Low-cost Co-Production of Hydrogen and Electricity

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Project ID
#FCP 37

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Overview

Timeline

- Contract signed: Nov. 13, 2006
- Contract end date: May 31, 2009
- To date: 20% complete

Barriers addressed

- Distributed hydrogen production from natural gas
  - A. Reformer capital costs
  - B. Reformer Manufacturing
  - C. Operation & Maintenance
- Fuel Cells
  - A. Durability
  - B. Cost
  - C. Performance

Budget

- Total project funding $4,973,601
- FY 2006 funding: nil
- FY 2007 funding: $2.48M*
  - 50/50 cost share

Partners

- Commercial site for Alaska demonstration
- Univ. of Alaska, Fairbanks for performance validation
- Planar SOFC system and project management by Bloom Energy

* DOE 2005 funding

Objectives

Overall	• Demonstrate cost-effective, efficient, reliable and durable solid oxide fuel cells for stationary applications • Determine the feasibility of a delivered cost of hydrogen below $2.50 per gge • Determine the economics of hydrogen and electricity co-production for comparison to stand alone hydrogen production facilities
2006 closed items	• Selection of commercial demonstration partner - interested in both stand-alone energy generation and use of delivered, cost effective hydrogen to fuel their fleet vehicles • Identification of hydrogen production solutions
2007	• Site selection, site design, site construction • Planar solid oxide fuel cell (PSOFC) system build • Down selection of hydrogen production system • Hydrogen production system build, test & optimization • Combined PSOFC & hydrogen production systems in-lab testing • PSOFC system readiness for 2008 field demonstration start

Approach

- Build and test a planar solid oxide fuel cell electricity generating facility that runs on natural gas
- Evaluate hydrogen production systems; select one for in-system, on-site demonstration; procure, test & integrate
- Commercial customer site demonstration of PSOFC technology for co-production of electricity and hydrogen
- Performance validation by independent, third party (University of Alaska, Fairbanks)

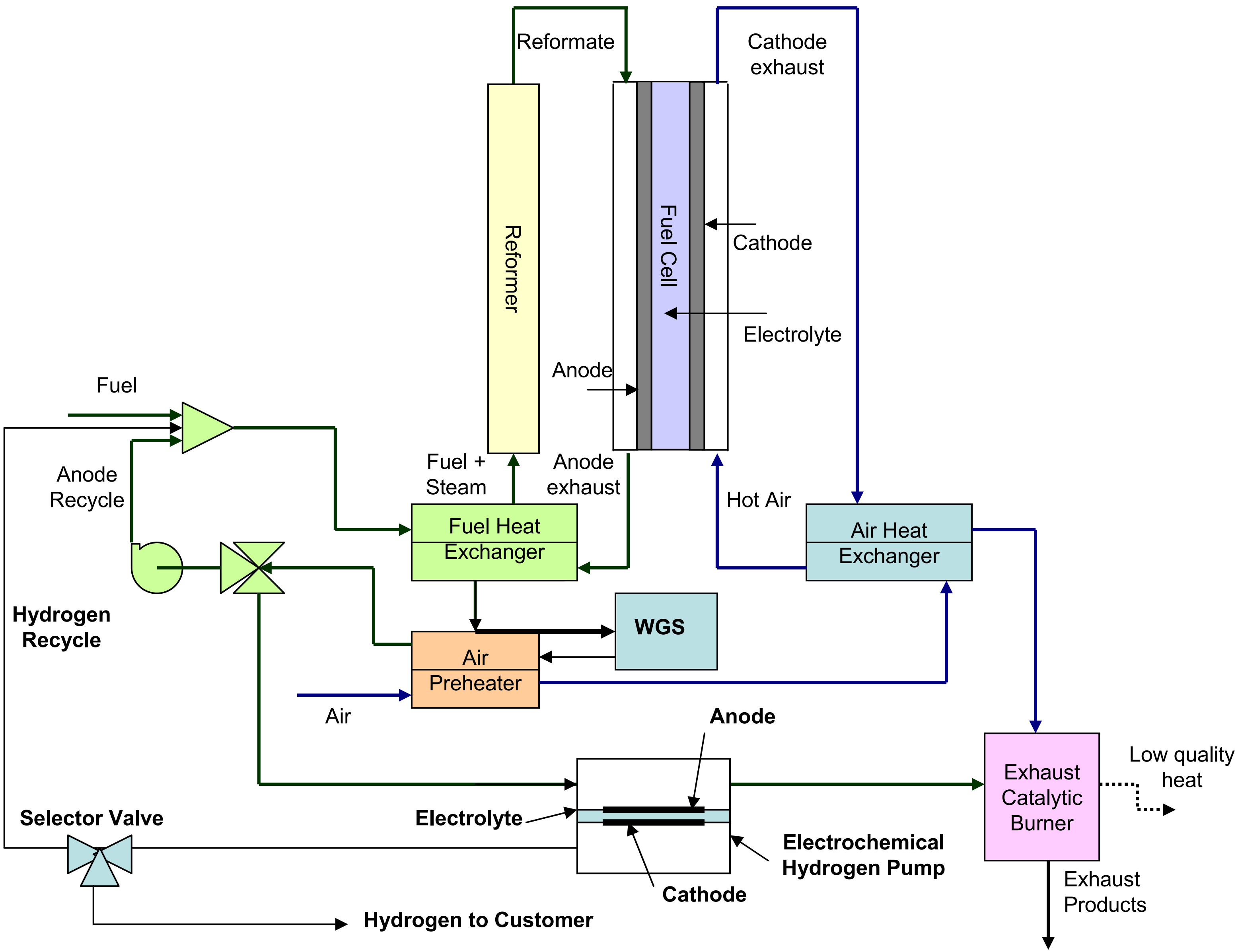
Technical Accomplishments/ Progress/Results

