



Civil Aviation Technology College

Fuel Cell as a Green Energy Generator in Aerial Industry

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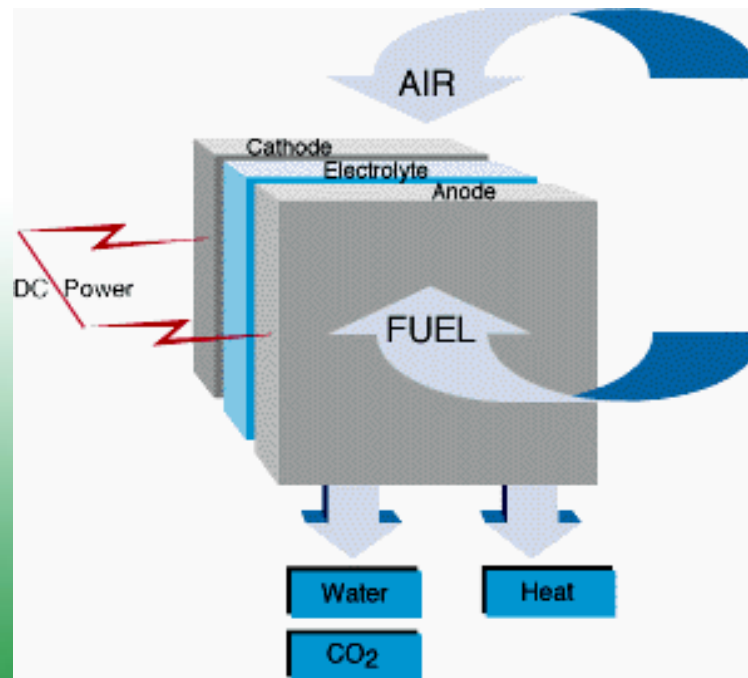
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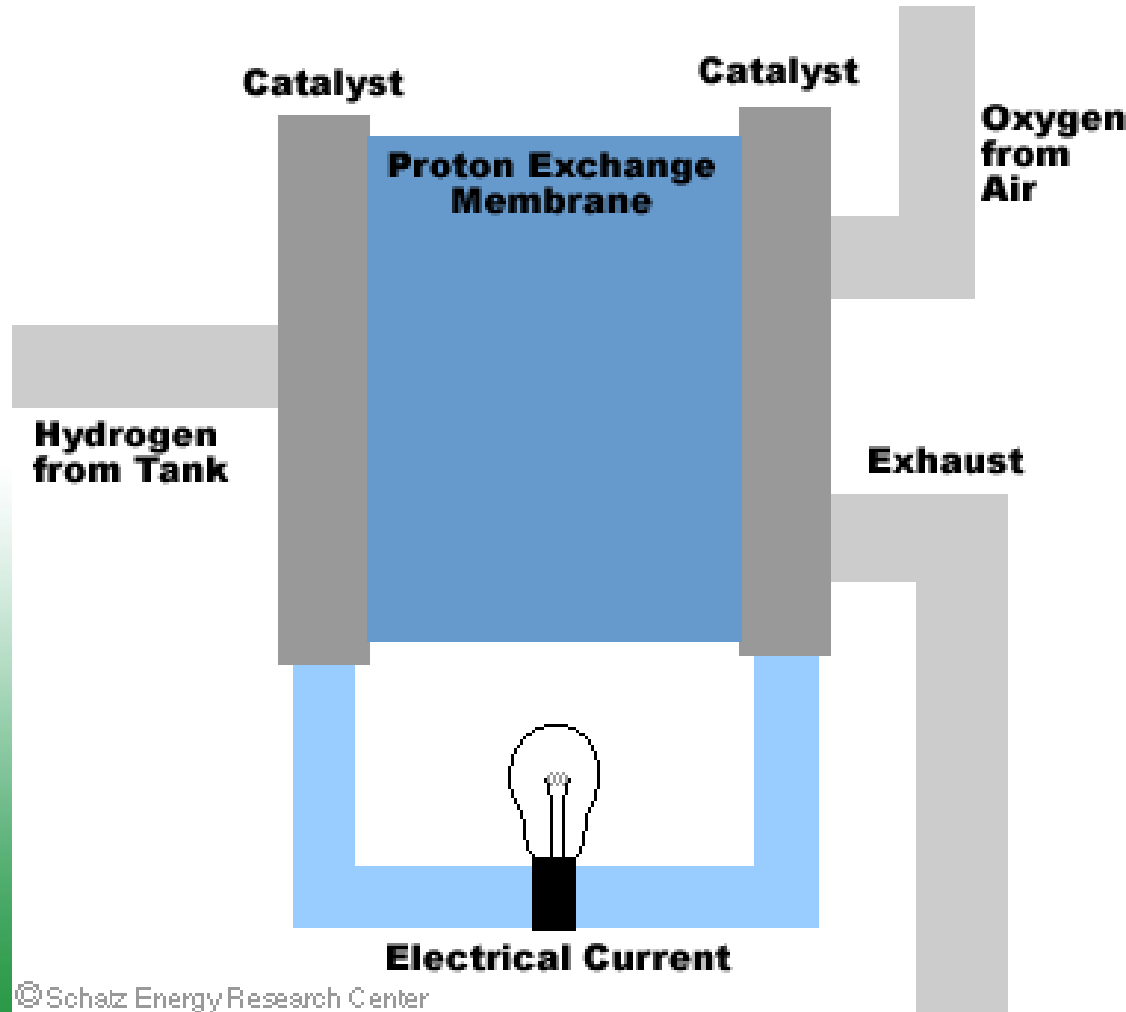
Fuel Cell Definition

an electrochemical energy conversion device

- To convert the chemicals hydrogen and oxygen into water, and in the process it produces electricity.

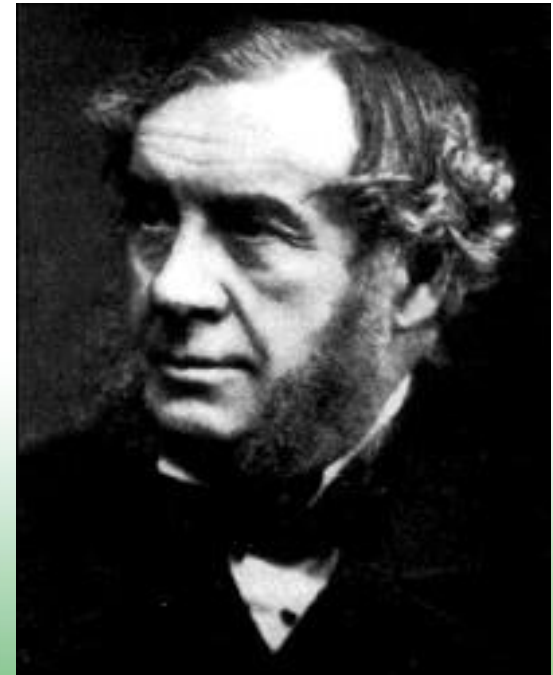
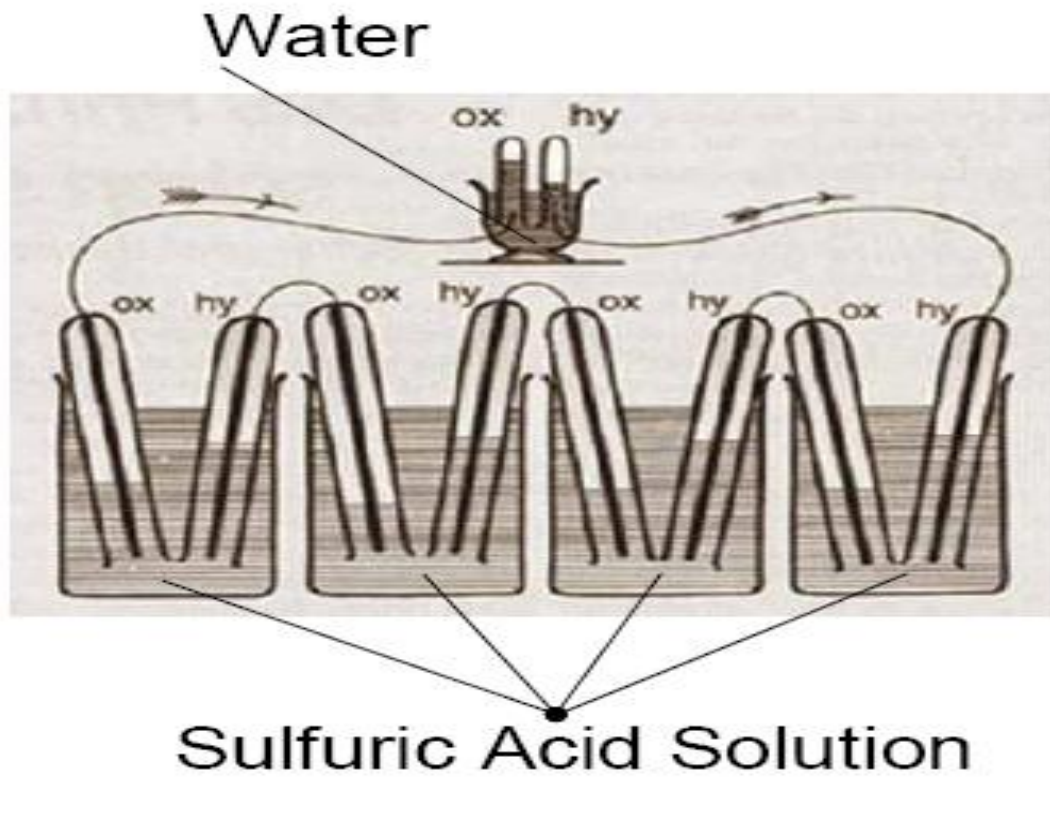


Principle of Operation



Fuel Cell History

1839: FIRST FUEL CELL (GROVE'S "GAS BATTERY")



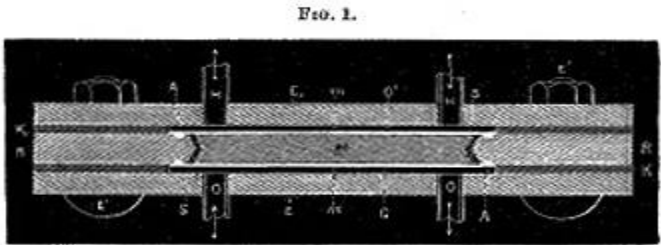
Sir William Grove

Fuel Cell History

1889: IMPROVED FUEL CELL

1959: THE ALKALI FUEL CELL

Francis Thomas Bacon with his Alkali Fuel cell.



1965: alkali fuel cell

A U.S. Army soldier operates a portable drill powered by a n alkali fuel cell.



1967: FIRST FUEL CELL VEHICLE

Karl Kordesch rides his alkali fuel cell motorbike.

