Fuel Cells
Clean Reliable Power

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GovEnergy
www.govenergy.gov

New Orleans, LA
August 6, 2007

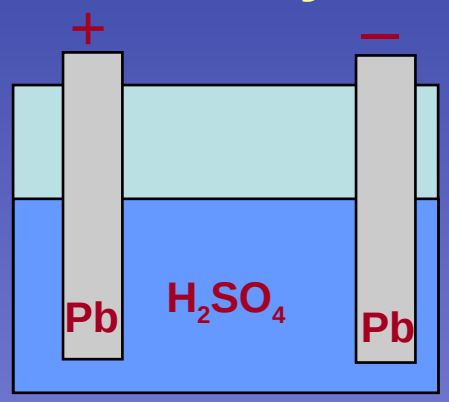
Outline

- Fuel Cell Basics
- Army (Construction Engineering Research Laboratory (CERL))
- Industry
- Commercial Products
- Resources

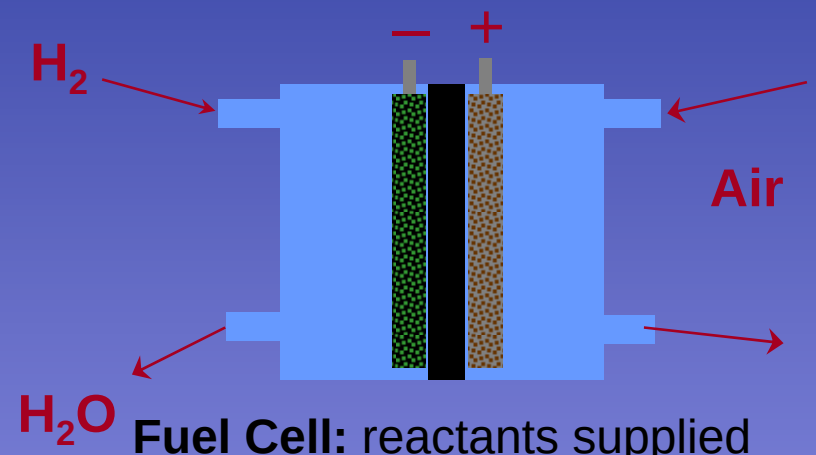
Fuel Cell – The Ultimate Rechargeable Battery

An electrochemical energy conversion device in which fuel and oxidant react to generate electricity without any consumption, physically or chemically, of its electrodes or electrolyte

Battery



Fuel Cell



Battery: reactants self contained and electrodes consumed

Lead-Acid Reaction

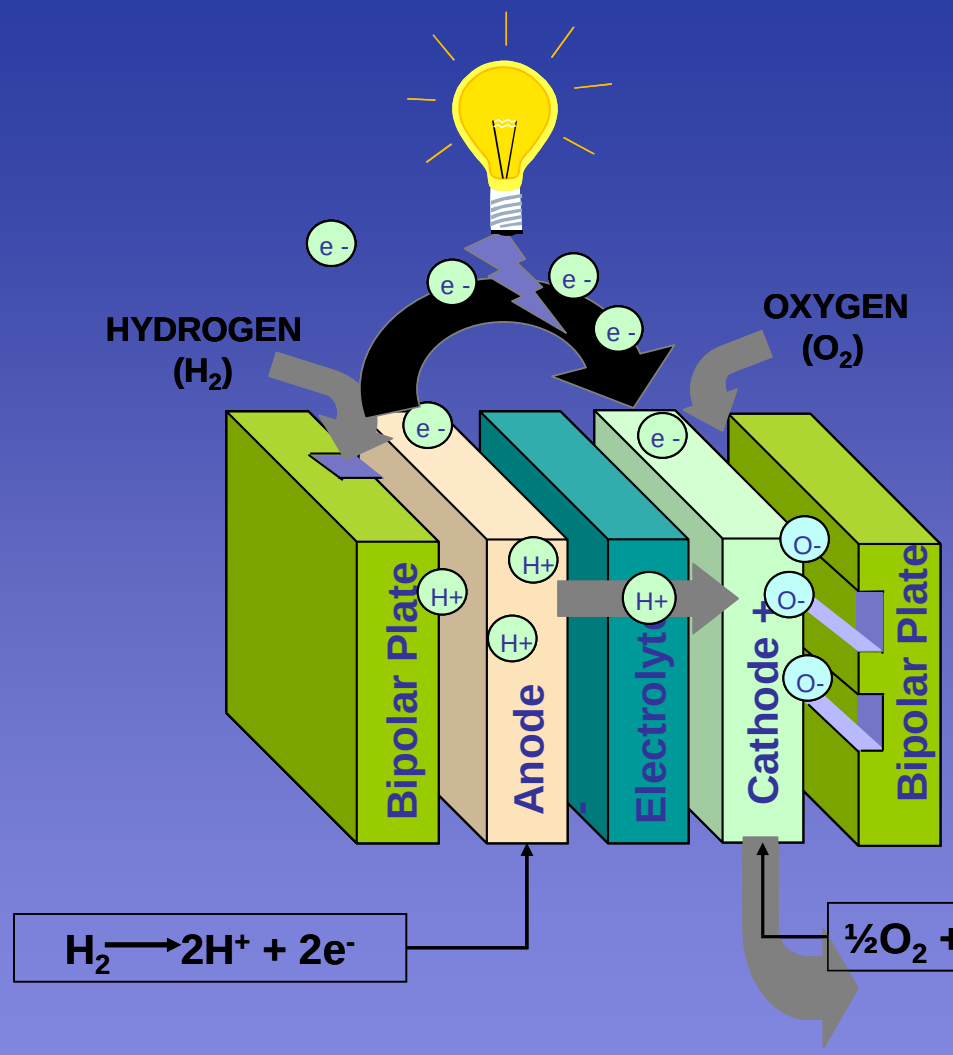
$Pb + PbO_2 + H_2SO_4 \leftrightarrows 2\ PbSO_4 + 2\ H_2O +$ heat + electrons