- 2006: Core technology demonstrated at Univ. of TN at Chattanooga
  - >8000 system hours logged at UTC as of 4/6/07
- Q1 2007: Alaska site visit exposes unique systems & site design criteria
  - Low temperature extreme of -35 deg C
  - Class 5 earthquake zone
  - “Dirty” natural gas delivery (occasionally includes liquids and sediments)
- Q1 2007: Down selection of hydrogen production solution
  - Anode exhaust hydrogen separation and recycle commercial solution chosen
  - Partial pressure swing adsorption (PPSA) R&D cycle will exceed project schedule
- Q1 2007: Hydrogen pump prototype designed, developed and delivered by a third-party supplier; testing begun

Future location of PSOFC
(new enclosure to be built)

Low-Cost Co-Production of Hydrogen and Electricity

PSOFC System Schematic with Hydrogen Byproduct

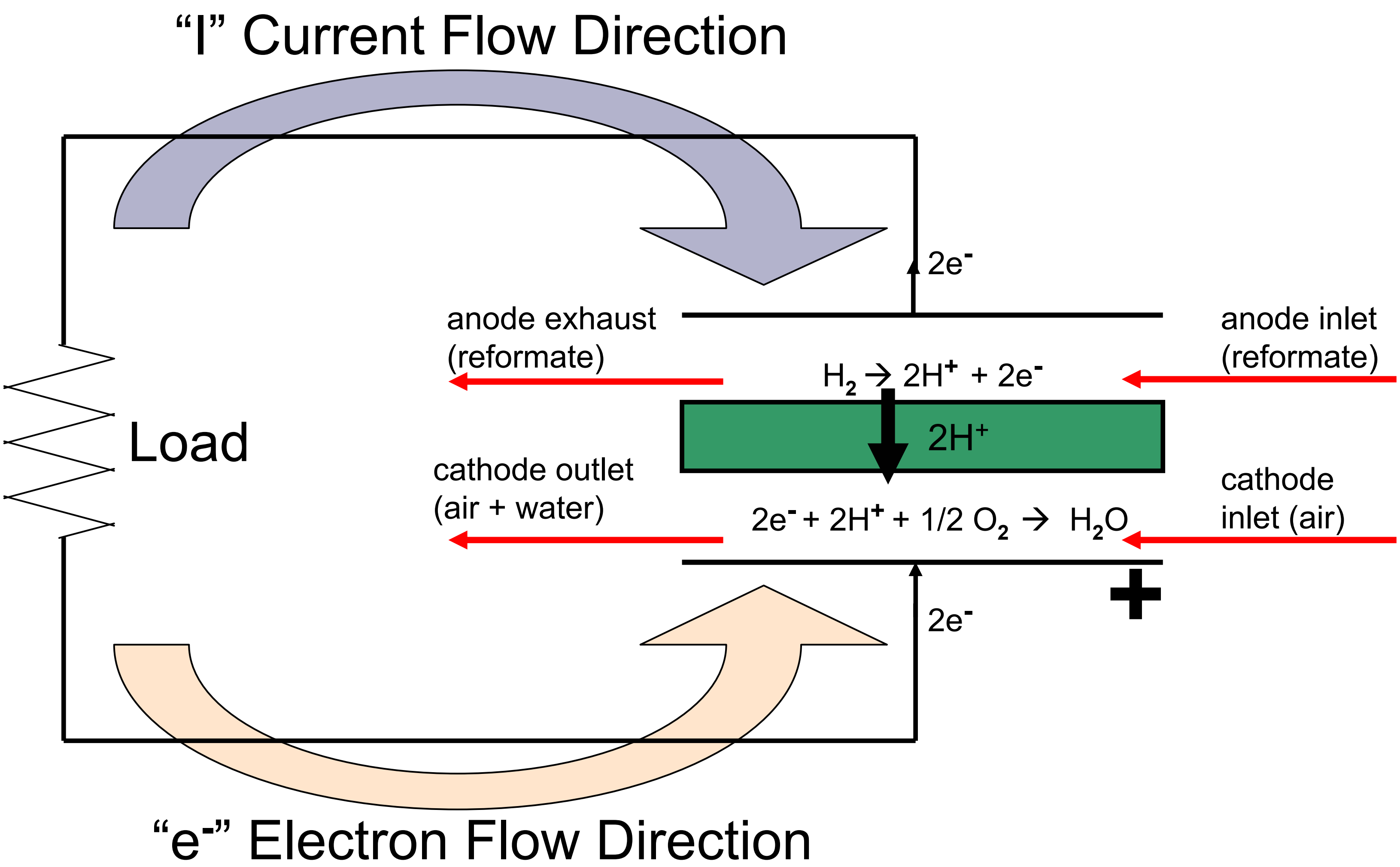


Advantages of Electrochemical Hydrogen Separation & Recycle

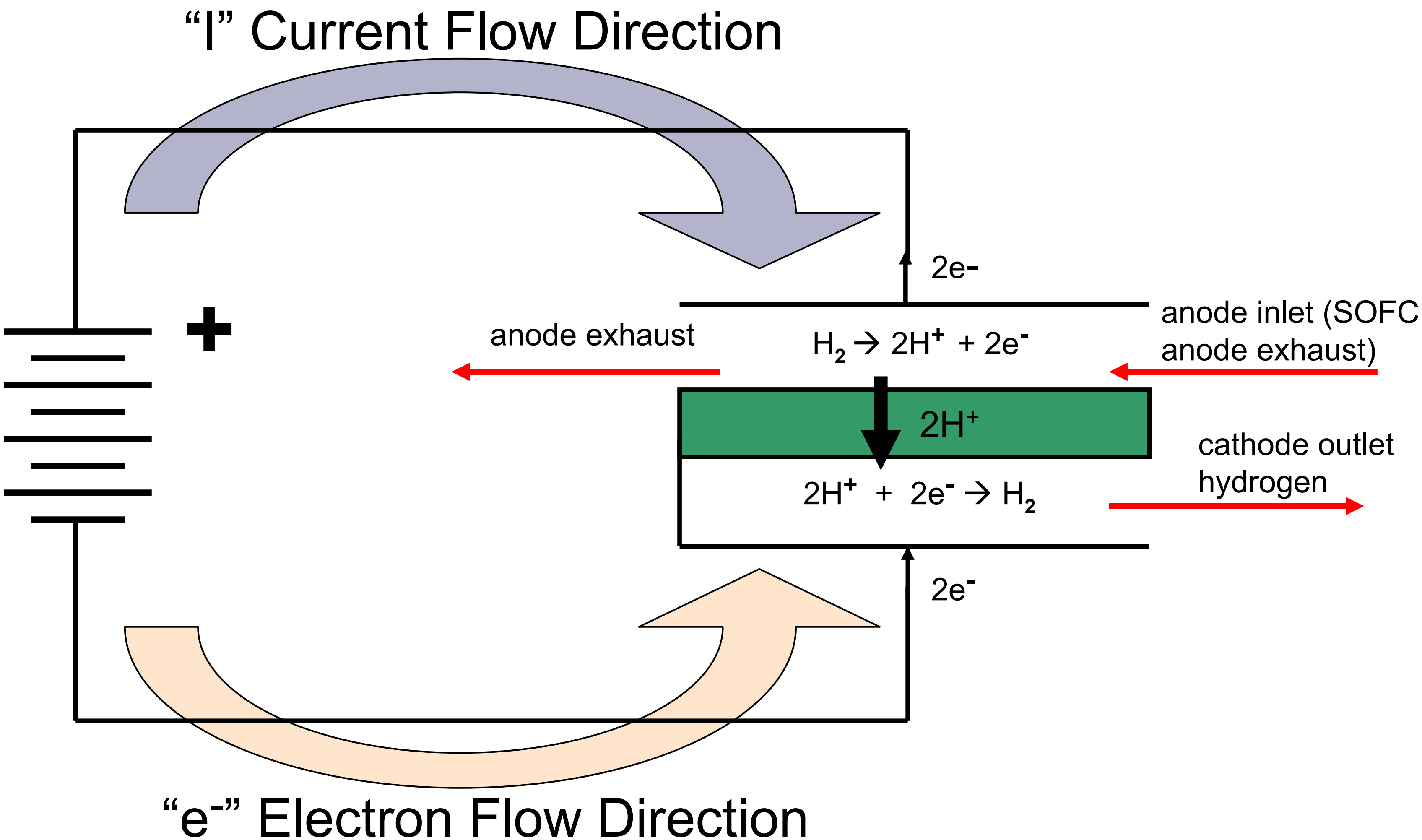
- High overall fuel utilization
- Higher cell Nernst voltage level

