

Low-cost Co-Production of Hydrogen and Electricity

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Bloom Energy
June 10, 2008

Project ID
#FC11

Overview

Timeline

- Contract signed: Nov. 13, 2006
- Contract end date: Nov. 13, 2009
- To date: 50% complete

Budget

- Total 2005 DOE funding: \$2,480,000
- Total project value: \$4,973,601
- FY 2006 DOE funding: nil
- FY 2007 DOE funding: \$111,008
- FY 2008 Est. DOE funding: \$1,426,792
- FY 2009 Est. DOE funding: \$942,200

Barriers addressed

- Distributed H₂ production from natural gas
- Fuel Cells
 - A. Durability
 - B. Cost
 - C. Performance

Partners

- Univ. of Alaska, Fairbanks for performance validation
- Planar SOFC (PSOFC) system and project management by Bloom Energy
- H2 Pump LLC, Latham, NY

Objectives

- Demonstrate cost-effective, efficient, reliable and durable solid oxide fuel cells for stationary applications
- Determine the economics of hydrogen and electricity co-production for comparison to stand alone hydrogen production facilities
- Determine the feasibility of a delivered cost of hydrogen below \$2.50 per gge

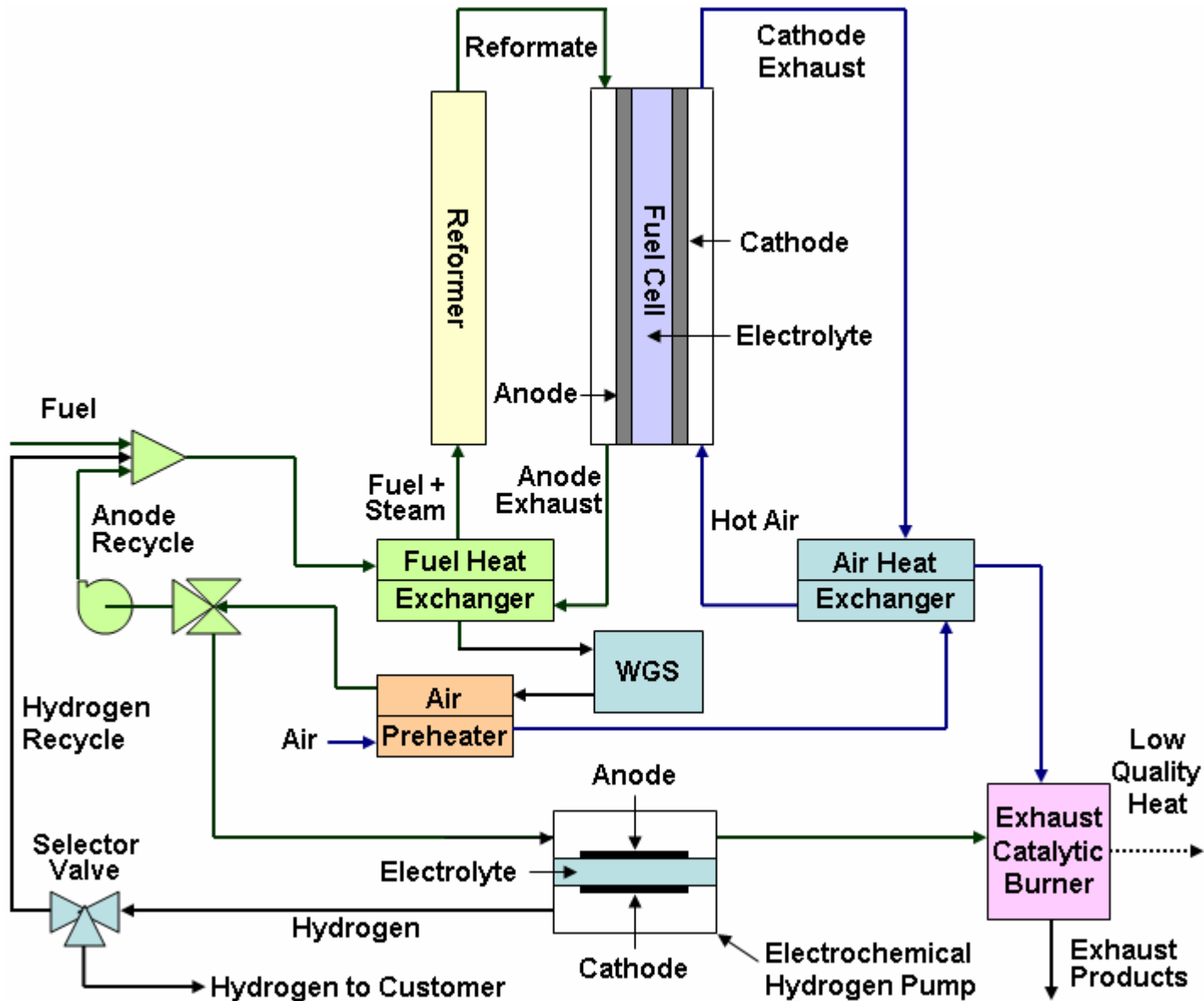
Milestones

- 2007 Milestones Met
 - Alaska demonstration-site selection, planning and design
 - Prototype scale H₂ pump testing
 - Optimization of PSOFC system
 - H₂ safety plan completed and reviewed
- 2008 Milestones
 - Site permitting, construction complete
 - Gas, electrical interconnections complete
 - PSOFC system installed and operational
 - Large scale H₂ pump specified, built, integrated into lab-based fuel cell & tested

Approach

- Phase One: System Preparation and Build
 - Task 1: Site selection & site design criteria (FY07)
 - Task 2: Initial H₂ pump design work (FY07)
 - Task 3: H₂ pump build and in-lab testing
 - PSOFC system build for site testing
 - Site build
- Phase Two: PSOFC Field Demonstration
 - H₂ pump system demonstration
 - Fuel cell demonstration in Alaska

PSOFC System Schematic with Hydrogen Byproduct



Site Design & Build

- Site design is complete