Fuel Cell: reactants supplied continuously and electrodes unchanged

Fuel Cell Reaction

$H_2 + O_2 \rightarrow H_2O$ + heat + electrons

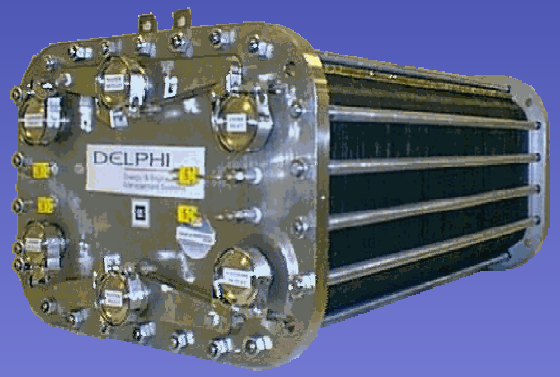
How it Works

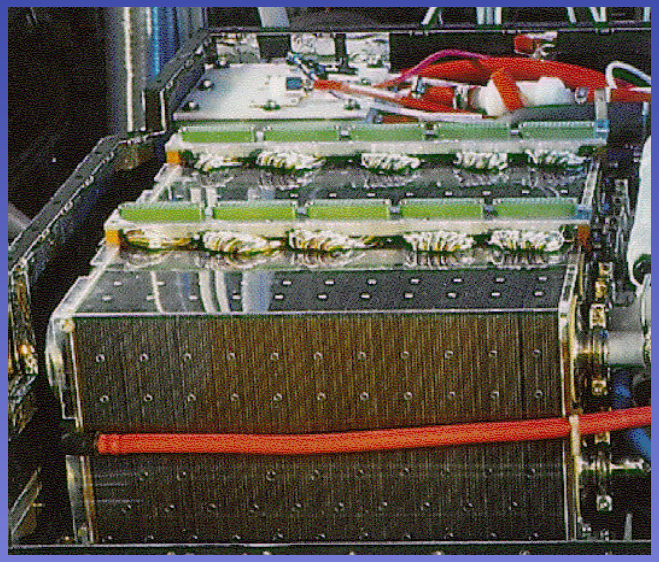


Protons, H^+, formed at the Anode diffuse through the electrolyte and react with electrons and oxygen at the Cathode to form water and heat.

Cells arranged in “stacks”