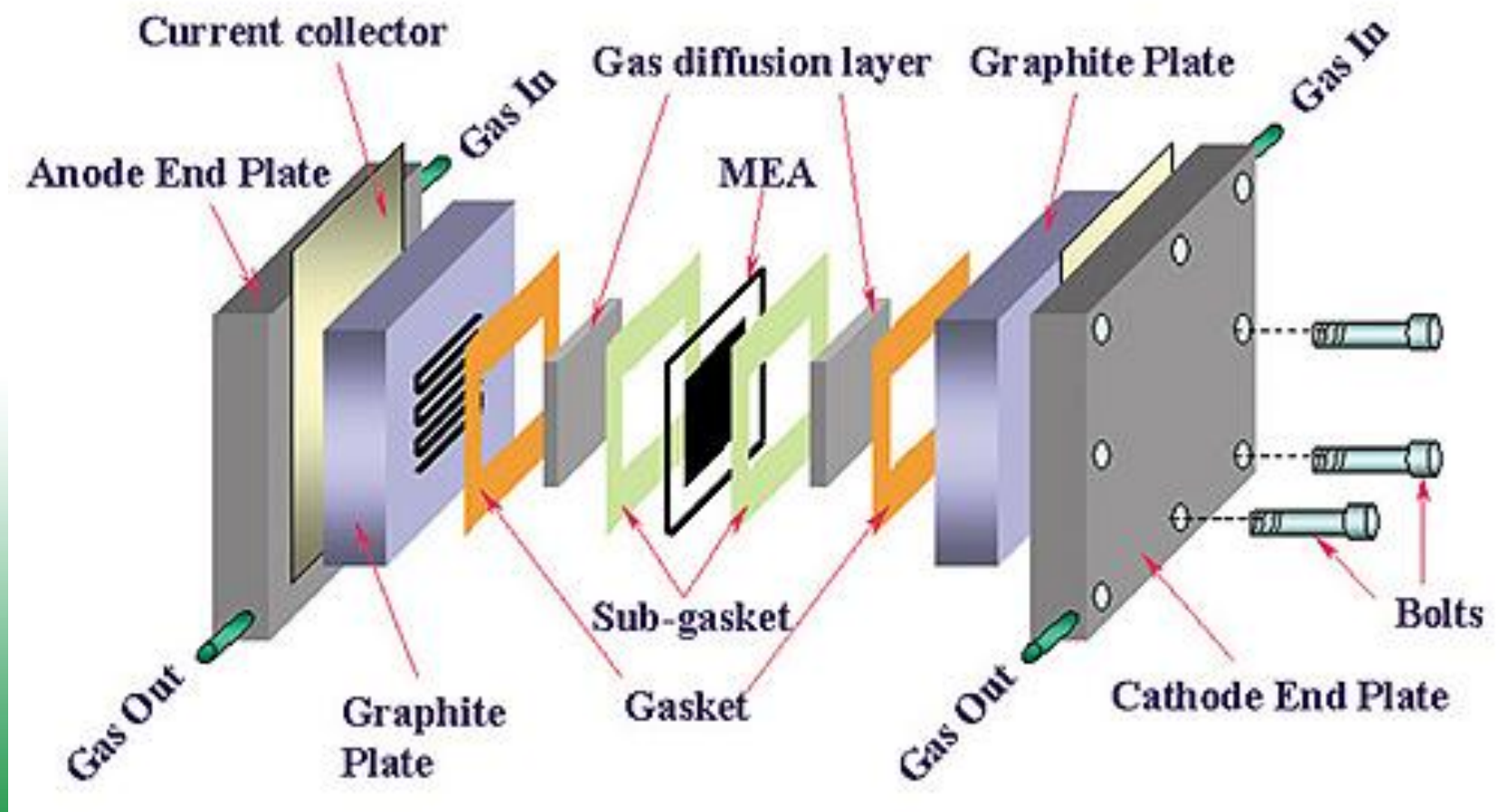




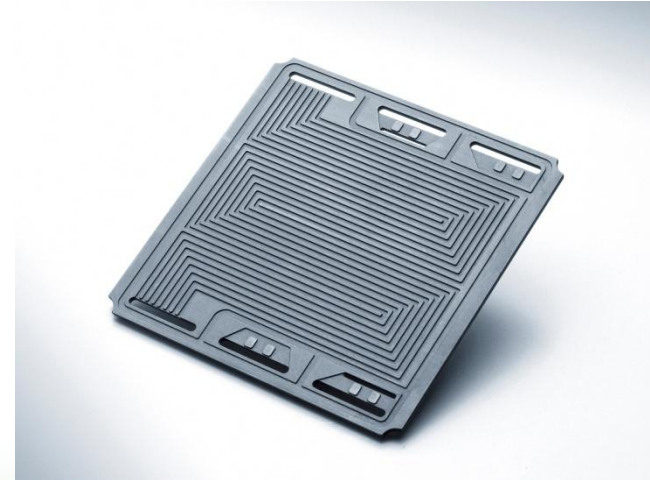
Fuel Cell Advantages

- High energy conversion efficiency
- Modular design- scale able to many sizes from 1 kW to 10's MW- offering a wide range of application
- Direct conversion avoids combustion process- allows for very low chemical and acoustical pollution(<60 dBA)
- Fuel flexibility
- Cogeneration capability- using waste heat
- Rapid load response
- High reliability- fewer moving parts
- Low Maintenance