 - System will be housed in an enclosure due to Alaska temperature extremes
- Site build & system operational permitting was smooth
 - Excellent effort by Municipality of Anchorage & Design-Build General Contractor
 - Bloom Energy provided PSOFC technical & code review with Municipality of Anchorage prior to permit submittal
- Enclosure build has commenced. Trenching, concrete, & utility interconnects begin after ground thaws.
- Excellent relationship & effort with local utilities
 - Chugach Electric, Enstar Natural Gas, Anchorage Water & Wastewater Utility

Alaska Fuel Cell Site



PSOFC Demonstration Targets

- Deliver approximately 25kW of power ✓
- Run system primarily on natural gas ✓
- Demonstrate system is capable of running on a liquid fuel
- 45% peak net electric efficiency when run in electric-only mode ✓
- Run the system at 480 volts ✓
- Delivery system to Alaska in Q1 2008
- Operate for one year with minimum 70% uptime
 - Provide primary power for site
 - Operate in parallel with the grid
- Remotely monitor system from Bloom Energy

PSOFC System

Accomplishments/Progress/Results

- Demonstrated rated power of 25kW PSOFC system on natural gas using standard Bloom Energy hot box
- All BoP components have been validated with a run exceeding 3000 hours on original hardware
- Demonstrated >45% PSOFC system efficiency
 $\eta = (\text{AC power exported to grid}) / (\text{LHV natural gas})$
- Operation learning from steady state and transient conditions on natural gas were implemented into the controls code
- Team of operators trained for round-the-clock system monitoring

PSOFC System Future Work

- Delivery system to Alaska in Q1 2008 *will move to Q3 2008*
- Operate for one year with minimum 70% uptime
- Connect the system to run in parallel to the grid while feeding an actual customer's load: *utility grid interconnection approval expected in June 2008*
- Remotely monitor system from Bloom Energy offices in California: *no issues expected*
- Demonstrate system is capable of running on a liquid fuel: *planned for June 2009*

