2004 DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Review

Back-up/Peak-Shaving Fuel Cells

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"This presentation does not contain any proprietary or confidential information."

The Back-up/Peak-Shaving Fuel Cell Team

- Prime Contractor: Plug Power, Inc
- The Program Team consists of the Plug Power GenCore Engineering and Product Development Group, Program Support and Plug Power's teammate BellSouth.

The GenCore Team has 45 full-time engineering and development members and over 100 members who support the Program in areas such as Marketing, Manufacturing, Supply Chain Management and Research & Systems Architecture

Program Overview and Objectives

❖ Program Overview:

The purpose of this program is to advance the state of the art of fuel cell technology with the development of a new generation of commercially viable, stationary, Back-up/Peak-Shaving fuel cell systems.

❖ Program Objectives:

- *Develop, build and test three identical fuel cell back up systems and field test them at three sites including an industry host site*
- *Identify technical barriers and objectives*
- *Develop a cost-reduced, polymer electrolyte membrane (PEM) fuel cell stack tailored to hydrogen fuel use*
- *Develop a modular, scalable power conditioning system tailored to market requirements*
- *Design a scaled-down, cost-reduced balance of plant (BOP)*
- *Certify design to Network Equipment Building Standards (NEBS) and Underwriters Laboratories (UL)*

Budget/Schedule

FY	$Total	$DOE	$Plug Power
FY03	$1,481,540*	$740,770*	$740,770*
FY04	$3,532,972	$1,766,486	$1,766,486
FY05	$1,990,910	$995,455	$995,455
FY06	$196,459	$98,229	$98,230

***Actual for 2003. The remaining years are projected.**

The program is on budget and schedule.

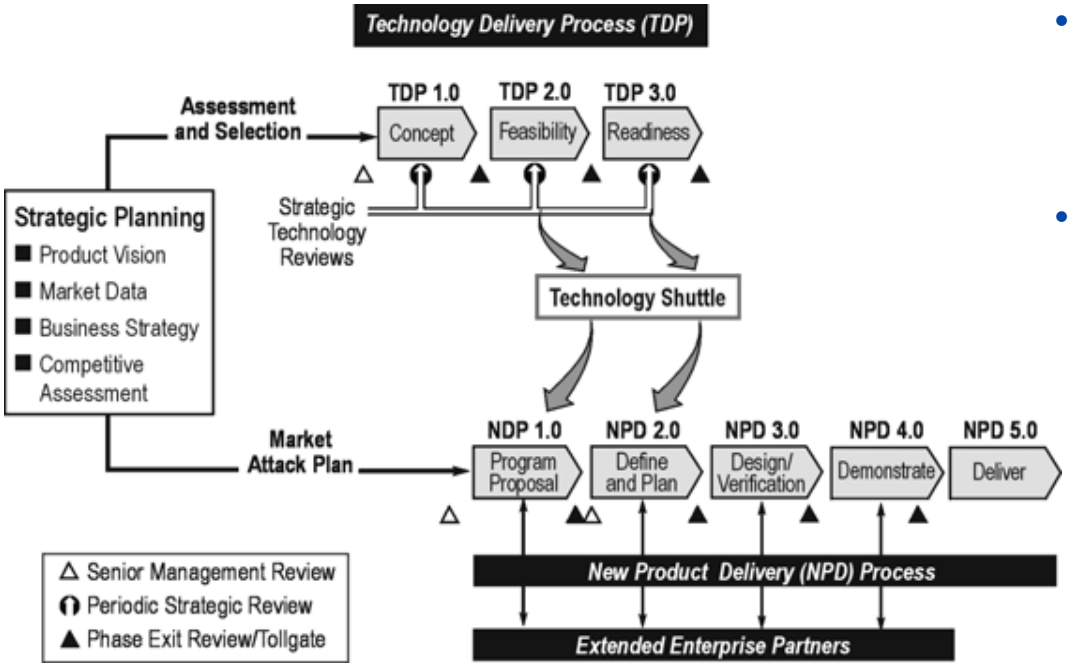
Technical Barriers and Targets

- Technical Barriers:
  - 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

- Technical Targets:
  - Technical Targets for Hydrogen Based Integrated Back Up Systems
    - Efficiency at Rated Power = > 50% LHV
    - Life = > 1500 hours
    - Cycle Capability = 500 cycles/lifetime
    - Start-up Time = < 1ms
    - Stack Cost = < $500/kWe

