# BACKUP/PEAK-SHAVING FUEL CELLS

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

Clean, Reliable On-site Energy

This presentation does not contain any proprietary or confidential information

# SAFE HARBOR STATEMENT

This presentation contains forward-looking statements, including statements regarding the company's future plans and expectations regarding the development and commercialization of fuel cell technology. All forward-looking statements are subject to risks, uncertainties and assumptions that could cause actual results to differ materially from those projected. The forward-looking statements speak only as of the date of this presentation. The company expressly disclaims any obligation or undertaking to release publicly any updates or revisions to any such statements to reflect any change in the company's expectations or any change in the events, conditions or circumstances on which such statement is based.

# OVERVIEW

| Timeline | |
|---|---|
| Project Start Date: | August 2003 |
| Project End Date: | April 2007 |
| Percent Complete: | 95% |

| Budget | |
|---|---|
| Total Project Funding | $ 7,201,881 |
| DOE Share | $ 3,600,940 |
| Plug Power Share | $ 3,600,941 |
| Funding Received in FY05 | $ 2,762,242 |
| Funding for FY06 | $ 149,251 |

## 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

## Partners

| | |
|---|---|
| Bell South | Telcordia Labs |
| Airgas | Argonne National Labs (Test Site) |
| | FAA (Test Site) |

# PROJECT OBJECTIVES

**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)

# APPROACH

| | PHASE I | PHASE II | PHASE III |
|---|---|---|---|
| Objective | Technology Assessment | Product Design and Validation | Field Demonstration |
| Status | Complete | Complete | In-Process |
| Key Activities | ❖ Develop system requirements with Bell South<br><br>❖ Technologies Assessed<br>• Dry Cathode Operation<br>• GenSys Stack Integration<br>• H2 Regeneration Options<br>• Power Conditioning Platform<br>• Advanced Electrical Energy Storage<br>• System Water Balance<br>• Advanced H2 Storage<br>• Scale System<br>• GenSys Stack | ❖ Develop Design<br><br>❖ Validate Design<br><br>❖ UL certification of system to FC-1<br><br>❖ Certify system to NEBS<br>•GR 487<br>•GR 63<br>•GR 1089 | ❖ Test one system at Bell South to validate customer requirements<br><br>❖ Test one unit at ANL to baseline system performance<br><br>❖ Field trial on unit at FAA (Tentative) |

## 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® 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

# TECHNICAL ACCOMPLISHMENTS – TECHNOLOGY ASSESSMENT

## Technology Go/No Go Results Summary

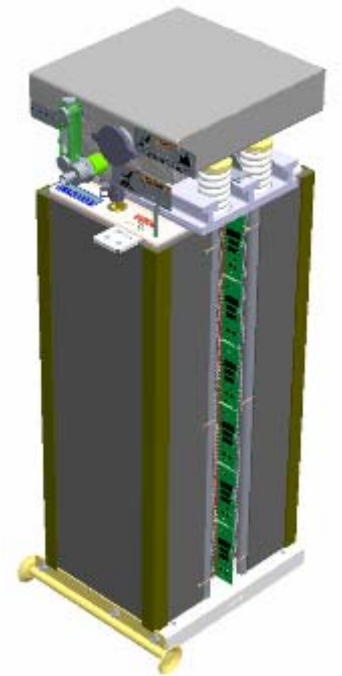
| Enabling Technology | Go/No Go | Comments |
|---|---|---|
| 2.1 Dry Cathode Operation | No Go | Will not yield in program timeframe |
| 2.2 GenSys® Stack Integration | No Go | Will not yield in program timeframe |
| 2.3. Power Scalable Stack | Go | In final design |
| 2.4. H2 Regeneration Options |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

# TECHNICAL ACCOMPLISHMENTS – PRODUCT DESIGN

Start of DOE Program

| | UPS –1 | Prototype | Final Design |
|---|---|---|---|
| Life | 800 Hours | 1500 Hours | 1500 Hours |
| Coolant | Paralux | Propylene Glycol | Propylene Glycol |
| H2 management | Purge | Blower EGR | Venturi EGR |
| Energy Storage | Batteries | Batteries | Ultra Caps |
| Stack Cells (Relative) | 100% | 79% | 71% |
| Humidifier | Enthalpy Wheel | Membrane | Membrane |

