Fuel Cell Activities at the NASA Glenn Research Center
Presentation to the Ohio Technical College
July 10, 2002

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

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Glenn Research Center
at Lewis Field

Let's start with a brief fuel cell tutorial...

Standard Fuel Cell Definition

- A non-polluting energy conversion device that transforms the chemical energy of a fuel and oxidant directly into usable electrical energy

Common Fuels

- Hydrogen
- Hydrocarbons - Gasoline, jet fuel (reformed, direct*)
- Alcohols - Methanol (reformed, direct)

Conventionally Used Oxidants

- Pure Oxygen
- Air

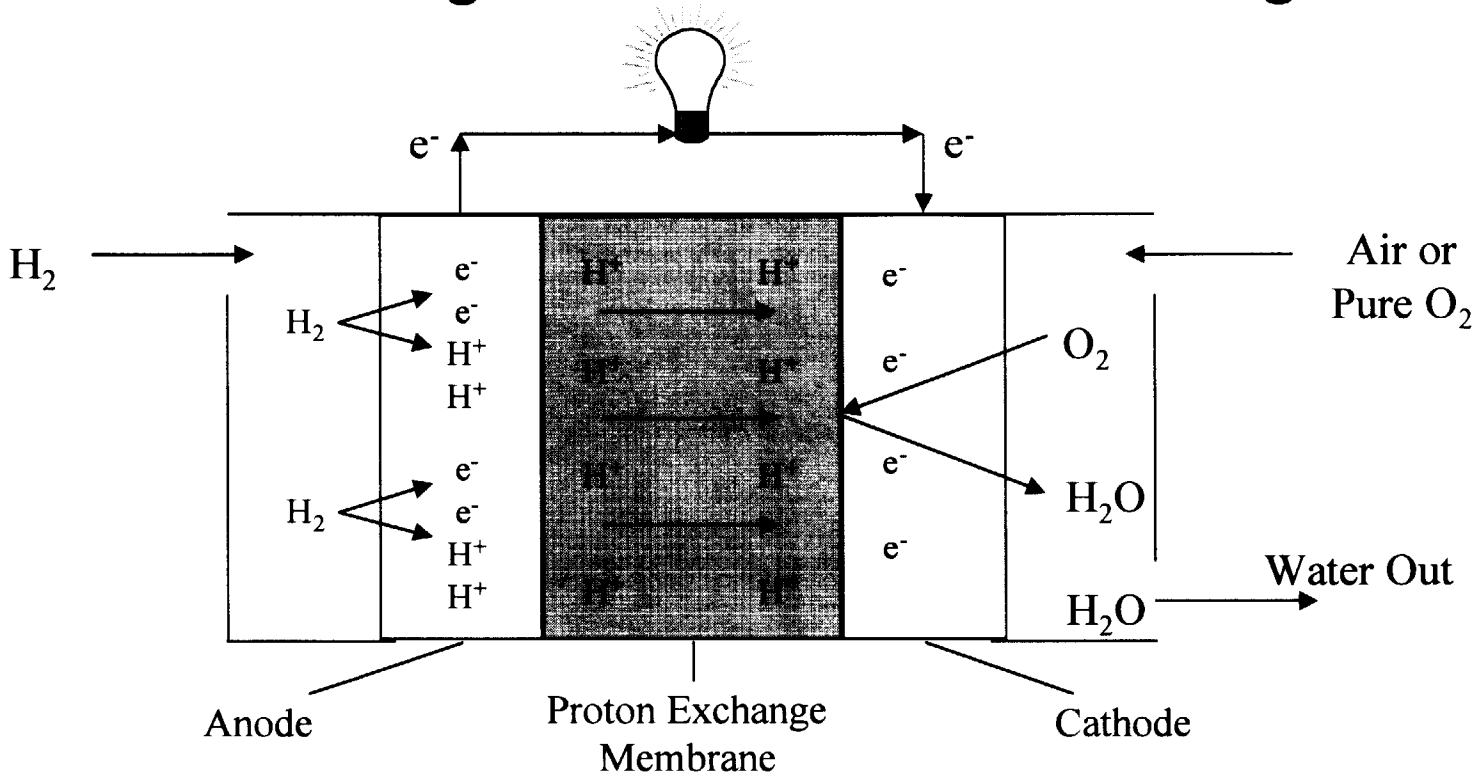
(* Limited testing on solid oxide fuel cells)

Practical Fuel Cell Definition

A device that:

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

Proton Exchange Membrane Fuel Cell Diagram



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

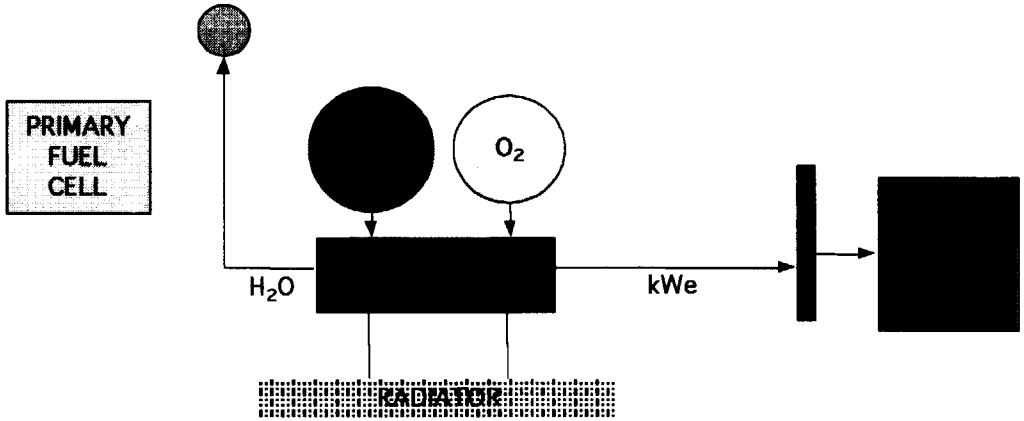
Cathode Reaction: $O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$

Overall Reaction: $2H_2 + O_2 \longrightarrow 2H_2O$ + Electricity + Heat

Why Fuel Cells Over Other Power Generating Devices?

- Provide continuous power as long as fuel and oxidant is supplied
  - » Never "Goes Dead", i.e. re-fill fuel tank
  - » Can run as closed loop system when paired with electrolyzer (regenerative fuel cell)
- Minimal or even zero emissions to environment
- Fuel cell systems are quiet (stack has no moving parts)
- Recapture and reuse of heat generated during operation
- Fuel cells can be part of hybrid power system
- Fuel cells are modular

Primary vs. Regenerative Fuel Cell System

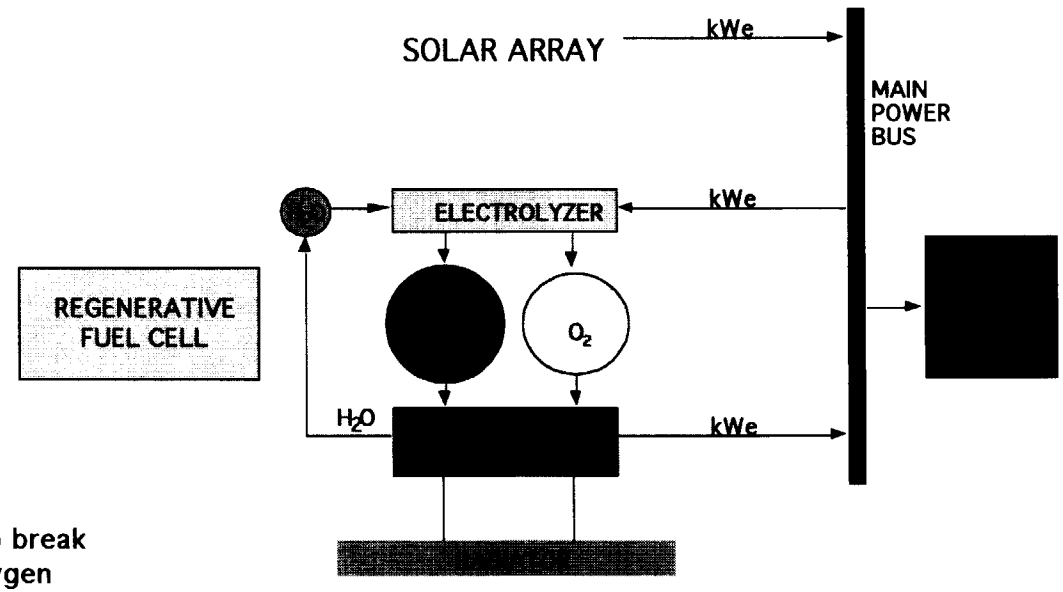


- Primary

  H_2-O_2 fuel cell combines gaseous hydrogen and oxygen to produce electrical power and water

- Regenerative Fuel Cell

  Couples electrolyzer* with a H_2-O_2 fuel cell, resulting in a closed-loop energy storage system



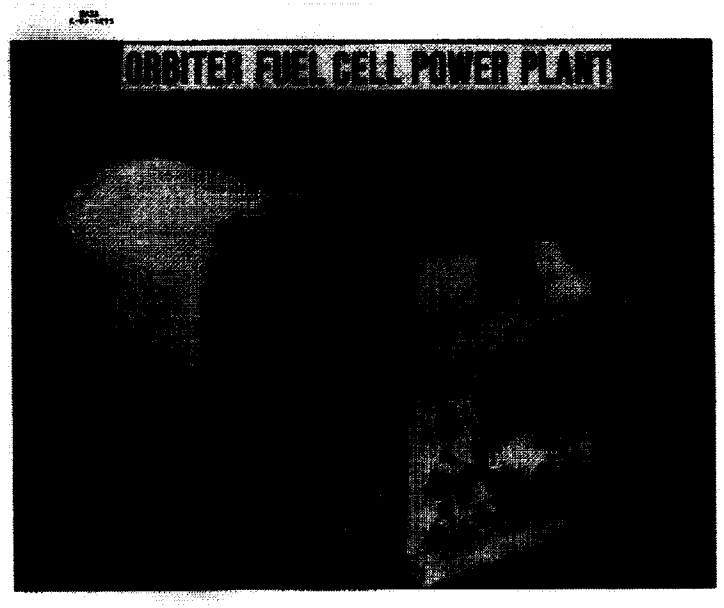
* Electrolyzer consumes electrical power to break down water into gaseous hydrogen and oxygen