Fuel Cell Component



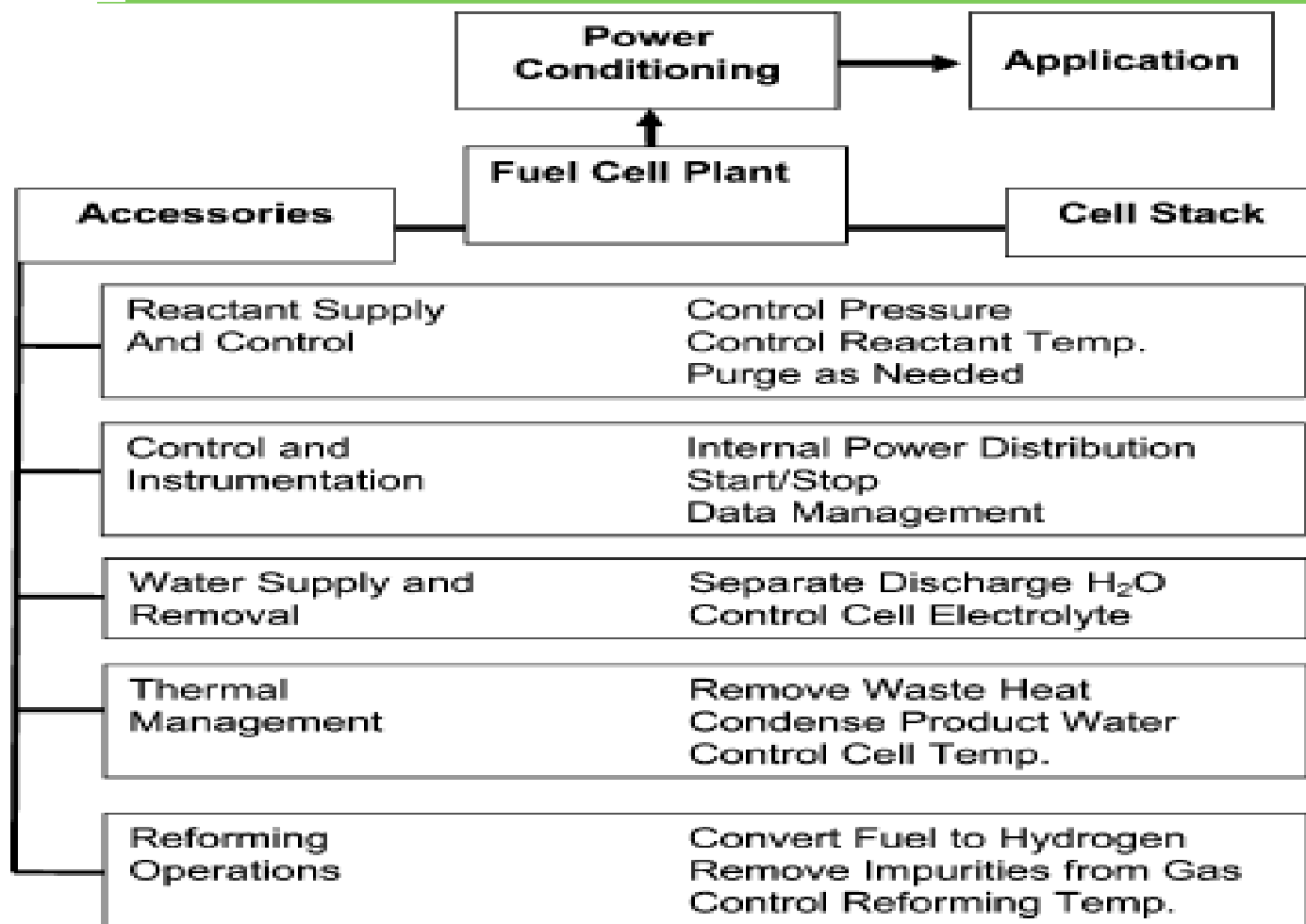
Fuel Cell Stack, Ballard Company



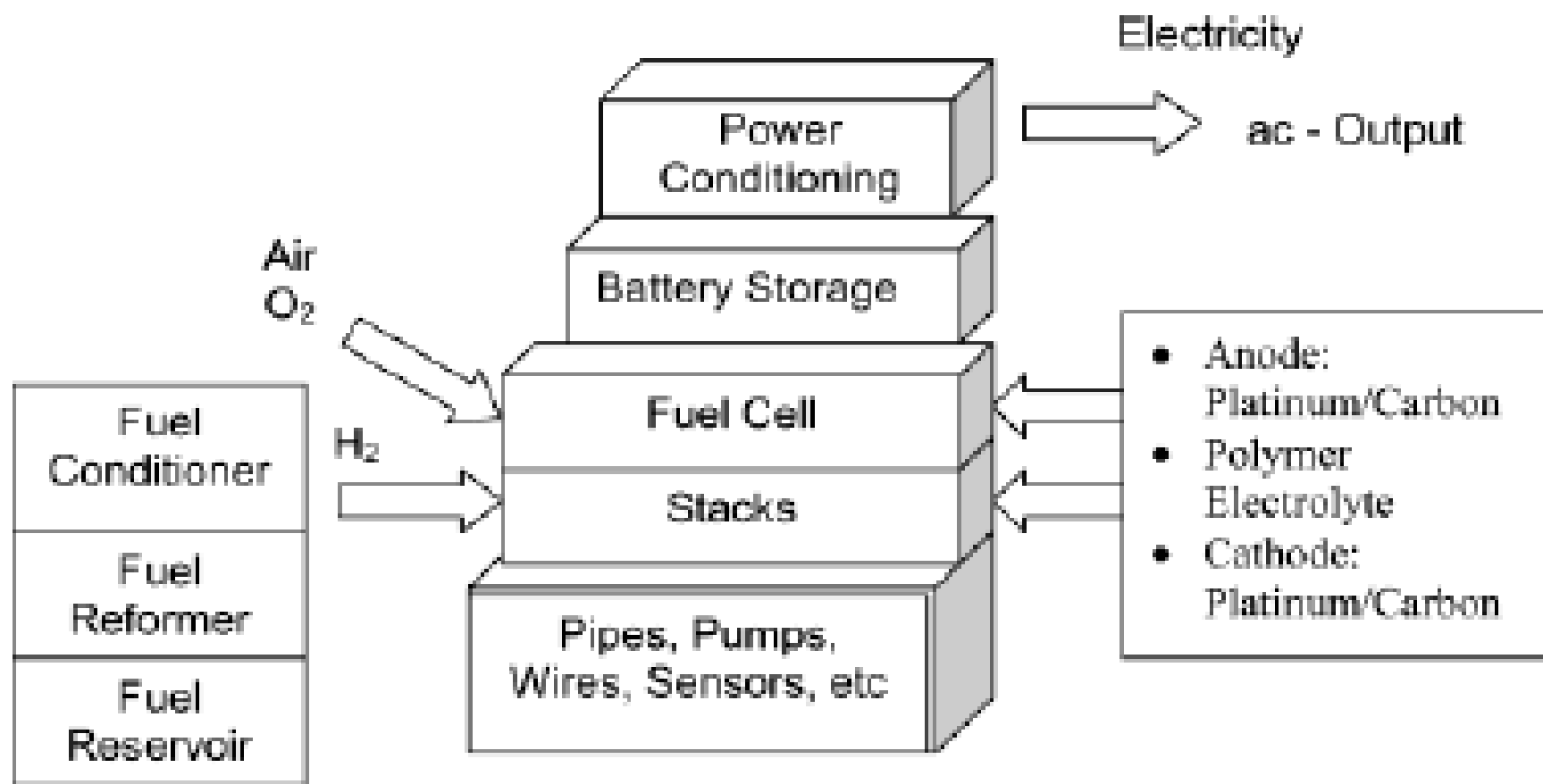
Graphite Plate



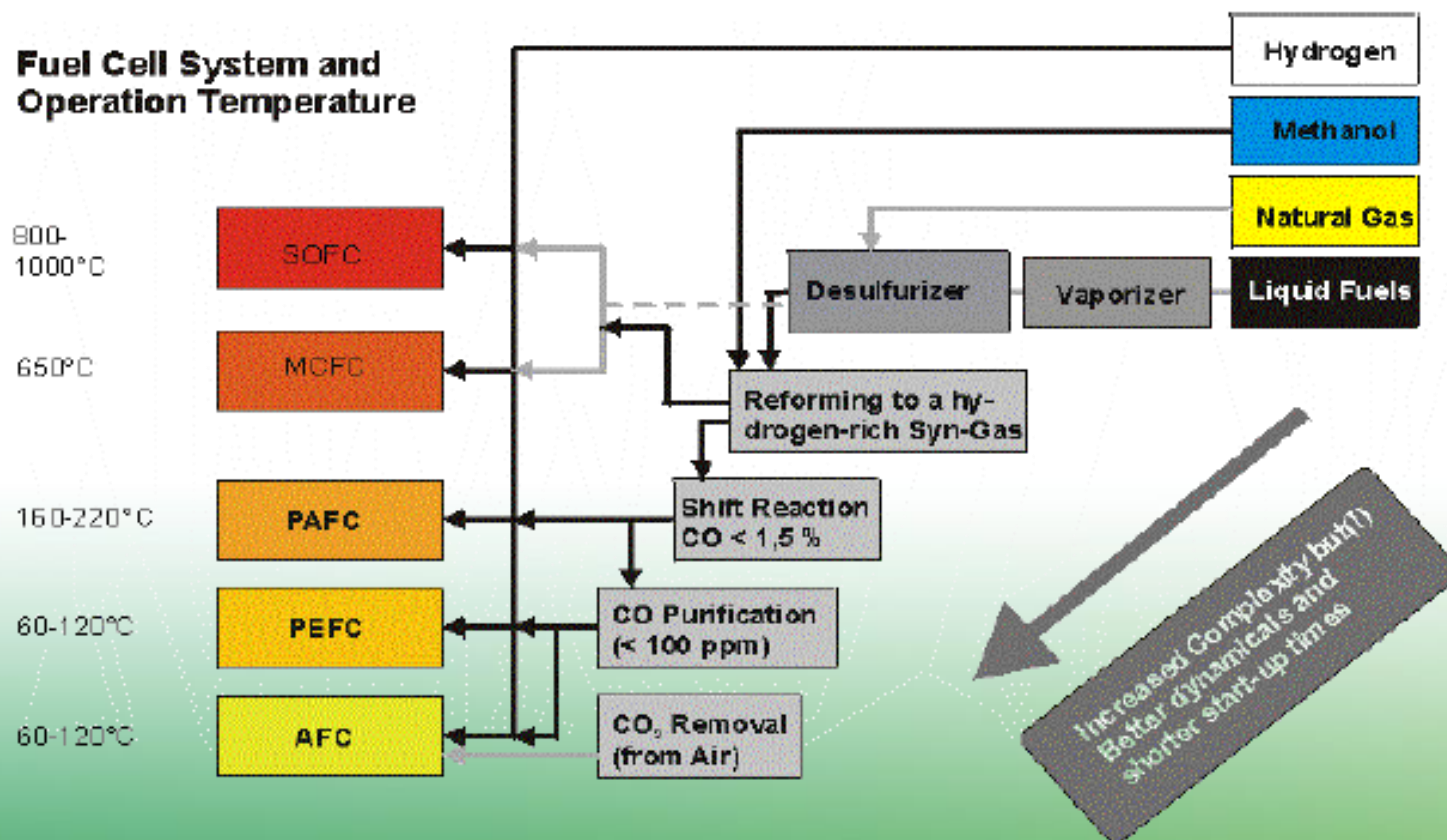
Fuel Cell System Block Diagram



Fuel Cell System



Fuel Cell Reforming Process



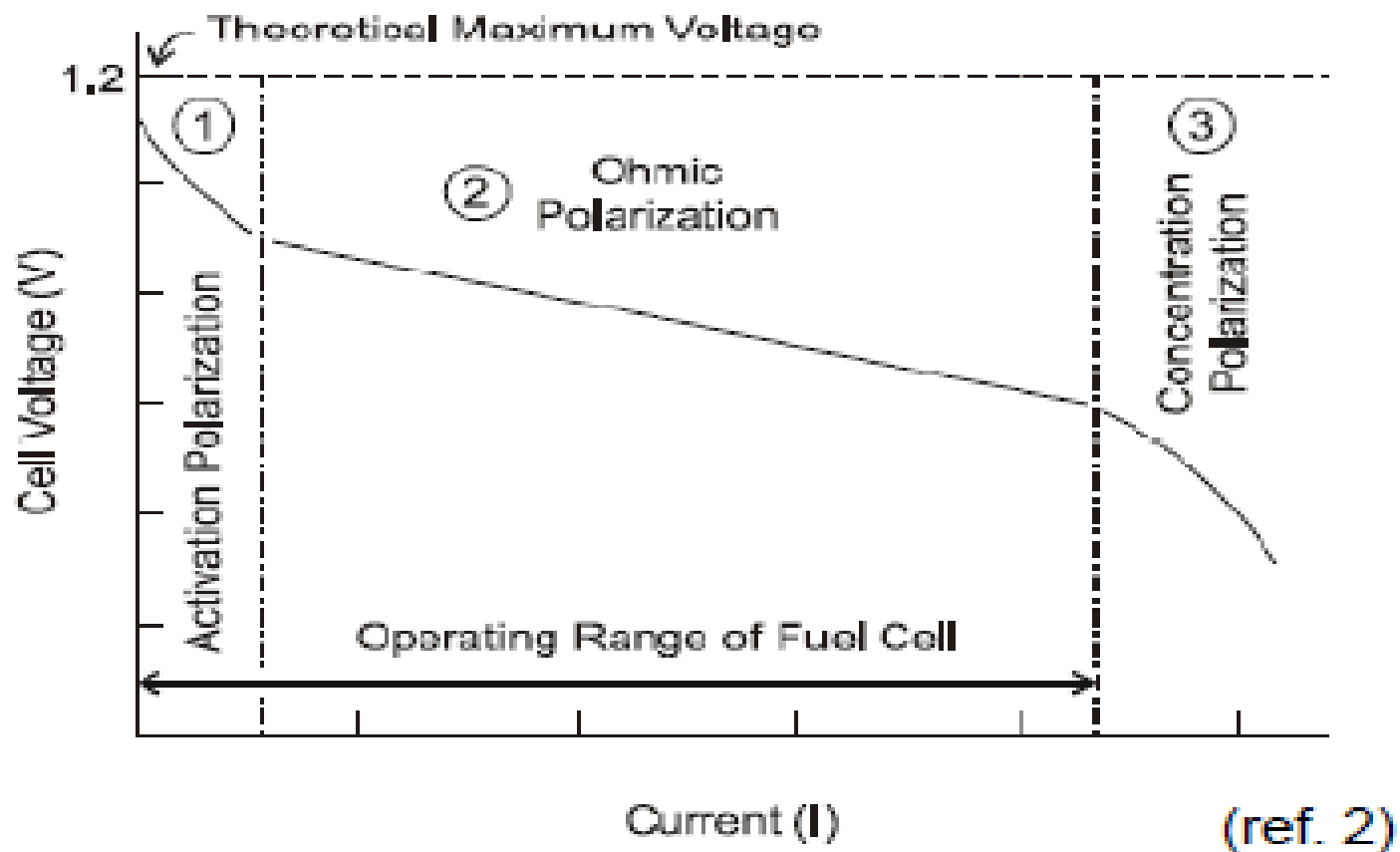
Reaction in the desulphurisation step: $\text{ZnO} + \text{H}_2\text{S} \rightarrow \text{ZnS} + \text{H}_2\text{O}$

Reaction in pre-reforming/reforming step: $\text{CH}_4 + \text{H}_2\text{O} \rightarrow 3 \text{H}_2 + \text{CO}$

Reaction in the shift converter (HT and/or LT): $\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$

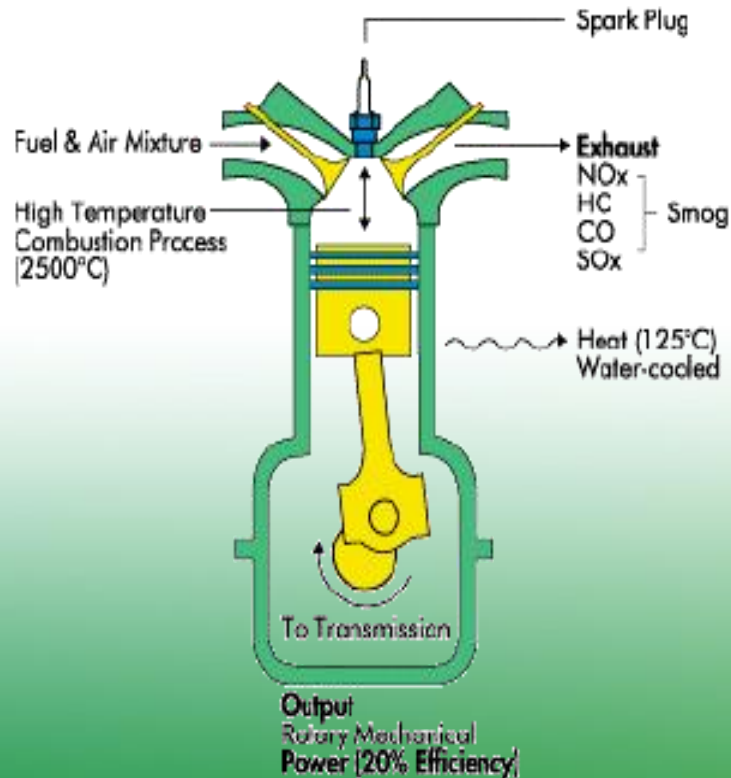
Reaction in PrOx-converter: $\text{CO} + \frac{1}{2} \text{O}_2 \rightarrow \text{CO}_2$

