V.J.6 150 kW PEM Stationary Power Plant Operating on Natural Gas

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Fiscal Year (FY) 2012 Objectives

- Investigate feasibility and value proposition of a 150-kW high-temperature (HT) proton exchange membrane (PEM) stationary fuel cell operating on natural gas (NG) reformate.
- Evaluate durability and reliability of PEM fuel cell components.
- Preliminary systems analysis of PEM powerplant with path to achieving >45% electrical efficiency.
- Demonstrate advanced fuel processing breadboard system capable of delivering H_2-rich, low-CO (<10 ppm), reactant stream to the PEM stack.

Technical Barriers

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

(A) Durability
(B) Cost
(C) Performance

Technical Targets

This project involves conducting various studies to investigate the feasibility and value proposition of a 150-kW HT PEM stationary fuel cell operating on natural gas reformate. Insights gained from these studies will be applied towards designing a power plant, such as described above, that meets the following 2015 DOE targets:

- Operating lifetime: 50,000 hrs
- Installed cost, natural gas: $3,000/kW
- Electrical efficiency at rated power: 45% electrical efficiency

FY 2012 Accomplishments

- Completed cell stack assembly (CSA) and systems analysis to arrive at a power plant baseline design capable of producing steam for reforming and achieving 40% electrical efficiency, with path to 45% electrical efficiency.
- Completed membrane durability testing on current generation membranes; used projections to evaluate lifetime for next generation membranes to be anywhere between 44,000 and 220,000 hrs.
- Prepared detailed technical/project plan for design and demonstration of advanced fuel processing breadboard system capable of delivering H_2 rich low-CO (<10 ppm) reactant stream to PEM stack (currently in progress).
- Completed methanation catalyst down-selection and durability testing.
- Completed preliminary sizing and design of methanator reactor.

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Introduction

DOE is supporting development of distributed generation stationary fuel cell power plants using natural gas as fuel. The primary considerations in developing such a power plant include efficiency, cost and durability. Previously, technologies based on phosphoric acid, solid oxide and molten carbonate technologies have been used to design stationary fuel cell power plants operating on natural gas. However, PEM-based technology was not considered that promising an alternative because of the poor durability of previous generation membranes and the inability to operate them at high enough temperatures to produce steam for reforming natural gas. Because of the low operating temperatures, PEM catalyst layers are also very intolerant to even ppm levels of CO present in the natural gas reformate. Recent advances in membrane technology have not only made them more durable but also allow higher temperature operation. We believe that these new generation membranes, in combination with UTC's experience in developing state-of-the-art reformer technology, will allow us to develop a natural gas-based PEM stationary power plants that meet DOE requirements/targets.

To date, we have conducted a CSA and systems level analysis to show that a power plant capable of achieving 45% electrical efficiency is indeed feasible. Using cell testing, we have obtained lifetime projections for the next generation membranes and shown that these membranes are indeed capable of attaining the DOE specified durability goals. We are currently working on designing and demonstrating an advanced fuel processing system that is capable of reforming natural gas to produce a H_2-rich stream with less than 10 ppm of CO, as required for operating PEM NG-based power plants.

Approach

Cell performance data along with a three-dimensional CSA model and a system model was used to evaluate different CSA and power plant configurations and to down-select the most promising design. Cell testing was conducted at the conditions listed in Table 1 to determine the durability of current generation membranes.

Briefly, the cell was operated at constant current density and the fluoride emission rate measured at regular intervals to determine the membrane life. This data was then used in conjunction with vendor data to obtain a life projection for next generation membranes. Currently, an advanced fuel processing system is being designed that is capable of reforming NG to a H_2-rich stream with less than 10 ppm of CO. Tests are being conducted to evaluate the kinetics and durability of reformer and methanation catalysts and detailed reactor designs are in progress.

Results

Steam for the reformer can be generated either inside the CSA coolers or, alternatively, outside the CSA by passing through the coolant through an expansion device under vacuum and then using a separator to separate the steam from liquid water. Table 2 summarizes the three different concepts with different steam generation approaches that were analyzed as a part of the system down-selection process. Tables 3 and 4 summarize the CSA operating conditions obtained using the three-dimensional CSA model.

TABLE 2. Summary of different concepts analyzed

Concept	Description
Concept 1	Ambient operation with steam generation outside CSA
Concept 2	Ambient operation with steam generation within CSA
Concept 3	Pressurized operation with steam generation within CSA

TABLE 3. Coolant operating conditions from CSA model

Concept	Flow rate per cooler (g/s)	Product water per cooler (g/s)	Coolant			
			Inlet		Exit	
			Temp (°C)	Press (kPag)	Temp (°C)	Press (kPag)
1	1.9	3.71e-3	47.0	-12.0	82.0	-6.5
2	0.7	-5.49e-2	67.0	-54.0	80.0	-48.5
3	0.9	-9.45e-3	47.0	-41.2	86.0	-35.7

Note: Negative values of product water added per cooler indicate removal of water from cooler.