H₂ Demonstration Targets

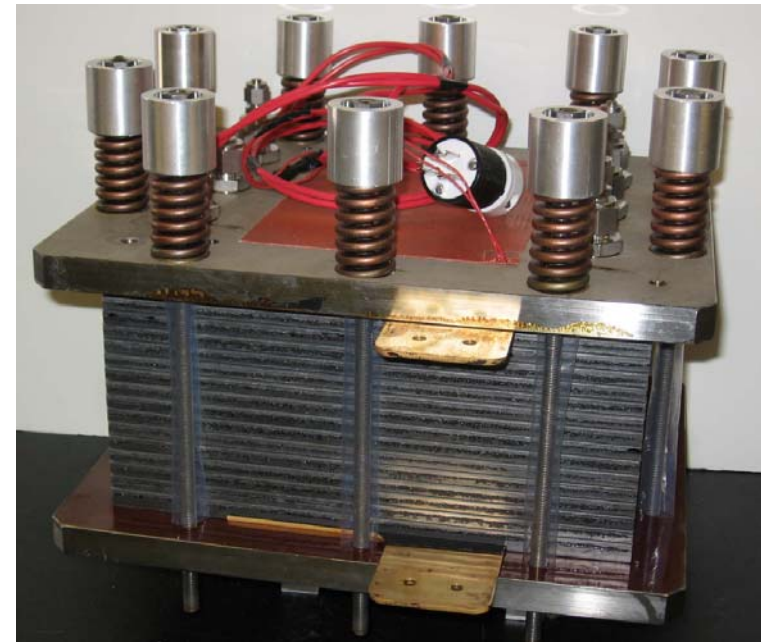
- Produce maximum of 19 kg of H₂ per day when PSOFC runs in H₂ mode
- Target purity of H₂ sufficient to power a PEM fuel cell
- Less than 5% performance degradation of H₂ production

H₂ Recovery

Accomplishments/Progress/Results

H2 Pump LLC's 15 cell prototype H₂ pumping module

- Anode exhaust from a Bloom Energy PSOFC stack was directed to the H₂ pump inlet and current applied to the pump
- H₂ output flows were measured as were the power and fuel utilization data
- Gas purity measurements were performed at the inlet and outlet of the device