Fuel Cell Performance

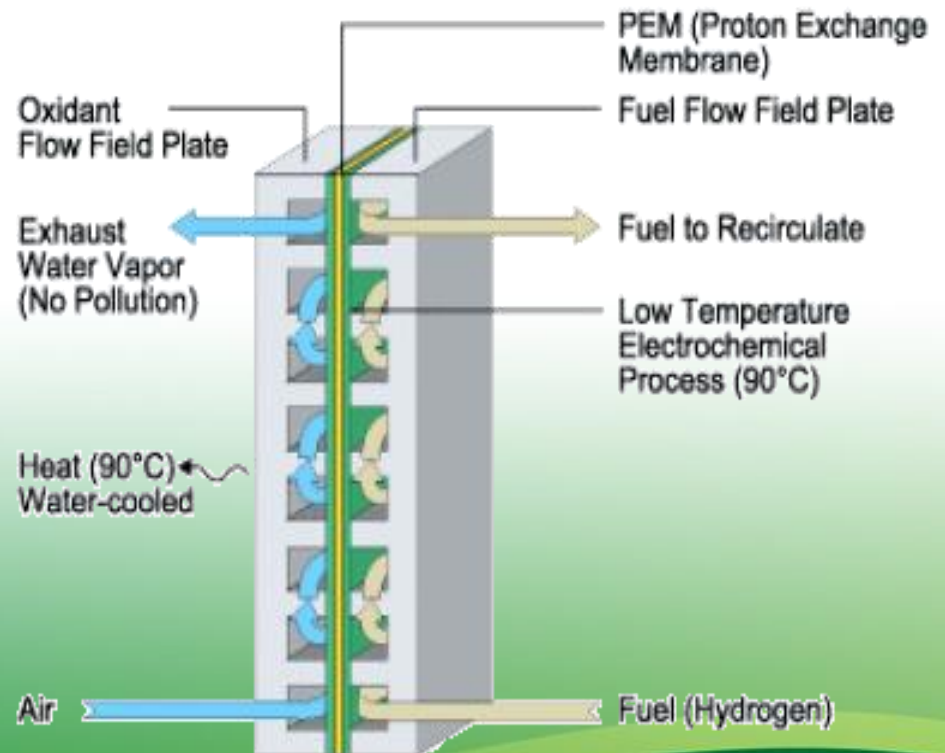


Fuel Cell vs. Internal Combustion Engine

Single Cylinder Internal Combustion Engine



Proton Exchange Membran Fuel Cell

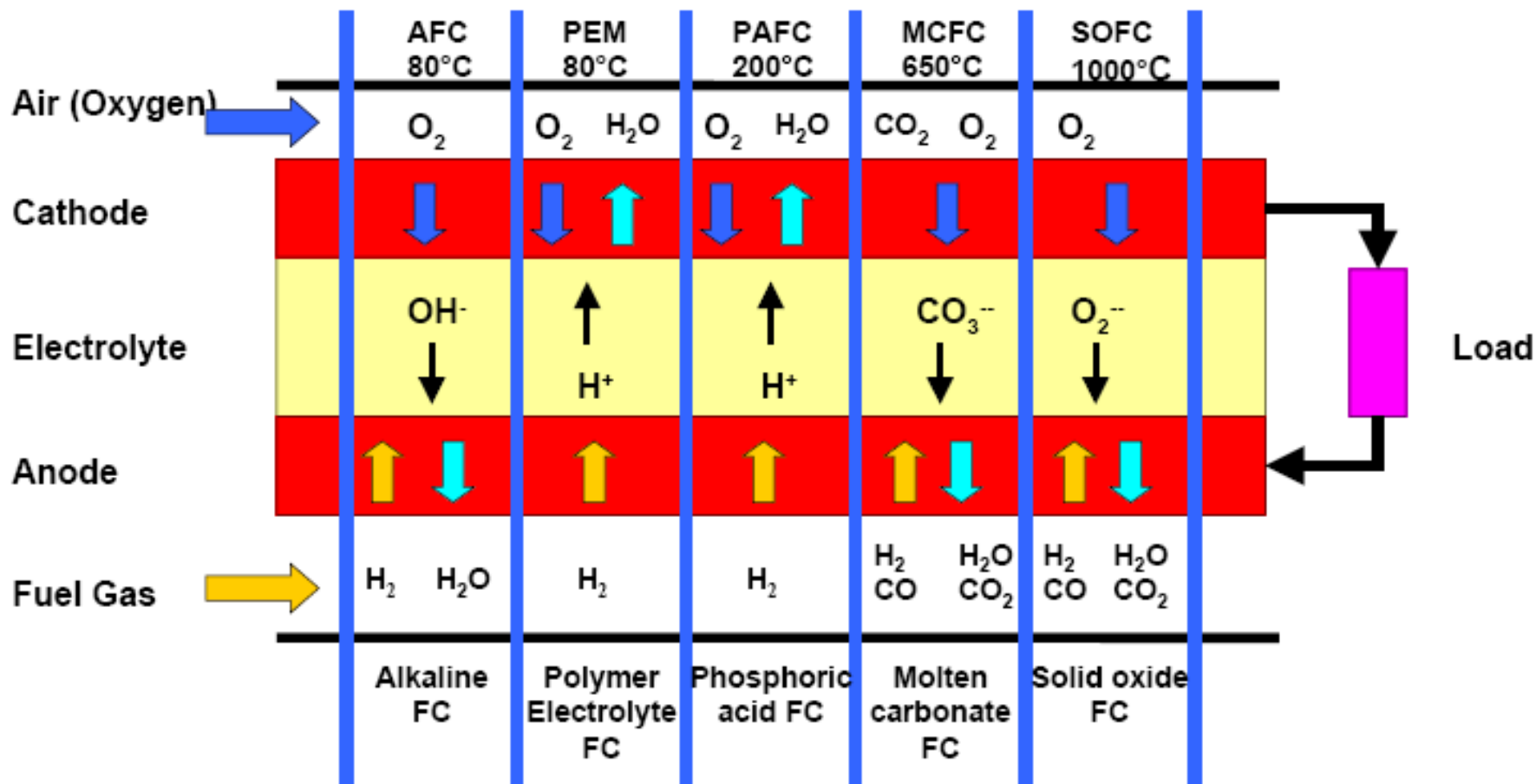




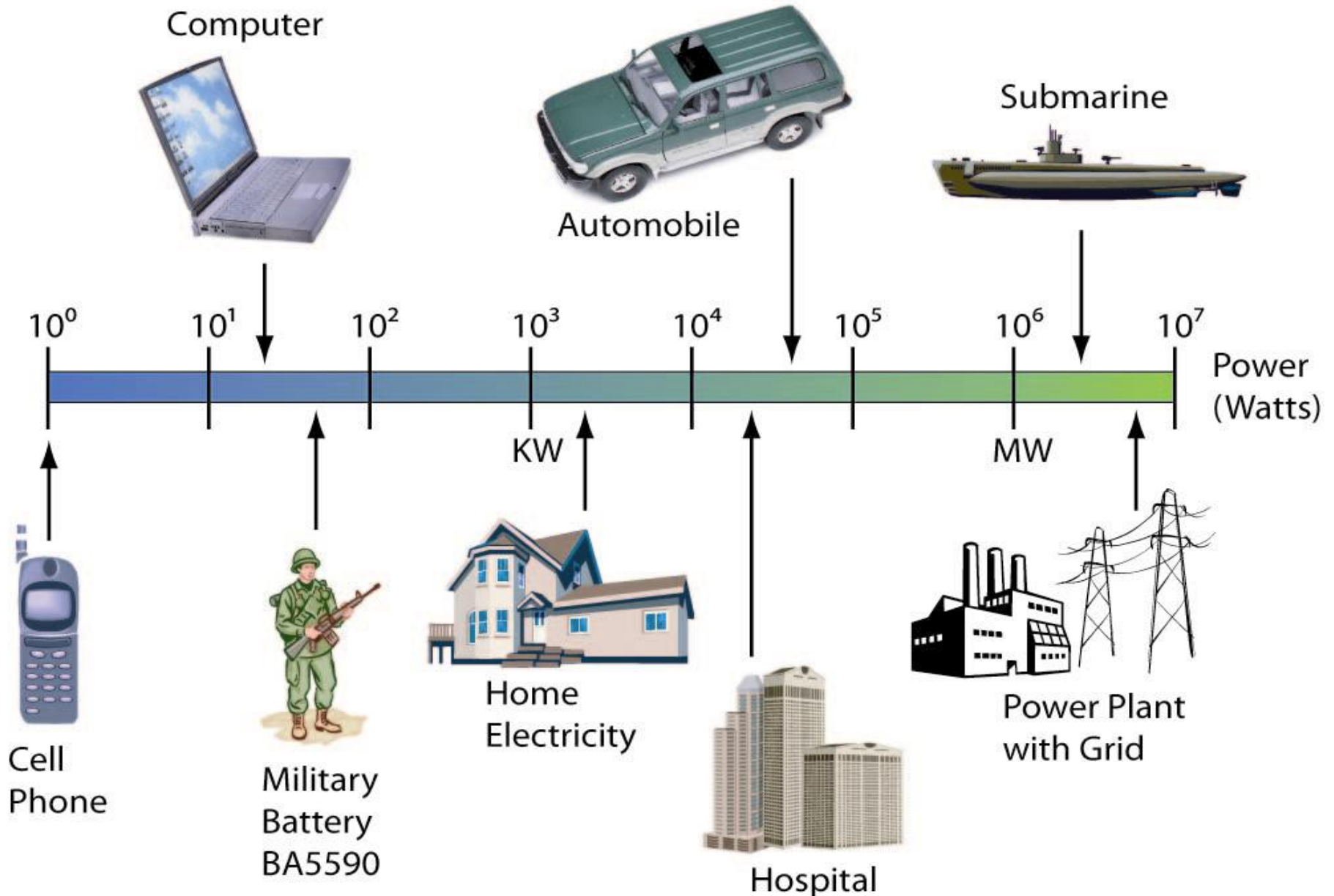
Types of Fuel Cell

Fuel Cell	Operating Conditions
Alkaline FC (AFC)	Operates at room temp. to 80 °C Apollo fuel cell
Proton Exchange Membrane FC (PEMFC)	Operates best at 60-90 °C Hydrogen fuel Originally developed by GE for space
Phosphoric Acid FC (PAFC)	Operates best at ~200 °C Hydrogen fuel Stationary energy storage device
Molten Carbonate FC (MCFC)	Operates best at 550 °C Nickel catalysts, ceramic separator membrane Hydrocarbon fuels reformed in situ
Solid Oxide FC (SOFC)	Operates at 900 °C Conducting ceramic oxide electrodes Hydrocarbon fuels reformed in situ
Direct Methanol Fuel Cell (DMFC)	Operates best at 60-90 °C Methanol Fuel For portable electronic devices

