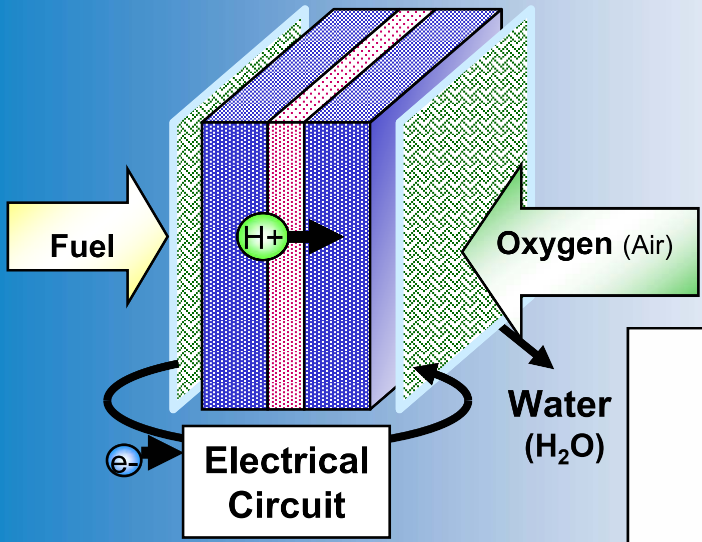
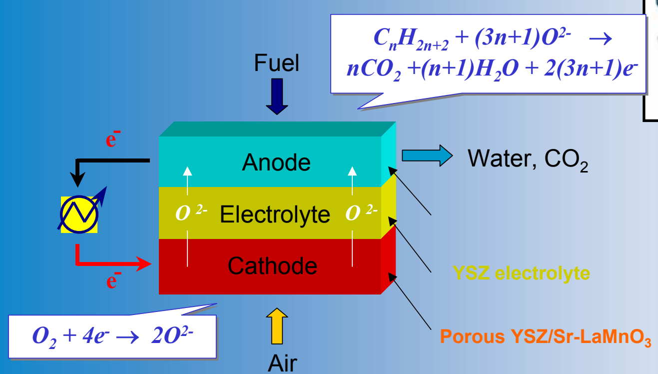
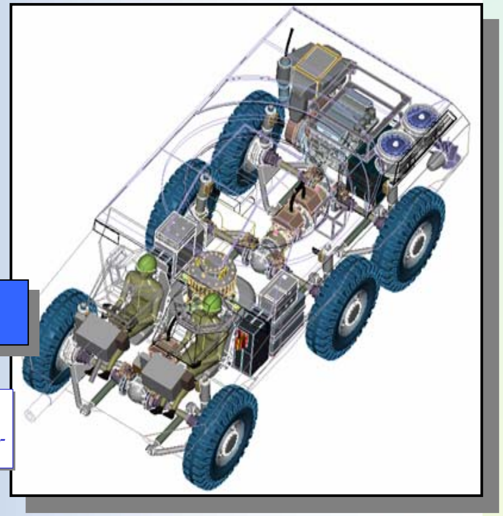
Power & Energy
Army Research Laboratory
Fuel Cell Programs



