

Fuel Cells for Space Programs

By Saurabh Kumar (SC22B146)



Abstract

- Fuel cell technology has been receiving more attention recently as a possible alternative to the internal combustion engine for our automobile.
- Improvements in fuel cell designs as well as improvements in lightweight high-pressure gas storage tank technology make fuel cell technology worth a look to see if fuel cells can play a more expanded role in space missions.
- The preliminary studies indicate that fuel cell systems have the potential for energy densities of greater than 500 W-hr/kg, greater than 500W/kg and greater than 400 W-hr/litre, greater than 200 W/litre. This level of performance makes fuel cells attractive as high-power density, high-energy density sources for space science probes, planetary rovers and other payloads.

- The power requirements for these space missions are, in general, much lower than the power levels where fuel cells have been used in the past.
- Adaptation of fuel cells for space science missions will require downsizing the fuel cell stack and making the fuel cell operate without significant amounts of ancillary equipment.
- Thus, fuel cells have become an essential component of space programs, providing a reliable and efficient power source for spacecraft and satellites. We will investigate the use of fuel cells in space programs, including their history, design, and operation.
- We will also explore the advantages of using fuel cells in space, such as their high efficiency and low emissions, as well as their drawbacks, such as their high cost and technical complexity. Finally, the assignment will consider the future of fuel cell technology in space programs, including new designs and applications.

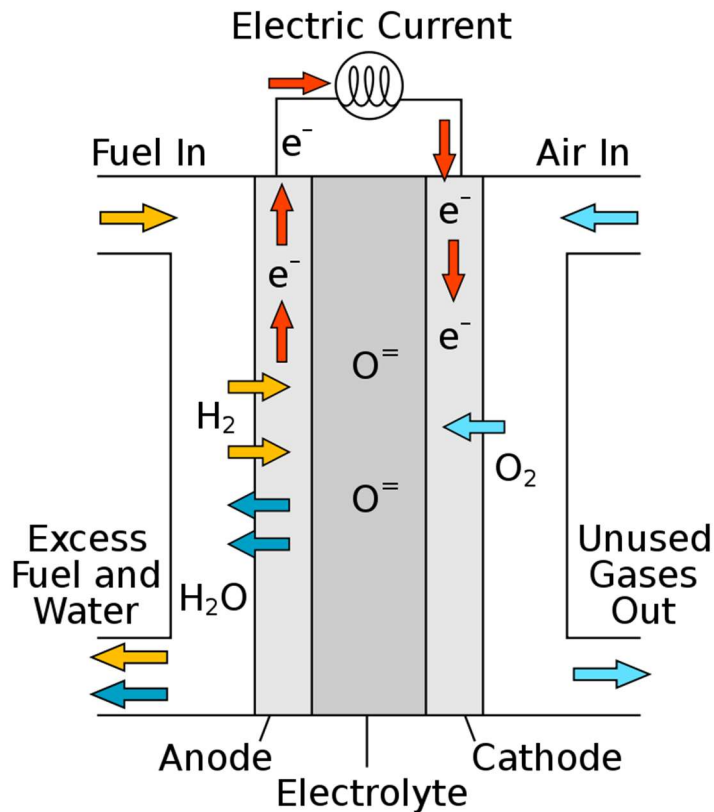
Introduction

- Space programs rely heavily on advanced technologies to operate and accomplish their objectives. Power sources are a critical component of these technologies.
- Fuel cells are one of the most promising power sources used in space programs due to their high energy density and efficiency, which makes them an ideal choice for long-duration missions.
- Fuel cells have been used in space programs since the 1960s, and their application has been expanding in recent years, with the development of new technologies and designs.

History

- The first fuel cells were invented in the early 19th century, but it was not until the 1960s that fuel cells were first used in space programs.
- The Gemini program was the first manned space program to use fuel cells as a power source. The fuel cells provided electricity, water, and oxygen for the spacecraft, reducing the weight and volume of the equipment required for these functions. Fuel cells were later used in the Apollo missions, providing power to the Lunar Module and Command Module.
- The first fuel cell-powered space mission was the Gemini V mission in 1965, which used a fuel cell to generate electricity and water for the astronauts. This was followed by the Apollo missions, which also used fuel cells to provide power and water for the astronauts.
- Fuel cells continued to be used in space programs throughout the 1970s and 1980s, with a particular focus on the Space Shuttle program. The Shuttle used fuel cells to provide electrical power, water, and heat for the crew, and the fuel cells were able to operate continuously for up to 14 days.
- One of the major advantages of fuel cells for space applications is their high energy efficiency. Unlike traditional combustion engines, which convert only a small fraction of the fuel's energy into useful work, fuel cells can convert up to 60% of the fuel's energy into electricity.
- Fuel cells are also extremely reliable and have a long lifespan, making them well-suited for long-duration space missions. In addition, fuel cells produce only water as a by-product, which is a valuable resource for astronauts in space.

