Fuel cells have a long history in space applications and may have potential application in aeronautics as well. A fuel cell is an electrochemical energy conversion device that directly transforms the chemical energy of a fuel and oxidant into electrical energy. Alkaline fuel cells have been the mainstay of the U.S. space program, providing power for the Apollo missions and the Space Shuttle. However, Proton Exchange Membrane (PEM) fuel cells offer potential benefits over alkaline systems and are currently under development for the next generation Reusable Launch Vehicle (RLV). Furthermore, primary and regenerative systems utilizing PEM technology are also being considered for future space applications such as surface power and planetary aircraft. In addition to these applications, the NASA Glenn Research Center is currently studying the feasibility of the use of both PEM and solid oxide fuel cells for low- or zero-emission electric aircraft propulsion. These types of systems have potential applications for high altitude environmental aircraft, general aviation and commercial aircraft, and high altitude airships. NASA Glenn has a unique set of capabilities and expertise essential to the successful development of advanced fuel cell power systems for space and aeronautics applications. NASA Glenn’s role in past fuel cell development programs as well as current activities to meet these new challenges will be presented.
Cleveland, Ohio
NASA Glenn Research Center
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Presentation at the Ohio Technical College

Fuel Cell Activities at the NASA Glenn Research Center
Let's start with a brief fuel cell tutorial...
Commonly used oxidants:
- Air
- Pure Oxygen

Common Fuels:
- Alcohol - Methanol (reformed, direct)
- Hydrocarbons - Jet fuel (reformed, direct)
- Hydrogen

Limited testing on solid oxide fuel cells:

Energy:
A fuel cell converts chemical energy of a fuel and oxidant directly into usable electrical energy.

Standard Fuel Cell Definition
at Lewis Field

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- species

| Returns the electrons, along with another chemical component, |
| Makes the charged species cross a barrier (to get the electrons back) |
| Makes the electrons perform electrical work |
| Makes species in a charged state |
| Strips electrons from one chemical species, leaving that |

A device that:

Practical Fuel Cell Definition
Proton Exchange Membrane Fuel Cell Diagram

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Overall Reaction: $2H_2 + O_2 \rightarrow 2H_2O + \text{Electricity + Heat}$

Anode Reaction: $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode Reaction: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Water Out

Pure $O_2$

Air or
Fuel cells are modular.

Fuel cells can be part of hybrid power system.

Recapture and reuse of heat generated during operation.

Fuel cell systems are quiet (stack has no moving parts).

Minimal or even zero emissions to environment.

(regenerative fuel cell)

Can run as closed loop system when paired with electrolyzer.

Never "Goes Dead", i.e. "Re-filling."

Provide continuous power as long as fuel and oxidant is supplied.

Why Fuel Cells Over Other Power Generating Devices?
down water into gaseous hydrogen and oxygen

Electrolyzer consumes electrical power to break

system

closed-loop energy storage

H2-O2 fuel cell, resulting in a

Regenerative Fuel Cell

Coupled electrolyzer with a

Regenerative Fuel Cell

H2-O2 fuel cell combines

power and water

oxygen to produce electrical

gaseous hydrogen and

Primary

Fuel Cell System

Regenerative

vs.

Primary
Major Fuel Cell Types

- Molten Carbonate
- Phosphoric Acid
- Solid Oxide
- Proton Exchange Membrane (PEM)
- Alkaline

Some of the more common fuel cells are:

- Fuel cells are classified based on their electrolyte
Alkaline Fuel Cells

decision of alkaline development

- Success of PEM fuel cells has resulted in
- Currently used on Space Shuttle
- First used on Apollo missions
- Primary user has been the space program
- Uses pure hydrogen and oxygen
- Operates at 80 - 260 °C
- Cathode: O₂ + 4e⁻ + 2H₂O → 4OH⁻
- Anode: 2H₂ + 4OH⁻ → 4H₂O + 4e⁻
- KOH electrolyte

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Proton Exchange Membrane (PEM) Fuel Cells

- Ballard Power Systems
- Fuel Cell Engine for bus

Terrestrial transportation, electronic equipment.
Applications include space and automotive.
Auto industry development due to major investments by
Cell and stack technology at a high state of
Generally requires external fuel reforming
Can use pure oxygen or air as oxidant

methanol Fuels include hydrogen, natural gas, and
Operates at 70-90°C

- Cathode: \( \text{O}_2 + 4e^- + 4H^+ \rightarrow 2H_2O \)
- Anode: \( 2H_2 \rightarrow 4H^+ + 4e^- \)

Uses proton-conducting polymer electrolyte
Applications
Gemini spacecraft was one of the first

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Solid Oxide Fuel Cells

- Applications: some interest exists in automotive stationary terrestrial powerplants, but applications have been limited to system that can be used with gas turbine in hybrid, internal reforming possible as fuels. Natural gas, coal gas, hydrocarbons used.
- Planar and tubular configurations.
- Operates at 800 - 1000 °C.
- Cathode: O₂ + 4e → 2O²⁻
- Anode: 2H₂ + 2O²⁻ → 2 H₂O + 4e⁻
- Electrolyte conducting ceramic material as an solid state device that uses oxide.

