Low-cost Co-Production of Hydrogen and Electricity

Fred Mitlitsky

Bloom Energy

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Project ID #FC11

Overview

Timeline

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

Barriers addressed

- Distributed H_2 production from natural gas
- Fuel Cells
  - A. Durability
  - B. Cost
  - C. Performance

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

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

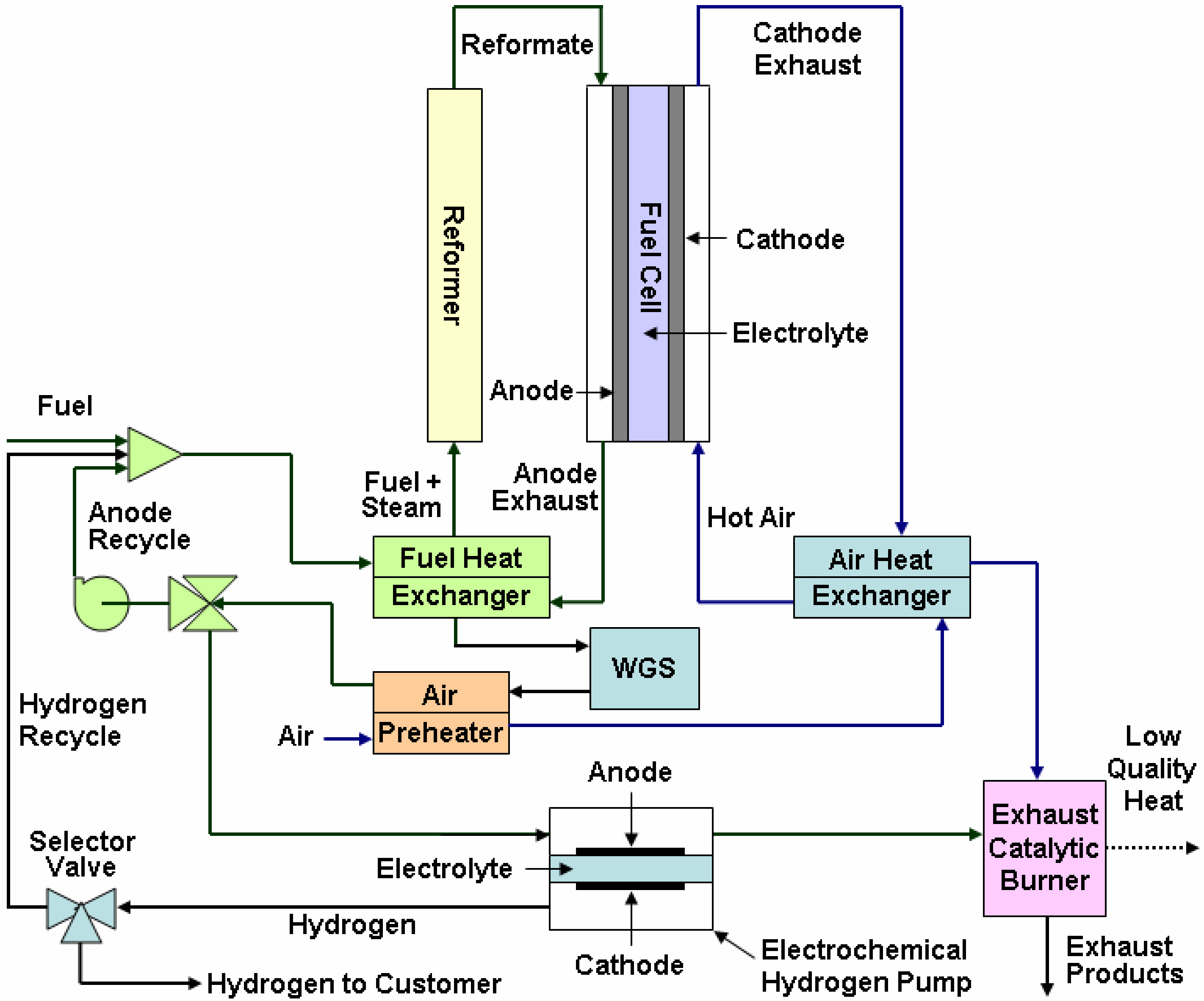
Milestones

- 2007 Milestones Met
  - Alaska demonstration-site selection, planning and design
  - Prototype scale H_2 pump testing
  - Optimization of PSOFC system
  - H_2 safety plan completed and reviewed
- 2008 Milestones
  - Site permitting, construction complete
  - Gas, electrical interconnections complete
  - PSOFC system installed and operational
  - Large scale H_2 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 H_2 pump design work (FY07)