Approach

- To advance PEM fuel cell technology with the development of a new generation of commercially viable, stationary, back-up/peak-shaving fuel cell systems.
  - The design will be the first product off of a mass-manufacturable platform for telecommunications, broadband and uninterruptible power supply markets.
  - It is an H2-in-DC-out product for telecommunications markets and will be evaluated by team member BellSouth.
  - The program will evaluate a variety of stack and BOP technology initiatives in order to develop a mass-manufacturable and commercially viable design.
  - Phase I employs Plug Power's Technology Delivery Process (TDP) which uses rigorous testing and evaluation methods to minimize new technology risks.



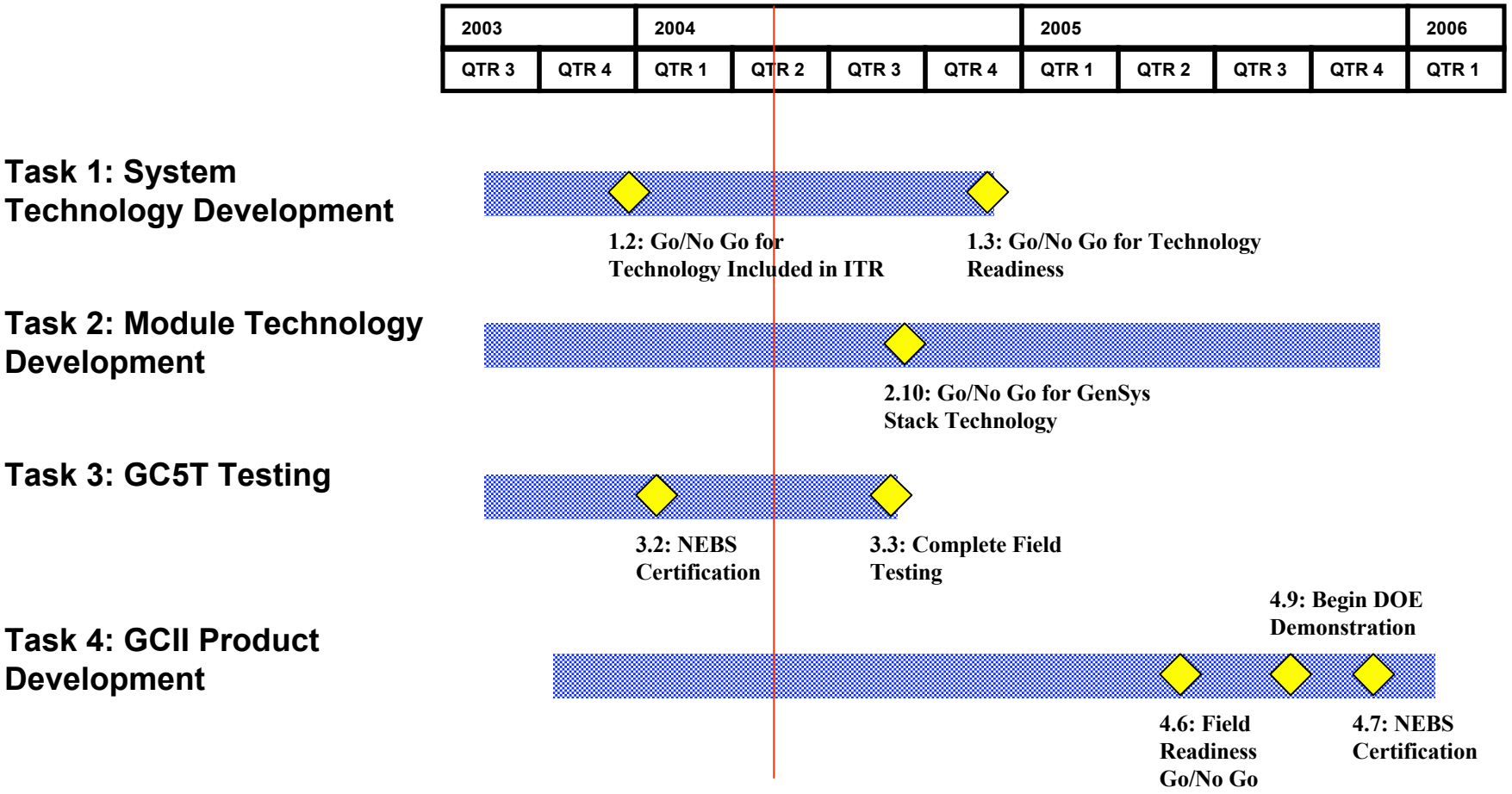
- Phase II uses Plug Power's New Product Delivery Process (NPD) to introduce technology initiatives as hardware modules for integration.
- Phase III also uses NPD to bring the hardware to an integrated system through field-testing and certification.

