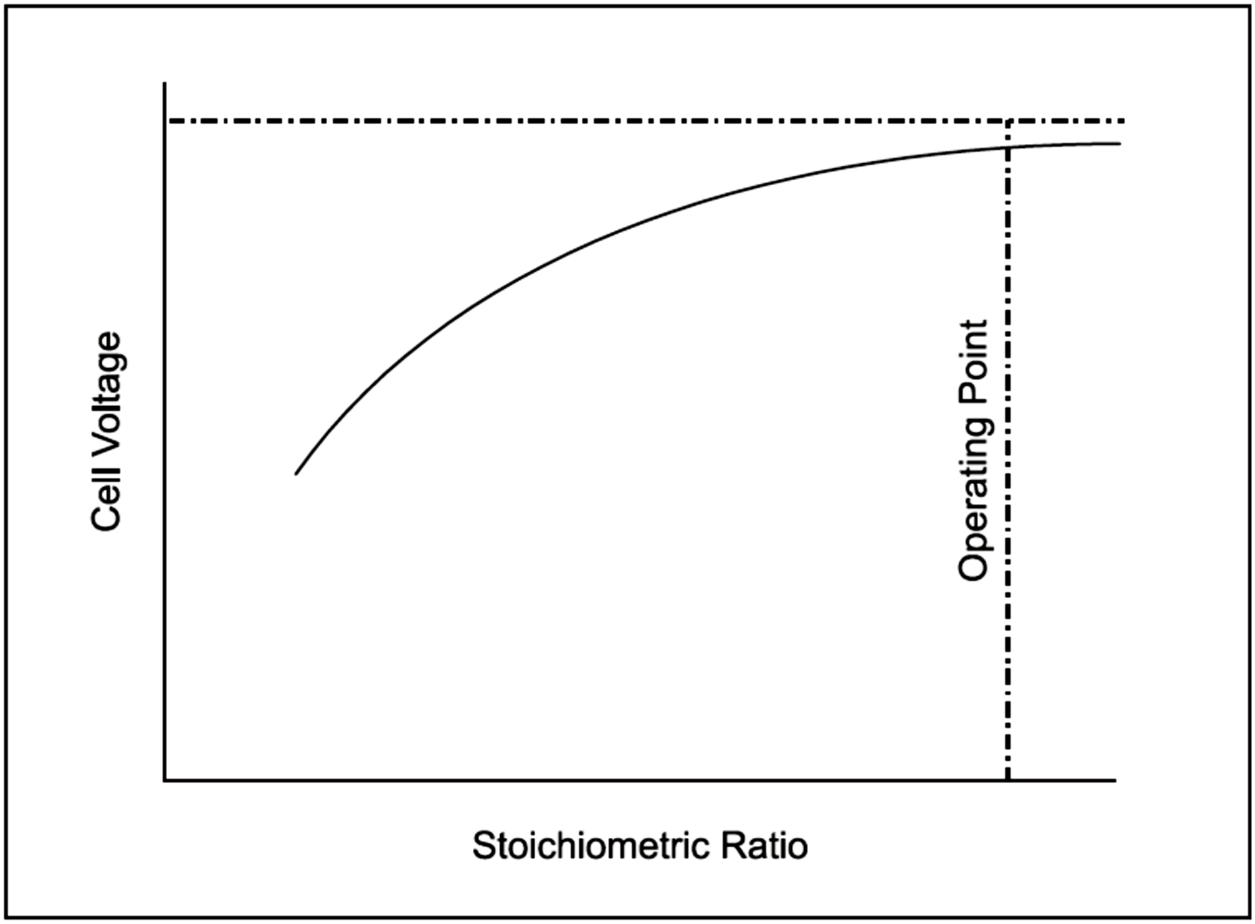

Figure 10: Effect of stoichiometry on fuel cell voltage

Humidity Effects

Adequate air generation is important for PEM fuel cell operation because water molecules move with hydrogen ions during the ionic phase change.

Dehydration can cause dehydration and cause cracks or holes in the membranes. This can cause short-term chemical reactions, local fuel mixing, hot spots and the possibility of fire.

On the contrary, excessive humidification will cause the formation of voids and their migration into the flow plate. This causes a phenomenon called "battery reversal" in which the battery responds by producing a zero or negative voltage. If there is enough negative current, the affected gas begins to behave as an electrolyte. This generates a lot of heat and can damage the battery. A battery monitoring system is often installed to check battery charge before battery damage occurs.

Humidity is usually measured as "relative humidity"; relative because it depends on the pressure and temperature of the gas. When an oil absorbs as much water as it can absorb at that pressure and temperature, it is considered saturated and its moisture content is 100%. If a saturated fat is heated (without adding additional water), the relative humidity will drop. (The relative humidity drops about 4 percent at each temperature) If the oil cools, some of the water will condense and the oil will remain saturated at that temperature.

Fuel cells generally operate at or near the saturation point of the operating temperature of the fuel (determined by the coolant). This ensures maximum water retention while preventing flooding.

Using water for good humidity prevents fuel consumption and keeps the temperature between 32 and 212 ºF (0 to 100 ºC). Beyond these limits, ice and boiling occur.

Another problem is that the humidifier must remain without electricity. A fault can cause a short circuit and corrosion current in the fuel cell system. Water becomes active when it accepts ions from its surroundings. To remove these ions, the water must continuously flow through a deionization filter.