Higher operating temperatures are much more conducive for steam generation. However, the CSA model indicates that it is difficult to achieve steam temperatures above 86ºC with the existing flow configuration and low to moderate operating pressures. Therefore, a concept with steam generation outside the stack was down-selected, the schematic for which system is shown in Figure 1 along with flows, operating pressures and component level power consumptions. Efficiencies and parasitic power for this baseline configuration are shown in Table 5. Higher efficiency can be traded for cost by increasing the number of cells. Figure 2 shows how variations in the parasitic power affect the required active area for a fixed electrical efficiency of 40%.

Figure 3 shows the fluoride emission vs. time for a current generation membrane as measured using the technique described earlier. Based on this data, the life of the current generation membrane was estimated to be around 23,000 hours. By extrapolating vendor data for next generation membranes, we have estimated that next generation membranes should last anywhere between 44,000 to 220,000 hours.

Conclusions and Future Directions

Our work to date has indicated that a 150-kW PEM stationary power plant based on NG is indeed feasible and can meet DOE requirements for efficiency and durability.

TABLE 1. Conditions for CSA analysis and membrane durability testing; 1% air bleed was used on the anode-side to mitigate CO contamination effects

Coolant			Cathode				Anode						
T_{in}	T_{out}	Flow	T_{out}	P_{out}	Util	O_2	T_{out}	P_{out}	Util	H_2	CO_2	CO	O_2
°C	°C	cc/min	°C	kPag	%	%	°C	kPag	%	%	%	%	%
60	90	315	80	50	60	21	60	50	80	79.8	20	0.001	0.2

TABLE 4. Reactant operating conditions and cell temperatures from the CSA model

Concept #	Avg cell temp (°C)	Hot spot temp (°C)	Cathode				Anode			
			Inlet		Exit		Inlet		Exit	
			Temp (°C)	Press (kPag)	Temp (°C)	Press (kPag)	Temp (°C)	Press (kPag)	Temp (°C)	Press (kPag)
1	75.9	84.1	37.0	13.3	68.2	0.0	71.0	7.3	60.7	0.0
2	78.1	82.6	37.0	13.3	79.3	0.0	71.0	7.3	77.4	0.0
3	83.7	88.9	37.0	56.3	78.8	50.0	71.0	52.3	76.9	50.0