Types of Fuel Cell

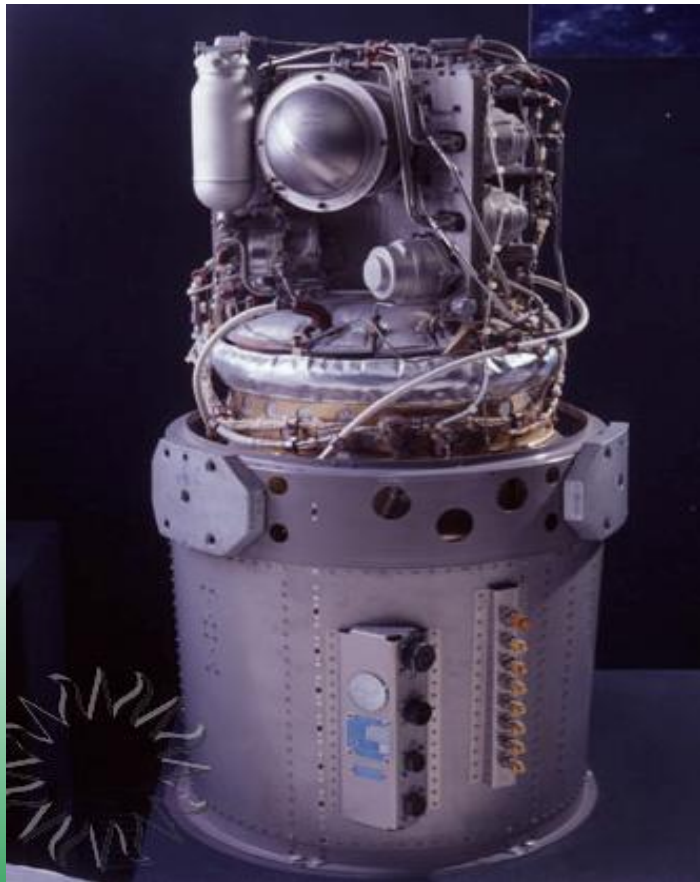


Fuel Cell Power Spectrum

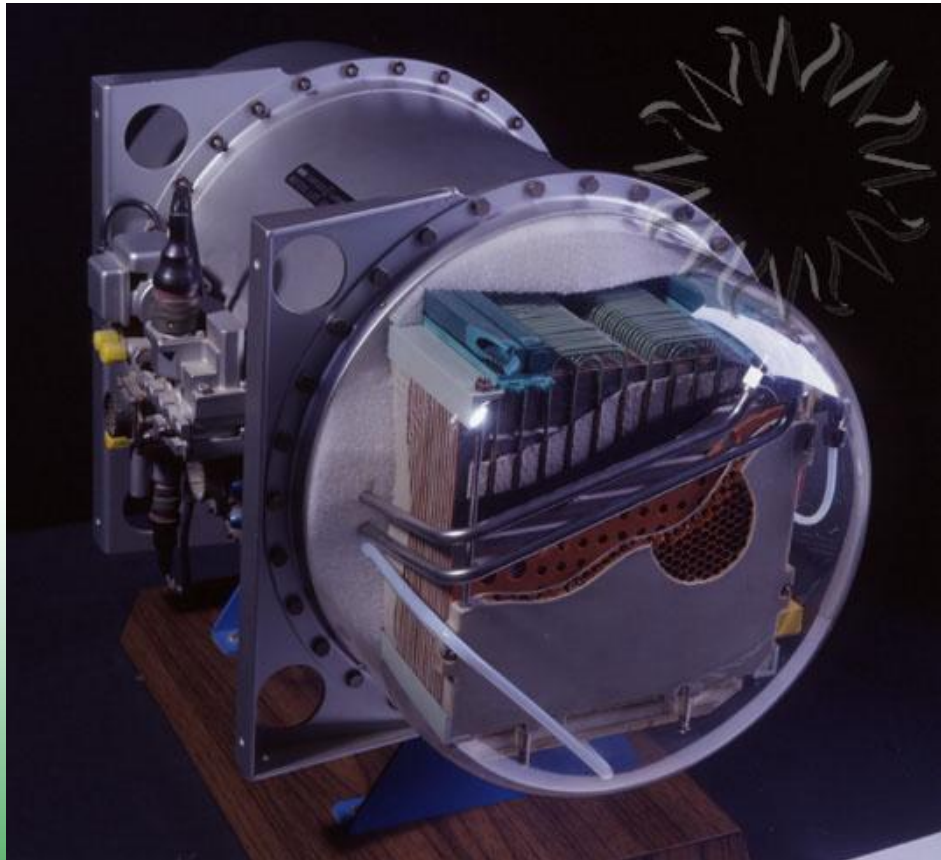


Space Application

Apollo Fuel Cell



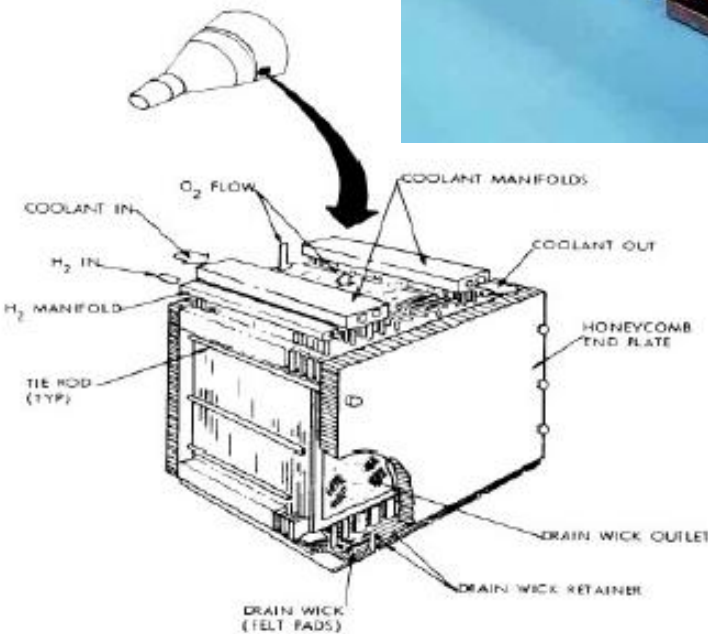
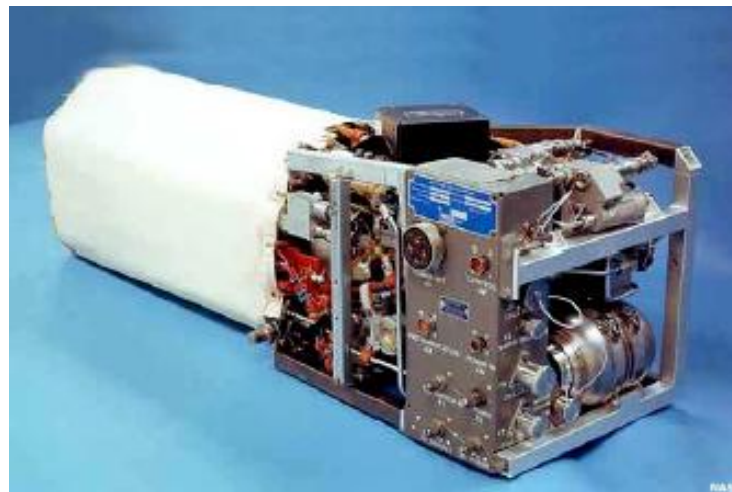
Gemini Fuel Cell



Space Application



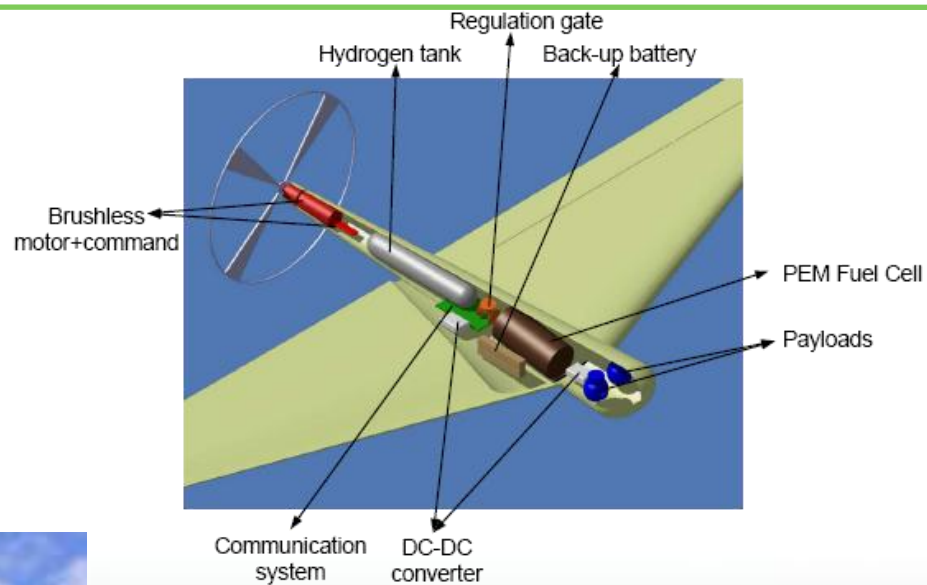
Space Shuttle Fuel Cell



Gemini Fuel Cell Stack

Aerial Application

Icare II Airplane



Mini Fuel Cell UAV



Helios



Aerial Application

Antares Airplane



Global Observer Airplane

Aerial Application

Aviation Fuel Cell Development Timeline

2003 2004 2005 2006 2007 2008 2009 2010



Jet-A Synthetic



Alpha SOFC unit



Power Current
Electrical System
with scaled unit



Hybrid aircraft unit
development

Fuel Cell APU
Feasibility studies

Develop Aircraft Specific SOFC Technologies



Boeing Fuel Cell Powered Airplane
Demonstrator

Fuel cell UAV feasibility study





Aerial Application

Fuel Cell Powered Demonstrator Airplane

Batteries, H₂ system, motor/propeller and controllers being designed.



First flight in 2006

Diamond HK-36 airframe being modified



20kW Fuel cell unit built by Intelligent Energy (UK)

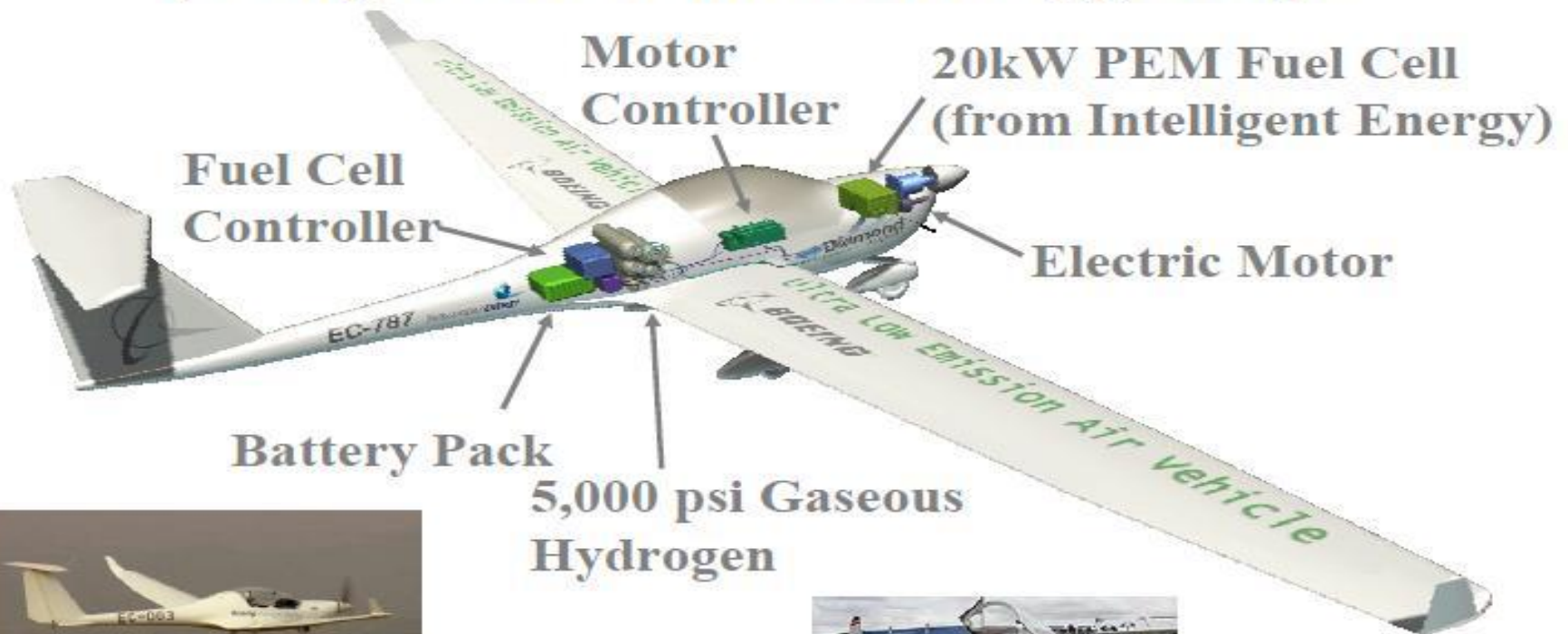
Integration in work



Aerial Application

Demonstrators are a means to get familiar with integration and operational issues

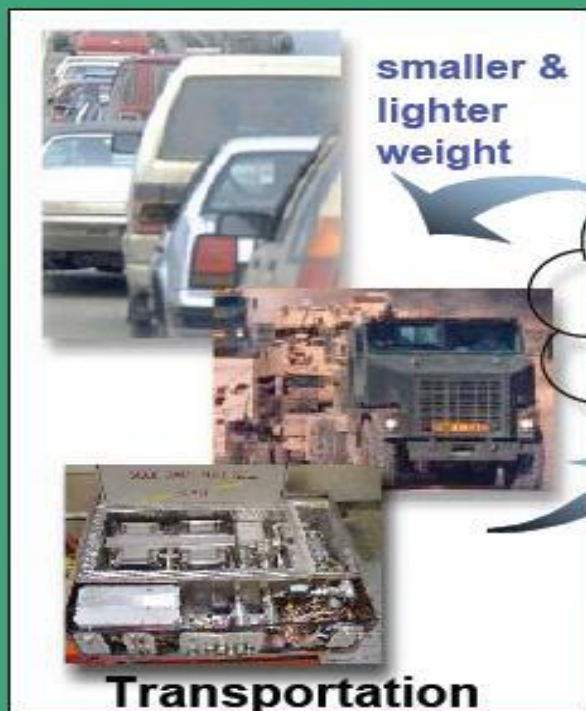
Boeing Fuel Cell Airplane Demonstrator – BR&T (Boeing Research and Technology) Europe