  - Task 3: H_2 pump build and in-lab testing
    PSOFC system build for site testing
    Site build
- Phase Two: PSOFC Field Demonstration
  - H_2 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
  η = (AC power exported to grid) / (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*

H_2 Demonstration Targets

- Produce maximum of 19 kg of H_2 per day when PSOFC runs in H_2 mode
- Target purity of H_2 sufficient to power a PEM fuel cell
- Less than 5% performance degradation of H_2 production

H_2 Recovery Accomplishments/Progress/Results

H2 Pump LLC's 15 cell prototype H_2 pumping module

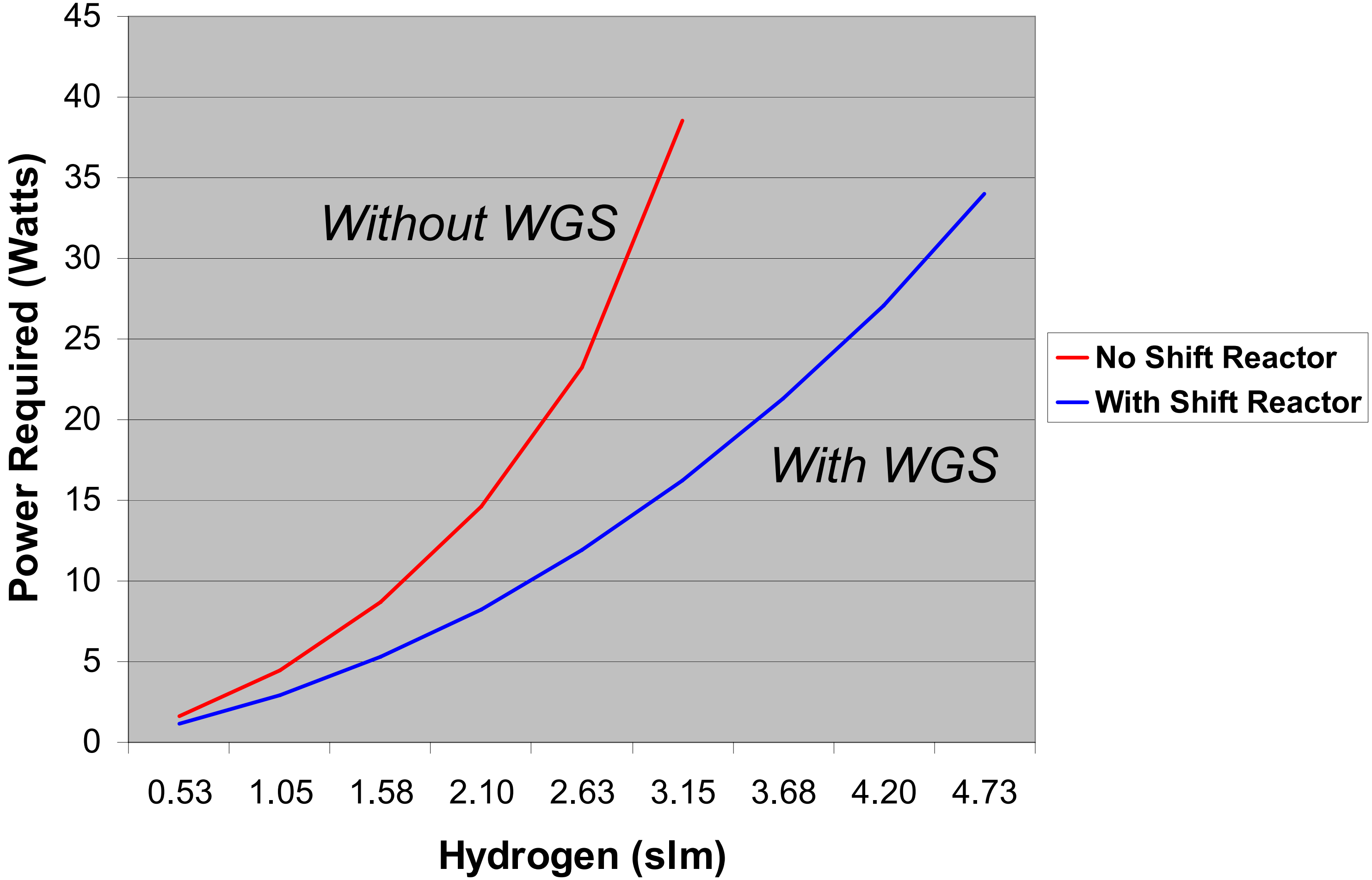
- Anode exhaust from a Bloom Energy PSOFC stack was directed to the H_2 pump inlet and current applied to the pump
- H_2 output flows were measured as were the power and fuel utilization data
- Gas purity measurements were performed at the inlet and outlet of the device