Higher system efficiency

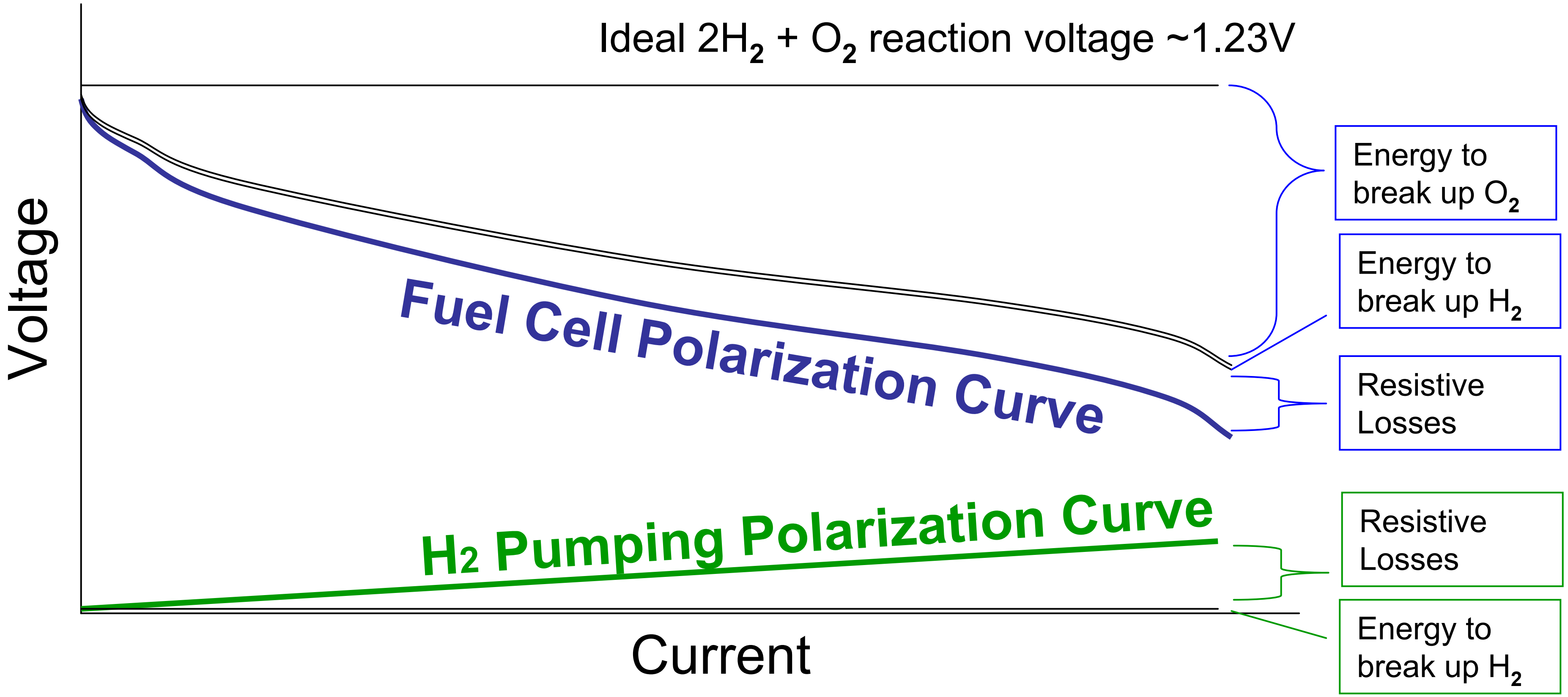
PEM Fuel Cell Fundamentals