Diesel Fuel ⇒ Electricity



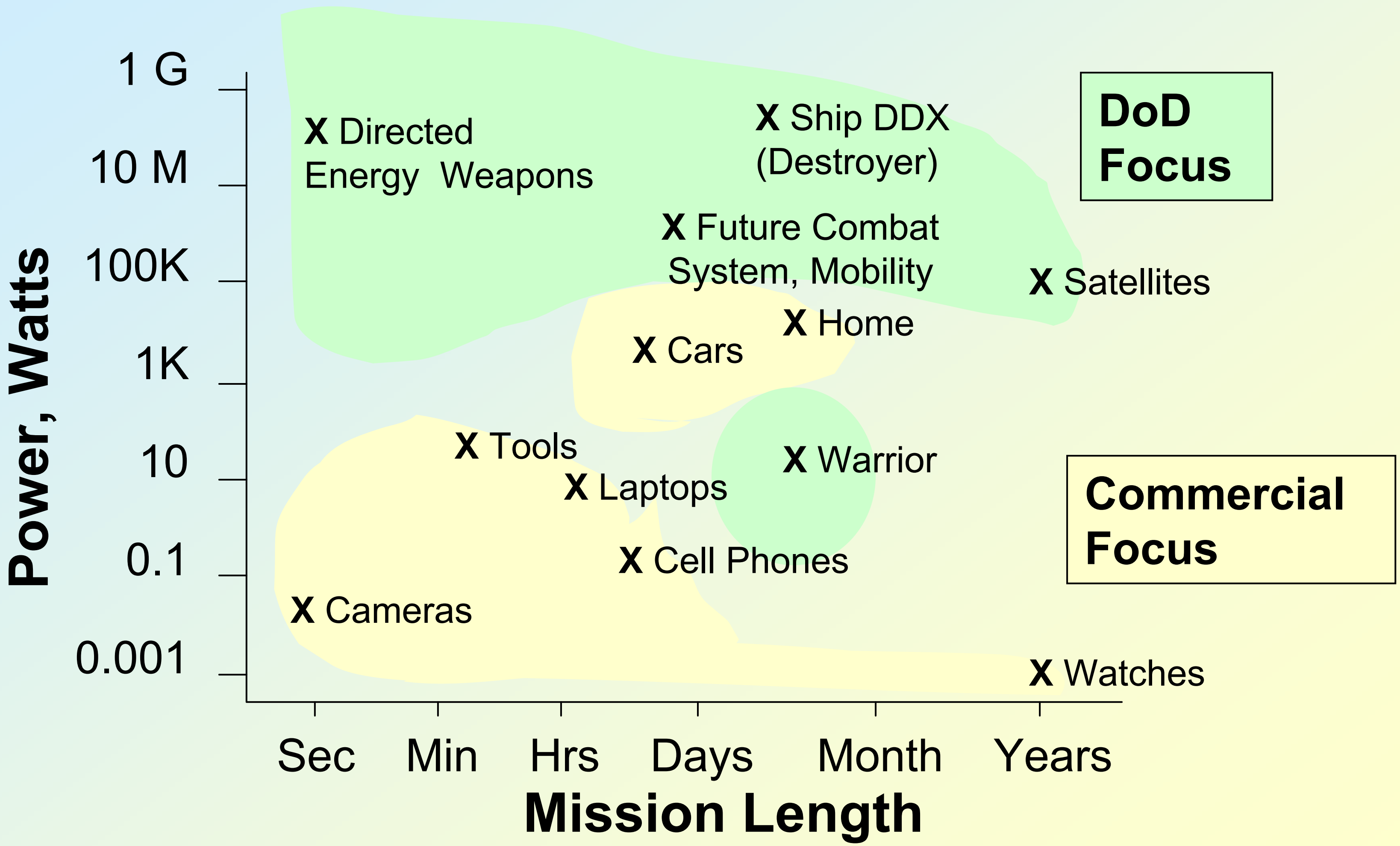


SOLID STATE ENERGY CONVERSION ALLIANCE MEETING

April 16 2003

Mr. John Hopkins

DoD and Commercial Industry Requirements



Power and Energy Taxonomy

Operational Regimes

Unit of Action

Responsive Deployable
Agile and Versatile
Lethal Survivable
Sustainable

System of Systems Platforms

- Ground
  Manned & Unmanned
  Mobile & Non-Mobile
- Air
  Manned & Unmanned
  Aircraft
- Soldier
  OFW, Land Warrior
- Unattended
  Ground
  Sensors &
  Munitions

Platform Applications

- Hybrid Electric/ Propulsion
- Environment Management
- Dynamic Armor
- EM, ETC, DE Weapons
- Active Protection
- C4 ISR
- Signature Management
- UGS, Munitions, Other

Technologies

Switches : Capacitors : Batteries : Power Converters : Fuel Cells : Fuel Reformation Thermal Management : Power Control: Power Generation

Warrior Power

Hybrid JP-8 fueled charger/rechargeable battery system capable of:

- eliminating non-rechargeable batteries
- weighing 1/3 less than non-rechargeables
- extending mission time per system up to 6X

Rechargeable batteries charged 2-3X faster

Power Management design tools reduce power consumption 2 to 5 times.

Required Technology:

- Energy Storage: Battery reactants with 6X increase in energy storage and 3X increase in power density
- Power Control: Efficient chargers for two hour charge time and techniques to reduce power consumption by 50% in Soldier Systems
- Power Generation: Logistic fuel reformation

Payoff in FY08
(1 Battalion, 96 Hour Mission):

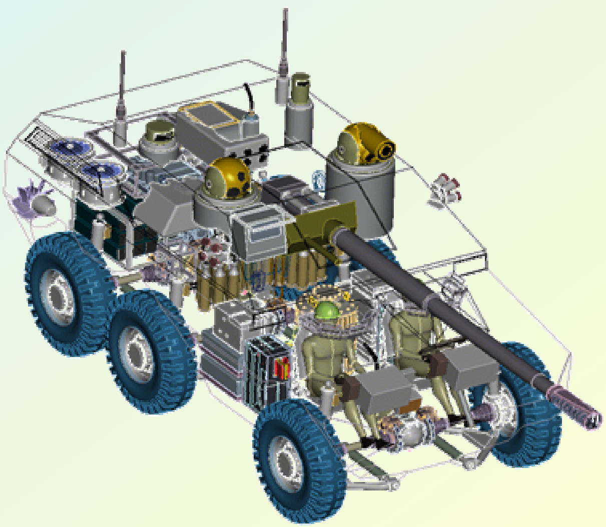
4400 Disposable Batteries, $500,000, 8800 pounds

VERSUS

200 Gallons JP-8, Rechargeable Batteries, $400, 1600 pounds for fuel

Hybrid-Electric Combat Vehicle

- Common power source for propulsion, EM/ETC gun, armor, and auxiliary - ability to shift power away from propulsion
- Enables improved stealth, near silent watch, and extended vehicle range
- > 50% increase in transient power at wheels- enhances mobility
- Increased flexibility of vehicle system integration yields up to 10% increase in useable internal volume