H2 Pump LLC

Why Use Electrochemical H_2 Pumping?

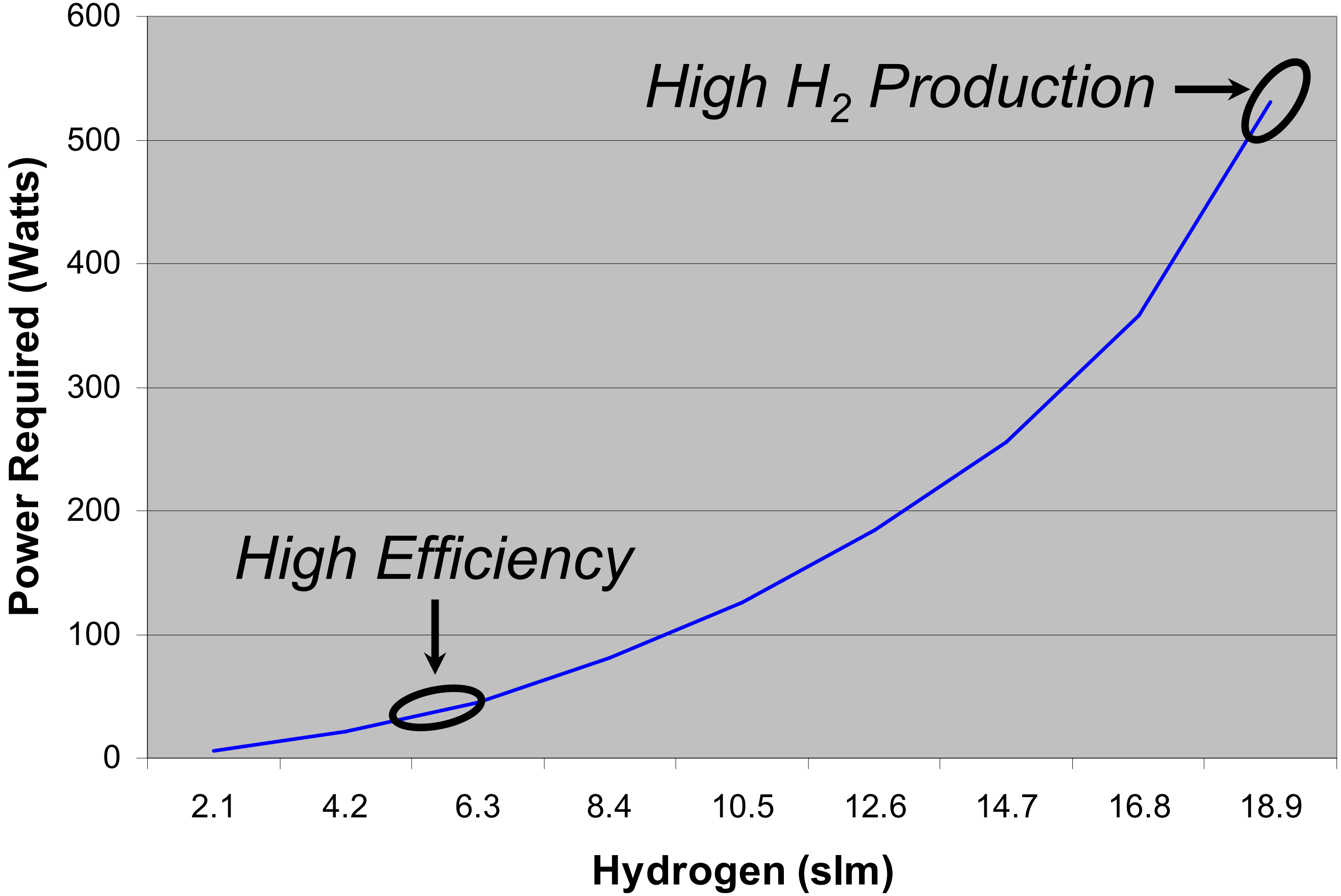
- Pumping is scalable
- High electrochemical efficiency (low power required/kg H_2)
  ~\$0.12/kg H_2 @ \$0.10/kW-hr electrical costs
- > 90% H_2 recovery from a variable % H_2 inlet gas composition
- Continuous flow device having near infinite turn down ratio with minimal parasitics when not pumping 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