## POWER SCALABLE STACK



UPS-1

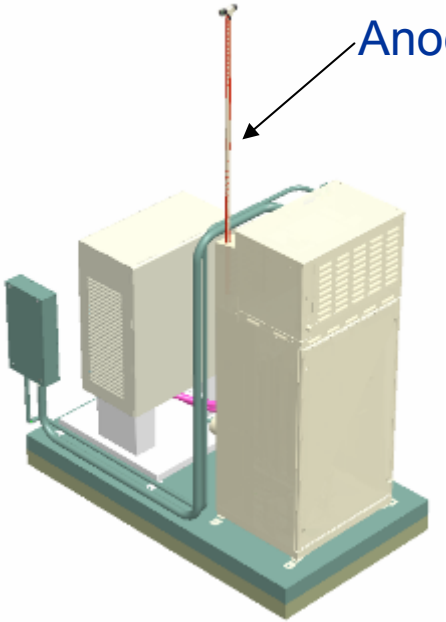
Key Changes

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

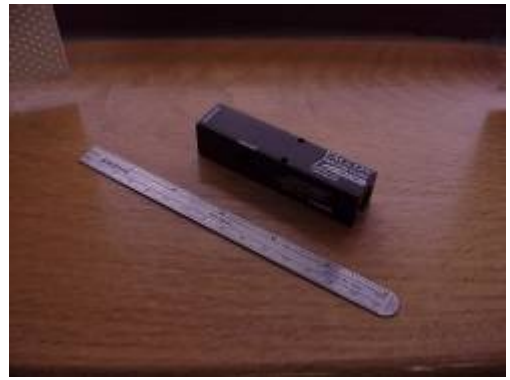
Final Design

| | UPS –1 | Prototype | Final Design |
|---|---|---|---|
| Volume (L) | 70 | 53 | 53 |
| Weight (Lbs) | ~100 | ~60 | ~60 |
| Stack Cells (Relative) | 100% | 79% | 71% |