- Required Technology
  - Power Generation: 2X more efficient and 2X more power dense generation
  - Energy Storage: Energy storage at 50 kW-hr (10's MJ) and pulsed power capacitors up to 5 MW
  - Power Control and Distribution: High power switches, control and distribution

Payoff in FY2010:

- Fuel savings up to 50%
- Reduction in armor and ammunition weight hence transport costs
- New capability for EM/ETC gun and dynamic armor

Power and Energy
Collaborative Technology Alliance

Consortium Partners

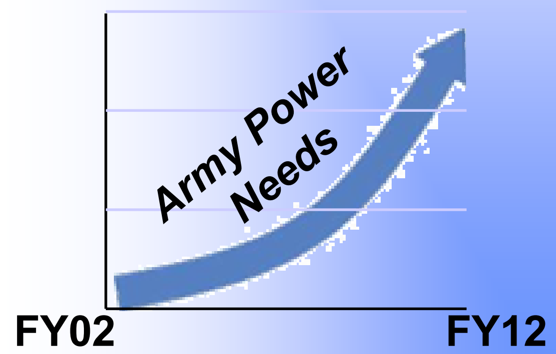
- Honeywell
- MIT
- Clark Atlanta
- Georgia Tech
- U of Maryland
- Motorola Labs
- NuVant Systems
- Case Western Res U
- Penn State Univ
- Tufts Univ
- U of Minnesota
- U of New Mexico
- U of Pennsylvania
- U of Puerto Rico
- U of Texas – Austin
- SAIC
- Rockwell Scientific
- United Defense LP
- Prairie View A&M
- Rensselear Polytechnic
- Texas A&M

Objectives

Research and develop technologies that enable lightweight, compact power sources and highly power dense components that will significantly reduce the logistics burden, while increasing the survivability and lethality of the soldiers and systems of the highly mobile mounted and dismounted forces of the Army's Objective Force.

Technical Areas

- Portable, Compact Power Sources (Non-electrochemical)
- Fuel Cells and Fuel Reformation
- Hybrid Electric Propulsion and Power



Power and Energy Collaborative Technology Alliance Program Overview

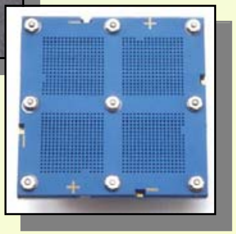
- Competitively awarded Cooperative Agreement for basic research signed May 31, 2001 by Army Research Laboratory with a 22-member Industry/Academia Consortium (now 21 members) led by Honeywell Engines, Systems & Services, Phoenix AZ
- 5-year Research Program with 3-year option, funded at approximately $6M per year with 6.1 dollars
- Companion Technology Transition task-order contract, also awarded to Honeywell, may use funding from various sources; currently has a ceiling of $60M over the eight-year period

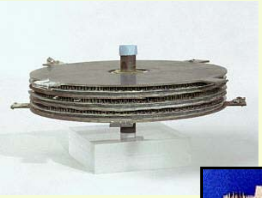
P&E TA 2: Fuel Cells and Fuel Reformation

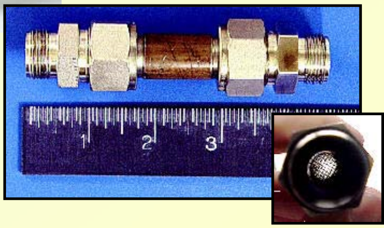
Objective: Provide enabling technologies for soldier portable fuel cell systems, including fuel processing for hydrogen generation and storage. Provide enabling technologies for logistics fuel reformation and fuel cells for vehicle propulsion.

Challenges:

- Battlefield robustness, including load following and temperature extremes
- Rate controlling catalytic chemical processes
- H_2 storage and/or microreforming of fuel
- Improved electrocatalysts, electrolytes for DMFC
- Range and variation in logistics fuel constituents: high sulfur content, etc.