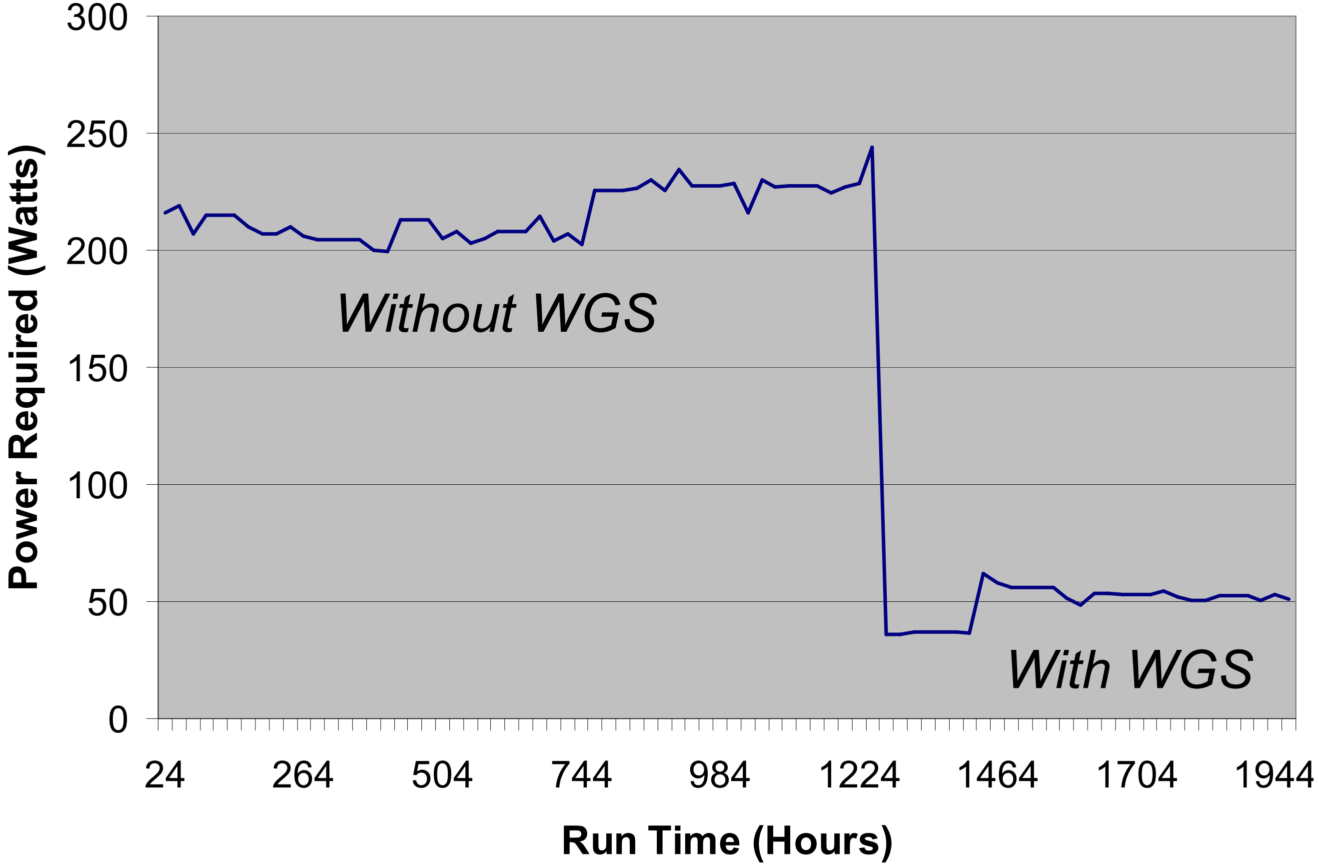
15-cell H_2 pump performance fed with PSOFC exhaust

