BACKUP/PEAK-SHAVING FUEL CELLS

Daniel Rodriguez
Plug Power
May, 18th, 2006
Project ID # GO13097

Clean, Reliable On-site Energy

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# Overview

## Timeline
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Project Start Date:</td>
<td>August 2003</td>
</tr>
<tr>
<td>Project End Date:</td>
<td>April 2007</td>
</tr>
<tr>
<td>Percent Complete:</td>
<td>95%</td>
</tr>
</tbody>
</table>

## Barriers

### Barriers Addressed:
- **DOE Technical Barriers for Distributed Generation Systems**
  - E. Durability
  - G. Power Electronics
  - H. Startup Time
- **DOE Technical Barriers for Fuel Cell Components**
  - O. Stack Material and Manufacturing Cost
  - P. Durability
  - R. Thermal and Water Management

## Budget

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Project Funding</td>
<td>$ 7,201,881</td>
</tr>
<tr>
<td>DOE Share</td>
<td>$ 3,600,940</td>
</tr>
<tr>
<td>Plug Power Share</td>
<td>$ 3,600,941</td>
</tr>
<tr>
<td>Funding Received in FY05</td>
<td>$ 2,762,242</td>
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<tr>
<td>Funding for FY06</td>
<td>$ 149,251</td>
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</table>

## Partners

<table>
<thead>
<tr>
<th>Bell South</th>
<th>Telcordia Labs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airgas</td>
<td>Argonne National Labs (Test Site)</td>
</tr>
<tr>
<td></td>
<td>FAA (Test Site)</td>
</tr>
</tbody>
</table>
High Level Objective

Develop new generation of commercially viable, stationary, backup/peak-shaving fuel cell systems.

- Develop, build and test three fuel cell backup systems and field test at three sites including an industry host (BellSouth)
- Identify technical barriers and objectives
- Develop a cost-reduced, proton electrolyte membrane (PEM) fuel cell stack tailored to hydrogen fuel use in back-up applications
- Develop a modular, scalable power conditioning system tailored to market requirements
- Design a scaled-down, cost-reduced balance of plant (BOP)
- Certify the design to Network Equipment Building Standards (NEBS) and Underwriters Laboratories (UL)
<table>
<thead>
<tr>
<th>Objective</th>
<th>PHASE I</th>
<th>PHASE II</th>
<th>PHASE III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Assessment</td>
<td>Technology Assessment</td>
<td>Product Design and Validation</td>
<td>Field Demonstration</td>
</tr>
<tr>
<td>Status</td>
<td>Complete</td>
<td>Complete</td>
<td>In-Process</td>
</tr>
<tr>
<td>Key Activities</td>
<td>❖ Develop system requirements with Bell South ❖ Technologies Assessed ❖ Develop Design ❖ Test one system at Bell South to validate customer requirements</td>
<td>❖ Validate Design ❖ Validate Design ❖ Test one unit at ANL to baseline system performance</td>
<td>❖ UL certification of system to FC-1 ❖ Certify system to NEBS ❖ Field trial on unit at FAA (Tentative)</td>
</tr>
<tr>
<td></td>
<td>❖ Dry Cathode Operation ❖ GenSys Stack Integration ❖ H2 Regeneration Options ❖ Power Conditioning Platform ❖ Advanced Electrical Energy Storage ❖ System Water Balance ❖ Advanced H2 Storage ❖ Scale System ❖ GenSys Stack</td>
<td>❖ UL certification of system to FC-1 ❖ Certify system to NEBS ❖ Field trial on unit at FAA (Tentative)</td>
<td></td>
</tr>
</tbody>
</table>
2003/2004 Recap

- In 2003 and 2004, the Program executed a broad-based initiative to determine requirements for the platform’s commercial design, collecting data by:
  - Extensive laboratory testing at Plug Power
  - Field testing of the GenCore\textsuperscript{®} prototype system (13 systems)
  - Certifying the prototype to UL and NEBS requirements
  - Developing a Backup Power Fuel Cell System Requirements Document (SRD) with BellSouth

- Additionally, the Program evaluated ten enabling technologies and selected six for inclusion in the commercial design

- Finally, the Program began the new product development of the commercial product design, combining the technical, certification and customer requirements with the feasible technology initiatives in the design of the next-generation platform
## Technology Go/No Go Results Summary