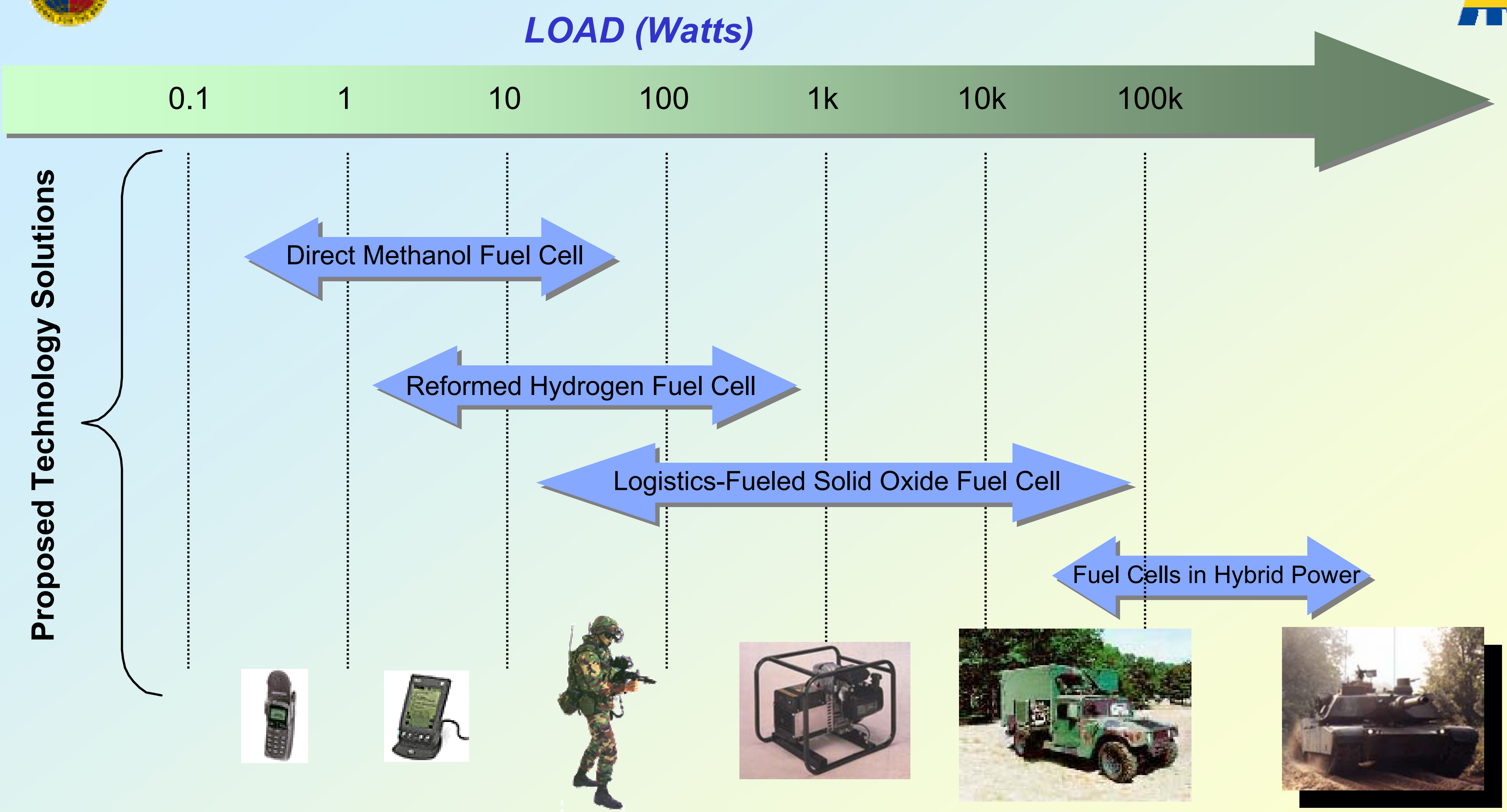




Research Tasks:

- DMFC Catalysts
- Polymeric Membranes
- DMFC design, model, prototype
- RHFC Catalyst and Support
- High-Temp MEA
- RHFC System
- Low-temp SOFC Materials
- Direct Hydrocarbon Reforming Anode
- SOFC Cell Fab, Evaluation, Testing
- Logistics Fuel Reformation Catalysts
- High-temp Fuel Desulfurization
- Logistics Fuel Reformation: CPOX and Desulfurization

Power Solutions with Fuel Cells



Fuel Cells and Fuel Reformation
PEM Fuel Cells
–Research Team –

Motorola Labs	→	DMFC Membranes DMFC/RHFC systems, peripherals, integration
DMFC Catalysts	←	Penn State, U. Puerto Rico NuVant Systems
U. of New Mexico	→	Methanol Reforming Catalysts
High Temperature (180C) Membrane Electrode Assembly	←	Case Western Reserve U.
Army Research Laboratory	→	DMFC Catalysts, Low Methanol Crossover Membranes (80C), High Temperature Membranes (180C)

Fuel Cells and Fuel Reformation
PEMFCs – DMFC & RHFC
Accomplishments for FY 02

DMFC Catalysts

- Catalyst screening methodology and system in place
- Computational study for transition state for reactions on catalyst surface

DMFC System (Motorola)

- Initial system design and modeling of 1W planar DMFC system
- Fabrication of 1W CMEMS DMFC substrate

MSR Catalyst Support (UNM)

- Successfully wall coated quartz tubes of 3mm ID and shown that the reactivity of this catalyst is better than the packed bed catalyst

HT PBI MEA (CWRU)

- Microband apparatus designed, built, tested for O_2 reduction.

RHFC System (Motorola)

- Initial Design and characterization of 2.5W fuel processor.