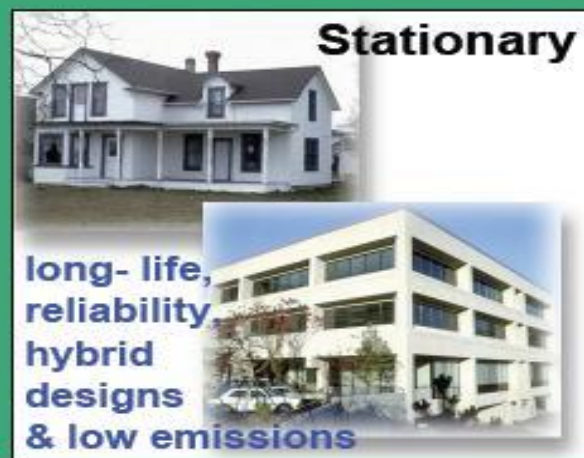


Aerial Application

Aircraft Applications Benefit From Other R&D



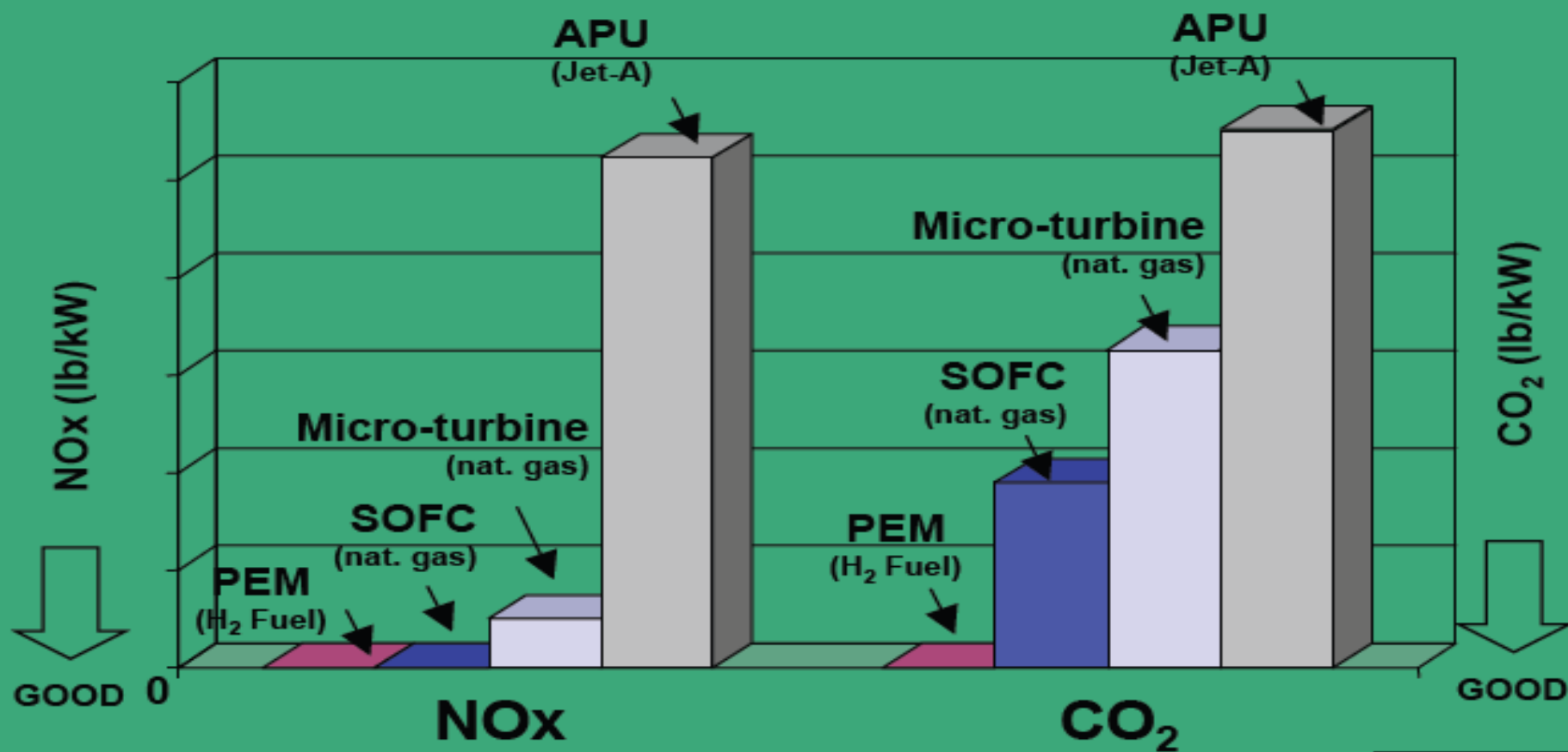
Solid Oxide Fuel Cell



SOFC R&D for other applications will provide increased efficiency, capability and quicker time to market.

Aerial Application

Fuel Cells Have Low Emissions

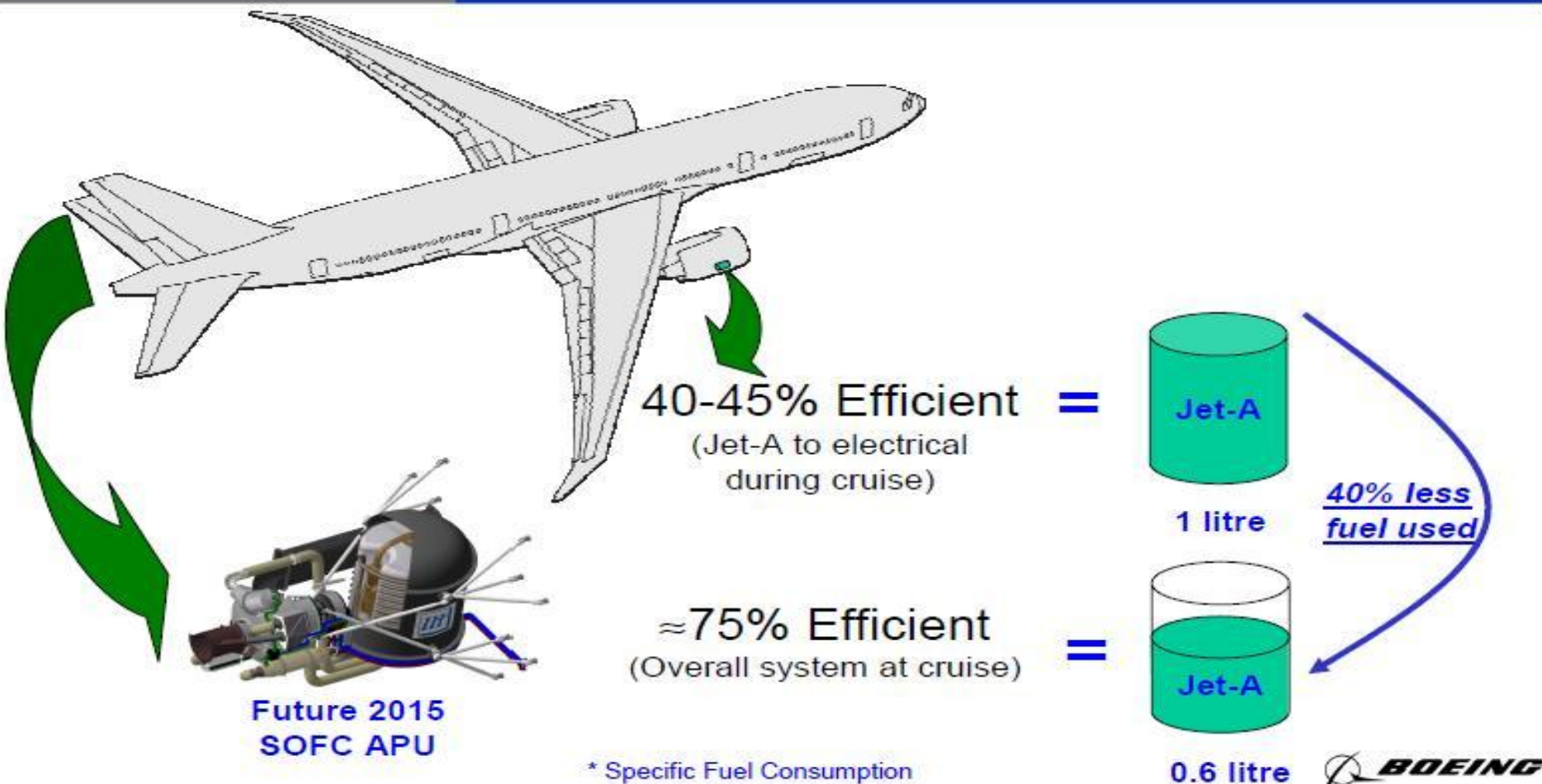




Aerial Application

**Commercial
Airplanes**

In-flight SFC* saving is $\approx 0.7\%$



Aerial Application

Commercial Airplanes

Fuel saving opportunity on the ground is very attractive



Typical Turbine-
powered APU

15% Efficient
(over average operating cycle)

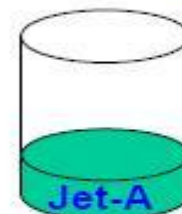
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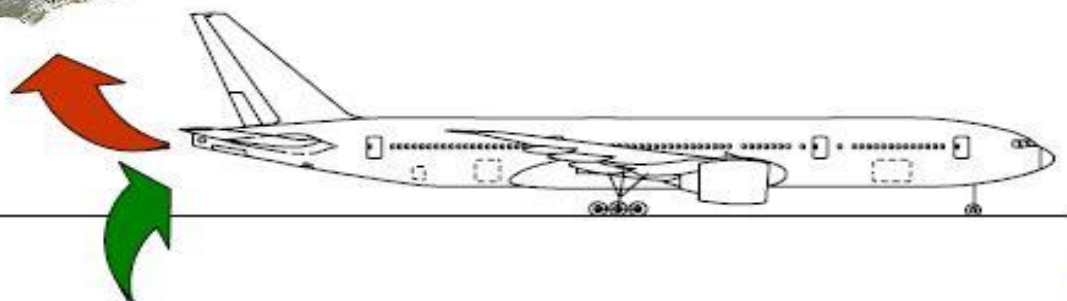
1 litre

75% less
fuel used

=

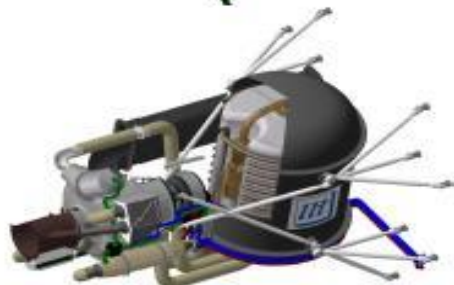


0.25 litre



Future 2015
SOFC APU

60% Efficient
(at std. sea-level conditions)