# H2 EXHAUST GAS RECIRCULATION OPTIONS




Start of DOE Program

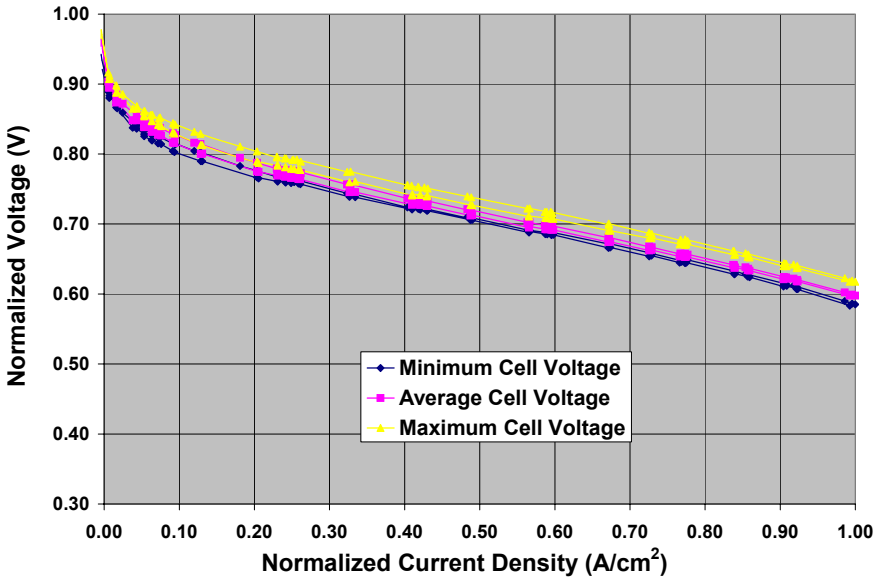


UPS-1 Prototype Final Design

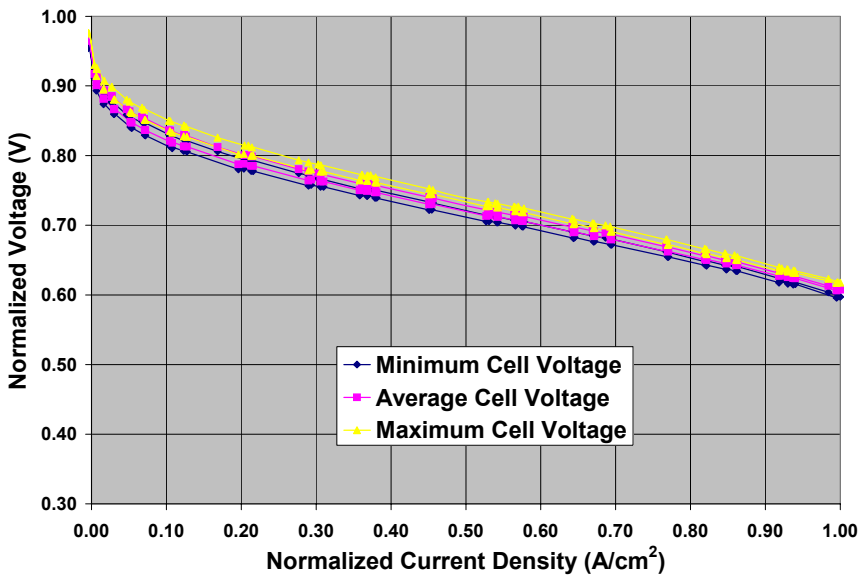
| | UPS –1 | Prototype | Final Design |
|---|---|---|---|
| Technology | Purge | Blower EGR | Venturi EGR |
| Siting/H2 Exhaust | 70 SLM, 30sec purge | < 1000 ppm | < 1000 ppm |

# VENTURI VS. BLOWER EGR 350 HOUR TEST

## Blower EGR

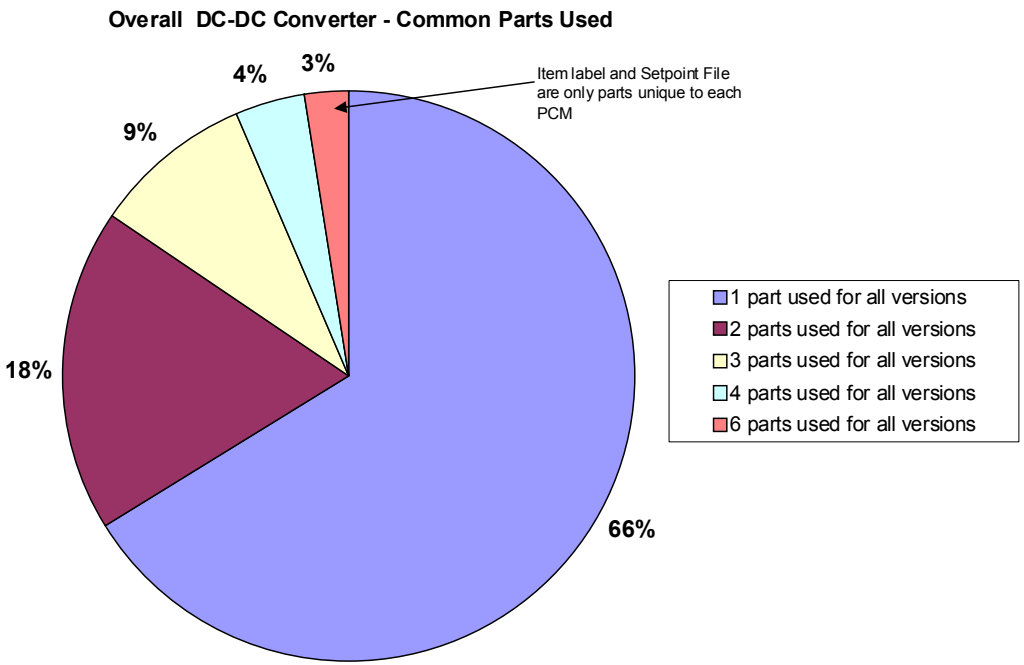



## Venturi EGR




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

| | 24V | 48 V Positive Ground | 48V Negative Ground | 120V |
|---|---|---|---|---|
| Main Output | 6000 W | 5000 W | 5000 W | 5000 W |
| 24V Aux. Output | None | 900W | 900W | 900W |
| Topology | Buck | Buck-Boost | Buck-Boost | Boost |
| Main Efficiency @ full power | >96.5% | >97% | >97% | >95% |
| Aux. Efficiency @ full power | NA | >87% | >92% | >92% |