The larger the stack the higher the voltage and power output





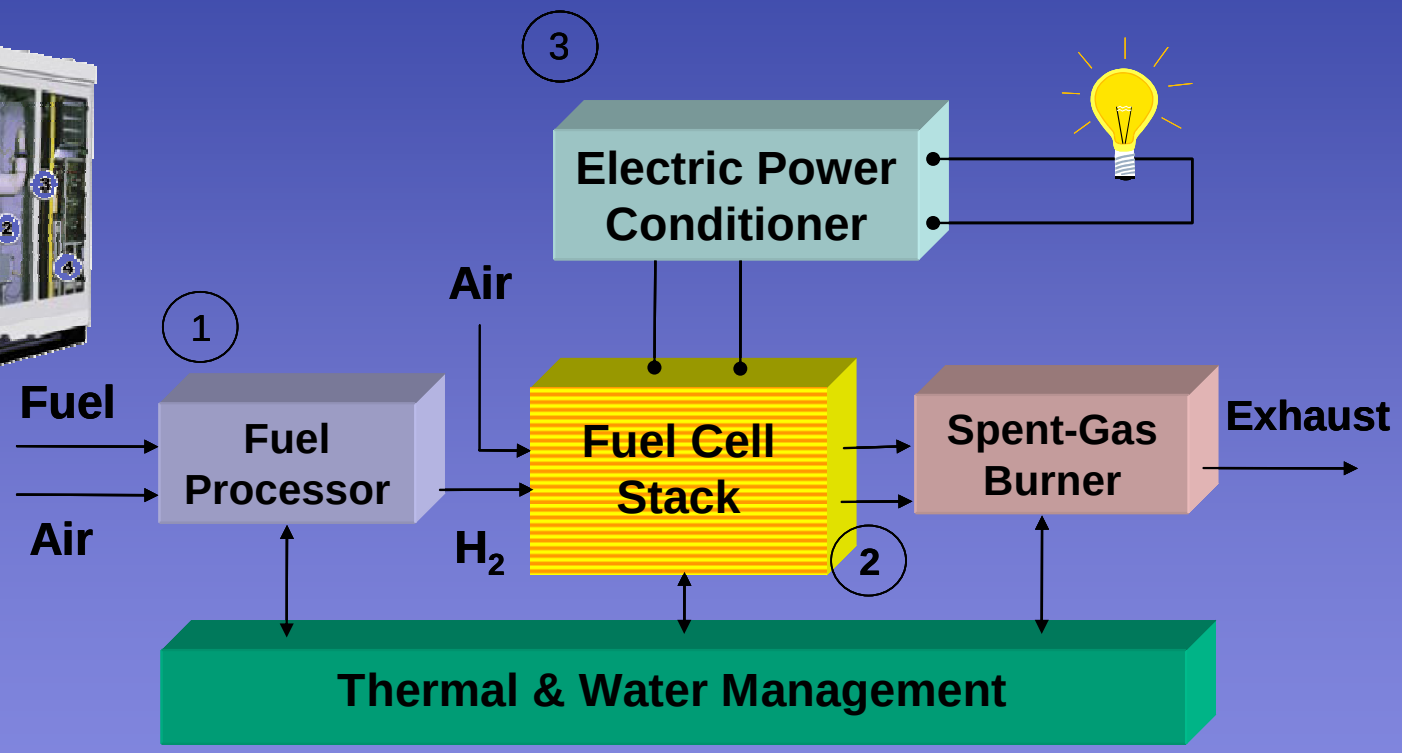
Cathode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ **1.2 V**

Anode: $2H_2 \rightarrow 4H^+ + 4e^-$ **- 0 V**

Total Cell: $2H_2 + O_2 \rightarrow 2H_2O$ **1.2 V per cell**

Power = Volts X Amps

Fuel Cell System



Types of Fuel Cells

Fuel Cell Type	Temperature / Electrolyte / Ion	Applications
Phosphoric Acid (PAFC)	175 – 200° C H_3PO_4 / H+	Electric utility Distributed power Transportation
Polymer Electrolyte Membrane (PEM)	60 - 100° C Perfluorosulfonic acid / H+	Electric utility Portable power Transportation
Alkaline (AFC)	**90 – 100° C** **KOH / OH-**	**Military** **Space**
Molten Carbonate (MCFC)	**600 – 1000° C** **(Li,K,Na)2CO3 / CO2-**	**Electric utility** **Distributed power**
Solid Oxide (SOFC)	**600 – 1000° C** **(Zr,Y) O2 / O-**	**Electric utility** **Distributed power** **APUs**

Phosphoric Acid Fuel Cell

200 kW 175-200°C

UTC Power

Applications

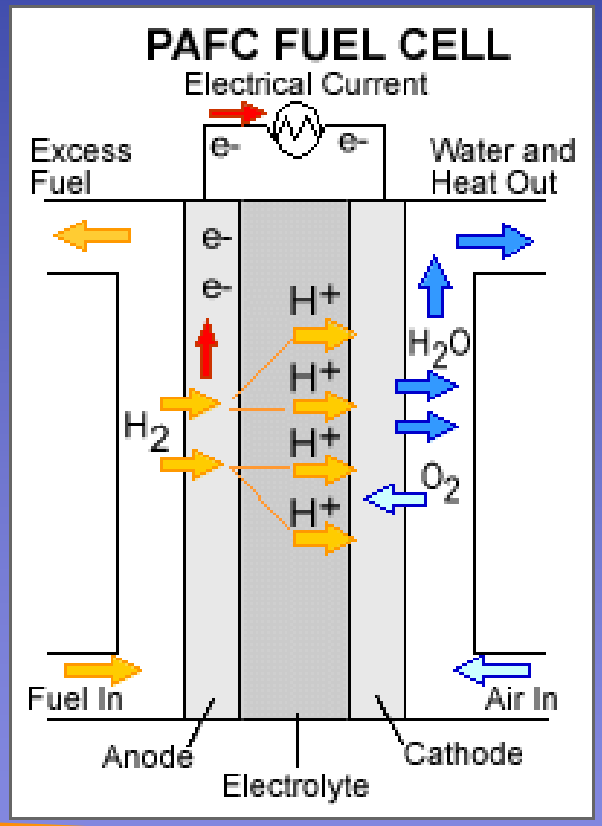
- Distributed power plants
- Combined heat and power
- Some buses