Fuel Cells and Fuel Reformation

PEMFCs – DMFC & RHFC

Goals for FY 03

DMFC Catalysts

- Prepare and characterize Pt-Ru-Ir ternary compositions by Reetz method & investigate stronger reducing agents for extending Reetz methods to Os and Mo (PSU)
- Identify transition states for water dissociation, CO(ads) and OH(ads) on Pt/Ru using quantum mechanical methods (UPR)

DMFC System (Motorola)

- Prepare morphological family of block copolymers targeting good film properties & evaluate potential of this family in DMFC applications.
- Fabricate 1-2W Prototype Operating 1 week at > 200Wh/L

MSR Catalyst Support (UNM)

- Reactivity tests on wall coated catalyst formulations

HT PBI MEA (CWRU)

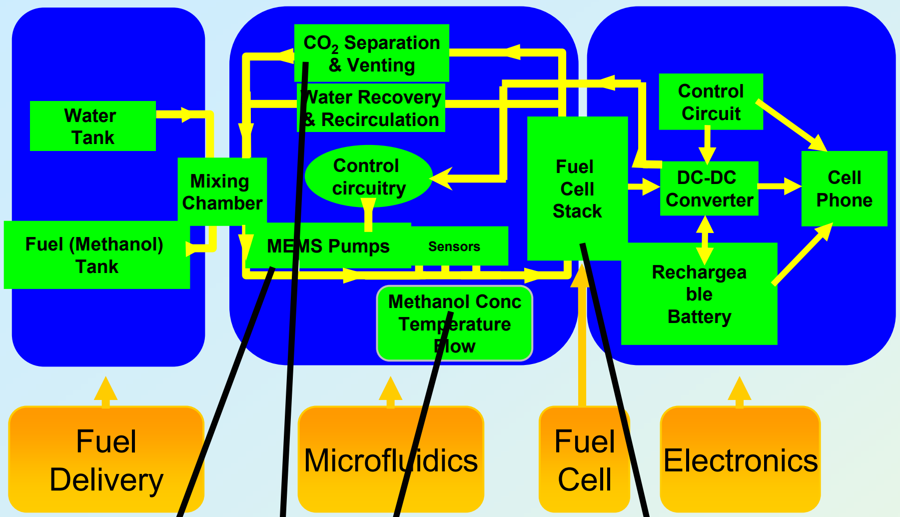
- Complete characterization of O2 kinetics on Pt alloy catalysts using microband cell

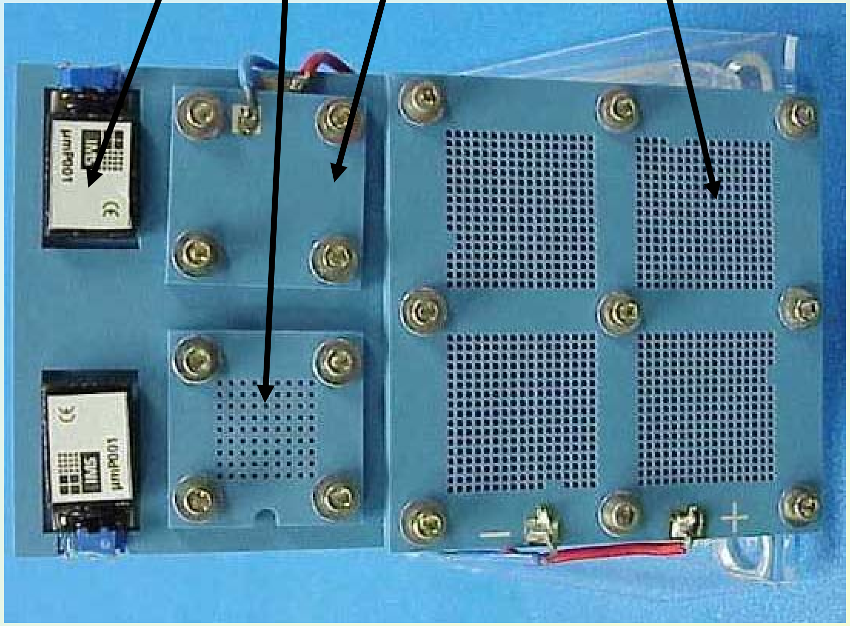
RHFC System (Motorola)

- Demonstrate 2-5W RHFC system
- Incorporate new materials generated from CTA work

PEM Fuel Cells

DMFC System: Motorola





1W DMFC Prototype

Fuel Cells and Fuel Reformation
SOFC and Logistics Fuel Reformation
– Research Team –