Design



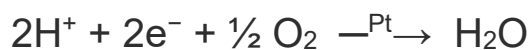
- A fuel cell combines a fuel (hydrogen or hydrogen source) with an oxidizer (oxygen or air) to produce electrical power. These electrochemical devices work similar to batteries, but they never run down or need to be recharged.
- A fuel cell has two electrodes (a cathode and an anode) that are separated by an electrolyte, similar to a battery. However, batteries have at least one solid metal electrode that is slowly consumed as electricity is produced. In a fuel cell, the electrode is not consumed, and the cell can produce electricity as long as more fuel and oxidizer are pumped through it.
- Fuel cells can use hydrogen directly, or they can obtain hydrogen from another fuel, like liquid methanol, which is renewable and can be transported more easily than hydrogen. With hydrogen fuel, heat and water are the only by-products. With methanol fuel, heat and water are still the major by-products, along with only a fraction of the carbon dioxide and

none of the other pollutants produced by a gasoline-burning engine.

- **Hydrogen-Oxygen Fuel cell reactions:**

On the anode side, hydrogen is oxidized to form two protons and two electrons. The protons conduct through the membrane, while the electrons travel outside the cell to drive a load.

On the cathode side, the protons and electrons combine with oxygen to form water.



- The design of fuel cells for space programs is similar to that of fuel cells used on Earth, but with some important differences. In general, a fuel cell consists of an anode, a cathode, and an electrolyte, which allow for the conversion of fuel into electricity.
- One major consideration in the design of fuel cells for space programs is weight. Since every gram of weight must be carefully managed for space missions, fuel cells must be as lightweight as possible. This means that the materials used in the construction of the fuel cell must be carefully selected to minimize weight while still providing the required durability and performance.
- Another important consideration is reliability. Since space missions can last for months or even years, fuel cells must be designed to operate reliably for long periods of time. This means that the fuel cell components must be designed to withstand the harsh conditions of space, such as radiation, extreme temperatures, and microgravity.
- One type of fuel cell commonly used in space applications is the proton exchange membrane (PEM) fuel cell. PEM fuel cells

use hydrogen as the fuel and oxygen from the air as the oxidizer. The anode and cathode are separated by a thin, permeable membrane that allows protons to pass through while blocking electrons. The protons react with oxygen at the cathode to produce water and electrical energy.

- PEM fuel cells are particularly well-suited for space applications because they are lightweight, have high power density, and are able to operate at low temperatures. They also produce only water as a by-product, which can be used by astronauts for drinking or other purposes.
- Overall, the design of fuel cells for space programs requires careful consideration of weight, reliability, and performance, and must be optimized for the specific requirements of each mission.

Space Programs and Fuel Cells

Fuel cells have been used in space programs for several decades, primarily as a power source for spacecraft and satellites. There are several reasons why fuel cells are well-suited for space applications:

- **High efficiency:** Fuel cells can convert fuel into electricity with high efficiency, typically around 50-60%, compared to traditional combustion engines, which have an efficiency of around 25%.
- **Low weight:** In space, weight is a critical factor, and fuel cells are lightweight and compact, making them an attractive option for space missions.
- **Long operating life:** Fuel cells can operate continuously for long periods without needing to be refuelled, making them well-suited for long-duration space missions.
- **Quiet operation:** Fuel cells operate quietly, which is important for space applications where noise can interfere with scientific experiments or communication systems.

- **Water production:** Fuel cells produce only water as a waste product, which can be used for drinking, hygiene, or other purposes on spacecraft.

➤ **Types of Fuel Cells for Space Programs**

There are several types of fuel cells that are currently used or being developed for space applications, including:

1. **Proton Exchange Membrane (PEM) Fuel Cells:** PEM fuel cells are a type of polymer electrolyte membrane fuel cell that operate at low temperatures and have high power density. They are commonly used in space applications, including the International Space Station (ISS).
 2. **Solid Oxide Fuel Cells (SOFCs):** SOFCs are a type of high-temperature fuel cell that can operate on a variety of fuels, including hydrogen, methane, and carbon monoxide. They have a high efficiency and are being developed for a range of space applications.
 3. **Alkaline Fuel Cells (AFCs):** AFCs are a type of fuel cell that uses a liquid alkaline electrolyte and operate at moderate temperatures. They have been used in space applications, including the Apollo missions.
- Fuel cells have been used in a variety of space missions, including the Space Shuttle, the International Space Station, and Mars rovers. For example, the Mars Curiosity rover is powered by a radioisotope thermoelectric generator (RTG) and a fuel cell system. The fuel cell system provides power during peak energy demand and charges the rover's batteries during off-peak periods. Similarly, the International Space Station is powered by a combination of solar panels and fuel cells, with the fuel cells providing backup power when solar panels are not generating enough electricity.

- Overall, fuel cells are a reliable and efficient power source for space applications and will likely continue to play an important role in future space missions.