Features

- Some fuel flexibility
- High efficiency in cogeneration (85-90%)
- Established service record
- Platinum catalyst

Status

- Commercially available but expensive
- Excellent reliability and availability
- Millions of hours logged



Reactions: Cathode: $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$

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

Polymer Electrolyte

100W – 130kW 60 – 100°C

Applications

- Transportation, Forklifts, etc.
- Power backup systems
- Consumer electronics with methanol fuel

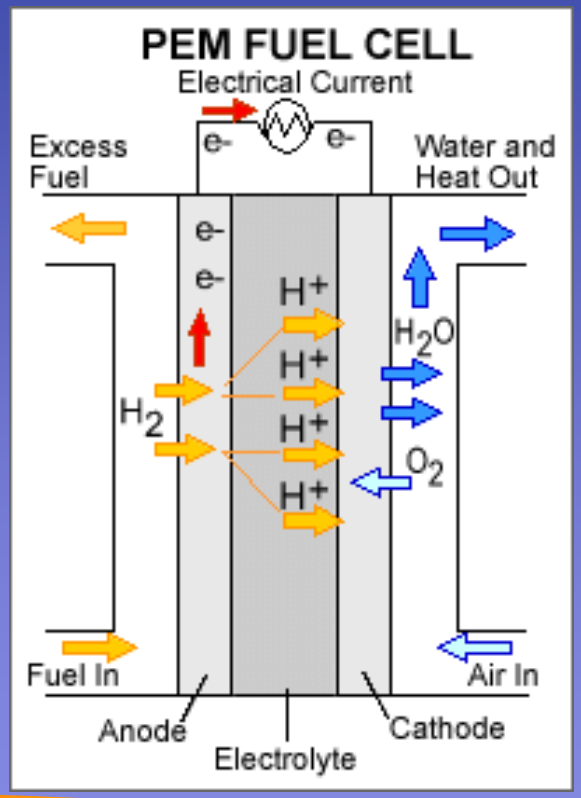
Features

- Quick start
- Low temperature
- Expensive Pt electrodes
- Easy manufacture
- Operating window limits
- 53-67% thermal efficiency

Toyota Forklift

Status

- Vehicle demonstrations underway
- Stationary/backup power "commercially" available