U. Texas at Austin → Low-Temperature SOFC Materials: Cathode and Electrolyte

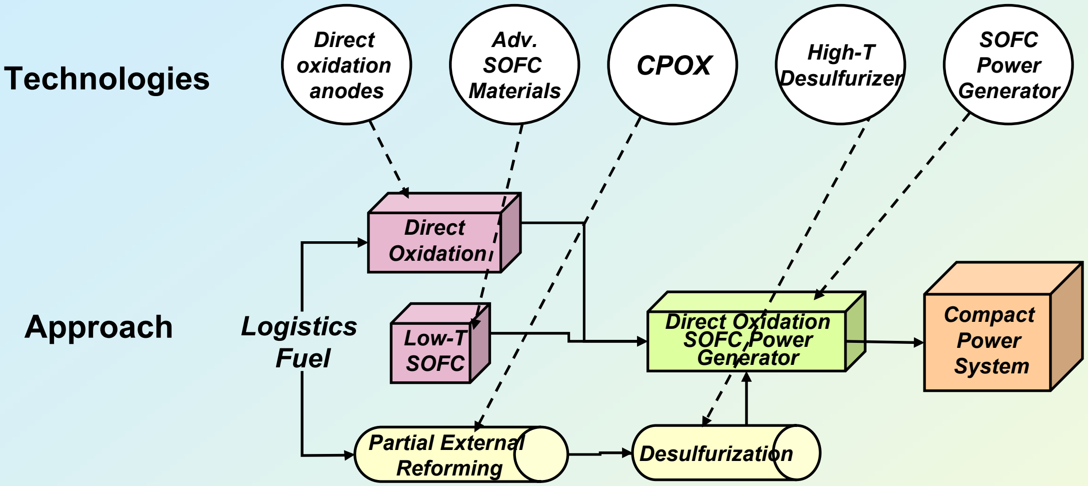
Direct Oxidation Anodes ← U. Pennsylvania

Tufts University → High-Temperature Fuel Desulfurization

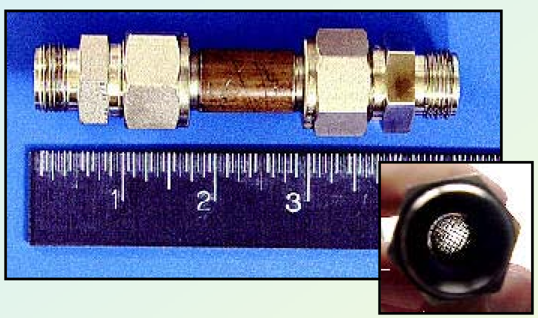
Catalytic Partial Oxidation for Logistics Fuel Reformation ← U. Minnesota

Army Research Laboratory → Water Gas Shift Catalysts for CO Cleanup

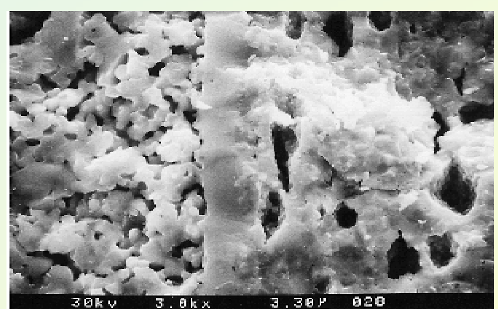
Fuel Cells and Fuel Reformation
SOFC and Logistics Fuel Reformation



The solid oxide fuel cell (SOFC) runs directly on hydrocarbons or logistics fuel or on hydrogen and CO generated from a fuel reformer, such as a catalytic partial oxidation reactor (CPOX)

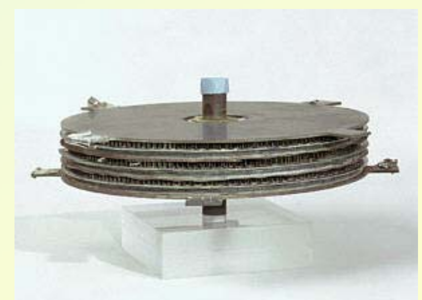


Catalytic Partial Oxidation Reactor (CPOX) for 1 kW SOFC stack



$LaMnO_3$ Cathode | ZrO_2 Electrolyte | NiO/ZrO_2 Anode

Cross section of SOFC cell



SOFC stack

SOFC Logistics Fuel Reformation & Direct Oxidation
Accomplishments for FY '02

- $LaGaO3$-based electrolytes shown to be stable against logistic fuels
- Developed Cu-CeO_2-SDC direct oxidation anodes for cells with SDC electrolyte.
- Developed Cu-CeO_2-Sc-doped zirconia (SDZ) direct oxidation anodes for cells with SDC electrolyte.
- Demonstrated stable performance while operating directly with butane fuel for both SDC and SDZ cells
- JP-8 and Diesel successfully reformed
- Evaluated different sorbent compositions at various operating conditions
- Showed that La_2O_3 is the preferred dopant in Cu-CeO_2, while ZrO_2 has a negligible effect on its sulfur capacity.

SOFC Logistics Fuel Reformation & Direct Oxidation
-Goals for FY '03-

- Continue development of low-temperature cathodes and direct oxidation anodes
  - Complete characterization of catalytic properties of anodes and cathodes
  - Test anode performance with higher hydrocarbon fuels (e.g. decane and toluene) that simulate the properties of JP-8
- Begin integrating cathode and anode improvements into a single fuel cell design
  - Construct and test cells that use Cu/ceria direct oxidation anodes developed at U. Penn with high performance, $SrCo_{0.8}Fe_{0.2}O_{3-\delta}$ cathodes developed at U. Texas
- Desulfurization of high-temperature reformate gas
  - Complete characterization of Cu-ceria-based sorbents
  - Begin integration of CPOX and desulfurization systems
- Begin integrating CPOX and SOFC systems
  - Test SOFC performance while running on partially reformed fuel produced by a CPOX reactor
  - Determine to what degree heavy hydrocarbon fuels will need to be reformed in order to avoid tar formation

Internal Fuel Cells Efforts

Areas of Focus

•Optimization of operating conditions and energy conversion for DMFC systems

•Synthesis and development of composite polymer membrane electrolytes with low permeability to methanol for DMFC applications.