Major Fuel Cell Types

- Fuel cells are classified based on their electrolyte
- Some of the more common fuel cells are:
  - Alkaline
  - Proton Exchange Membrane (PEM)
  - Solid Oxide
  - Phosphoric Acid
  - Molten Carbonate

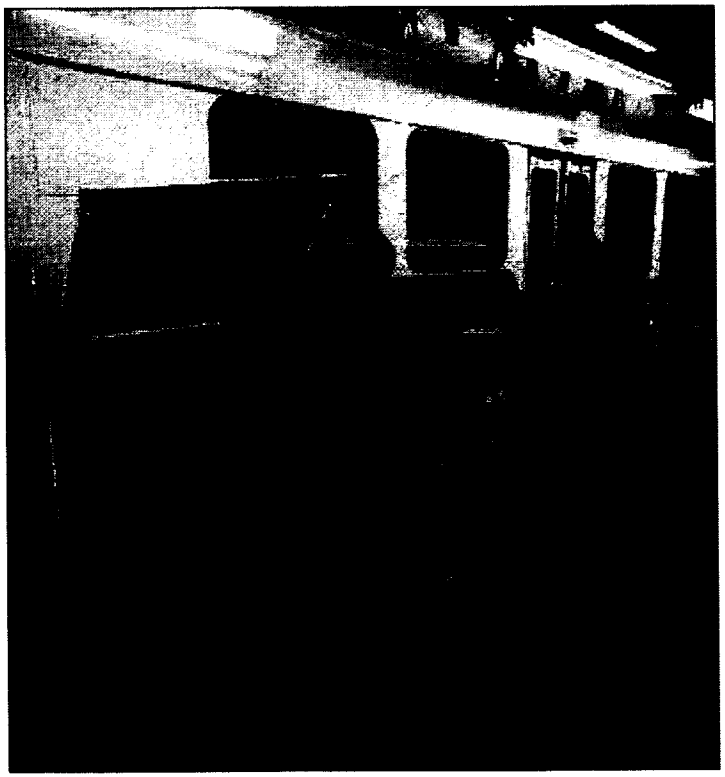
Alkaline Fuel Cells

- KOH electrolyte
  - Anode: $2H_2 + 4\ OH^- \rightarrow 4H_2O + 4e^-$
  - Cathode: $O_2 + 4e^- + 2H_2O \rightarrow 4\ OH^-$
- Operates at 80 - 260 °C
- Uses pure hydrogen and oxygen
- Primary user has been the space program
  - First used on Apollo missions
  - Currently used on Space Shuttle
- Success of PEM fuel cells has resulted in decline of alkaline development



Proton Exchange Membrane (PEM) Fuel Cells

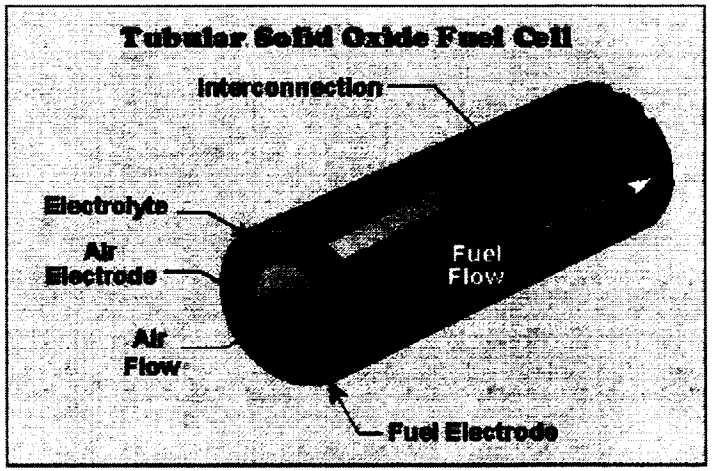
- Gemini spacecraft was one of the first applications
- Uses proton-conducting polymer electrolyte
  - Anode: $2H_2 \rightarrow 4H^+ + 4e^-$
  - Cathode: $O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$
- Operates at 70-90 °C
- Fuels include hydrogen, natural gas, and methanol
- Can use pure oxygen or air as oxidant
- Generally requires external fuel reforming
- Cell and stack technology at a high state of development due to major investments by auto industry
- Applications include space and automotive transportation, electronic equipment, terrestrial