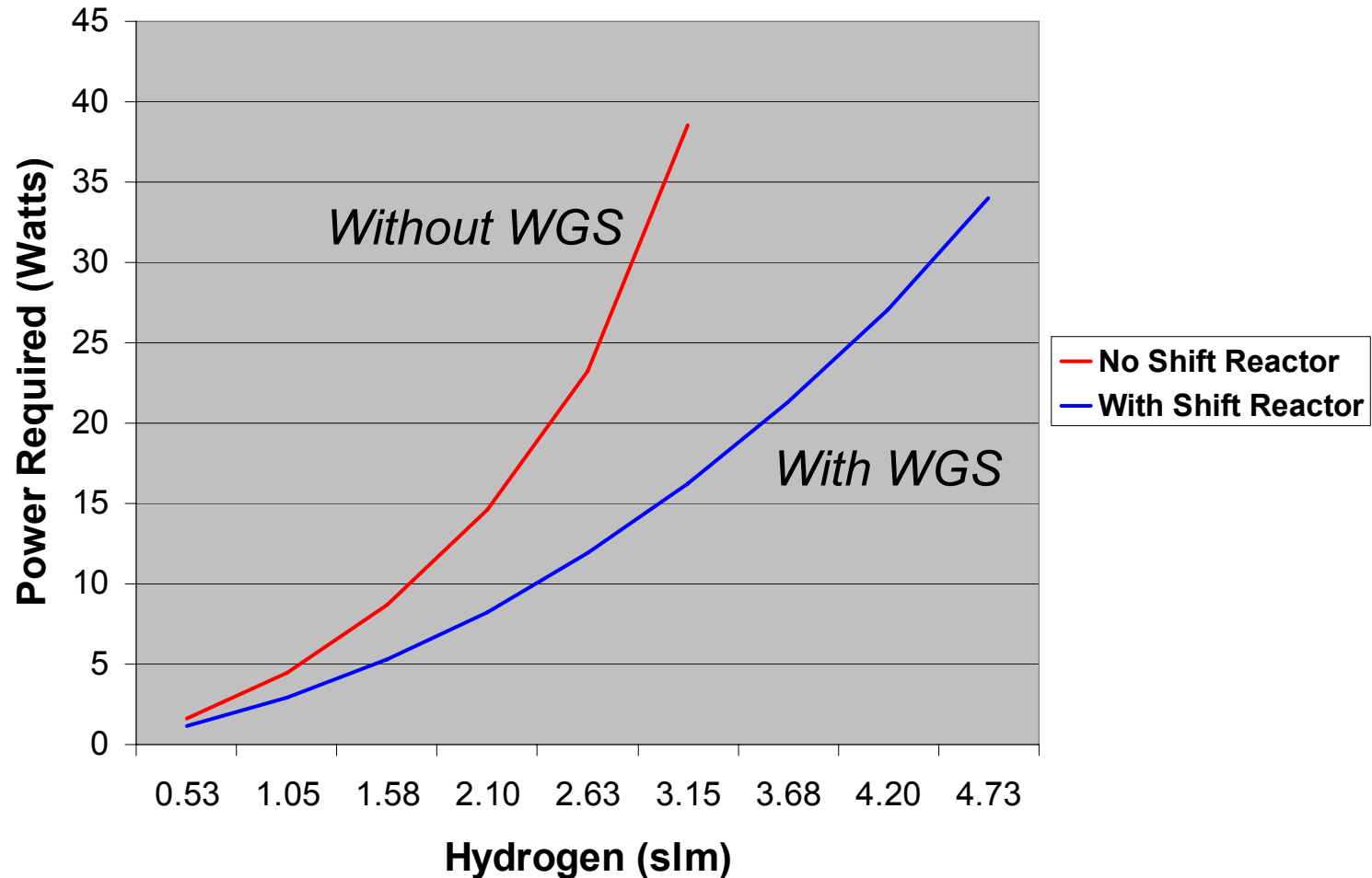


H2 Pump LLC

Why Use Electrochemical H₂ Pumping?

- Pumping is scalable
- High electrochemical efficiency (low power required/kg H₂)
~\$0.12/kg H₂ @ \$0.10/kW-hr electrical costs
- > 90% H₂ recovery from a variable % H₂ inlet gas composition