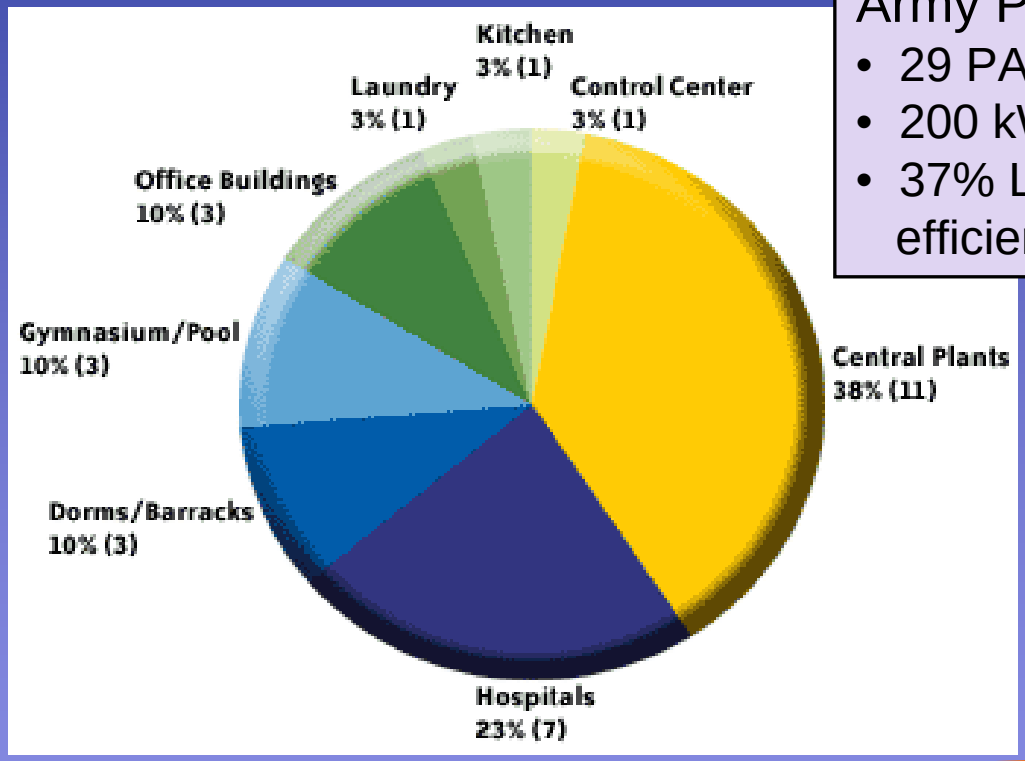


Reactions: Cathode: $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$

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

Applications/Opportunities

http://dodfuelcell.cecer.army.mil/pafc/index.php4



Army Program (CERL) began in 1997.

- 29 PAFC power plants installed.
- 200 kW at 480V 3 phase.
- 37% LHV electric, up to 85% overall efficiency

Total run time 875,345 hrs

- **Energy saved $6,000,000**
- **NO_x abated 282 tons**
- **SO_x abated 595 tons**
- **CO abated 24 tons**
- **CO_2 abated 36,043 tons**

CERL Phosphoric Acid FC Fleet Experience

PAFC: 29 power plants, 16 states

CERL Fuel Cell Fleet Performance through October, 2003	
875,345	Hours of Operation
142,730	MWHrs Produced
10,548	MMBtu of Thermal Delivered
37% 85%	LHV Electric Efficiency Overall Efficiency
$5,959,345	Energy Saved
66.2%	Power Plant Fleet Availability

PAFC Project completed in 2003

Photos Courtesy Frank Holcomb, CERL, July 2007

http://dodfuelcell.cecer.army.mil/pafc/index.php4

CERL Case study: Westover Air Reserve Base Boiler Plant (9/19/1997 - 9/30/02)

Hours of Operation	38,118	Hours
Total Electric Output	7,209	MWhrs
Average FC Output	189.1	kW
Capacity Factor	82.2%	
Availability	86.9%	

Fuel Cell Configuration: Model PC25C

Energy bill savings estimated at $54,000/yr

Electric Savings:	$106,000
Thermal Savings:	$11,000
TOTAL SAVINGS:	$117,000
Natural Gas Cost:	($63,000)
NET SAVINGS:	$54,000

- ***Grid connected***
- ***Low grade thermal output heats boiler make-up water***
- ***High grade thermal output to condensate return loop***
- ***Total estimated thermal utilization ~45%***

CERL Polymer Electrolyte Fuel Cell Fleet Experience

PEM Residential: 56 sites, 5 manufacturers

CERL Fuel Cell Fleet Performance	
523,378	Hours of Operation
1,293,133	Total kWh
23	Average Electrical Efficiency
32	Average Overall Efficiency
86%	Power Plant Fleet Availability

Plug Power
5 kW Output
Propane Fueled

http://dodfuelcell.cecer.army.mil/res/index.php4

Plug Power
5 kW Output
Natural Gas Fueled

ReliOn Fuel Cells
3 kW Total Output
Hydrogen Fueled

Primary and Back-up Electric Power

Four PureCell 200 power plants serving as primary and backup power

Net Electric Output (kW AC)	200
Net Electrical Efficiency* (%), LHV	40
Total Heat Output (Btu/hr)	870,000
Overall (Cogeneration) Efficiency** (%)	Up to 90
Fuel Cell Stack Life (yr)	5 (today) 10 (2008)
Noise (dBA at 30 ft)	60
Emissions	Meets CARB '07‡
Availability Average*** (%)	93

**Current Generation **Beginning of life value*

****Units serviced by UTC Power; includes service time*

‡California Air Resources Board 2007 emission standards

Courtesy Bob Tierney, UTC Power, July 2007

First National Bank of Omaha Data Center

PureCell™ System Model 200*

Part of a UPS system which prevents even a millisecond of downtime.

http://www.fuelcellmarkets.com/article_default_view.fcm?articleid=13728&subsite=420

Fuel Cells in Critical Applications

PureCell™ system installed at telecom facility

- Verizon switching facility
- Major hub of telecom traffic
- 7 fuel cells provide:
  - primary power (diesel gen-sets as back up, then grid)
  - 1/3 building cooling w/ absorption chillers
  - ½ building heating
- $500K annual savings for first 5 years
- 10-year payback
- 11.1 million lbs CO_2 avoided per year

Verizon, Garden City, New York; installed 2005

Courtesy Bob Tierney, UTC Power, July 2007

Fuel Cells in Critical Applications

PureCell™ system installed at hospitals

- **Six active fuel cells at hospitals**
  - **US: NYC, TX, CT**
  - **Int'l: Japan (2), Germany**
- **Excellent fit for fuel cells**
  - **24/7 operation**
  - **high thermal demand**
  - **high reliability needs**
- **St. Francis example**
  - **High heat for boiler feed water**
  - **Low heat for domestic water**
  - **Designed to operate in grid independent mode in case of outage**

