IV.H.12 50-kW (net) Integrated Fuel Cell Power Systems

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Objectives

The objective of this project is to demonstrate a fully integrated, gasoline fueled 25-50 kWnet proton exchange membrane (PEM) power plant using a catalytic partial oxidation (CPOx) fuel processing system (FPS). The objectives will be pursued in two phases representing sub-objectives:

- Phase one, Fuel Processor One (FP1), testing focus on start time, steady state and transient operation of the FPS and generation of fuel cell-quality reformate. Testing conducted in FY 2003.
- Phase two, Power Plant One Reformate (PP1R); testing focus on demonstrating full integration of PEM fuel cell power plant. Testing conducted in FY 2004.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- I. Fuel Processor Start-up/Transient Operation
- J. Durability
- K. Emissions and Environmental Issues
- L. H_2 Purification/CO Clean up
- M. Fuel Processor System Integration and Efficiency
- N. Cost

Approach

- Build and test FP1, CPOx based integrated FPS assembly.
- Build PP1R power plant from FP1.
- Test PP1R assembly (fully integrated PEM power plant).
- Have ANL conduct verification testing on the PP1R assembly.
- Tear down and analyze PP1R test article.

Accomplishments (FY 2004)

- Built PP1R power plant (in Q4 2003).
- Completed development testing of the fully integrated power plant PP1R.
- Assisted ANL in completing verification testing of PP1R.
- Analyzed and presented data at the DOE annual merit review meeting.
- Started tear down and post test analysis of PP1R power plant.

Future Directions (FY 2004)

- Complete tear-down and post-test analysis of PP1R power plant.
- Complete tear-down report.

Introduction

UTC Fuel Cells is committed to the commercialization of PEM fuel cell power plants for transportation applications. The implementation of hydrogen fuel cell powered vehicles is contingent on a feasible powerplant and a suitable means of storage and distribution of hydrogen. One means to address the latter issues is generation of hydrogen from gasoline onboard the vehicle. In such a case, no hydrogen needs to be stored on the vehicle, nor is a hydrogen distribution network required. UTCFC has in place a program addressing the technology development and verification of each of the necessary components, subsystems and fully integrated power plant. The focus of this project is a fuel cell power plant capable of delivering up to 50kW net dc power using a CPOx based fuel processor operating on gasoline fuel.

Approach

Figure 1 provides a schematic of the gasoline fuel cell power plant showing the distinction between FP1 and PP1R. The major subsystems include the Fuel Processing Subsystem, the Power Subsystem and the Balance of Plant (BOP). The BOP includes the Thermal Management Subsystem, the Air and Water Subsystems and the Controller and associated electrical equipment.

A photograph of the PP1R powerplant is shown in Figure 2; this is a fully assembled PEM power plant operating on gasoline that includes the CSA, FPS, TMS and controller.

Results

The PP1R powerplant was tested at UTCFC's facilities in South Windsor, CT. In addition, Argonne National Laboratory representatives conducted seven days of verification testing with PP1R. Table 1 provides the powerplant test data summary compared against the DOE Technical Targets (Reference 1).

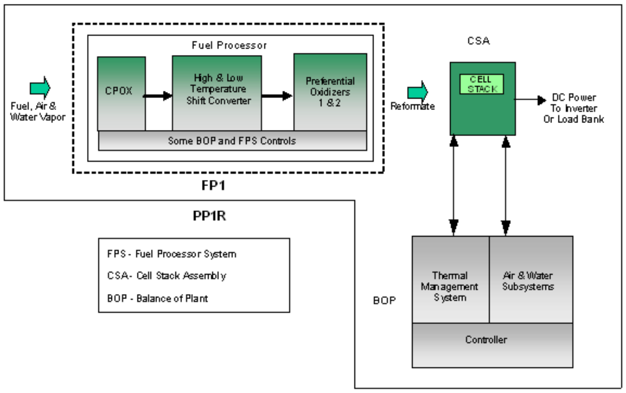

Figure 1. PP1R System Schematic

Figure 2. PP1R Powerplant

Figures 3 and 4 present the PP1R steady state efficiencies and emissions versus net power. These data were taken from runs that used heated nitrogen start up of the FPS.