Project Safety

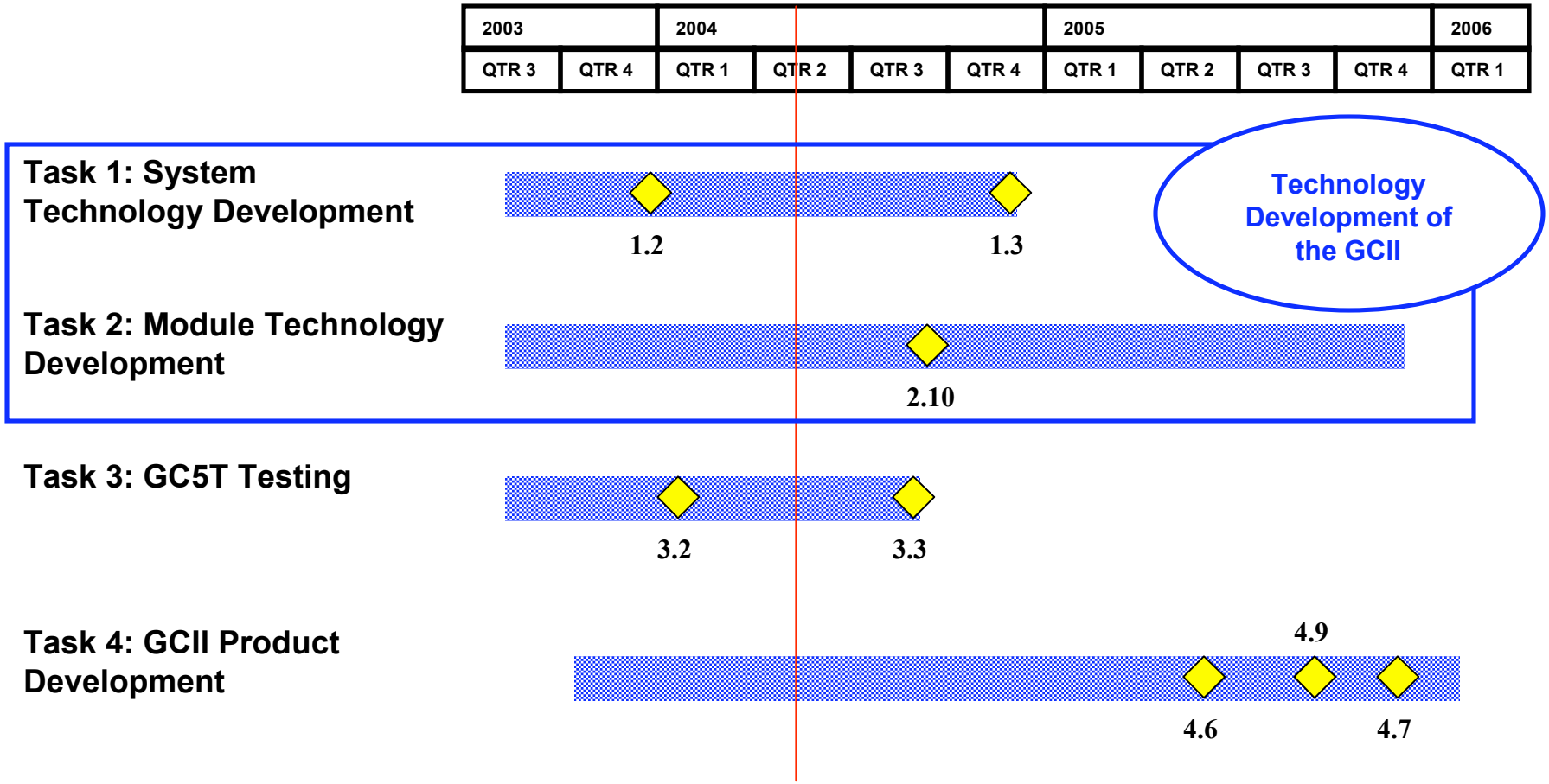
- Full time Environmental Safety and Health manager provides oversight.
- Annual laboratory safety training of all personnel.
- Laboratories designed to meet OSHA Class I, Div. 2 requirements.
- Standard operating procedures prepared and maintained for all test and laboratory equipment.
- Safety reviews of all test systems and laboratories prior to energizing.
- Chemical inventory and storage records audited annually.
- All products subjected to industry certifications as required (e.g., UL, CSA, NEBS and CE).