- Continuous flow device having near infinite turn down ratio with minimal parasitics when not pumping hydrogen
- Can pump hydrogen “on demand”
- Creates required system pressure (up to ~5 psig)

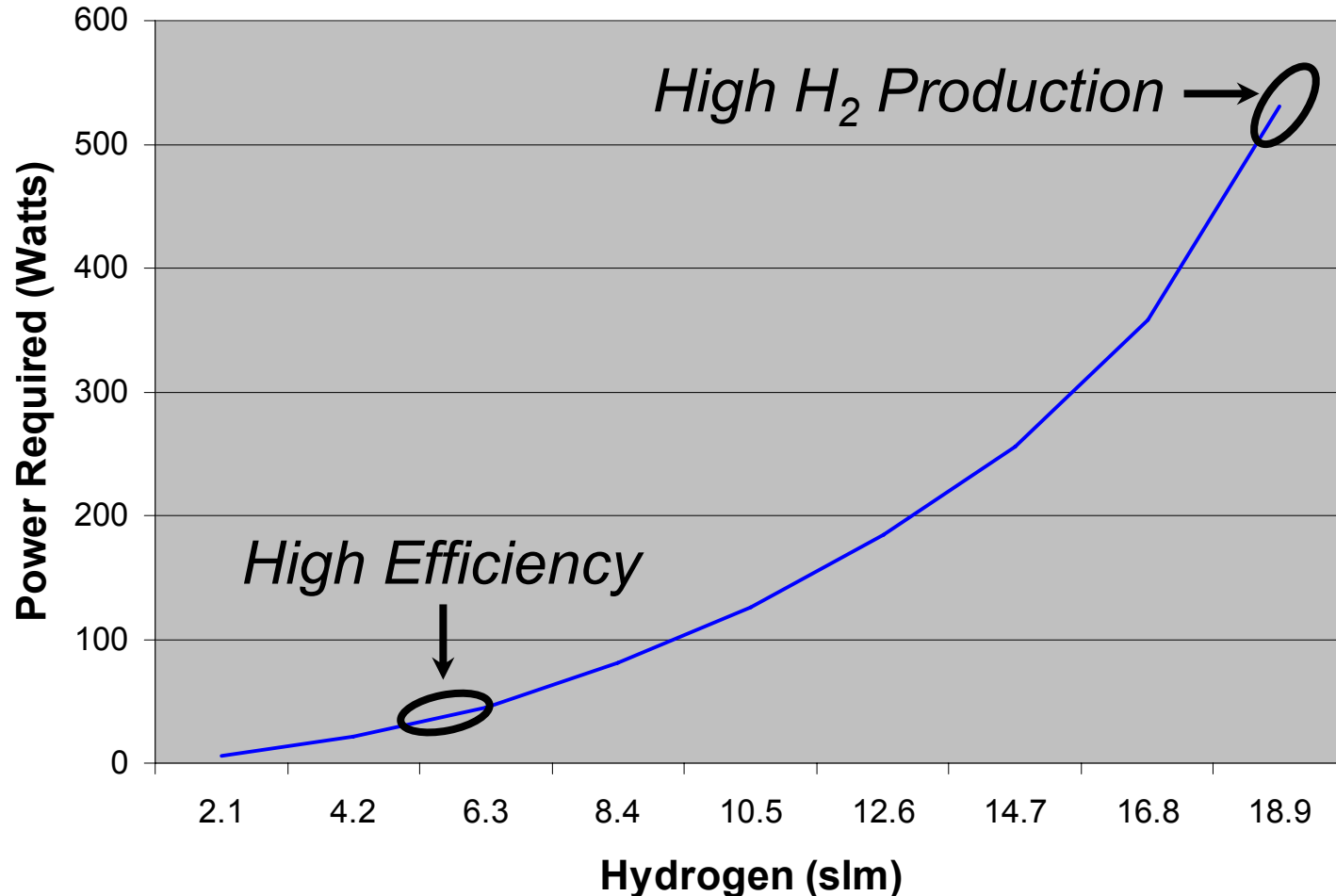
Power Required to Pump Hydrogen with and without Water Gas Shift (WGS) Reactor