St. Francis Hospital, Hartford, CT; installed 2003

Courtesy Bob Tierney, UTC Power, July 2007

Stationary Fuel Cell Power Systems

Fuel Cell Energy
2 MW MCFC

Plug Power 7kW Residential
PEFC

Siemens-Westinghouse 100kW SOFC

UTC Fuel Cells
200kW PAFC

Ballard 250kW PEFC

Plug Power 10 kW Residential unit

Courtesy of Breakthrough Technologies Institute: www.fuelcells.org

Specialty Vehicle Applications

Deka-Nuvera Alliance

Nuvera is global manufacturer of FC systems

1. *hydrogen power modules for industrial & vehicle and equipment*
2. *on-board gasoline fuel processors and fuel cell stacks for automotive applications*
3. *natural gas and hydrogen power systems for on-site power and cogeneration*

East Penn Manufacturing Co.

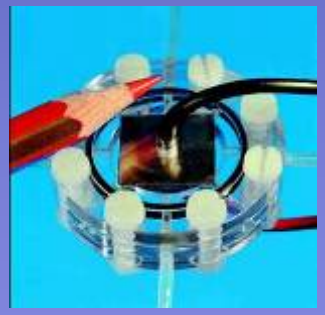
1. *world's biggest battery production plant for motive power solutions*
2. *hybrid fuel cell power pack solutions for class I and class II fork lift trucks*
3. *fuel cell forklift truck showcase started in early 2006*

Portable Fuel Cell Power Systems

MTI Micro Fuel Cells RFID scanner

Ballard FC powered laptop

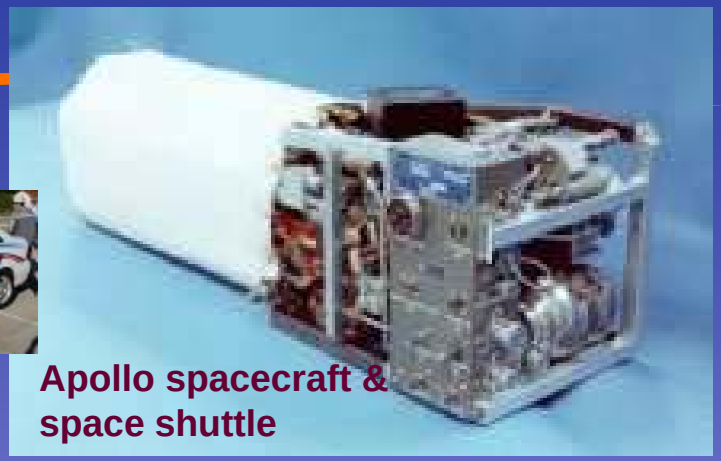
Plug Power FC powered video camera



Fraunhofer ISE Micro-Fuel Cell

Courtesy of Breakthrough Technologies Institute: www.fuelcells.org

Other Applications



Apollo spacecraft & space shuttle

auxiliary power unit (APU)

highway road sign (Plug Power)

forklift (Toyota)