PEM Hydrogen Pumping Fundamentals

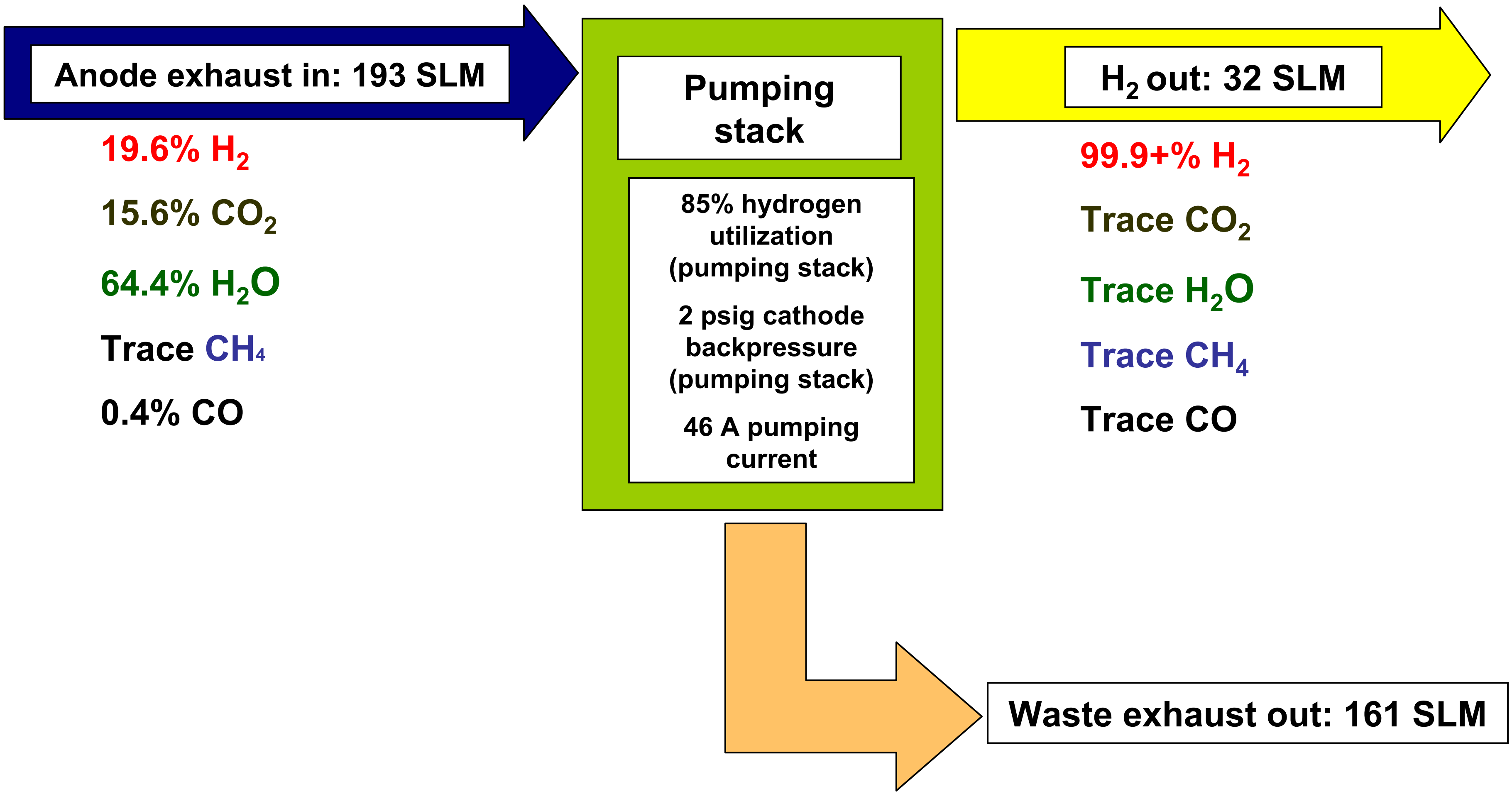


PEM Hydrogen Pumping Characteristics