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NASA
Solid Oxide Fuel Cell/Gas Turbine System Concept
So, what role has NASA played in fuel cell development?
The NASA Glenn Research Center (GRC) has a long history in fuel cell technology. The center has conducted research at GRC to bring fuel cell technology to a level that qualified it for the shuttle onboard power system. Advanced state of fuel cell technology to a level conducted at GRC.

Fuel cell and the Apollo alkaline fuel cell were the Gemini proton exchange membrane (PEM) technology advancement programs on.

NASA missions and programs experience in the development of fuel cell technologies for

GRC.

The 1970's.
Glen Research Center

Program
DOE/ERI Phosphoric Acid-Fuel Cell
Culminating management of the

Lunar/Mars applications in support
Examination regenerative fuel cell

Electric vehicles
for the PEM fuel cell program
Vehicle that served as the impetus
Conduct study of feasibility of

Space Shuttle
Technology chosen for use on the
and performance of alkaline fuel cell
Continued to work to improve life

The 1980's

NASA GRC Has a Long History in Fuel Cell Technology
NASA has a long history in Fuel Cell Technology at Lewis Field.

- Helios Solar Airplane
- Regenerative fuel cell power system
  - Begun development of lightweight
  - In conjunction with FAST partners

- Fuel Cells for Transportation Plan
  - Led team to produce the DOE's 10-year

- System for use on scientific balloons
- Hydrogen/Oxygen PEM fuel cell power
  - Demonstrated operation of a 200 W

The 1990s
What about the future?

But that was the past.
Space Applications for Fuel Cell Power Systems
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Prototype Program
- Breadboard and engineering model PEM powerplant development and
  - Higher peak-to-nominal power capability
  - Improved reliability and maintainability
  - Lower weight
  - Longer life
  - Enhanced safety

Fuel Cell Technology for Space Vehicle Applications
- PEM fuel cell technology offers major advantages over existing alkaline

Fuel Cell Power Plant Development for Reusable Launch Vehicles

Aircraft Potential applications include lunar and Mars surface power, planetary

Hydrogen-oxygen utilizing Regenerative Fuel Cell Stack

Develop passive ancillary component technology for use with a

Regenerative Fuel Cells

WHAT NASA IS DOING NOW
Fuel Cell Power Systems

Potential Air Applications for

High Altitude Aircraft

High Altitude Environments

General Aviation

Propulsion and Avionics

High Altitude Airships

Photo courtesy of Lockheed Martin
Electric Drive Aircraft Propulsion
- Areas under consideration include cell chemistries and advanced materials, and novel cell, stack, component, and system designs.

- Develop and demonstrate revolutionary energy conversion technologies to achieve reduced emissions.

- Focused on the elimination of CO2 emissions from civil transport aircraft by conversion of their propulsion systems to hydrogen fuel, and by the introduction of new energy conversion technologies.
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- Development of propulsion systems
  - Integrated fuel cell-high voltage electric hybrid propulsion
  - Aircraft performance modeling
  - Fuel cell system design, component, and material development
  - Advanced fuel cell assessment
  - Air-breathing H2 fuel cell

- Distributed propulsion aircraft concepts
  - Distributed electric and hybrid architecture for voltage power management and system design
  - Demonstrating combined fuel cell-high efficiency electric propulsion concepts

- Green Efficient Aircraft Propulsion
  - Zero CO2 Emissions Technologies
    - H2-fueled aeropropulsion
    - Fuel cell/electric drive technologies
    - Investigate application of suspects of aeropropulsion technologies

Fuel Cells for Low Emission Commercial Aircraft
NASA CRRC has the expertise and capabilities essential to the successful development of advanced fuel cell power systems for space and aeronautics applications.
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General Aviation

Upgrade Shuttle

Mars

Mars / Lunar

ISS

RTV

Fuel cell activities

at NASA-GRC are applicable across a broad range of current and future aero and space missions.