As shown in Figure 3, the overall system efficiencies were below the DOE targets primarily

Table 1. PP1R Test Data Summary

	DOE Technical Target	PP1R Test Data (a)
System Efficiency at Rated (50kW)	≥31%	(b)
System Efficiency at Highest Achievable Net Power (17.4kW)	NA	22%
System Efficiency at 25% of Rated (12.5kW)	≥34%	25%
System Efficiency at 25% of Highest Achievable Net Power (4.4kW)	NA	20%
Powerplant Power Density (c)	≥140 W/L	86 W/L
Powerplant Specific Power (c)	≥140 W/kg	73 W/kg
Cost	≤300 $/kWe	Not Available
Transient Response, 10% to 90% power	≤15 seconds	Not Tested
Start Time to Rated Power	≤10 minutes	14 minutes (d, e)
Emissions (g, h)	≤Tier 2 Bin 5	< Tier 2 Bin5 (f)
	CO <4.2g/mile	CO 5ppm (~0.05g/mile)
	NOx <0.07g/mile	NOx 0.2ppm (~0.001g/mile)
	PM <0.01g/mile	PM – Not Measured
	NMOG <0.09g/mile	NMOG – Not Measured
Duration of Operation	≥1000 hours	100 hours (i)

Notes:
- (a) Efficiency and emissions data for onload operation was gathered using hot nitrogen start up, rather than start burner startup
- (b) Rated power was not achieved.
- (c) Based on actual overall weight and volume of powerplant and 50kW rated power.
- (d) CPO reformer is cold soaked to ambient temperature of 30°C. Selective oxidizers and CSA begun at operating temperature.
- (e) Start time is to point when CSA is onload
- (f) Target was bettered for CO and NOx; PM and NMOG were not measured
- (g) Concentrations provided are the maximums of the averages at each power over the operable power range, at the powerplant exhaust
- (h) Emissions in g/mile were back calculated for the powerplant exit conditions using the EPA Urban Dynamometer Driving Schedule
- (i) Approximate total of onload hours. Longest duration of operation between component change-outs was approximately 40 hours

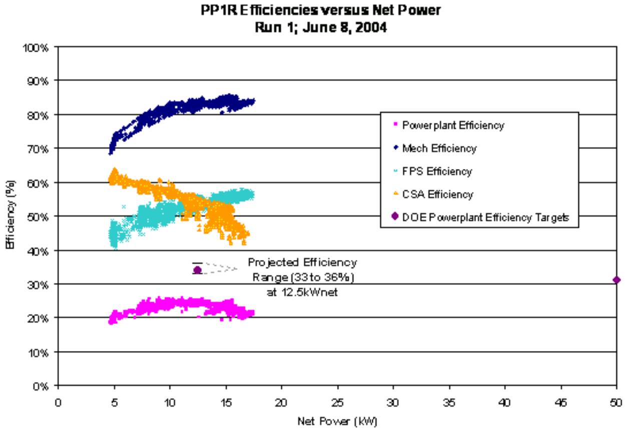

Figure 3. PP1R Efficiencies

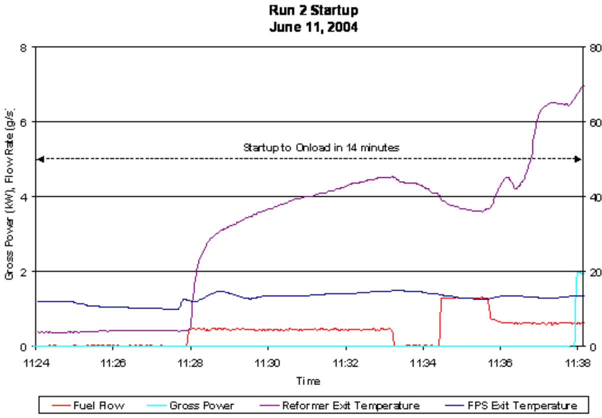

Figure 4. PP1R Emissions

due to the CSA performance on the gasoline CPOx reformate. Resultant FPS efficiencies are low since the CSA fuel utilization had to be lowered to avoid very low cell stack assembly (CSA) voltages, which is captured in the FPS efficiency calculation. A clear cause of the low CSA performance was not determined, but trace amounts of unreacted hydrocarbons in the gasoline CPOx reformate are suspected. If the CSA had performed like it does on simulated reformate, then the design fuel utilization could have been used. In that case the overall efficiency is projected to have been in the range of 33 to 36% at 25% of rated power.