Material technology that can increase performance of fuel cells

- Fuel cells' performance can be improved by using advanced materials. There are several types of fuel cells, and the specific materials used in each type may vary, but some general material technologies that can increase the performance of fuel cells are:
- **Catalysts:** Catalysts are materials that accelerate the rate of chemical reactions. In fuel cells, catalysts are used to enhance the rate of electrochemical reactions at the anode and cathode. Platinum is a commonly used catalyst for many types of fuel cells, but it is expensive and limited in supply. Researchers are exploring new catalysts, such as non-precious metal catalysts, to improve the performance of fuel cells.
- **Membranes:** Membranes are used in fuel cells to separate the anode and cathode and allow the flow of ions. The membrane needs to be selectively permeable to prevent the mixing of fuel and oxidant, while allowing the transfer of ions. Researchers are exploring new membrane materials that are more durable and can operate at higher temperatures.
- **Electrodes:** Electrodes are used in fuel cells to provide a surface for the chemical reactions to occur. The surface area of the electrodes can affect the performance of the fuel cell. Researchers are exploring new electrode materials, such as carbon nanotubes or graphene, that can provide a larger surface area and improve the efficiency of the fuel cell.
- **Sealants:** Fuel cells operate at high temperatures and pressures, which can cause leaks and reduce their lifespan. New sealant materials, such as perfluoro elastomers and

ceramic sealants, are being developed to improve the durability and performance of fuel cell seals.

- **Bipolar plates:** Bipolar plates are used in fuel cells to distribute the fuel and oxidant and to collect the electrical current. Bipolar plates need to be conductive, durable, and resistant to corrosion. Researchers are exploring new bipolar plate materials, such as carbon fibre composites, that can be lighter and more durable than traditional metal plates.
- **Gas diffusion layers:** Gas diffusion layers are used in fuel cells to distribute the fuel and oxidant and to remove waste heat and water. Researchers are exploring new gas diffusion layer materials, such as carbon nanofibers, that can be more efficient in removing waste heat and water and improving the performance of the fuel cell.
- Overall, advanced materials technology can play a critical role in improving the performance of fuel cells, making them more efficient, durable, and cost-effective for a wide range of applications, including space programs.

Advantages of Fuel Cells for Space Programs

- Fuel cells offer several advantages over traditional power sources in space programs. Firstly, fuel cells offer higher efficiency than traditional power sources. For example, the Space Shuttle fuel cells had an efficiency of 50%, while traditional power sources, such as batteries and solar panels, have an efficiency of around 15-20%.
- Secondly, fuel cells have a longer lifespan than batteries. Fuel cells can operate continuously as long as the fuel and oxidizer are supplied, whereas batteries have a limited lifespan and need to be replaced regularly.

- Thirdly, fuel cells are lightweight and compact compared to traditional power sources. This is particularly important for space programs where weight and space are critical factors.
- Fourthly, fuel cells offer a continuous source of power, unlike solar panels that are affected by day and night cycles and weather conditions. Additionally, fuel cells can operate in zero-gravity conditions, which makes them suitable for space programs.
- Finally, fuel cells offer the potential for a closed-loop system, where water produced by the fuel cell is recycled and reused. This is essential for long-duration space missions, where water supply is a critical factor.

Challenges of Fuel Cells for Space Programs

- While fuel cells offer several advantages for space programs, they also pose some challenges. One of the main challenges is the storage of hydrogen, which is the most commonly used fuel for fuel cells. Hydrogen is a highly flammable gas and requires careful handling and storage. Additionally, the storage of hydrogen adds weight and volume to the spacecraft, which can be a significant disadvantage.
- Another challenge is the limited lifespan of fuel cell components. Fuel cells require regular maintenance and replacement of components, which can be difficult and expensive in space. Furthermore, fuel cell components are sensitive to radiation and other environmental factors that can affect their performance and lifespan.
- Finally, the production of hydrogen requires energy and resources, which can be a challenge for long-duration space missions. The production of hydrogen on spacecraft using water and solar power is a potential solution, but this technology is still in the experimental stage.

Future Prospects of Fuel Cells for Space Programs

- Despite the challenges, fuel cells offer a promising future for space programs. The development of new technologies, such as advanced materials and manufacturing processes, can improve the efficiency and lifespan of fuel cells, making them more reliable and cost-effective.
- Additionally, the use of alternative fuels, such as methane and ammonia, can reduce the storage and handling challenges associated with hydrogen. Methane and ammonia are easier to store and handle and offer high energy density.
- Furthermore, the development of closed-loop systems that recycle and reuse water produced by fuel cells can significantly reduce the water supply requirements for long-duration space missions.

References

- <https://www.hydrogenfuelnews.com/history-of-hydrogen-fuel/8553516/>
- https://www.nasa.gov/centers/glenn/technology/fuel_cells.html
- <https://ui.adsabs.harvard.edu/abs/2012cosp...39.1136S/abstract>
- <https://beta.nsf.gov/news/material-technology-can-increase-performance-fuel>
- **Photos Credits:**
 - https://en.wikipedia.org/wiki/Solid_oxide_fuel_cell#/media/File:Solid_oxide_fuel_cell.svg
 - <https://infinityfuel.com/wp-content/uploads/2016/12/space-nasa-aus.jpg>