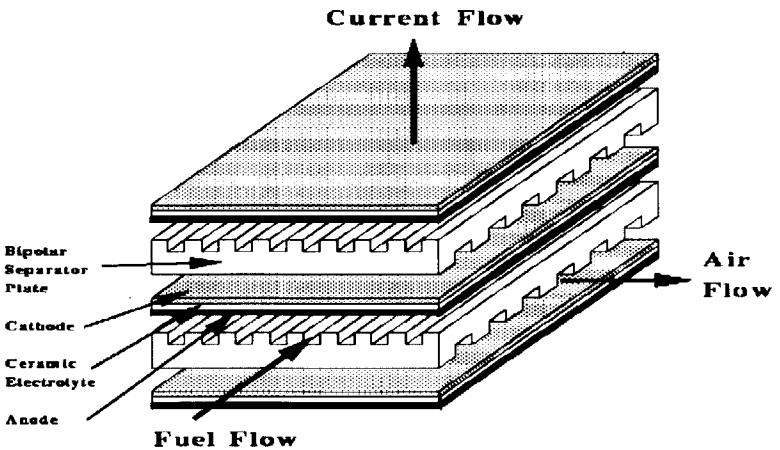


Fuel Cell Engine for Bus -
Ballard Power Systems

Solid Oxide Fuel Cells

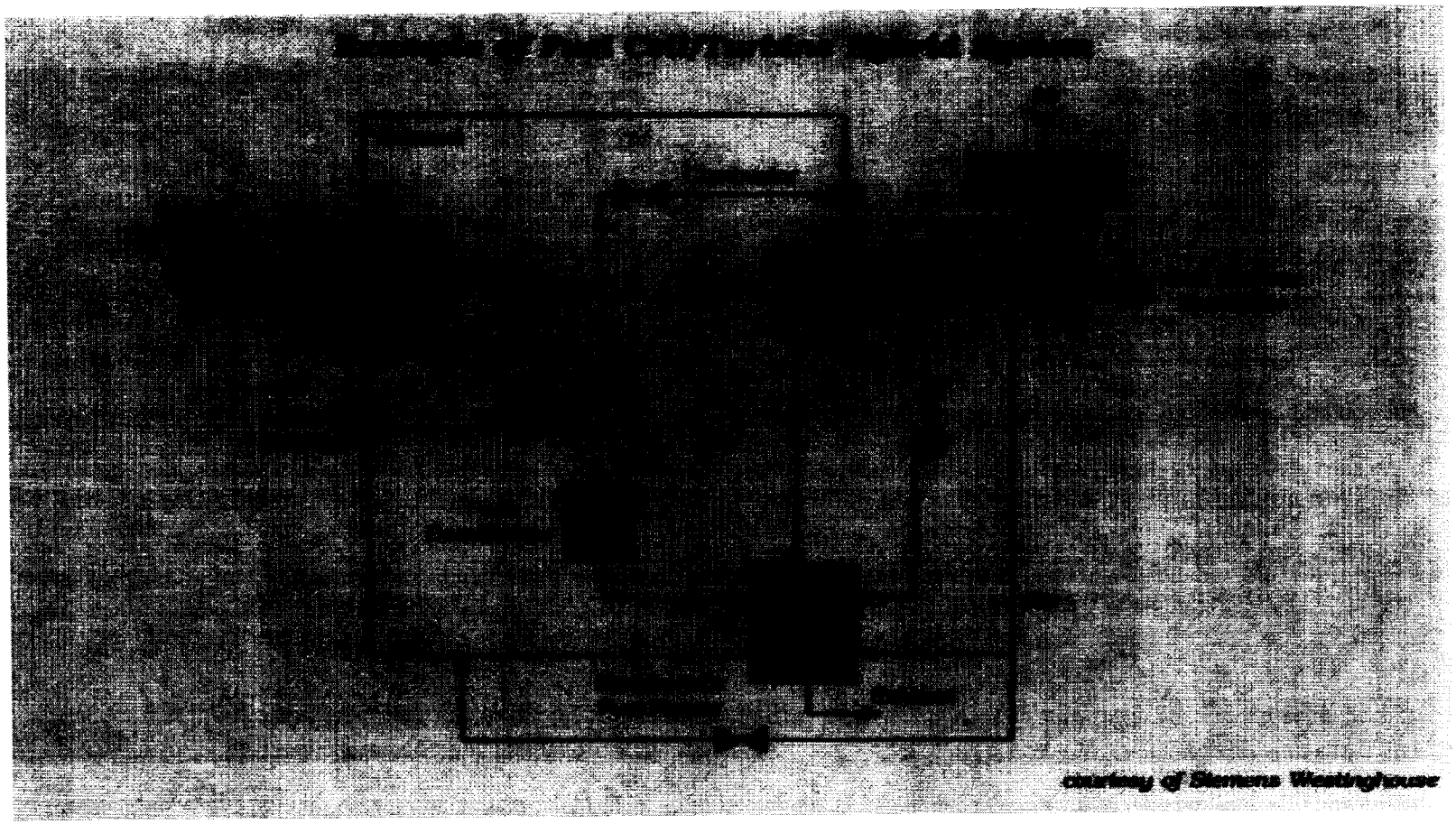
- Solid state device that uses oxide conducting ceramic material as an electrolyte
  - Anode: $2H_2 + 2O^{2-} \rightarrow 2H_2O + 4e^-$
  - Cathode: $O_2 + 4e^- \rightarrow 2O^{2-}$
- Operates at 800 - 1000 °C
- Planar and tubular configurations
- Natural gas, Coal gas, hydrocarbons used as fuels
- Internal reforming possible
- Can be used with gas turbine in hybrid system
- Applications have been limited to stationary terrestrial powerplants, but some interest exists in automotive applications





Planar Solid Oxide Fuel Cell Design

Solid Oxide Fuel Cell/Gas Turbine System Concept



Concept by Siemens Westinghouse

So, what role has NASA played in fuel cell development?