•Improved performance of MEAs at ~ 200 °C, based on a organic/inorganic hybrid membrane

•Advanced materials and processes for logistic fuel processing, leading to high-performance, lightweight, compact power sources for Army applications

•Desulfurization of Logistics Fuel (JP-8, Diesel, etc.)

Key Accomplishments – FY02/03

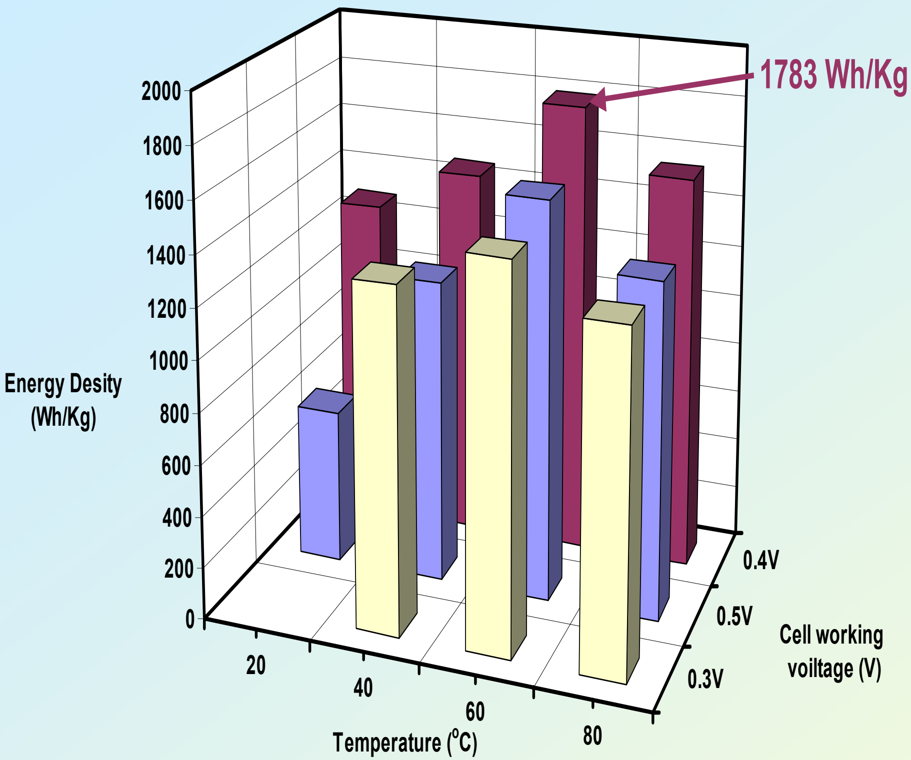
•Documented the best performance of DMFC operating conditions considering methanol crossover

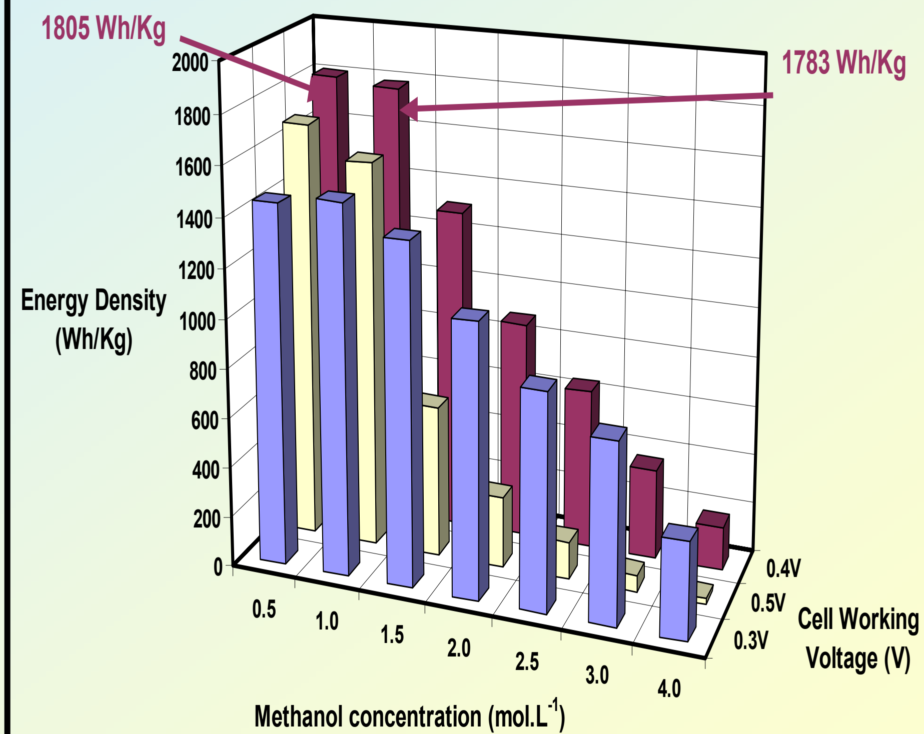
•Optimal DMFC energy density achieved at 60 °C, with 1M methanol and cell voltage at 0.4 V ~ 1800 Wh/Kg at 0.4V