Today's Commercial Products

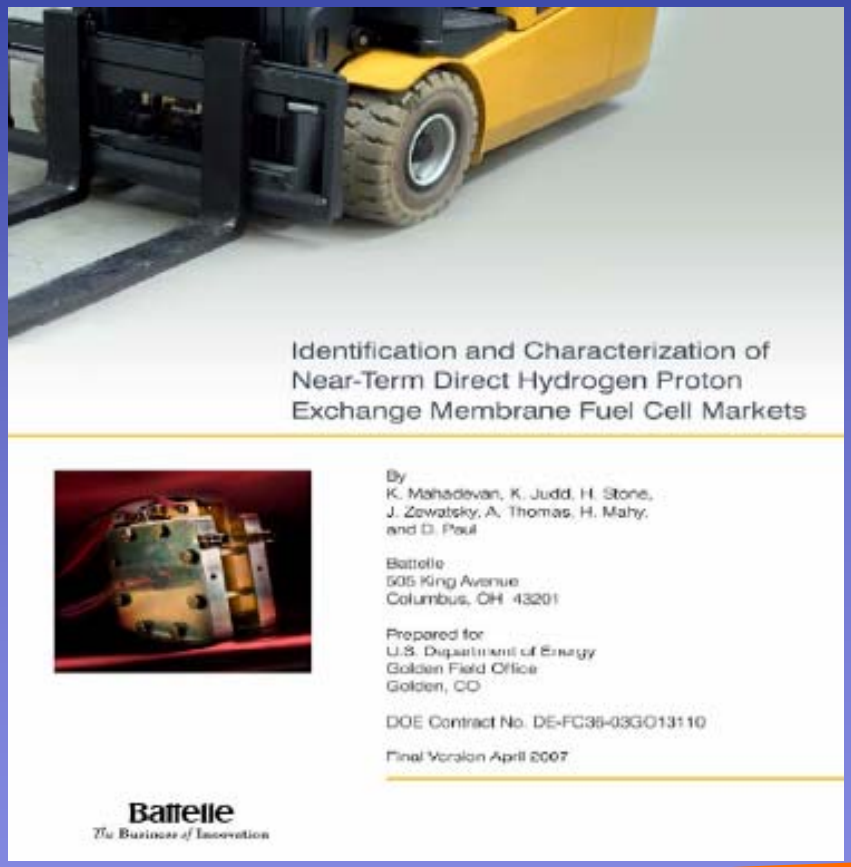
www.fuelcells.org/usfccproductlist.pdf

Product Name	Application	Output	Configuration	Warranty	Product Available
Mark 1030	Cogen.	1.3kW	PEM	Yes	Today
Mark 1020 ACS	Back-up power / Light Mobility	300W - 5000W	PEM	Yes	Today
DFC 300MA	Stationary	300 kW	MCFC	Yes	Today
HyPM HD Power Modules	Mobility	4-65 kW	PEM	Yes	Today
ElectraGen™ 5	Backup	5 kW	PEM	2 year	Today
Mobion 1M	Micro/ Portable	1w	DMFC	Yes	IQ 2007*
PowerFlow PFS-009	Portable, Stationary, Backup, APU	9 kWe	PEM	Yes	Today
GenCore® 5T	Backup	5kw (net)	PEM	2yrs	Today
T-2000	Backup	600w - 2kW	PEM	2 yr	Today
EFOY 1200	Mobile / Backup	1,200 Wh/day	DMFC	3 yrs	> 500 sales points and at 30 online stores
PureCellTM System Model 5	Backup	5 kW	PEM	Yes. Several options	Demonstrators; Commercial offering in 2007

sample/short list

Near-term Pre-automotive Markets for PEM

Battelle Study



Identification and Characterization of Near-Term Direct Hydrogen Proton Exchange Membrane Fuel Cell Markets

By
K. Mahadevan, K. Judd, H. Stone, J. Zewatsky, A. Thomas, H. Mahy, and D. Paul

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Prepared for
U.S. Department of Energy
Golden Field Office
Golden, CO

DOE Contract No. DE-FC36-03GO13110

Final Version April 2007

Battelle
The Business of Innovation

www.eere.energy.gov/hydrogenandfuelcells/pdfs/pemfc_econ_2006_report_final_0407.pdf

For More Information

www.hydrogen.energy.gov

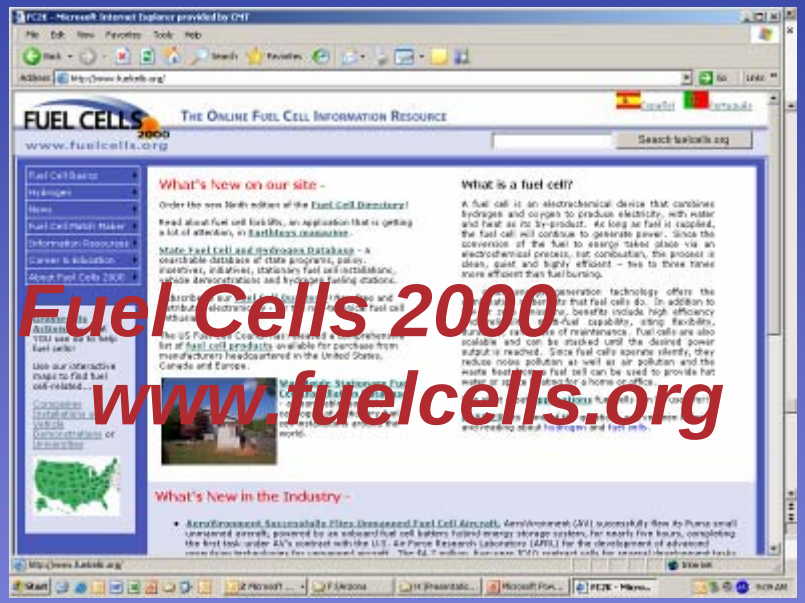
Follow the "H2IQ" link to information resources, including fact sheets on fuel cells and early markets

References to specific companies or products are for illustration purposes only. DOE does not endorse or recommend any of the companies or products listed herein.

Find....