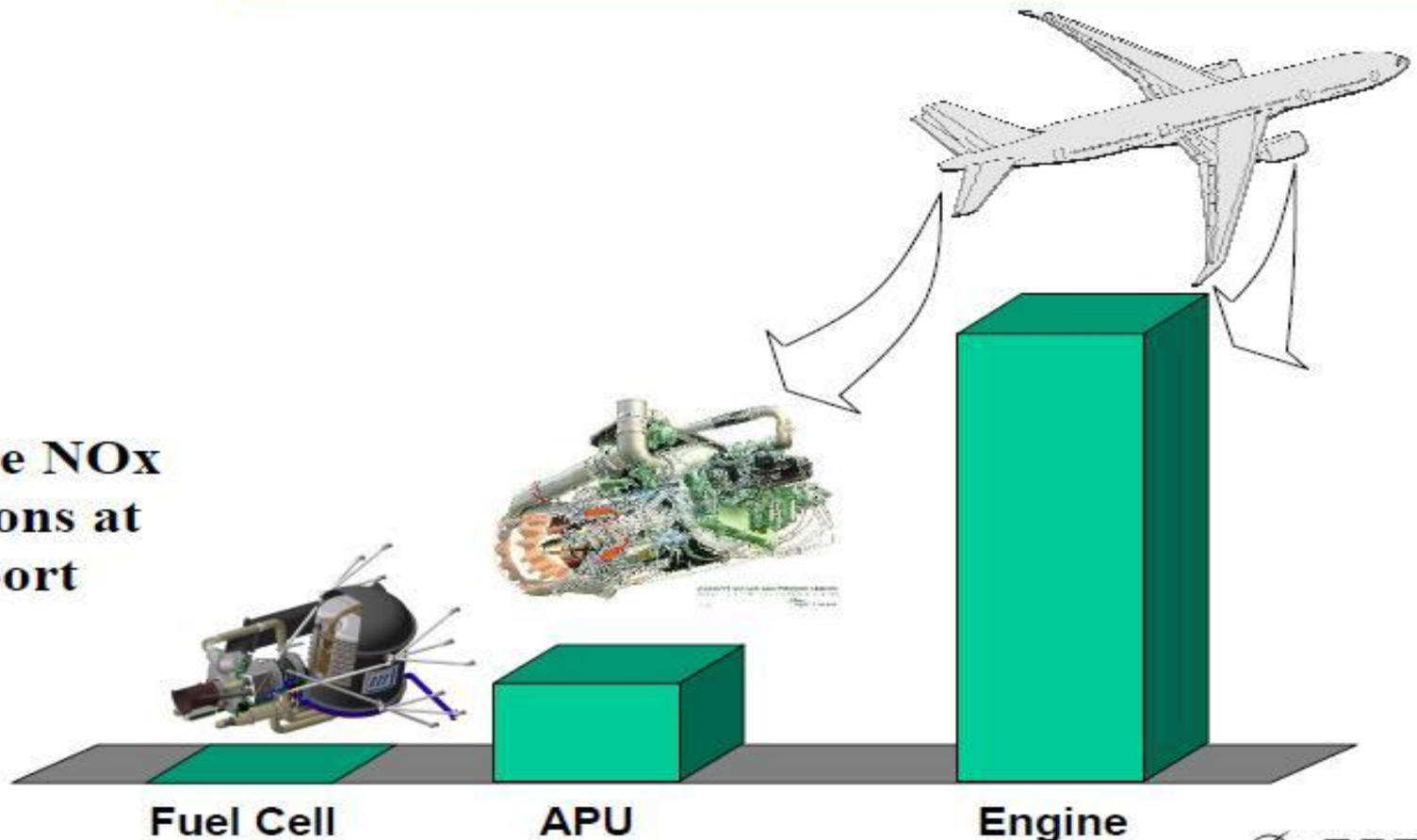


Aerial Application

**Commercial
Airplanes**

**Fuel cell APU can cut airplane
NOx emissions at the airport**

**Airplane NOx
Emissions at
Airport**





Aerial Application

Industrial SOFC Technology Can Be Leveraged For Aerospace



*Industrial 250kW Solid Oxide
Fuel Cell Installations*

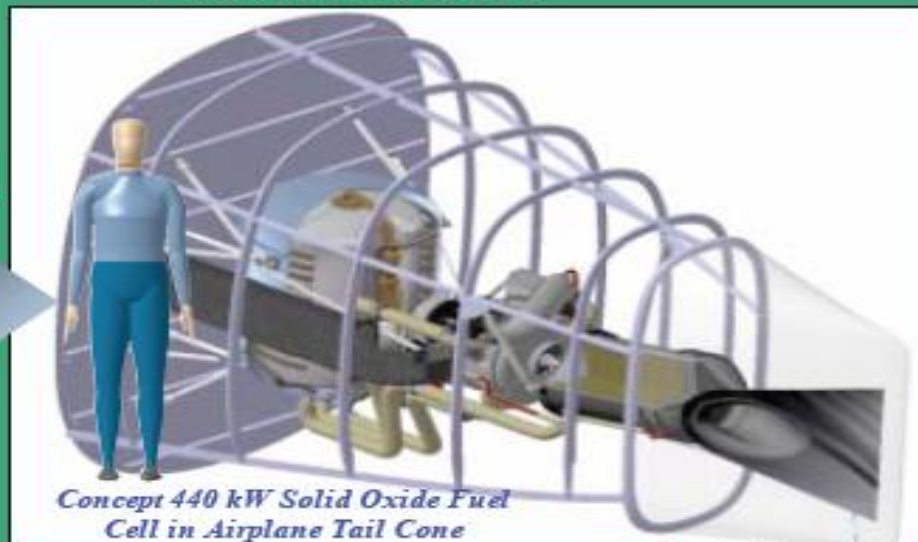
2003 Industrial

- Cost
- Efficiency
- Commercialization
- Reliability

2015 Aerospace

Same as industrial plus:

- Weight & Size
- Altitude Operation
- Jet-A fuel
- Safety
- Vibration & shock



*Concept 440 kW Solid Oxide Fuel
Cell in Airplane Tail Cone*



Aerial Application

More Electric Airplane (MEA) Background

- Efficiency changes in 787 due to:
 - Composite airframe
 - Efficient no-bleed engines
- Transition in power sources in the MEA
 - Increase in electric power to ~1.5 MW

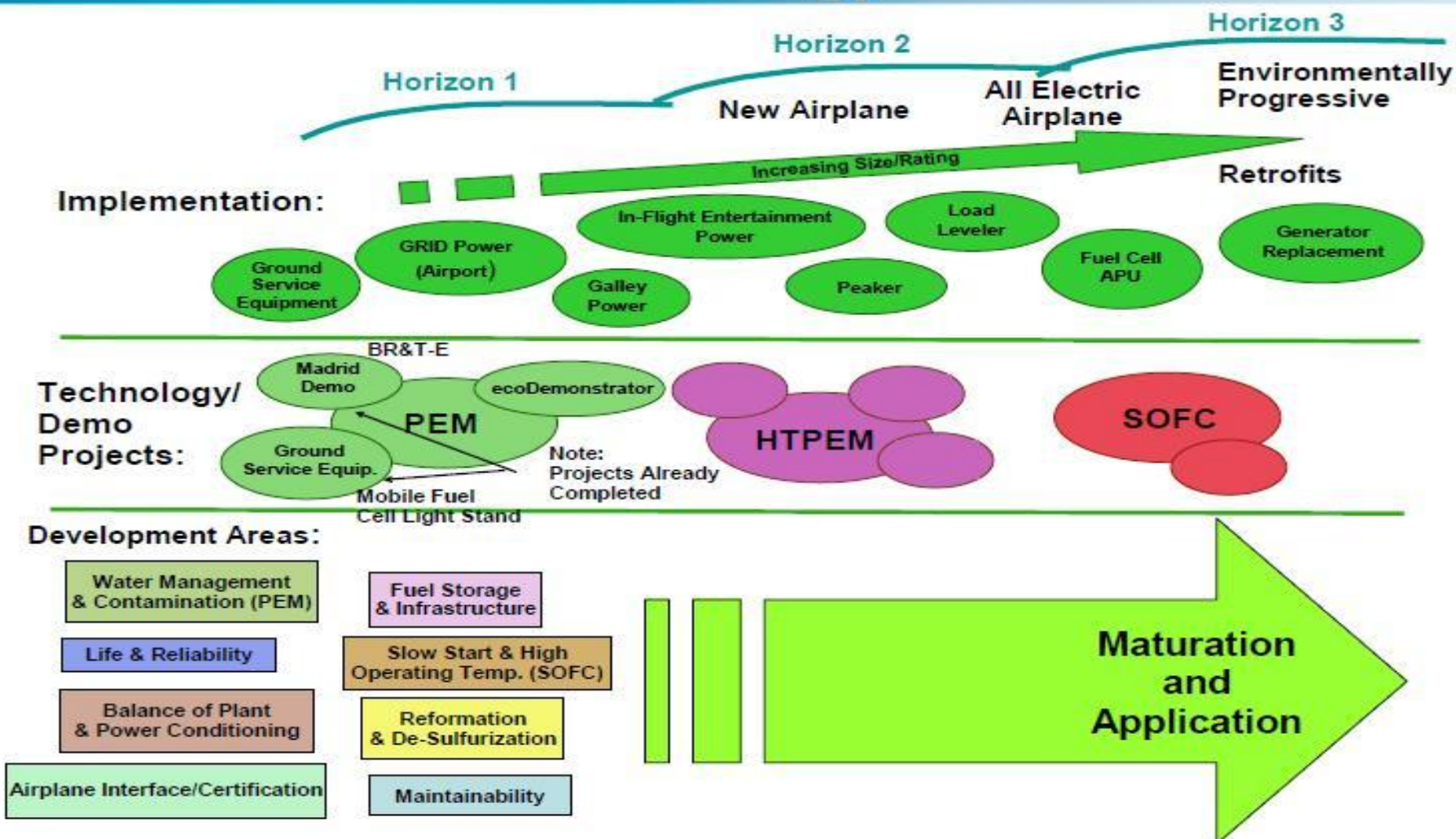


Power Source	Bleed	No Bleed + MEA
Electrical	Cabin Lighting, Avionics, Fuel Pumps, etc.	Engine start, De-Ice, ECS & Pressurization, Cabin Lighting, Avionics, Fuel Pumps, Brakes, Flight Controls, etc.
Hydraulic	Brakes, Flight Controls, Landing Gear, etc.	Flight Controls, Landing Gear
Pneumatic	Engine start, De-Ice, ECS & Pressurization	Cowl De-Ice



Aerial Application

Proposed Path to Fuel Cell Technology for Aviation

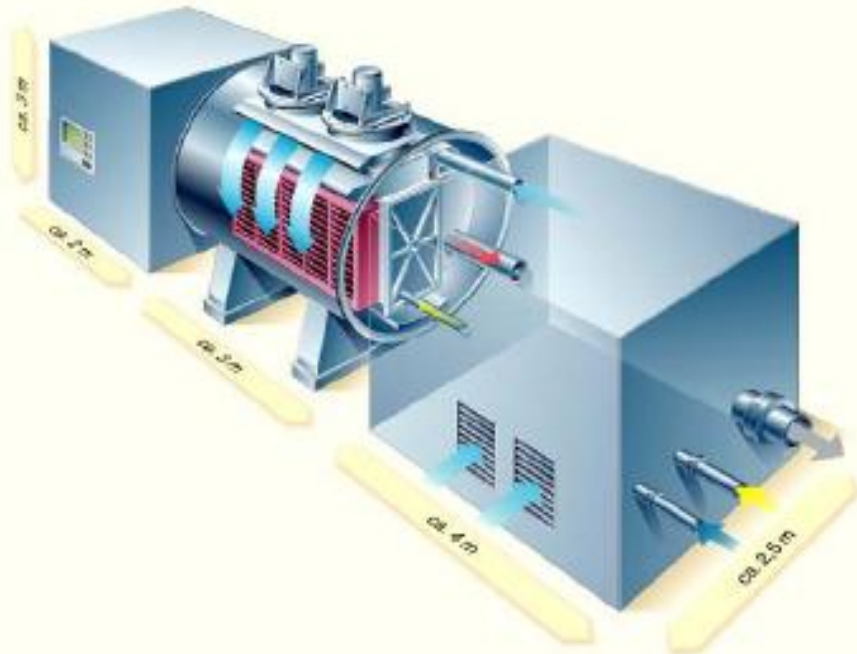




Power plant Application



Power plant Application



**MTU's „Hot-Module“ Development
for CHP Power Plants**

Courtesy of MTU





Power plant Application

Polymer Electrolyte Membrane (PEMFC)