Glenn Research Center

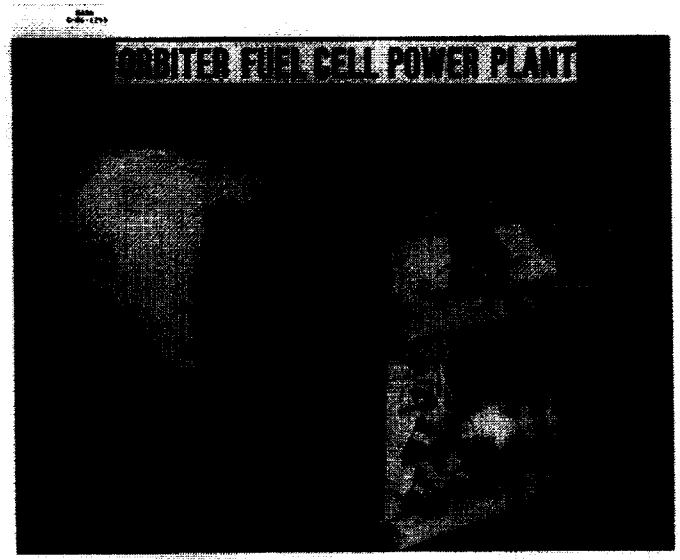
at Lewis Field

NASA GRC Has a Long History in Fuel Cell Technology

The NASA Glenn Research Center (GRC) has decades of experience in the development of fuel cell technologies for NASA missions and programs.

The 1970's

- Parallel technology advancement programs on the Gemini proton exchange membrane (PEM) fuel cell and the Apollo alkaline fuel cell were conducted at GRC.
- Advanced state of fuel cell technology to a level that qualified it for the shuttle onboard power system



NASA GRC Has a Long History in Fuel Cell Technology

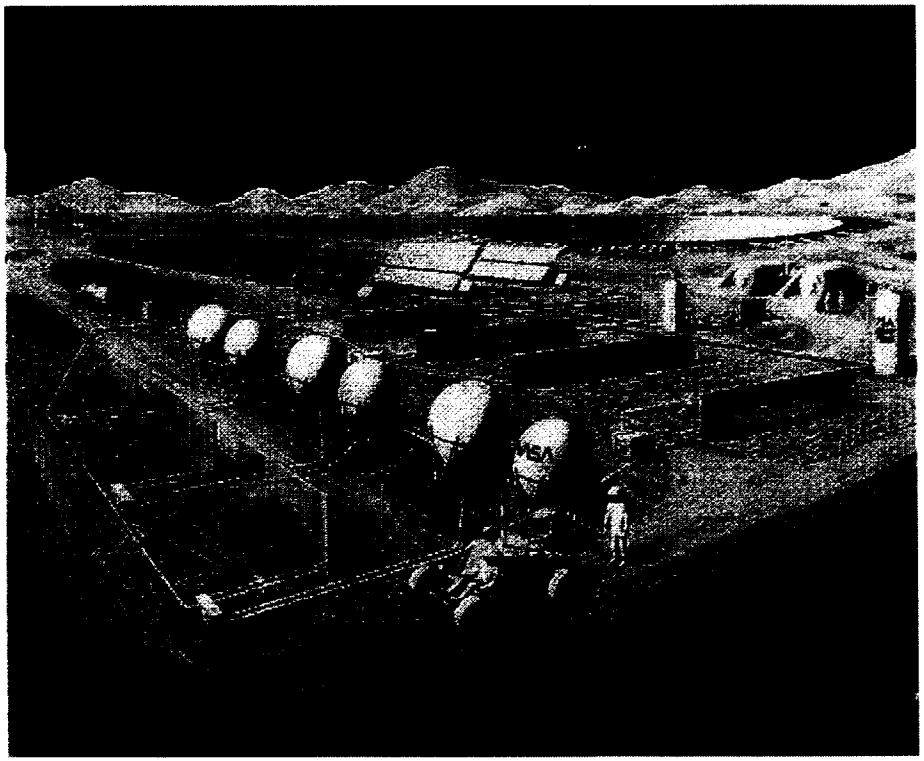
The 1980's

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

- Conducted study of feasibility of using PEM fuel cell in an electric vehicle that served as the impetus for the PEM fuel cell program for electric vehicles