Plug Power has a history of following the strictest industry safety standards both in its operations and products

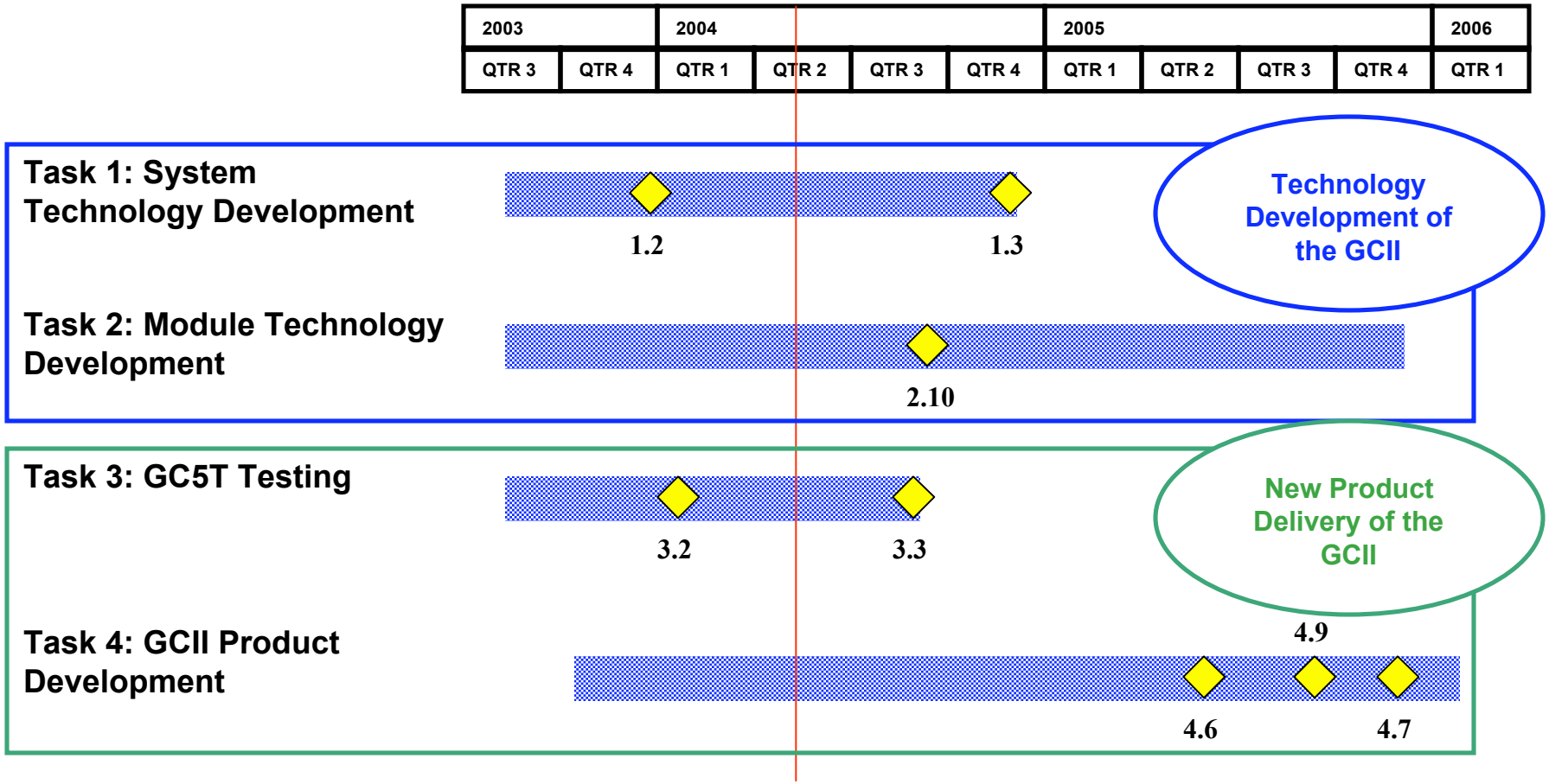
Program Timeline



Program Timeline



Program Timeline



Milestone Schedule

Task	Months	Milestone	Predecessor Tasks
Technology Development of the GCII ⇒ Months 1-28 ⇒ Technology Readiness			
1.0 System Technology Development	1-16		
1.1 Select Technology Concepts (TDP 1.0)	1-3		Program Start
1.2 Construct Models/ITR (TDP 2.0)	4-5	1.2: ITR Go/No Go	1.1
1.3 Conduct System-Level Testing (TDP 3.0)	6-16	1.3: Technology Readiness Go/No Go	1.2
2.0 Module Technology Development	1-28		
2.1 Develop Dry Cathode Stack Operation	7-13		1.1, 1.2, 1.3
2.2 Integrate GenSys Stack	13-28		1.1, 1.2, 1.3
2.3 Develop Power-Scalable Stack	1-28		1.1, 1.2, 1.3
2.4 Develop H2Regeneration Options	1-28		1.1, 1.2, 1.3
2.5 Develop Power Conditioning Platform	1-28		1.1, 1.2, 1.3
2.6 Introduce Advanced Electrical Energy Storage	7-18		1.1, 1.2, 1.3
2.7 Develop System Water Balance	1-28		1.1, 1.2, 1.3
2.8 Develop Advanced Hydrogen Storage	1-28		1.1, 1.2, 1.3
2.9 Scale System	7-13		1.1-2.8