H_2 Pump Capability with WGS PSOFC @ 0A with 5.37 slm Reformed Natural Gas



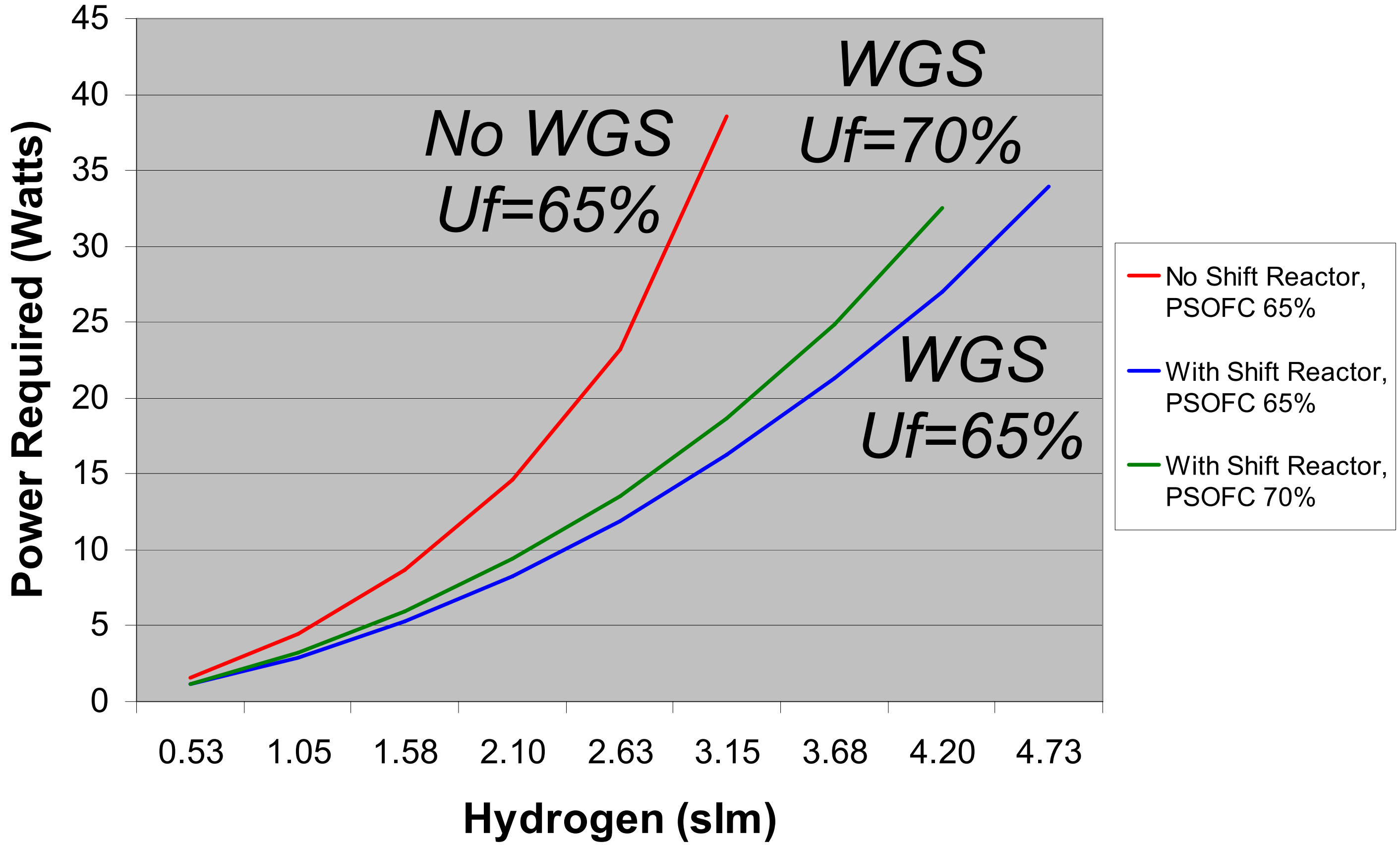
15-cell H_2 pump performance extrapolates to a 120-cell H_2 pump design to meet goal of 19 kg/day at high H_2 production

Pump Daily Power Readings Extracting 4.83 slm of H_2 (with & without WGS)



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

Water Gas Shift (WGS) Reactor Testing Summary



With extra H_2 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 H_2 Pump

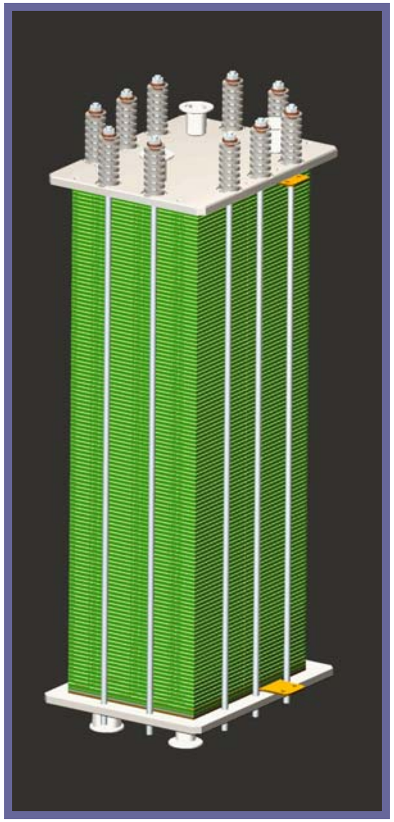
- Testing with an H_2 pump showed that with a relevant Bloom Energy PSOFC anode exhaust gas composition, 980:1 reduction in CO_2 and 2600:1 reduction in CO from input to outlet was achievable at low power

- Therefore, 10% CO_2 on the inlet will result in ~100 ppm CO_2 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

H_2 Future Work

- Test & optimize 120-cell H_2 pump at Bloom Energy California facility
- Integrate 120-cell H_2 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
  η = (AC power exported to grid) / (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