- **The latest news, reports & announcements**
- **Status information about program solicitations**
- **Fuel cell and hydrogen "basics" information**

And More Information



Fuel Cells 2000
www.fuelcells.org

US Fuel Cell Council
www.usfcc.com

Matching Government Needs with Energy Efficient Fuel Cells Proceedings

http://www1.eere.energy.gov/hydrogenandfuelcells/meeting_govt_needs.html

Hydrogen and Fuel Cell Product Catalog

http://www.hydrogenassociation.org/general/productsSearch.asp

Thank You

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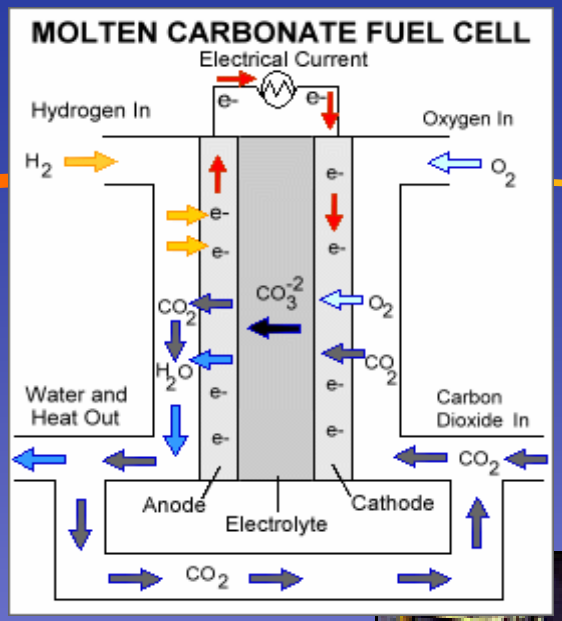
Back-Up Slides

Molten Carbonate Fuel Cells



Applications

- Distributed power plants
- Combined heat and power

Features

- Fuel flexibility (internal reforming)
- High efficiency
- High temperature good for cogeneration
- Base materials (nickel electrodes)
- Corrosive electrolyte

Status

- Early Commercial but expensive

Reactions: Cathode: $\frac{1}{2}O_2 + CO_2 + 2e^- \rightarrow CO_3^=$

Anode: $H_2 + CO_3^= \rightarrow 2H_2O + CO_2 + 2e^-$

Fuel Cell Energy MCFC stack

Solid Oxide Fuel Cells

Applications

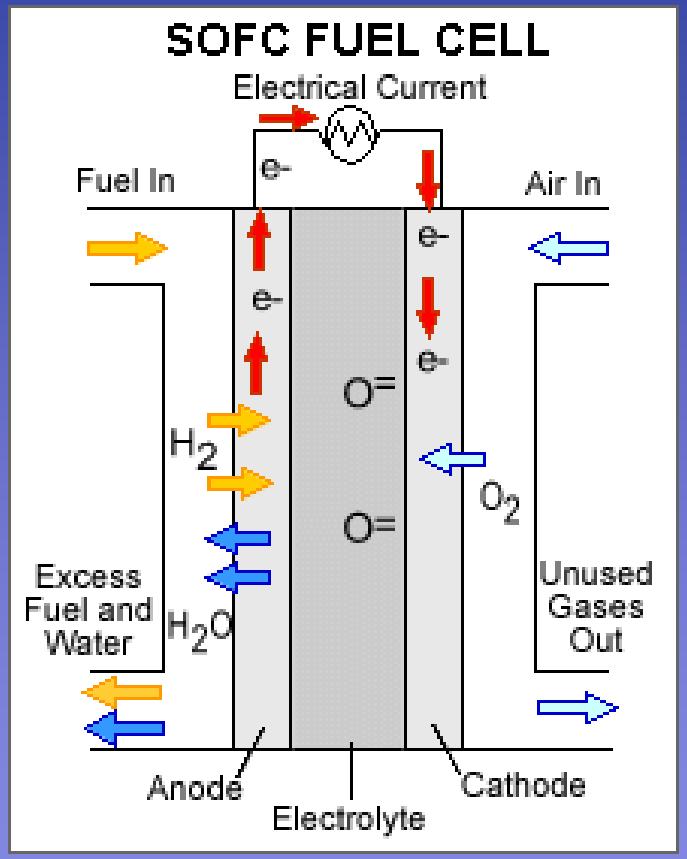
- Truck APUs
- Distributed power plants
- Combined heat and power

Features

- Slow start – subject to thermal shock
- High temperature
- High power density (watts/liter)
- Can use CO and light hydrocarbons directly
- "Cheap" components, solid electrolyte
- Low-yield manufacture

Status

- Vehicle APUs



Equations - Cathode: $O_2 + 2e^- \rightarrow 2O^=$

Anode: $H_2 + O^= \rightarrow H_2O + 2e^-$

Thank You, Again!

GovEnergy
www.govenergy.gov

New Orleans

August 5-8