2.10 GenSys Stack	1-28	2.10: Stack Go/No Go	1.1, 1.2, 1.3

Milestone Schedule

Task	Months	Milestone	Predecessor Tasks
New Product Delivery of the GCII ⇒ Months 1-30 ⇒ Product Readiness			
3.0 GC5T Testing	1-13		
3.1 Perform UL Testing	1-6		Program Start
3.2 Perform NEBS Testing	1-6	3.2: NEBS Certification	Program Start
3.3 Perform Field Testing	1-13	3.3: Field Testing Complete	Program Start
4.0 GCII Product Development	3-30		
4.1 Develop Master Strategy Proposal (NPD 1.0)	3-10		1.1, 3..3
4.2 Design and DVT Testing (NPD 2.0)	10-20		1.2, 3.2 – 3.3
4.3 Build Confirmation and Life Test Systems	16		4.2
4.4 Perform Integrated System Testing	16-20		4.3
4.5 Build Verification Test Units (NPD 3.0)	20		4.4
4.6 Conduct Field Demonstration	20-30	4.6: Start Field Demonstration	4.5
4.7 Certify Design to NEBS	20-30	4.7: NEBS Certification	4.5
4.8 Certify Design to UL	20-30		4.5
4.9 Demonstrate GCII at DOE (NPD 4.0)	26-30	4.9: DOE Demonstration	4.6

Technical Accomplishments

While there have been technical accomplishments in each of the program's 25 subtasks, the following slides will highlight the most significant