15-cell H₂ pump performance fed with PSOFCC exhaust

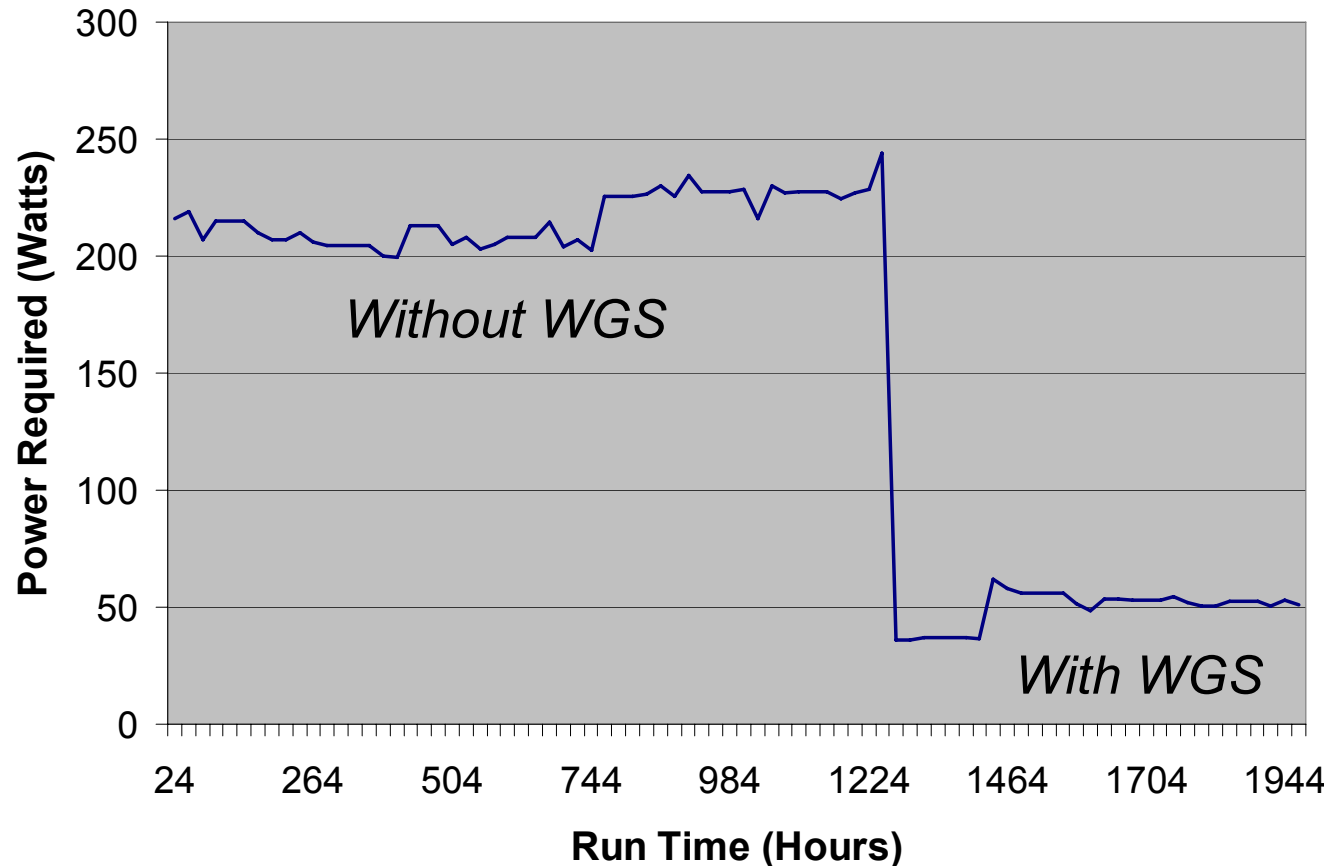
H₂ Pump Capability with WGS

PSOFC @ 0A with 5.37 slm Reformed Natural Gas



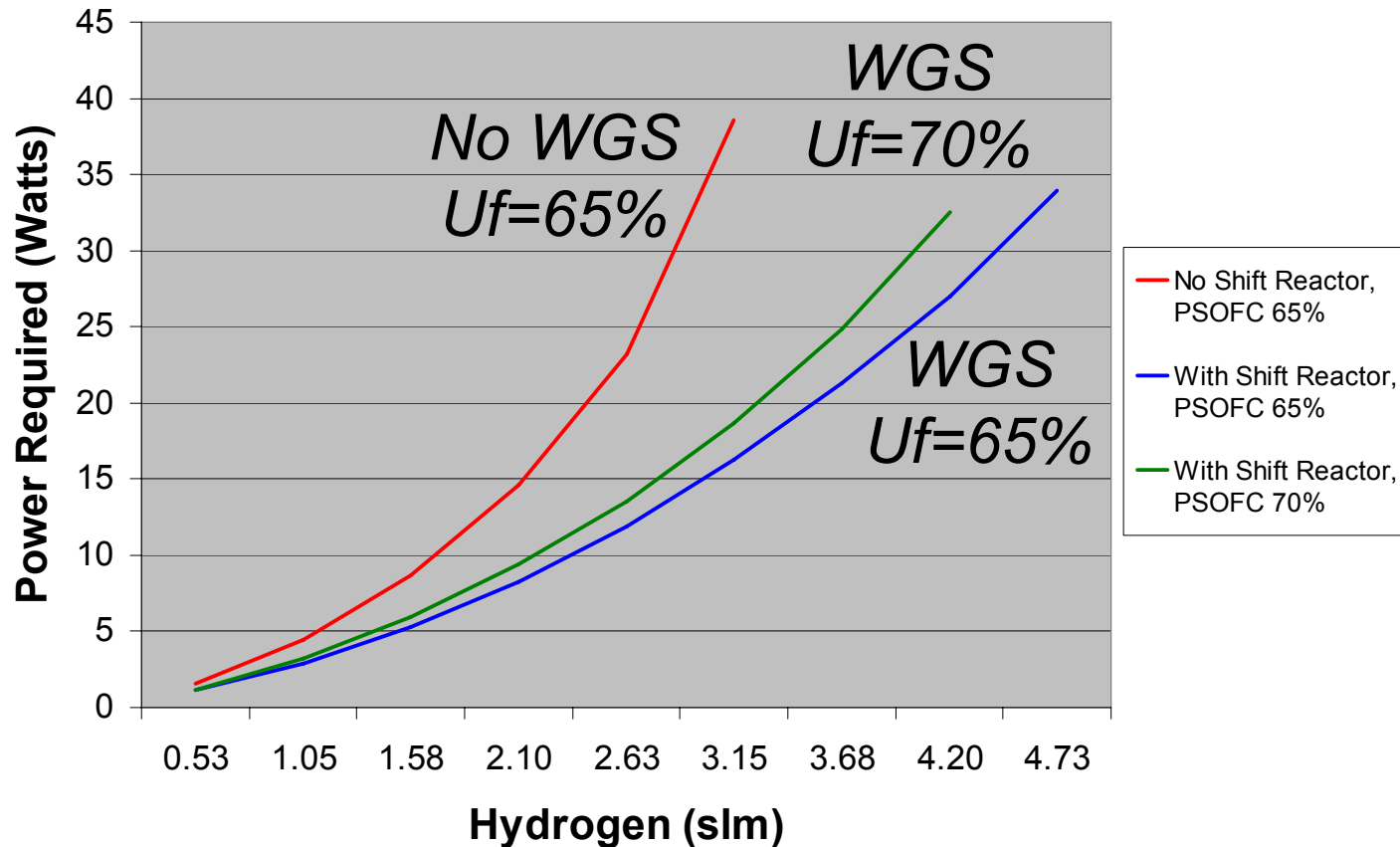
15-cell H₂ pump performance extrapolates to a 120-cell H₂ pump design to meet goal of 19 kg/day at high H₂ production