•Devised and synthesized an inexpensive interpenetrating polymer network (IPN) that is conductive and up to 15 times more selective for water than methanol compared with Nafion

•Demonstrated a thermally stable nano-scale water-gas shift reaction catalyst

Operating Conditions for DMFC Fuel Cell

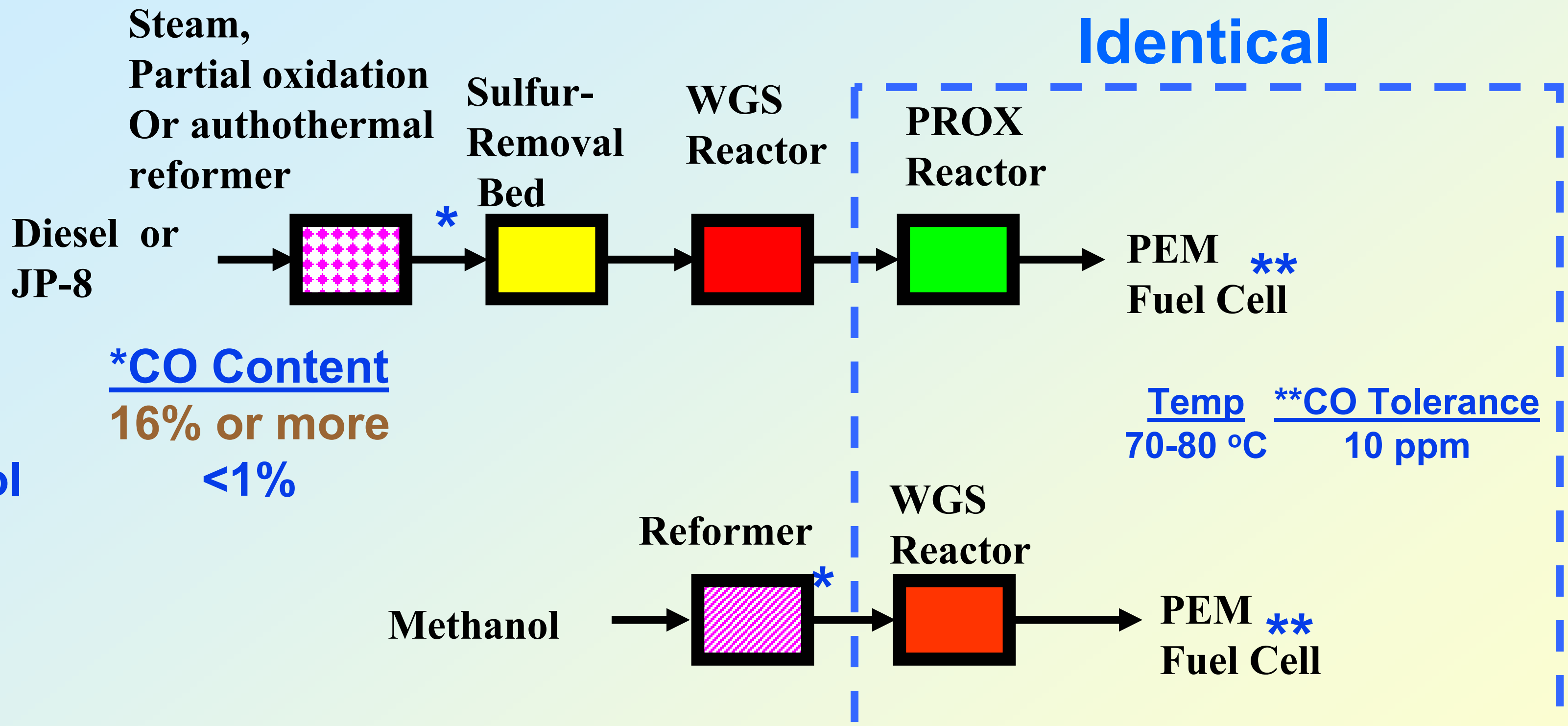




Effect of Cell Temperature on Energy Density for a DMFC with 1M Methanol Operation

Effect of Methanol Concentration on Energy Density for a DMFC at 60°C operation

Research on Fuel Reformation



Fuel	*CO Content
Diesel	16% or more
Methanol	<1%

Water-Gas Shift (WGS) Reaction

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad \Delta H^o = -41.2 kJ/mol$$

WGS is needed to reduce CO levels

Summary

- *Army must focus fuel cell investment on service challenges and problems*

- *Fuel Cells on Soldiers and Vehicles will Enable dramatic capability and operational improvements*

- *Increased Army investment (FY04-09) will aid development of key power and energy technologies*

- *Assistance/ leveraging from other services, national labs, industry: high impact for transformed force*

Key Investment Areas:

Soldier Power

Logistics fuel reforming