- Construct Models/Integrated Test Rig (ITR): The following technology modules have been evaluated in module test rigs:
  - Task 2.3 - Develop Power-Scalable Stack
  - Task 2.4 - Develop H2 Regeneration Options (Advanced Exhaust Gas Recirculation option)
  - Task 2.5 - Develop Power Conditioning Platform
  - Task 2.8 - Develop Advanced Hydrogen Storage (Both Standard Steel Bottle and Composite Cylinder options)
- Examples of critical tests that have been run to date and their associated data are contained in the following table:

Technical Accomplishments

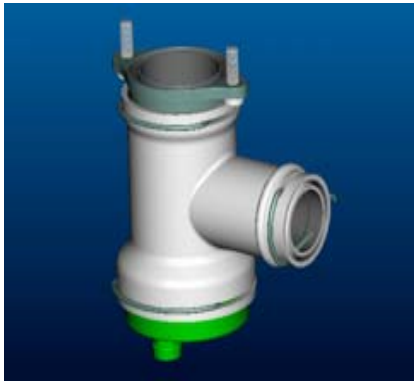
Critical System and Module DVT Test Results

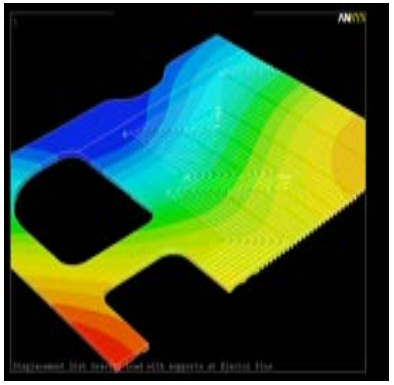
Parameter	Tests	Results	Issues
System Duty Cycle (> 50 start/stops per year)	• 200 start/stop cycles, continuous • 200 start/ stop cycles, with dormancy and conditioning cycles • Performance testing with stop/start cycling	**Passed**	• Are currently performing duty cycle tests > 225 start/stops in the laboratory and Environmental Chamber Over 500 starts/stops in field testing. • Reliability testing will be continued as additional plans to remove risk
Operating Hours (1500 hours life)	• 2000 hour validation	**In Process**	• A system to date, running the predicted duty cycle, has run over 1500 hours • Stacks have run > 2000 hours and modeling and vendor data show components should last • Trends are positive, reliability fleet coming on line.
Time to Fuel Cell Governing (30 seconds)	• 0 to 5 kWe ramp test @25C • 0 to 5 kWe ramp test @ -40C/25C/+46C	**Passed**	• This is the time it takes for the fuel cell to be exporting 5 kWe with none required from the EESM • All tests performed in 15 seconds or lower
Environmental Siting (-40C to +46 C +solar loading operation with 1.5% power de-rate/each 10C > 25C)	• 5 kWe output test @ +46C +solar loading • Dormancy to net zero output at –40C	**Passed**	• Cabinet temperatures oscillate to low temperatures (down to –9C) for short durations (15 seconds) at startup. Not considered a freeze issue. •

Technical Accomplishments

- Task 2.3 Develop Power Scalable Stack: Executing the initiatives under this task will provide the product with a stack that has comparable performance to Plug Power's residential, reformate stack but reduces the number of required cells by 20%, the weight by almost 50% and the volume by 45%. The following initiatives are technology ready:
  - Reduced stack footprint and thin plates
  - Molded-in gaskets
  - Reduced end-hardware size
  - Integrate insulators and thermostat into end hardware
  - Reduced cost, scalable scanner card interface
  - Next Generation MEA (cut-in July/04)