# ADVANCED ELECTRICAL ENERGY STORAGE

UPS-1

Final Design

| | UPS-1 | FINAL DESIGN |
|---|---|---|
| Technology | Batteries | UltraCaps |
| Energy Storage | 3 MJ<br>(5kW for 10 minutes) | 150 kJ<br>(5kW for 30 Seconds) |
| Weight | 108 lbs | 44 lbs |

# ADVANCED ELECTRICAL ENERGY STORAGE


- 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)

# TECHNICAL ACCOMPLISHMENTS – PRODUCT DESIGN

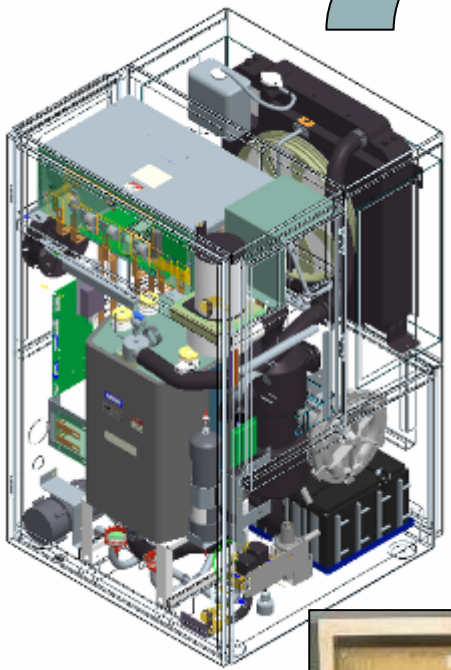
## Scale System

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 servicability

# TECHNICAL ACCOMPLISHMENTS – PRODUCT DESIGN

Pro/Engineer



Foam Core

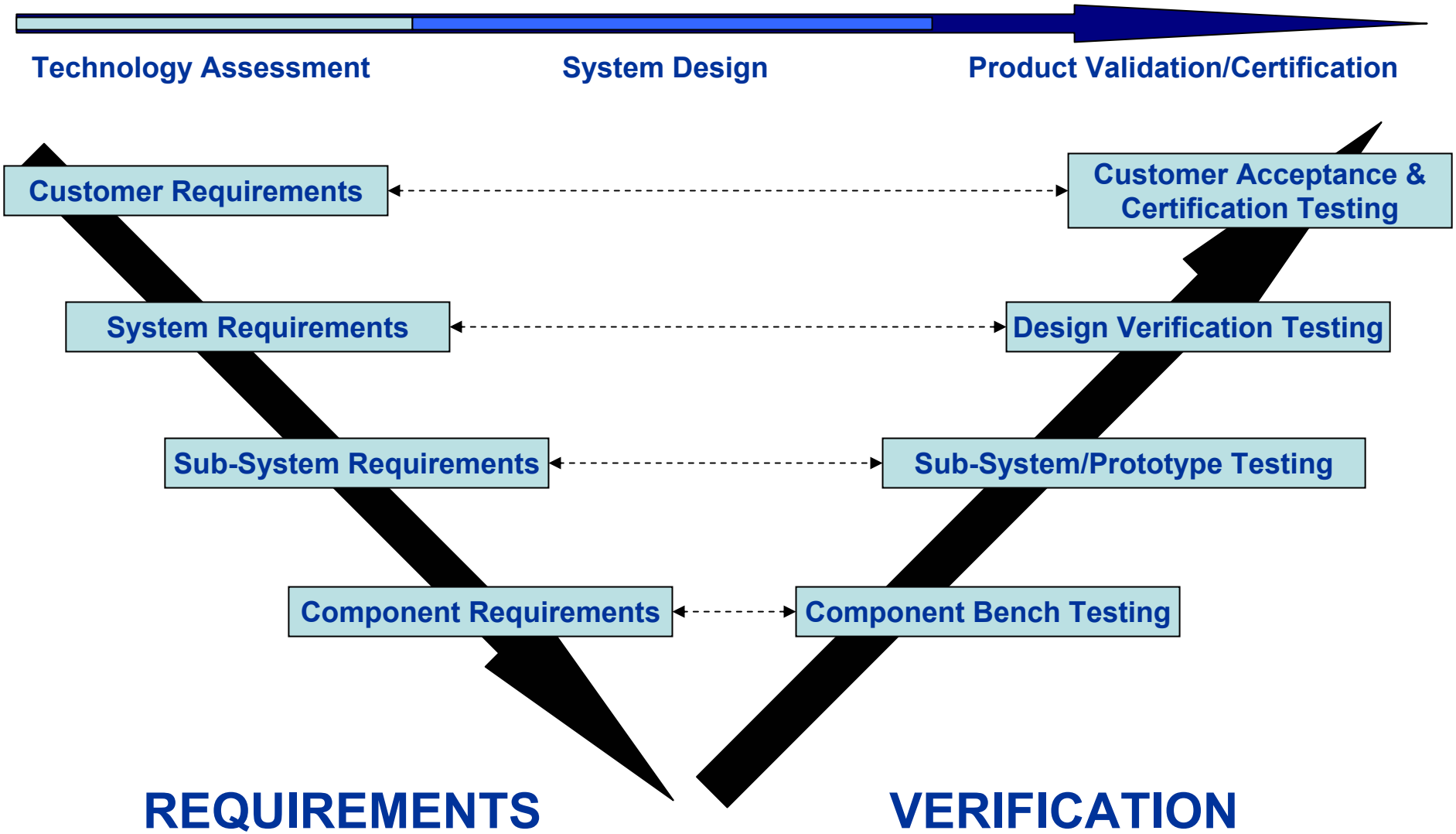
Wood “Buck”

## FINAL DESIGN EVOLUTION

Functional Hardware

# TECHNICAL ACCOMPLISHMENTS – DESIGN VALIDATION

## Product Development and Design Verification Cycle



# 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
- Weathertightnesss
- 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

| Partner | Scope | Status |
|---|---|---|
| BELLSOUTH | Validate system meets customer requirements | ❖ System shipped on 3/3/06 |
| Argonne NATIONAL LABORATORY | Perform baseline performance testing | ❖ System shipped on 3/15<br>❖ System installed<br>❖ Test plan developed<br>❖ Testing has begun |
