
Presentation for the 2007 Fuel Cell Seminar
15-19 October 2007, San Antonio, TX

JJ Kowal

UNCLASSIFIED UNLIMITED DISTRIBUTION
Approved for public release; distribution is unlimited.
The Army's Communications and Electronics Research, Development and Engineering Center (CERDEC) Fuel Cell Team, located at Fort Belvoir, VA, is actively investigating fuel cell power sources from milliwatt to kilowatt levels to fit the Army's power needs. Currently, many smaller fuel cell programs in progress at CERDEC use a packaged non-logistic fuel. Soldier and Man portable fuel cells combine the portability of batteries with the use of an external energy-dense fuel to fill the gap in power between batteries and generators. For this reason, CERDEC is actively working to assess the state of technology and attempt to field fuel cell power systems with several programs showing promise in providing reliable, small, and lightweight Soldier power solutions. This presentation will focus specifically on the development updates in the Soldier and Man portable power program areas. Over the past year several fuel cell power systems have been tested in CERDEC facilities.
2007 Fuel Cell Seminar
15-19 October 2007, San Antonio, TX

JJ Kowal, Elizabeth Ferry, Jon Cristiani, Terry Dubois, Scott Coombe, Chris Bolton
• Army & CERDEC Fuel Cell Background
  – Current and Future Goals
  – Customers, Partners, Contractors
• CERDEC Fuel Cell Testing
  – Logistic Fuel Processing
  – Soldier Power Systems
  – Solid Oxide Fuel Cells
Mission: Rapidly develop and transition suitable fuel cell technologies to applications where they are most needed.

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
FY04 – FY08
Focus Area Target Metrics

Soldier & Sensor Power (1W-100W)
- GOALS:
  - 20W, package fuel
  - 700 Wh/kg (72hr)
  - 0.7 kg (dry)
  - TRL 6

Man-Portable Power (100W-500W)
- GOALS:
  - 250W, JP-8
  - < 10 kg (dry)
  - TRL 5

Auxiliary Power Units (500W-10kW)
- GOALS:
  - 2 kW, JP-8
  - < 150 kg (dry)
  - Noise < 69 dBA
  - TRL 5
Army Power Division
Mission and Products

Army Power Division Mission: Conduct research, development and system engineering leading to the most cost-effective power, energy, and environmental technologies to support Army’s soldier, portable, and mobile applications.

**Technical Objectives**

**Power for Dismounted Soldier**
- 1.1lbs 400Whr/kg TRL 4/6
- 1.1lbs 600Whr/kg TRL 3/5
- 3lbs, flat 140Whr/kg TRL 4/6
- 25W 1.5lbs TRL 4/6
- 50-100W 3.5lbs TRL 4/5
- 150-250W 25lbs TRL 4/6

**Mobile Power**
- 250W-2kW 50W/kg TRL 3/5
- 3-5kW 90W/kg TRL 3/6
- 3kW/18BTUh 205kg TRL 3/5

**ATO D.CER.2008.08**
- Half-Sized BA5590 Li/CFx Battery
- Half-Sized BA5590 Li-Air Battery
- Soldier Conformal Rechargeable Battery
- Soldier Hybrid Direct Methanol Fuel Cell Power Source
- Soldier Hybrid Fuel Cell Power Source
- Portable Hybrid Power Sources & Chargers, JP-8 fueled

**ATO R.LG.2009.01**
- Transitional Hybrid Power Source, Log-fueled
- Universal Tactical Auxiliary Power Unit
- Co-generation and Tri-generation System

**Tactical Power-Logistics Fuel**

- Stirling Engines
- Logistical Fuel Processing
- Tri-generation
Logistical Fuel Processing Research and Development

Technical Challenges with Logistics Fuel Processing

- Catalyst Evaluation
- Reformate Composition Analysis
- Liquid Fuel Analysis

Systems Analysis:
- Process Modeling
- Computational Fluid Dynamics

Fuel Cell Auxiliary Power Unit Development

- Testing & Evaluation:
  - Prototyping
  - First Article T&E
  - Independent Evaluation