Molded Stack End Hardware, Molded Fittings, FEA of Plate Stress

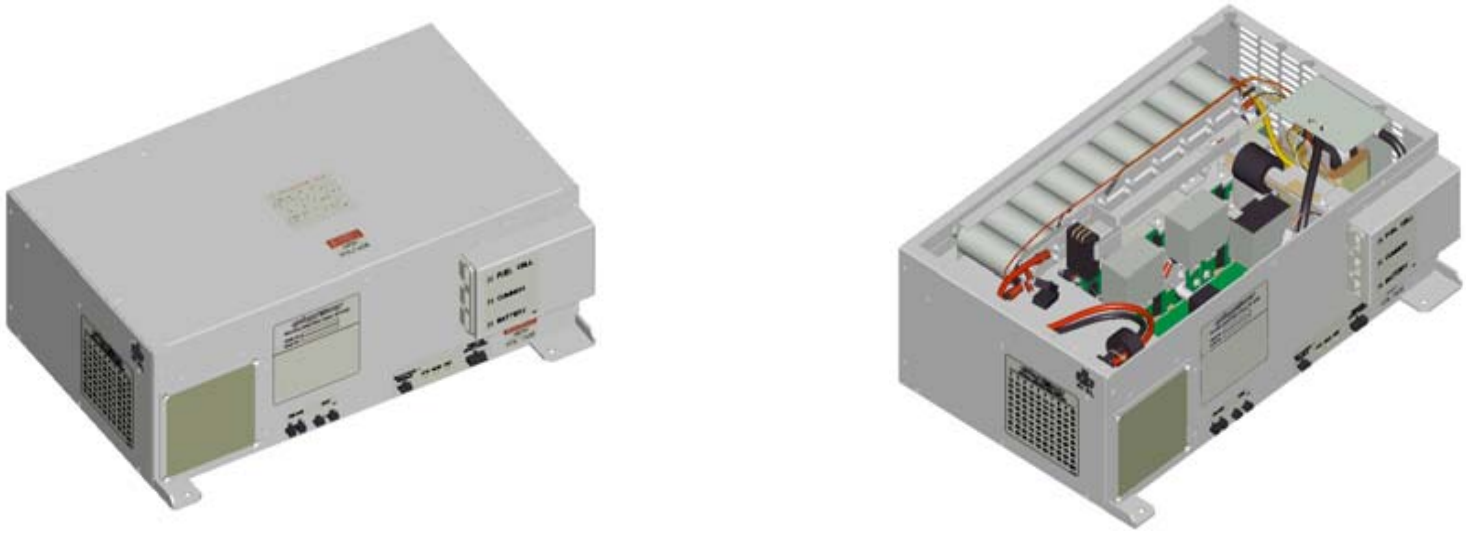




Technical Accomplishments

- Task 2.5 Develop Power Conditioning Platform: Back-up power market requires a variety of voltage settings and grounding schemes. This platform provides a significant volume and weight reduction over its predecessor.
  - 13% efficiency gain
  - Greater than 50% cost reduction
  - Feasibility, qualification and ITR integration testing is complete.
  - EMI testing complete and the platform is FCC Class A. Working Class B.
  - UL testing is complete

Power Conditioning Platform, GC5T Version, with Cover and Without



Technical Accomplishments

- Task 2.9 Scale System: The purpose of this task is to scale the system's BOP to meet reliability, size and cost targets. The first iteration of the design is complete.
  - 66% volume reduction
  - 53% weight reduction
  - 48% cost reduction

First Iteration of System Scaling

Technical Accomplishments

- Task 2.10 GenSys Stack: Efforts are focused on plate thickness reduction and gasket configuration as the major cost reduction activities. While water management as it effects peroxide formation and reactant distribution are the major thrusts for stack life improvement.
  - Computational study of plenum configurations underway
    - Intent: Improve Stack Power Density and Reduce Stack Weight by Right-Sizing the Distribution Plenum
    - Method: Advanced CFD Analysis using FLUENT
    - Have selected reactant plenum size which achieves cell-cell and channel-channel flow distribution criteria.
    - Have CFD Tool and Understanding in place to quantify flow distribution impact of hardware changes
  - Impact of stack orientation on performance underway
    - Experimental work complete (performance testing of horizontal orientation)
  - Gasket technology development for cost reductions in process (from drop-in to molded-on)
    - Delivery of molded on gaskets 2Q04