| FEDERAL AVIATION ADMINISTRATION | In application field demonstration | ❖ System will ship in August 2006<br>❖ Testing will complete in February 2007 |

# FUTURE WORK

- 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

# SUMMARY

- 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

# RESPONSES TO PREVIOUS YEAR REVIEWER COMMENTS

- "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.

# PUBLICATIONS AND PRESENTATIONS

- W.D. Ernst, Small Scale Distributed Stationary Systems – A Status Report. 9th Grove Conference. Westminster, England, October 2005.

- Bin Du, Qunhui Guo, Richard Pollard, Daniel Rodriguez, Christopher Smith, and John Elter, "Proton Exchange Membrane Fuel Cells (PEMFCs): Technology Status and Challenges for Commercial Stationary Power Applications". JOM is Journal of The Minerals, Metals & Materials Society, Volume 58, Issue 5, May, 2006

PLUG POWER. PLUG WILL.

plug power
FUEL CELL SYSTEMS


**HEADQUARTERS**
968 Albany-Shaker Road
Latham, New York 12110
Phone: (518) 782-7700
Fax: (518) 782-9060

**WASHINGTON, D.C.**
499 South Capitol Street, SW
Suite 606
Washington, D.C. 20003
Phone: (202) 484-5300
Fax: (202) 554-2896

**EUROPE**
7301 BC Apeldoorn
P.O. Box 880
The Netherlands
Phone: 31 55 53 81 000
Fax: 31 55 53 81 099

**www.plugpower.com**