XI.3 Highly Efficient, 5 kW CHP Fuel Cells Demonstrating Durability and Economic Value in Residential and Light Commercial Applications

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Objectives

- Demonstrate the durability and economic value of GenSys Blue.
- Verify its technology and commercial readiness for the marketplace.

Relevance to ARRA and DOE-FCT Goals

- Deploy 12 GenSys Blue, natural gas-fueled, micro-combined heat and power (CHP) fuel cell units that provide economic savings and environmental benefits for residential and light commercial users.
- Maintain five U.S., high-tech jobs in New York State and provides work for U.S. suppliers and field service contractors.

Accomplishments

- Controls and efficiency improvements resulting in faster start-ups, thermal response time, heat modulation and increased total efficiency from 89 to 94%.
- Manufacturability improvements to enclosure, piping, insulation and wiring which has reduced build time from over 120 hours to below 50.
- Reduction in material cost from $90k to $58k in volumes less than 20 units.
- Steady-state system model was developed and much progress made on the dynamic model.
- Long-term reliability testing established in Plug Power labs with over 3,500 run hours demonstrating, increasing reliability and decreasing failure rates.

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Introduction

The high-temperature proton exchange membrane (PEM) fuel cell system is the culmination of a nine-year technology development effort that has produced numerous technical innovations. Plug Power began exploring the application and feasibility of high-temperature PEM technology in 1999 with the creation of an "Alpha" system to demonstrate technical feasibility. It was quickly evident that the high-quality heat produced and the resulting system simplification would make this a preferred technology for micro-CHP applications–one that held the promise of a commercial, grid-connected, stationary fuel cell product that provided a cost benefit to the end user. Indeed, high-temperature PEM technology offers a unique value proposition over low-temperature PEM systems in applications where heat utilization is required. In a low-temperature system, the quality of the heat supplied is insufficient to meet consumer needs and comfort requirements, so peak heaters or supplemental boilers are required. Low temperature systems operate between 55 and 75°C and after capturing the heat and delivering it to an end use the resultant temperature is a maximum of around 50°C preventing it from being used as a stand-alone heating device. By contrast, the higher operating temperature of the polybenzimidazole (PBI) membrane technology allows the fuel cell to operate at temperatures that can produce heat sufficient to meet the comfort demand without the additional equipment.

GenSys Blue is a pre-commercial, 5 kW, natural gas-fueled product technically ready to be demonstrated in real-world residential and light commercial installations. There are no major technical risk areas to be described. Further refinements in the areas of PBI technology, stacks, advanced controls, and fuel reforming will be made from the standpoint of design hardening or design for manufacturing criteria, as Plug Power begins to separate technology development from product development with this fuel cell system.

Approach

Plug Power is executing a demonstration project that will test multiple units of its high-temperature, PEM fuel cell system in residential and light commercial micro-CHP applications in California. The specific objective of the proposed demonstration project is to substantiate the durability of GenSys Blue, and, thereby, verify its technology and commercial readiness for the marketplace. In the proposed demonstration project, Plug Power, in partnership with the National Fuel Cell Research Center (NFCRC) at the University of California, Irvine (UCI), and Sempra, will execute two major tasks:

- **Task 1**: Internal durability/reliability fleet testing. Six GenSys Blue units will be built and will undergo an internal test regimen consisting of typical residential load profiles to estimate failure rates.
- **Task 2**: External customer testing. Six GenSys Blue units will be installed and tested in real-world residential and light commercial end user locations in California.

Results

Five percent of Plug Power's employees are supporting this effort maintaining an internal and external reliability fleet of 12 GenSys Blue natural gas power systems. Automotive suppliers are delivering stack, reformer and balance of plant components.

The NFCRC at UCI began its dynamic modeling efforts of the GenSys Blue system this year. The team began with the modification of an older SU-1 based model to a high-temperature PBI model. SU-1 was Plug's attempt to penetrate the residential market with low-temperature PEM technology. After achieving reasonable correlation with a simplified system model, the team's focus became the integration of the system components, including autothermal reformer, anode tail-gas oxidizer, cathode recirculation and the burner model.

Sempra Energy and members of the Plug Power team have begun to finalize the list of sites for the California fleet and have begun preliminary planning and design. In evaluating homes as installation candidates, the criteria for selection consists of the owner being a Sempra Energy employee with an understanding of the technology, a home with a persistent need for the generated heat (presence of a heated pool or equivalent), a home with close proximity to UCI and with upper-half California population electrical requirements. Sempra received a robust response to their polling for volunteers and three leading candidates have been down selected. The final selection process should be complete by the end of July.

With the "go ahead" from DOE to begin work on this project after its award but prior to contract signing, the team ordered the parts and began building the systems to the upgraded design. To date, Plug Power has received in roughly $740,000 in materials. This material has enabled the assembly of the first six systems which have been installed and are currently in test within our labs. Additionally, 70% of all critical components and long lead items have been received for the next three systems.

The team commenced long-term reliability testing on the internal fleet installed in Plug Power labs (Figure 1). Each system is being tested according to a predetermined test plan with the goal of generating preliminary fleet reliability statistics which we can use to make engineering improvements and programmatic decisions. It is this information that will allow us to gauge our readiness for the commercial market.