- 1-10 kW
- 25-40 % efficiency LHV
- \$ 5,000 /kW

Phosphoric Acid Fuel Cells (PAFC)



- 200-1000 kW
- 40 % efficiency LHV
- \$ 3,500 / kW

Molten Carbonate Fuel Cells (MCFC)



- 250- 1,000 kW
- 45 % efficiency
- \$ 3,000-4,000 / kW

Solid Oxide Fuel Cells (SOFC)



- 1-250 kW
- 45-48 % efficiency
- \$10,000 - 20,000/kW



Power plant Application

Innovation and R&D Required for large Market

2005-2008



Efficiency, LHV
35-45

55

65



Early Markets

- Schools & Universities
- Government Buildings
- CHP; Free Fuel
- National Parks
- Military Bases
- State RPS Programs

2008-2010

- 5 kW – 75 kW PEMFC
- 250 – 1 MW MCFC, and SOFC
- 5- 40 kW SOFC
- \$ 1,500-\$2,000 / kW

2010-2020

- 75 kW – 250 kW PEMFC
- 250 – 3 MW MCFC, SOFC
- 2 – 50 kW SOFC
- 1MW + SOFC-CT
- <<\$ 800 /kW



Transportation Application





Transportation Application





Transportation Application

Mercedes



Honda



GM



University of Delaware



Europe



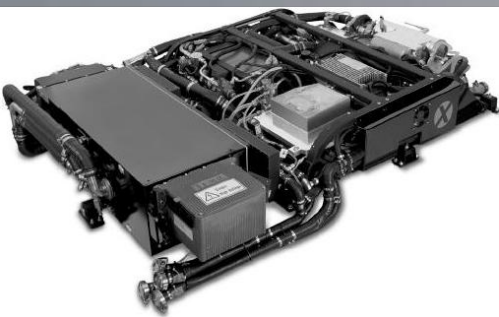


Transportation Application



Mercedes-Benz

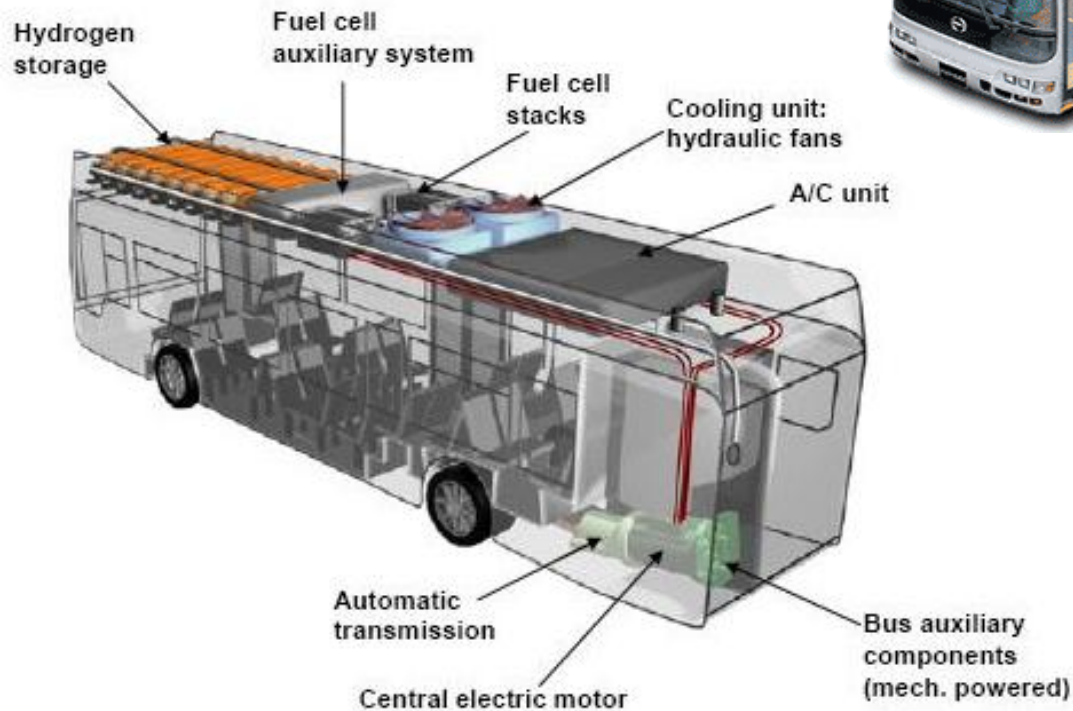
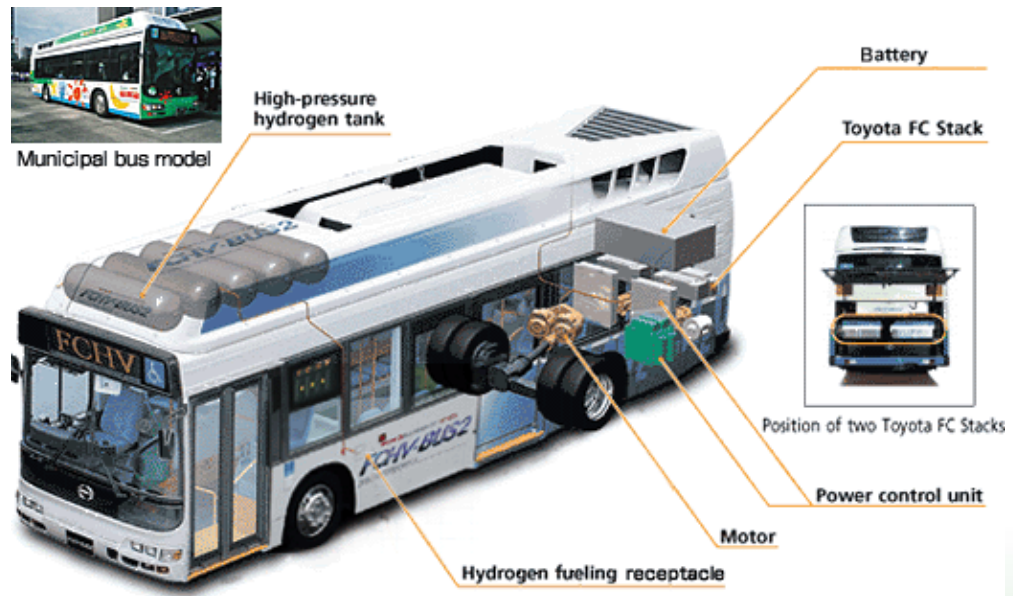
The B-Class F-Cell



Available Summer 2010

Transportation Application

Toyota&Hino Bus



Citaro Bus, Mercedes Benz

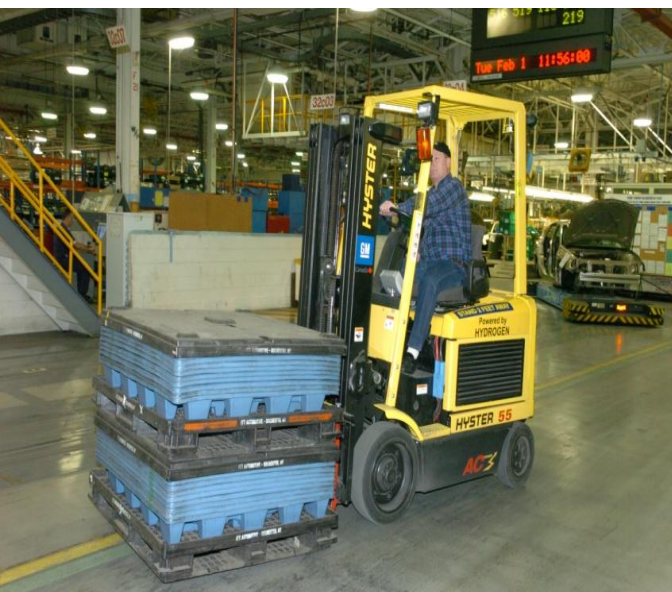
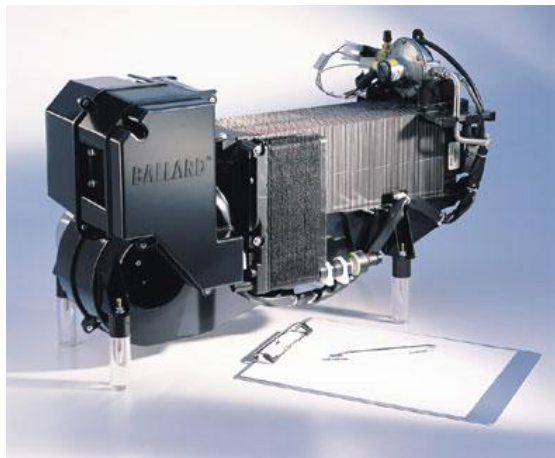


Transportation Application

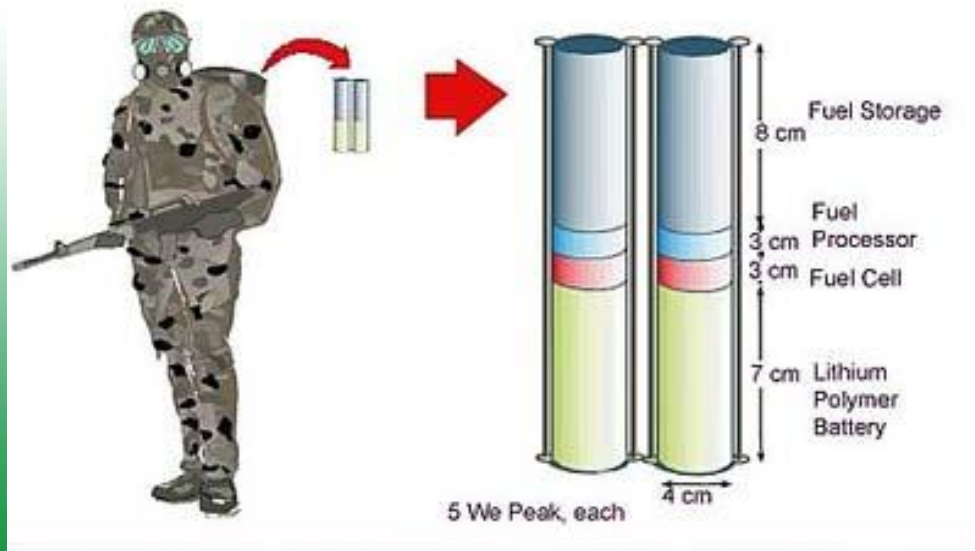




Transportation Application



Portable Application





Fuel Cell R&D and Materials Research Needs

➤ Key Areas of R&D(SOFC)

- ✓ Stable Interconnect under anode and cathode environments
- ✓ Advanced Electrodes
- ✓ Seals
- ✓ Low cost fabrication methods
- ✓ High power density
- ✓ Durability

➤ Key Areas of R&D(PEMFC)

- ✓ Durable electrolyte
- ✓ High temperature electrolyte
- ✓ Lower Pt. Loadings
- ✓ Complex Fuel Processing



Fuel Cell in Iran, University & Research Center

➤ University

**Amirkabir, Sharif, Tehran, Khajeh Nasir Tousi,
Tarbiat Modarres, Iran Science & Technology, ...**

➤ Research Center

Esfahan Engineering, SANA



Fuel Cell in Iran, Conference & Seminar

- Hydrogen & Fuel Cell Conference(second)
- Fuel cell Seminar (5th)





“Yes, My friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it ... will furnish an inexhaustable source of heat and light ... Water will be the coal of future”

Jules Verne, The Mysterious Island, 1874

Email: Micropropulsion@yahoo.com

Civil Aviation Technology College