- Product Development:
  - Production Engineering
  - Specification Development
  - Life Cycle Cost Analysis

<table>
<thead>
<tr>
<th>FY08 Reformation Goals</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Rated Power (kWe)</td>
<td>0.5 - 5</td>
</tr>
<tr>
<td>Fuel (Diesel/JP-8)</td>
<td></td>
</tr>
<tr>
<td>Sulfur content (ppm wt%)</td>
<td>&gt; 1500</td>
</tr>
<tr>
<td>Aromatics (vol %)</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>70%</td>
</tr>
<tr>
<td>Power Density (W/L)</td>
<td>150</td>
</tr>
<tr>
<td>Specific Power (W/kg)</td>
<td>170</td>
</tr>
<tr>
<td>Start-up Cold start (-25degC)</td>
<td>&lt; 30 min.</td>
</tr>
<tr>
<td>Lab demo (21degC)</td>
<td></td>
</tr>
<tr>
<td>Lifetime (w/o replacement)</td>
<td>2000 hrs</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>-40 - 52 deg C</td>
</tr>
<tr>
<td>Maximum H₂S in Product Stream</td>
<td></td>
</tr>
<tr>
<td>SOFC (mol%)</td>
<td>5 ppm</td>
</tr>
<tr>
<td>PEM (mol%)</td>
<td>50 ppm</td>
</tr>
<tr>
<td>Turn Down Ratio</td>
<td>&gt; 5 : 1</td>
</tr>
<tr>
<td>Acoustic Signature (dBA @ 1m)</td>
<td>50</td>
</tr>
<tr>
<td>Cost</td>
<td>$800 / kWe</td>
</tr>
</tbody>
</table>
Developed Jointly with CERDEC and DARPA
Rated 20W continuous
Reformed Methanol Fuel Cell (RMFC)
Fuel: 67% Methanol / 33% Water

Dimensions: 9.30” X 5.38” X 1.80”
Start Up Time: 23 min. AVG

System Dry Weight: 1.2 kg
Fuel Cartridge Weight: 0.35 kg (250 mL)

20W Mission Energy Density:
24 hr 210 W-hours/kg
72-hr 360 W-hours/kg

Orientation independent except upside down

Started and operated continuous from -5 °C to 45°C
In Development with CERDEC and DARPA
Rated 25W continuous
Reformed Methanol Fuel Cell (RMFC)
Fuel: 67% Methanol / 33% Water

Dimensions: 9.30” X 5.38” X 1.80”
Start Up Time: 20 min.

System Dry Weight: 1.2 kg
Fuel Cartridge Weight: 0.35 kg (250 mL)

25W Mission Energy Density:
24 hr 270 W-hours/kg
72-hr 410 W-hours/kg

Orientation independent except upside down
• 10 Rev. A units were taken to the Joint Readiness Training Center in Ft. Polk, LA and soldiers were trained on the use of the fuel cell power system

• The JRTC Science and Technology team keeps soldiers who will soon be deployed informed on new technologies that will be fielded in the near future
• Soldiers were very pleased with the lighter weight compared to batteries and showed acceptance of the system for certain missions (OP).

• Major issues expressed by soldiers were:
  – Safety
  – High Temp. Operation
  – Integration with Applications
Smart Fuel Cell FCPS

In Development with PM Soldier Warrior and CERDEC
Rated 20W continuous
Direct Methanol Fuel Cell
Fuel: 100% Methanol

Dimensions: 2.31” X 3.06” X 9.75”
Start Up Time: Instant

System Weight: 1.18kg
Fuel Cartridge Weight: 0.47 kg (500 mL)

20W Mission Energy Density:
24 hr 291 W-hours/kg
72-hr 556 W-hours/kg

Orientation dependent
Protonex P2

In Development with CERDEC and AFRL
Rated 30W continuous
PEM Fuel Cell
Fuel: Sodium Borohydride (NaBH₄)

Dimensions: 7.2” X 7.2” X 3.6”
Start Up Time: <1 min.