The project is experiencing a high number of facility, test equipment and program issues causing uncharged downtime. While we do not count facility related shutdowns against reliability statistics, there is a strong likelihood that these failures, which would rarely be seen in the field, cause damage to systems. We have attempted to add hardware and software provisions against these accidents (such as loss of natural gas supply) but their impact (fuel starvation, for example) must be evaluated in reviewing long term test results. Raw reliability numbers and system degradation rates should be considered conservative when viewed against these disturbances (Table 1).

A noted noise factor in our test plan is our inability to closely control the ambient temperatures in which the systems operate. This makes cabinet temperature and heat loss vary from system to system as they are commissioned between January and May. Three systems began operation in January with an ambient temperature

FIGURE 1. Internal Reliability Testing Fleet

TABLE 1. GenSys Blue Reliability Fleet Statistics

HT GenSys Reliability Fleet Stats Through										
4/8/2010 0:00										
System S/N	Commissioned Date	System Runtime (Hours)	Current Stack Runtime	Burner Runtime	Electrical kWh	Thermal kWh	Startup Reliability	Heat Operational A(t)	CHP Operational A(t)	Comments
EpsilonPlus8	1/8/2010 14:50	720	720	488	2086	5624	0.86	1.00	1.00	Stack in Union system since mid Feb
EpsilonPlus9	1/11/2010 15:14	580	580	791	865	6821	0.84	0.93	0.32	Needs new stack, original stack did not run since 3/17/10
Foxtrot2	1/8/2010 14:59	1403	1403	1064	3236	14024	0.84	0.94	0.83	Running on high steady load
Foxtrot3	3/2/2010 10:47	657	657	126	1193	4217	0.65	0.93	0.88	Running on dynamic load profile
Totals	-	3360	3360	2469	7380	30685	-		-	
Average	-	840	840	617	1845	7671	0.80	0.95	0.76	

of ~10°C. The remaining systems are seeing ambient temperature ranges of 20-30°C for their first 1,000 hrs.

Another noise factor is the introduction of control upgrades as the team learns about the long-term operation of the system. These will allow newer systems to operate more robustly as control upgrades are implemented. This process is inevitable but must be considered when evaluating overall fleet reliability trends.

The statistical significance of the current data is moderate with relatively high confidence intervals since collected run hours per system average below 1,000 hrs. The team's confidence in the data set will improve dramatically over the next quarter when average run times per system should be well over 2,000 hours with a fleet total of over 10,000 hours. At this point the team will feel more comfortable using conclusions from the fleet to guide program decision making and investment.

The failure and maintenance call rate has a decreasing trend. March 2010 data is mostly an accumulation of three systems worth of data for three months of operation. April 2010 data is the cumulative reliability statistics of four months of operation with four systems (Foxtrot3 is commissioned in March).

Controls, thermal management and air delivery module problems dominate as the cause of unscheduled shutdown events. Failure modes unique to 2010 hardware improvements have been discovered and highlighted. Controller lockups due to software bugs and stepper motor position losses were the major contributors to downtime. Coolant leaks did not cause a downtime but counted as failures. All failures were contained and controls provisions are added to resolve the issues.

The fleet has experienced one stack failure in system EpsilonPlus9 after just less than 1,600 hours of operation (~1,000 hours debug and 580 hours reliability test). This stack was suspect upon commissioning and was useful in debugging the system and collecting runtime hours until a replacement could be built. The team believes the stack failed due to an internal coolant leak and it is scheduled for autopsy and analysis (Figure 2).

In the past year the team participated in community events designed to increase the public's awareness and education level regarding renewable energy in general and micro-CHP technology in particular. The first event was showcasing a GenSys Blue system at Union College in Schenectady, New York for their alumni day. Members of the team explained the system and its economic benefits to over 50 Union College alumni, members of the faculty and their families. The second event was also a showcase at Ballston Spa High School in Ballston Spa, NY for the annual New York State Science, Technology, Engineering and Mathematics Educational Collaborative where team members introduced the system and its benefits to New York State educators from all over the state.

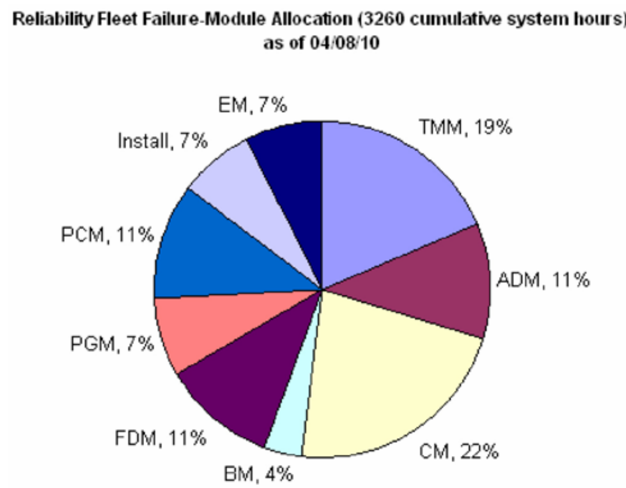

FIGURE 2. Fleet Failure Mode Allocation

Conclusions and Future Directions

The internal test fleet is built and commissioned. A reliability activity complete with metrics has been established. Sites have begun to be selected for the external customer testing in California. Future milestones include:

- First Go/No-Go decision.
- Completion of the system model by NFCRC.
- Ship six systems to California.
- Maintain the reliability fleet, capturing requirements from the California market.