- Examined regenerative fuel cell (RFC) energy storage concepts for Lunar/Mars applications in support of the Space Exploration Initiative

- Culminated management of the DOE/GRI Phosphoric Acid-Fuel Cell program



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NASA has a Long History in Fuel Cell Technology

The 1990's

- Demonstrated operation of a 200 W hydrogen/oxygen PEM fuel cell power system for use on scientific balloons

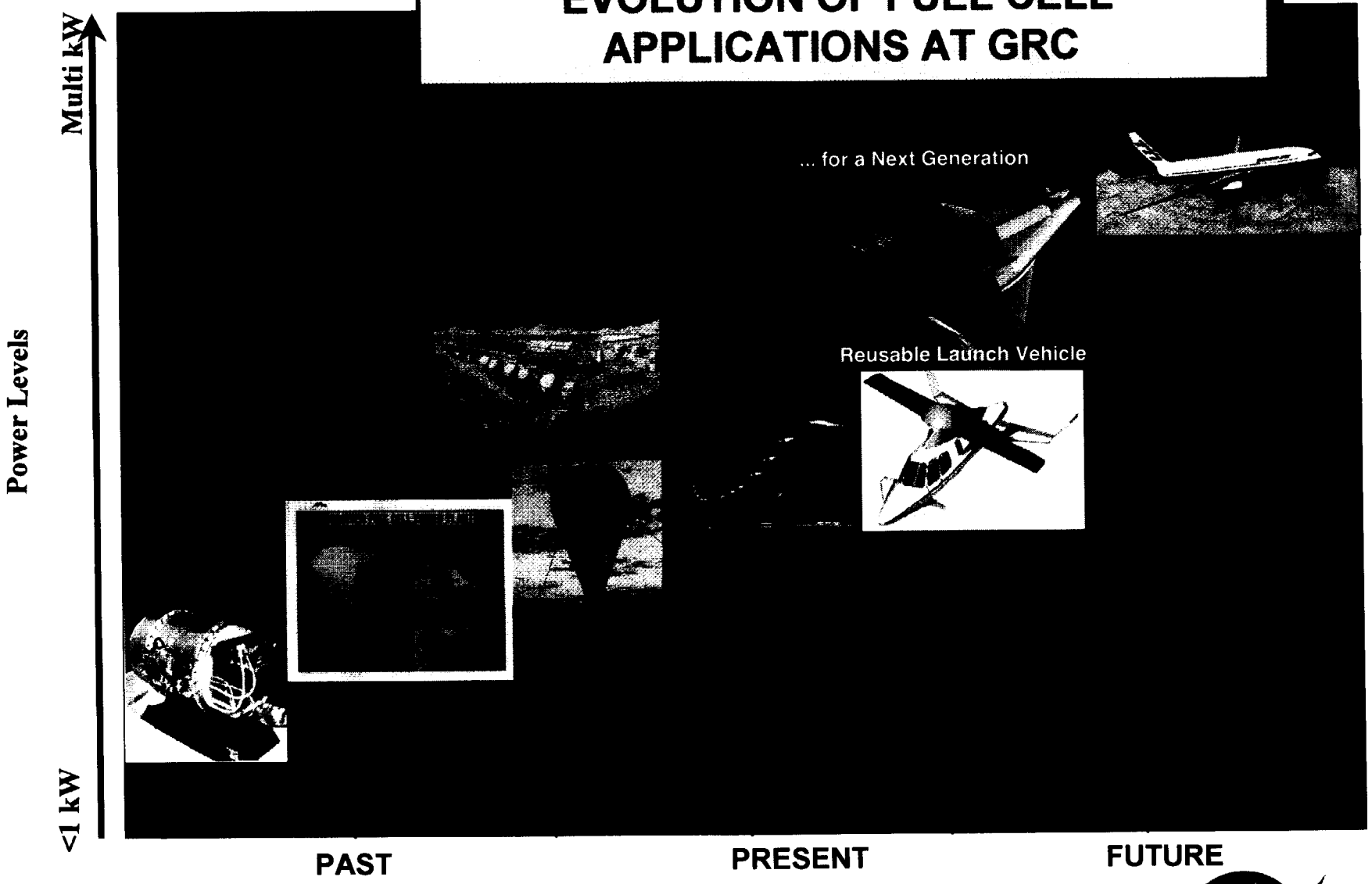
- Led team to produce the DOE's 10-year Fuel Cells for Transportation Plan

- In conjunction with ERAST partners, began development of lightweight regenerative fuel cell power system for Helios Solar Airplane

But that was the past.

What about the future?