<table>
<thead>
<tr>
<th>Enabling Technology</th>
<th>Go/No Go</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Dry Cathode Operation</td>
<td>No Go</td>
<td>Will not yield in program timeframe</td>
</tr>
<tr>
<td>2.2 GenSys® Stack Integration</td>
<td>No Go</td>
<td>Will not yield in program timeframe</td>
</tr>
<tr>
<td>2.3 Power Scalable Stack</td>
<td>Go</td>
<td>In final design</td>
</tr>
<tr>
<td>2.4 H2 Regeneration Options</td>
<td>Go</td>
<td>In final design - Advanced Exhaust Gas Recirculation (EGR) Option. No electrolyzer.</td>
</tr>
<tr>
<td>2.5 Power Conditioning Platform</td>
<td>Go</td>
<td>In final design</td>
</tr>
<tr>
<td>2.6 Advanced Electrical Energy Storage</td>
<td>Go</td>
<td>In final design - Non-lead acid solution in place</td>
</tr>
<tr>
<td>2.7 System Water Balance</td>
<td>No Go</td>
<td>Will not yield in program timeframe</td>
</tr>
<tr>
<td>2.8 Advanced H2 Storage</td>
<td>No Go</td>
<td>Will not yield in program timeframe</td>
</tr>
<tr>
<td>2.9 Scale System</td>
<td>Go</td>
<td>In final design</td>
</tr>
<tr>
<td>2.10 GenSys Stack</td>
<td>No Go</td>
<td>Will not yield in program timeframe – Key technology initiatives incorporated into GenCore Stack</td>
</tr>
</tbody>
</table>
### TECHNICAL ACCOMPLISHMENTS – PRODUCT DESIGN

#### Start of DOE Program

<table>
<thead>
<tr>
<th></th>
<th>UPS –1</th>
<th>Prototype</th>
<th>Final Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life</td>
<td>800 Hours</td>
<td>1500 Hours</td>
<td>1500 Hours</td>
</tr>
<tr>
<td>Coolant</td>
<td>Paralux</td>
<td>Propylene Glycol</td>
<td>Propylene Glycol</td>
</tr>
<tr>
<td>H2 management</td>
<td>Purge</td>
<td>Blower EGR</td>
<td>Venturi EGR</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>Batteries</td>
<td>Batteries</td>
<td>Ultra Caps</td>
</tr>
<tr>
<td>Stack Cells (Relative)</td>
<td>100%</td>
<td>79%</td>
<td>71%</td>
</tr>
<tr>
<td>Humidifier</td>
<td>Enthalpy Wheel</td>
<td>Membrane</td>
<td>Membrane</td>
</tr>
</tbody>
</table>

Plug Power Proprietary and Confidential
TECHNICAL ACCOMPLISHMENTS – PRODUCT DESIGN

POWER SCALABLE STACK

Key Changes

• Cast End Hardware
• Cost Reduced MEA
• Thinner Plates
• Improved Scanner Cards

<table>
<thead>
<tr>
<th></th>
<th>UPS –1</th>
<th>Prototype</th>
<th>Final Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (L)</td>
<td>70</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>Weight (Lbs)</td>
<td>~100</td>
<td>~60</td>
<td>~60</td>
</tr>
<tr>
<td>Stack Cells (Relative)</td>
<td>100%</td>
<td>79%</td>
<td>71%</td>
</tr>
</tbody>
</table>

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TECHNICAL ACCOMPLISHMENTS – PRODUCT DESIGN

H2 EXHAUST GAS RECIRCULATION OPTIONS

Start of DOE Program

Anode Purge

<table>
<thead>
<tr>
<th>UPS-1</th>
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<th>Final Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Purge</td>
<td>Blower EGR</td>
</tr>
<tr>
<td>Siting/H2 Exhaust</td>
<td>70 SLM, 30sec purge</td>
<td>&lt; 1000 ppm</td>
</tr>
</tbody>
</table>

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Results showed similar stack performance after 350 hour test
**POWER CONDITIONING PLATFORM**

**GenCore DC/DC Converter**
- DC/DC was developed to be easily modified to accommodate different voltage ranges
- 66% of the DC/DC converter parts are common across the platform
- Only 3% of the parts are unique to on every converter

---

**Main Output**
- 24V: 6000 W
- 48 V Positive Ground: 5000 W
- 48 V Negative Ground: 5000 W
- 120V: 5000 W

**24V Aux. Output**
- None
- 900W
- 900W
- 900W

**Topology**
- Buck
- Buck-Boost
- Buck-Boost
- Boost

**Main Efficiency @ full power**
- 24V: >96.5%
- 48 V Positive Ground: >97%
- 48 V Negative Ground: >97%
- 120V: >95%

**Aux. Efficiency @ full power**
- NA
- >87%
- >92%
- >92%

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Plug Power Proprietary and Confidential
TECHNICAL ACCOMPLISHMENTS – PRODUCT DESIGN

ADVANCED ELECTRICAL ENERGY STORAGE

<table>
<thead>
<tr>
<th></th>
<th>UPS-1</th>
<th>FINAL DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Batteries</td>
<td>UltraCaps</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>3 MJ (5kW for 10 minutes)</td>
<td>150 kJ (5kW for 30 Seconds)</td>
</tr>
<tr>
<td>Weight</td>
<td>108 lbs</td>
<td>44 lbs</td>
</tr>
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</table>

Plug Power Proprietary and Confidential
Ultra Caps are ideally suited to the GenCore application due to the short start up time (<30s).