System Dry Weight: 0.96 kg
Fuel Cartridge Weight: 1.32 kg (hydrated)

20W Mission Energy Density:
24 hr 200 W-hours/kg
72-hr 350 W-hours/kg

Orientation independent

Operated continuous from -5 °C to 45 °C
Jadoo IFS24

In Development with CERDEC and SOCOM
Rated 45-55W continuous (user selectable 24/12 VDC)
PEM Fuel Cell
Fuel: Metal Hydride

Dimensions: 11” X 6.4” X 3.5”
Start Up Time: immediate

System Dry Weight: 2.86 kg
Fuel Cartridge Weight: 2.30 kg
System + Fuel Weight: 5.16 kg

Metal hydride is used to fuel this technology demonstrator and is not the final fueling solution

Started and operated from 0 °C to 40 °C
INI Power Soldier Portable Power System

 Tested at CERDEC Labs
 Rated 15W continuous
 Direct Methanol Laminar Flow Fuel Cell
 Fuel: 100% Methanol

 Start Up Time: instant
 System Dry Weight: 1.8 kg

 15W Mission Energy Density:
 24 hr  160 W-hours/kg
 72-hr  350 W-hours/kg
 (cartridge weight not included)
Fuel Cell Comparisons

System Efficiency vs Load

Efficiency based on Fuel (LHV for liquids)

Percent of Full Rated Load

Efficiency is not the whole story…
Fuel Cell Comparisons

Mission Length vs. Mission Weight, 20W Continuous

- SFC - FCPS (500 ml cartridges)
- UltraCell EVT (250 ml cartridges)
- FY08 CERDEC Hybrid Goal
- Protonex P2 23W (400 g SBH)
- Protonex P2 15W (400g SBH)
- BA - 5590

FY08 CERDEC Goal: 700Whr/kg
72-hour (3-day) mission
# Fuel Cell Issues

<table>
<thead>
<tr>
<th>Unit</th>
<th>Pros</th>
<th>Cons / Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>INI Power</td>
<td>Potentially lighter weight</td>
<td>Orientation, Shock/vibration, Technical Maturity</td>
</tr>
<tr>
<td>Jadoo</td>
<td>Reliability, Durability, Orientation</td>
<td>Currently heavy, Supportability</td>
</tr>
<tr>
<td>Protonex</td>
<td>Durability, Orientation</td>
<td>Supportability, Reliability</td>
</tr>
<tr>
<td>Smart Fuel Cell</td>
<td>Size, Weight</td>
<td>Orientation, Supportability, Reliability</td>
</tr>
<tr>
<td>Ultracell</td>
<td>Supportability, Durability</td>
<td>Orientation, Emissions, Reliability</td>
</tr>
</tbody>
</table>

Issues for all: Safety (disruptive technology), High Temp Operation
Both currently undergoing test plan at CERDEC

Adaptive Materials Inc. (AMI)
• 50 Watts
• System Weight: 2.3 kg
• Cartridge Weight: 0.4-0.9 kg

Nanodynamics
• 50 Watts
• System Weight: 4.5 kg
• Cartridge Weight: 0.8 kg

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
Fuel Cells vs. Batteries

**Advantages**
- Higher efficiency
- Potential cost benefits
- Long, continuous run times
- Lighter weight for longer missions (especially over 72 hours)

**Drawbacks**
- Air-breathing
- More complex
- Cost
- Reliability
- Robustness

* High potential for improvement
Conclusions

• The development of fuel cells is promising but there are still technical challenges to solve to transition from the lab to the battlefield

• Presently, packaged fuel is acceptable for units under 500W

• There is not yet a clear technology, fuel strategy, or power level that is most suitable for soldier power applications

• Fuel cells will only be used where appropriate when the technologies are sufficiently developed and commercially viable