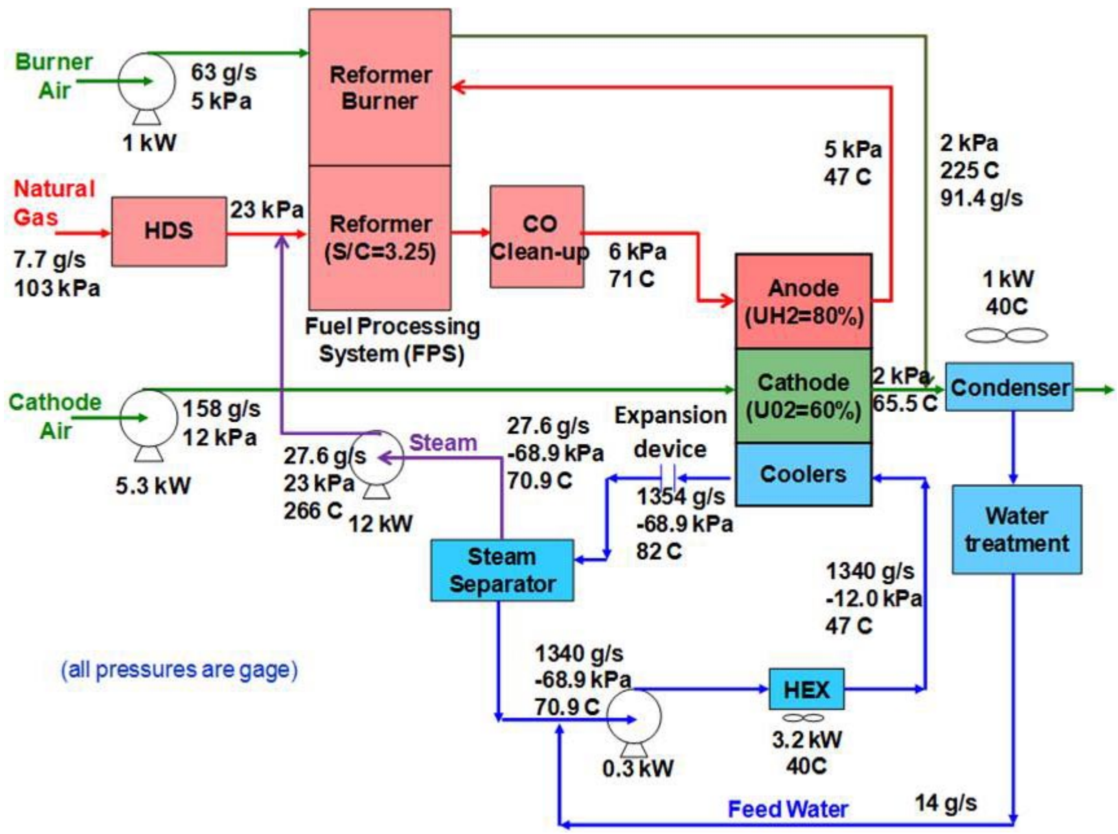

FIGURE 1. Schematic for down-selected baseline 150 kW PEM system based on concept 1

TABLE 5. Summary of operating efficiencies and parasitic power

Cell efficiency	54.4%
FPS efficiency	88.5%
PCS efficiency	97.0%
Mech. efficiency	85.7%
Electrical efficiency	40.0%
Gross kW	180
Parasite power (kW)	25.0

FPS – fuel processing system; PCS – power conditioning system

Preliminary systems analysis demonstrates that a 40% electrical efficiency can be achieved easily and that there is a path to achieving 45% efficiency by trading efficiency for cost by increasing the number of cells in the stack. The remainder of FY 2012 will focus on the following tasks:

- Develop and demonstrate an advanced fuel processing system (reformer plus methanator) capable of reforming NG to a H_2-rich stream with less than 10 ppm CO. (Go/No-Go decision: CO ppm levels cannot be reduced to less than 10 ppm.)
- Develop a high-level mass-energy balance model for the system.
- Conduct single-cell tests to evaluate performance and durability of next generation membranes and catalyst layers. (Go/No-Go decision: membrane durability cannot meet 50,000 hr requirement.)

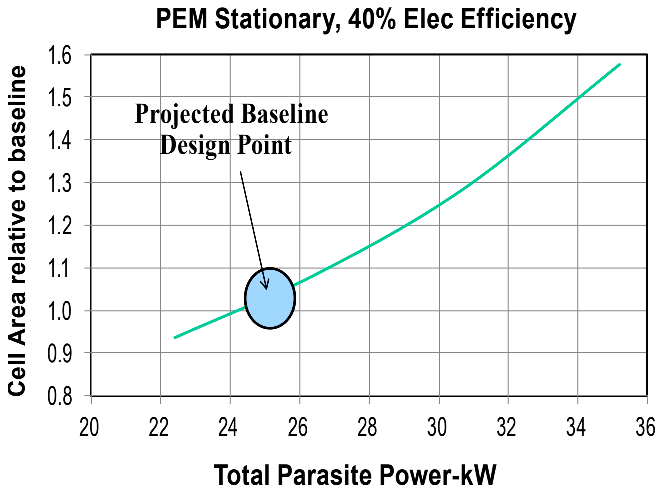

FIGURE 2. Effect of variation in total parasitic power on total active area required for 40% electrical efficiency

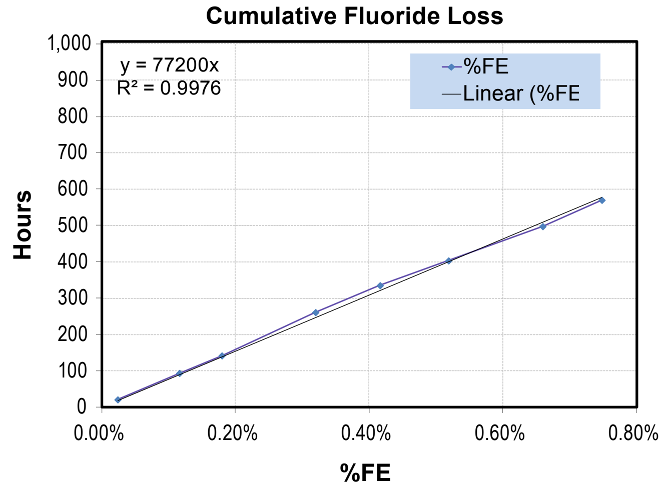

FIGURE 3. Cumulative fluoride loss vs. testing time for current generation membrane

FY 2012 Publications/Presentations

1. "Quarterly Research Performance Progress Report on 150 kw PEM fuel cell power plant verification", Jan 2012.

2. "PEM Stationary Power Plant", DOE Gate Review, Golden, CO, Feb 2012.

3. "Quarterly Research Performance Progress Report on 150 kw PEM fuel cell power plant verification", Apr 2012.