Technical Accomplishments

- New flowfield design complete
  - Machined plate testing complete
  - First molded plates on site, assembled and tested
  - Molded plates demonstrate clear superiority to machined
  - Prototypes have demonstrated 2X lower turndown ratios at equivalent stoichiometry
- Stack Latitude testing underway
- Experiments begun to determine back diffusion rate of H2O in MEA
  - Hydration of membrane vs. anode flooding
  - Will be used to validate anode flowfield design

Technical Accomplishments

- Task 3.1 and 3.2 Perform UL and NEBS Testing on the GC5T:
  - United Laboratories was selected as the certifying lab for UL
  - UL certification to ANSI Z21.83 received 12/03
  - Telcordia Labs was selected as the certifying lab for NEBS
  - NEBs “Level III” testing to GR 487, GR 1089 and GR 63 completed 3/04

Left: GC5T Undergoing UL Ventilation Testing, Right: GC5T in a Bunker Undergoing NEBS Shotgun Testing

Technical Accomplishments

- Task 3.3 Perform Field Testing of GC5T: Two examples.

Albany International Airport

- GenCore platform prototype installation
- First of its kind in the world
- -48V DC backup power directly onto DC bus, 5kW maximum output, running on industrial grade hydrogen
- Approximately 30 hours of backup at this location

Site Host's Cell Tower

- GC5T Installation
- -48V DC backup power directly onto DC bus, 5kW maximum output, running on industrial grade hydrogen
- Over 1000 fleet operational hours and 1000 start/stops to date

Interactions and Collaborations

- Plug Power's Teaming with BellSouth
  - BellSouth will provide industry product requirements for the GCII
  - Plug Power will deliver a GCII system to BellSouth for evaluation
  - Through design reviews and product evaluations BellSouth will provide Plug Power feedback to ensure the final GCII design is commercially viable
- Plug Power and Airgas
  - Plug Power has entered into an agreement with Airgas whereby Airgas will be a supplier of hydrogen to GenCore customers
  - Plug Power is leveraging this relationship to learn as much as possible about commercial industrial hydrogen handling and logistics
- Plug Power and Telcordia
  - Plug Power has contracted Telcordia Labs as its NEBS testing agency
  - Telcordia has provided invaluable insight and learning to Plug Power about commercial industry requirements for backup telecommunications equipment and NEBS testing

Future Work

- Remainder of FY 2004
  - Focus on Technology Readiness for the GCII design
    - Complete Technology Selection and Feasibility Testing for:
      - Dry Cathode Stack Operation
      - Electrolysis Module and System Water Balance
    - Complete Module Testing and ITR Integration for:
      - Dry Cathode Stack Operation
      - Electrolysis Module and System Water Balance
      - Advanced Electrical Energy Storage Module
    - Conduct System-Level Testing on most Technology Modules
    - Continue to Develop the GenSys Stack:
      - Evaluate GenSys flowfield design for a range of operating conditions
      - Computationally study the impact of plate thickness on stack electrical and thermal management
      - Continue computational study of plenum configurations for GenSys
      - Continue study of impact of stack orientation on GenSys performance
      - Characterize how single low cell in stack will impact stack durability
      - Determine impact of dormancy on performance of GenSys stack
      - Complete Freeze/Thaw Tolerance Evaluation
      - Continue gasket technology development for cost reductions

Future Work

- Remainder of FY 2004 (cont.)
  - Wrap up GC5T Field testing
    - Complete field testing, collect data and integrate findings into GCII design
  - Begin GCII Product Design Development
    - Develop Master Strategy Proposal
      - Develop Requirements Document with Team Mate BellSouth
    - Begin Design and DVT Testing
    - Build Confirmation and Life Test Systems
    - Begin Integrated System Testing
- FY 2005 – 2006
  - Complete Technology Module Development through the Engineering Change Process
  - Complete Development of the GenSys Stack
    - Investigate opportunities for automated or semi automated assembly of stacks
    - Investigate dry cathode operation of GenSys stack
  - Complete Design and DVT Testing
  - Complete Integrated System Testing
  - Build Verification Test Units
  - Conduct GC II Field Demonstration at BellSouth
  - Certify Design to NEBS and UL
  - Demonstrate GCII at 2 DOE sites