EVOLUTION OF FUEL CELL APPLICATIONS AT GRC



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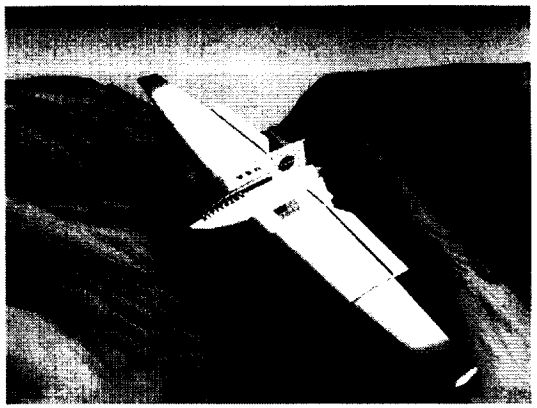
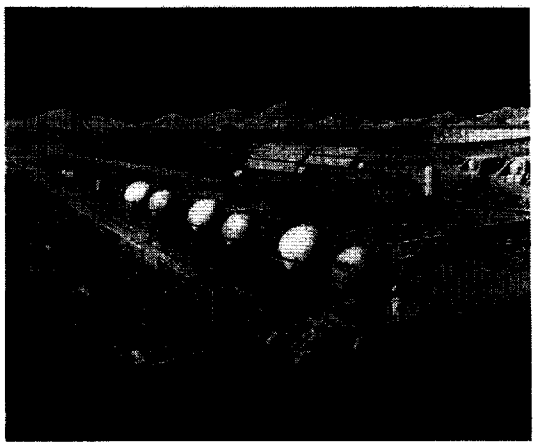
Space Applications for Fuel Cell Power Systems

Reusable
Launch
Vehicles

Planetary
Aircraft





Planetary
Surface
Power

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NASA

WHAT NASA IS DOING NOW

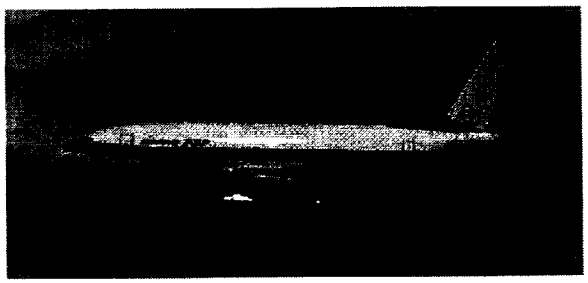
Regenerative Fuel Cells

- Develop passive ancillary component technology for use with a hydrogen-oxygen unitized regenerative fuel cell stack
- Potential applications include lunar and Mars surface power, planetary aircraft

Fuel Cell Power Plant Development for Reusable Launch Vehicles

- PEM fuel cell technology offers major advantages over existing alkaline fuel cell technology for space vehicle applications
  - Enhanced safety
  - Longer life
  - Lower weight
  - Improved reliability and maintainability
  - Higher peak-to-nominal power capability
- Breadboard and engineering model PEM powerplant development and prototype program

Potential Air Applications for Fuel Cell Power Systems



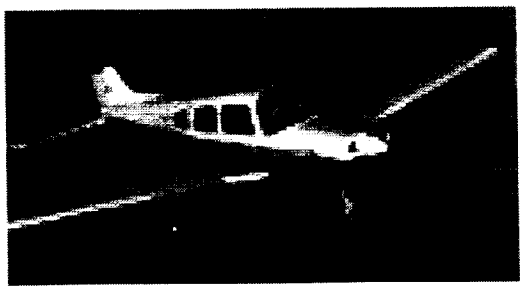
Commercial Aviation Propulsion and APU's