Ultra Caps will last the life of the system (10 years) while the batteries will need to be replaced every three years.

Ultra Caps are currently approximately 4 times more expensive than batteries.

Ultra Caps are more tolerant to ambient temperature ranges (-40 to 46 C).
Scale System

PRODUCT CHARACTERISTICS

• Re-packaging incorporates several years of design learning from original GenCore

• Component count is significantly reduced, improving reliability by reducing opportunities for failure

• Re-packaging improves manufacturability and servicingability
TECHNICAL ACCOMPLISHMENTS – PRODUCT DESIGN

Pro/Engineer → Foam Core

FINAL DESIGN EVOLUTION

Wood “Buck” → Functional Hardware
TECHNICAL ACCOMPLISHMENTS – DESIGN VALIDATION

Product Development and Design Verification Cycle

Technology Assessment  System Design  Product Validation/Certification

Customer Requirements  Customer Acceptance & Certification Testing

System Requirements  Design Verification Testing

Sub-System Requirements  Sub-System/Prototype Testing

Component Requirements  Component Bench Testing

REQUIREMENTS  VERIFICATION
TECHNICAL ACCOMPLISHMENTS – DESIGN VALIDATION

GR 1089 - Electromagnetic Compatibility (EMC) and Electrical Safety
- System-level Electrostatic Discharge (ESD)
- Electromagnetic Interference (EMI)
- Lightning and AC Power Faults
- Steady-state Power Induction
- Electrical Safety
- Bonding and Grounding

GR-63: Network Equipment Building Systems (NEBS) Requirements for Physical Protection
- Temperature and humidity
- Altitude
- Flammability
- Earthquake
- Vibrations
- Airborne contaminants
- Acoustic noise
- Illumination

GR-487: Generic Requirements for Electronic Equipment Cabinets
- Water and Dust Intrusion
- Wind Driven Rain
- Rain Intrusion
- Lawn Sprinklers
- Weathertightness
- Acoustical Noise Suppression
- Wind Resistance
- Impact Resistance
- Firearms Resistance
- Fire Resistance
- Corrosion Resistance
- Shock and Vibration
- Transportation Shock
- Transportation Rail
- Transportation Vibration
- Installation Shock
- Environmentally Induced Vibration
- Earthquake Resistance (Zone 4)
## TECHNICAL ACCOMPLISHMENTS – FIELD DEMONSTRATIONS

<table>
<thead>
<tr>
<th>Partner</th>
<th>Scope</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bellsouth</td>
<td>Validate system meets customer requirements</td>
<td>❖ System shipped on 3/3/06</td>
</tr>
</tbody>
</table>
| Argonne National Laboratory | Perform baseline performance testing | ❖ System shipped on 3/15  
❖ System installed  
❖ Test plan developed  
❖ Testing has begun |
| Federal Aviation Administration | In application field demonstration | ❖ System will ship in August 2006  
❖ Testing will complete in February 2007 |
The program is scheduled to be complete by April 2007. The following items activities will be completed:

- Validation of customer requirements at BellSouth
- Completion of baseline testing at Argonne National Laboratory
- Completion of field trial at FAA
The program has completed all of the objective of this program except the field demonstrations which have been scheduled.

All activities will be completed within the original program budget.

5 of 10 technology initiative proved feasible and are incorporated into the final design.

A cost-reduced, proton electrolyte membrane (PEM) fuel cell stack tailored to hydrogen fuel use in back-up applications was developed.

A modular, scalable power conditioning system tailored to market requirements was developed.

A scaled-down, cost-reduced balance of plant (BOP) was incorporated into the final design.

The final design was certified to the Network Equipment Building Standards (NEBS) and FC-1 by Underwriters Laboratories (UL).
BACK-UP SLIDES
“Argonne National Laboratory; Bell Labs, etc. are potential demonstration partners not collaborators.”
- BellSouth provided customer requirements which were incorporated into the design requirements

‘No future “research” is planned. Future plans include engineering and packaging systems for the demonstration.’
- Plug Power continues corporate research and development on fundamental fuel cell topics this and several other product opportunities. As this program is a demonstration, final tasks under this program are only related to the field demonstration.

PLUG POWER. PLUG WILL.