As can be seen from Table 1 and Figure 4, the powerplant CO and NO_x emissions were extremely low (approximately 1/100th) when compared to the Tier 2 Bin 5 emissions limits. UTCFC back-calculated emissions in g/mile from the powerplant exit conditions using the EPA Urban Dynamometer Driving Schedule (Reference 2). The driving cycle was translated from speed to power output for each speed assuming an average sized light duty truck.

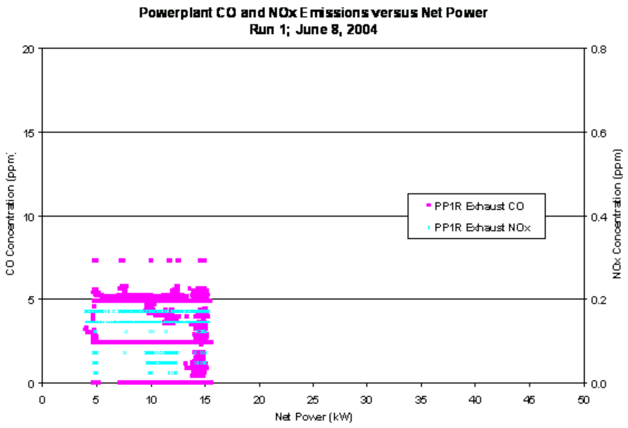

Figure 5. Start Time Demonstration

Powerplant emissions of NMOG and PM were not measured.

Figure 5 provides data that shows the powerplant was able to start-up and go onload in approximately 14 minutes. In comparison, the previous S200 power plant (operated in 2001) took approximately 45 minutes (Reference 3). The start time for PP1R was longer than the DOE target primarily due to the choice of fuel nozzle in the start burner that was found to be undersized. To be conservative the CSA coolers were started, which takes about 3 minutes, prior to the light-off of the start burner.

The testing of the system using the start burner for quick start-up was done after several sets of steady-state data were recorded. PP1R was started using a heated nitrogen stream for warm-up of the FPS prior to reforming when these sets of steady-state data were recorded. After about twenty burner starts some of the FPS reactors, particularly the reformer and HTSC, were beginning to show significant performance decay. This method of startup probably is not suitable in combination with the reformer and HTSC catalysts used in this system and the startup method needs to be reevaluated prior to use in future power plants.

Emissions of CO and NO_x were essentially not detectable during the operation of the start burner when measured at the FPS exit. This is hypothesized to be because the FPS acts as a catalytic converter for any CO in the start burner exhaust and the start burner runs at a low enough temperature (<600°C) to avoid virtually any NO_x generation.

UTCFC is in the process of completing tear-down and post test analysis of the PP1R power plant and a subsequent report for that tear down activity.

Conclusions

The PP1R test results showed significant improvements over the previous generation gasoline reformate system (S200) for start time. However, for yet to be determined reasons, the CSA performance on the gasoline CPOx reformate was low and greatly reduced the power range and efficiency of the PP1R powerplant.

UTCFC recommends focusing further effort on the development of FPS technology with objectives of providing the PEM fuel cell with high purity hydrogen. This would provide a means to avoid poor CSA performance from diluents and/or contaminants, which were suspected to be the cause of poor performance in the PP1R power plant.

References

1. U.S. Department of Energy. *Multi-Year Research, Development and Demonstration Plan*, The Hydrogen, Fuel Cells & Infrastructure Technologies Program (HFCIT), June 3, 2003

2. *Code of Federal Regulations, Title 40, Chapter I: Environmental Protection Agency, Subchapter Q, Part 600: Fuel Economy of Motor Vehicles.*

3. Smith, M.J (UTC Fuel Cells). *Atmospheric Fuel Cell Power System for Transportation,* DOE Hydrogen, Fuel Cells and Infrastructure Technologies Program 2001. June 2001.

FY 2004 Publications/Presentations

1. Tosca, M. and M. Riley, *Atmospheric Fuel Cell Power System for Transportation*, DOE Hydrogen, Fuel Cells and Infrastructure Technologies Program 2004 Annual Merit Review, Philadelphia, PA. May 2004.