High Altitude Environmental Aircraft

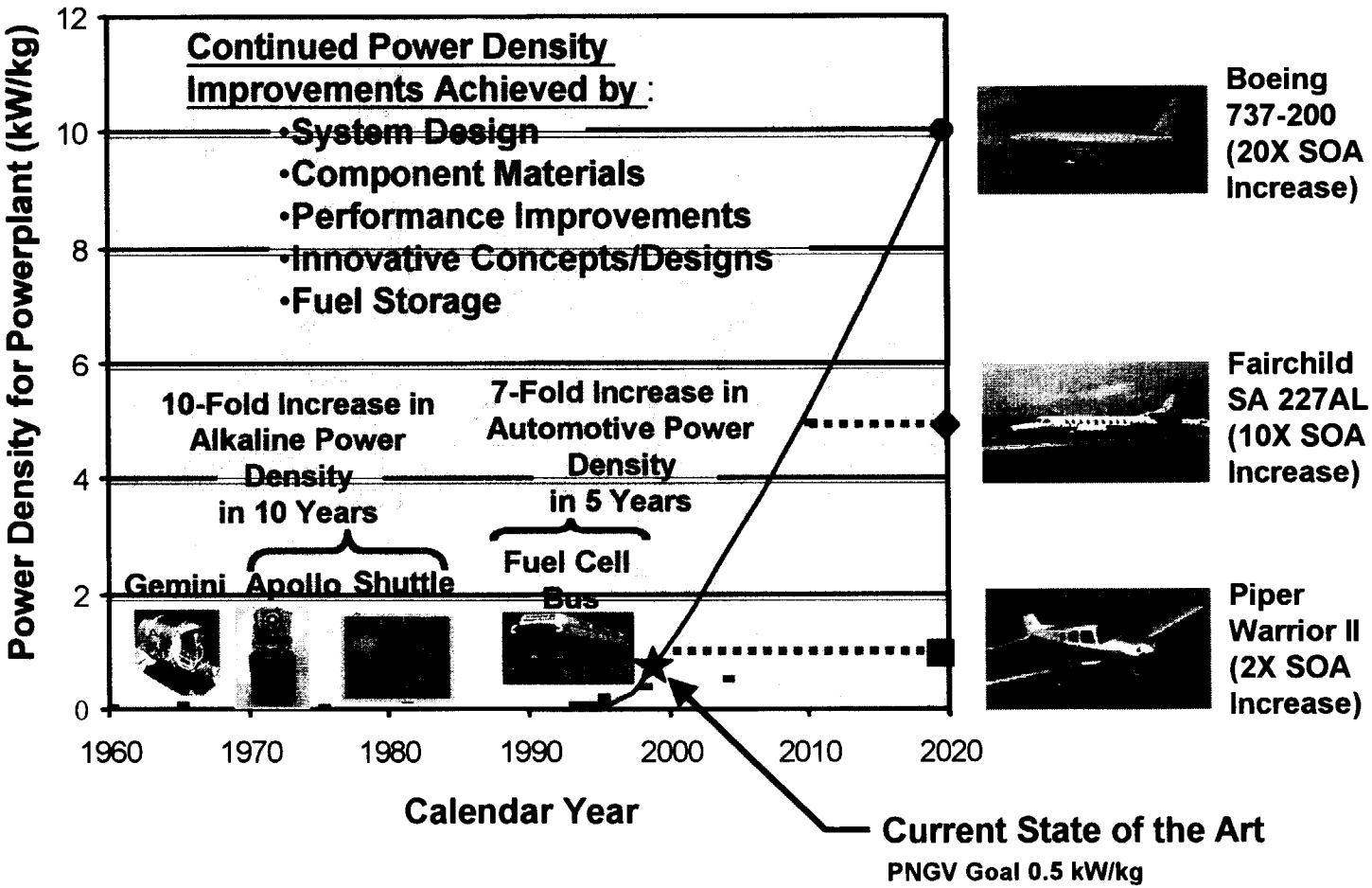
High Altitude Airships

(Photo Courtesy of Lockheed Martin)

General Aviation Propulsion



Electric Drive Aircraft Propulsion



WHAT NASA IS DOING NOW

Fuel Cells for Low-Emission Commercial Aircraft

- **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**
- **Develop and demonstrate revolutionary energy conversion technologies to achieve reduced emissions aircraft operations**
- **Areas under consideration include cell chemistries and advanced materials, and novel cell, stack, component, and system designs**

Fuel Cells for Low Emission Commercial Aircraft

Zero CO2 Emissions Technologies

Investigate application of fuel cell/electric drive technologies to H2-fueled aeropropulsion

Revolutionary Aeropropulsion Concepts:

Provide balanced investments in aeropropulsion technology research to pursue concepts capable of 2X payload-range for commercial aircraft and enabling near-zero emissions

Green Efficient Aircraft Propulsion

Demonstrate combined fuel cell-high voltage power management and distribution as a viable architecture for distributed propulsion aircraft

- **Air-breathing H2 fuel cell feasibility testing and assessment**
- **Advanced fuel cell material development**
- **Investigation of novel stack, component, and system designs**
- **Fuel cell system modeling**
- **Aircraft performance modeling for fuel cell and hybrid propulsion systems**
- **Integrated fuel cell-high voltage electric propulsion simulator development**

NASA GRC Expertise and Capabilities

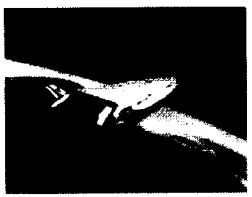
NASA GRC has the expertise and capabilities essential to the successful development of advanced fuel cell power systems for space and aeronautics applications

- System analysis
  - Fuel cell subsystem modeling
  - Aircraft performance modeling
  - CFD analysis
- Fuel cell component design and testing
  - Cell and stack-level
  - Reactant storage
  - Ancillaries
- Fuel cell subsystem design and testing
- Power management and distribution
- System controls
- Fuel cell materials research
- Thermal management
- Advanced motor development for electric propulsion
- Full scale power system testing
- Facilities for testing in relevant space and aeronautics environments

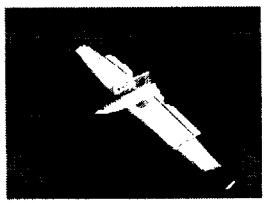
NASA Fuel Cell Activities

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

ISS

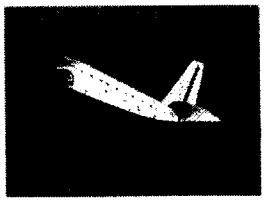


RLV

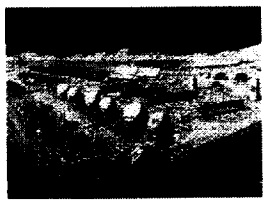


Mars Flyer

General Aviation



Shuttle Upgrade



Lunar / Mars Bases

Ultra-Long Duration Balloons

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