Pump Daily Power Readings Extracting 4.83 slm of H₂ (with & without WGS)



- Water Gas Shift (WGS) reactor installed at 1272 hours
- Fuel utilization (U_f) of PSOFC increased from 65% to 70% at 1440 hours

Water Gas Shift (WGS) Reactor Testing Summary



With extra H₂ extracted from water by the WGS reactor, it was feasible to increase the fuel utilization (Uf) on the PSOFC from 65% to 70% (5.79 slm to 5.37 slm of Natural Gas fuel to the PSOFC respectively)

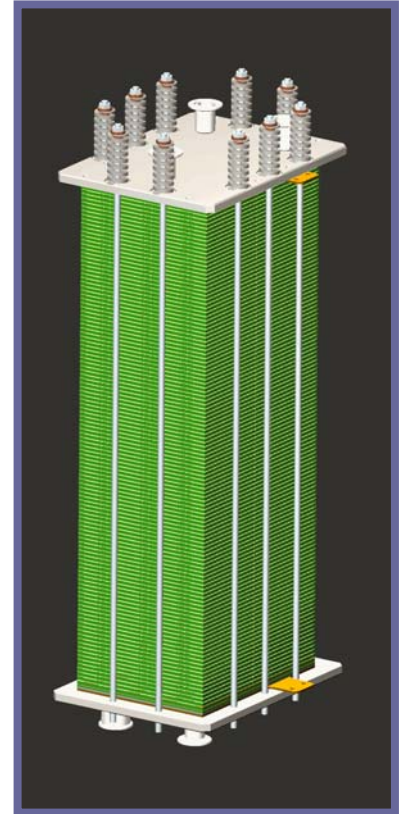
Gas Purity Analysis Summary

First Prototype H₂ Pump

- Testing with an H₂ pump showed that with a relevant Bloom Energy PSOFC anode exhaust gas composition, 980:1 reduction in CO₂ and 2600:1 reduction in CO from input to outlet was achievable at low power
- Therefore, 10% CO₂ on the inlet will result in ~100 ppm CO₂ at the outlet and 1% CO in the inlet will result in ~4 ppm while operating at low power
- Higher power/higher flows for hydrogen production will increase the purity
 - Proportional to flow
 - Proportional to square root of power

H₂ Future Work

- Test & optimize 120-cell H₂ pump at Bloom Energy California facility
- Integrate 120-cell H₂ pump with California-located Bloom Energy PSOFC system
- Economic analysis of hydrogen production



Summary

- >3000 hr PSOFC system run validated system design and balance of plant components
- Demonstrated rated power of PSOFC system
- Demonstrated >45% PSOFC system efficiency
 $\eta = (\text{AC power exported to grid}) / (\text{LHV natural gas})$
- Demonstrated remote monitoring of PSOFC system
- Hydrogen pump design validated with 15-cell prototype connected to PSOFC test stand
- 120-cell hydrogen pump in fabrication
- Alaska site construction commenced