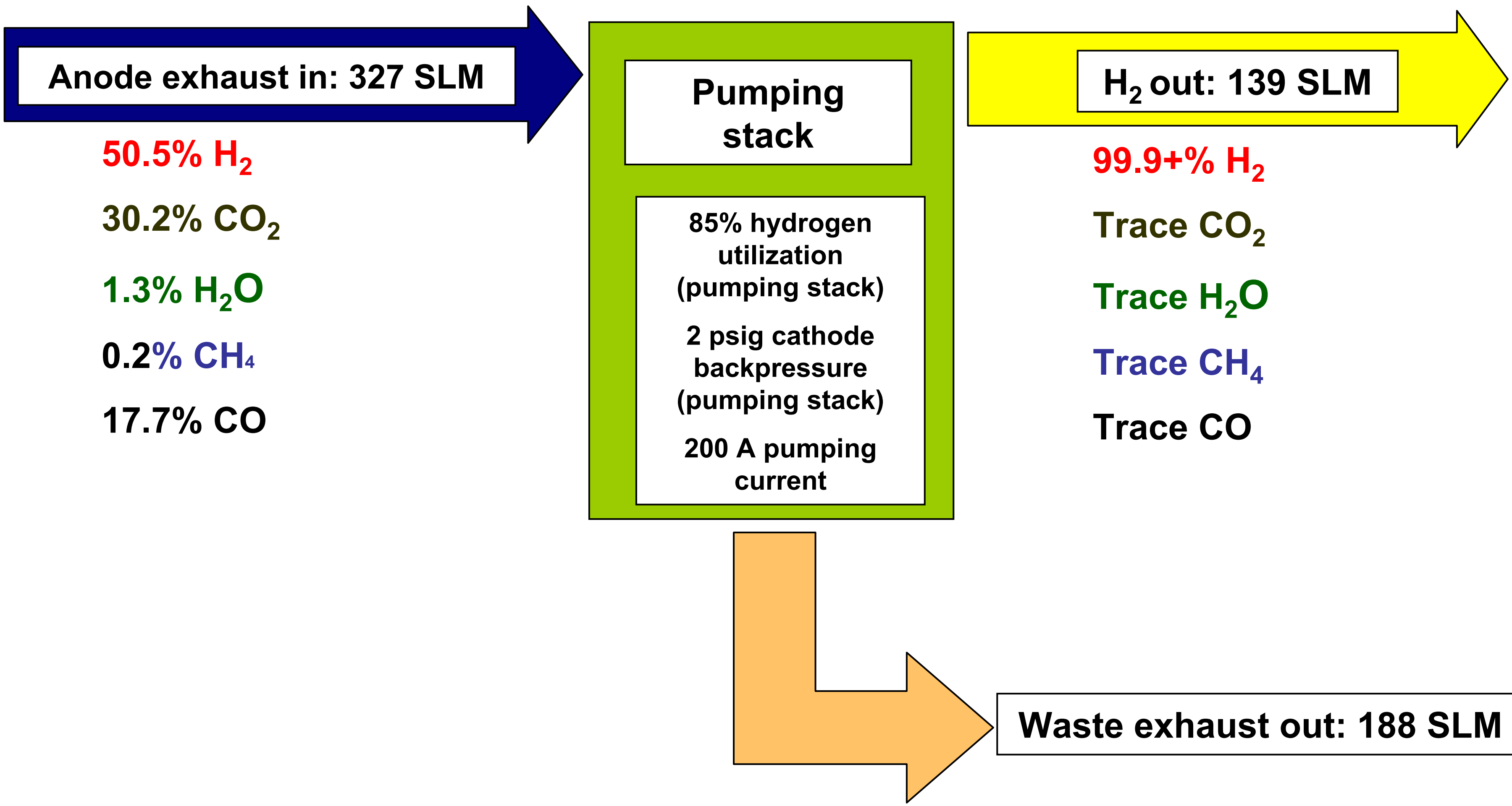
Alaska Project Hydrogen Pumping

(Hydrogen recycled to PSOFC fuel inlet)



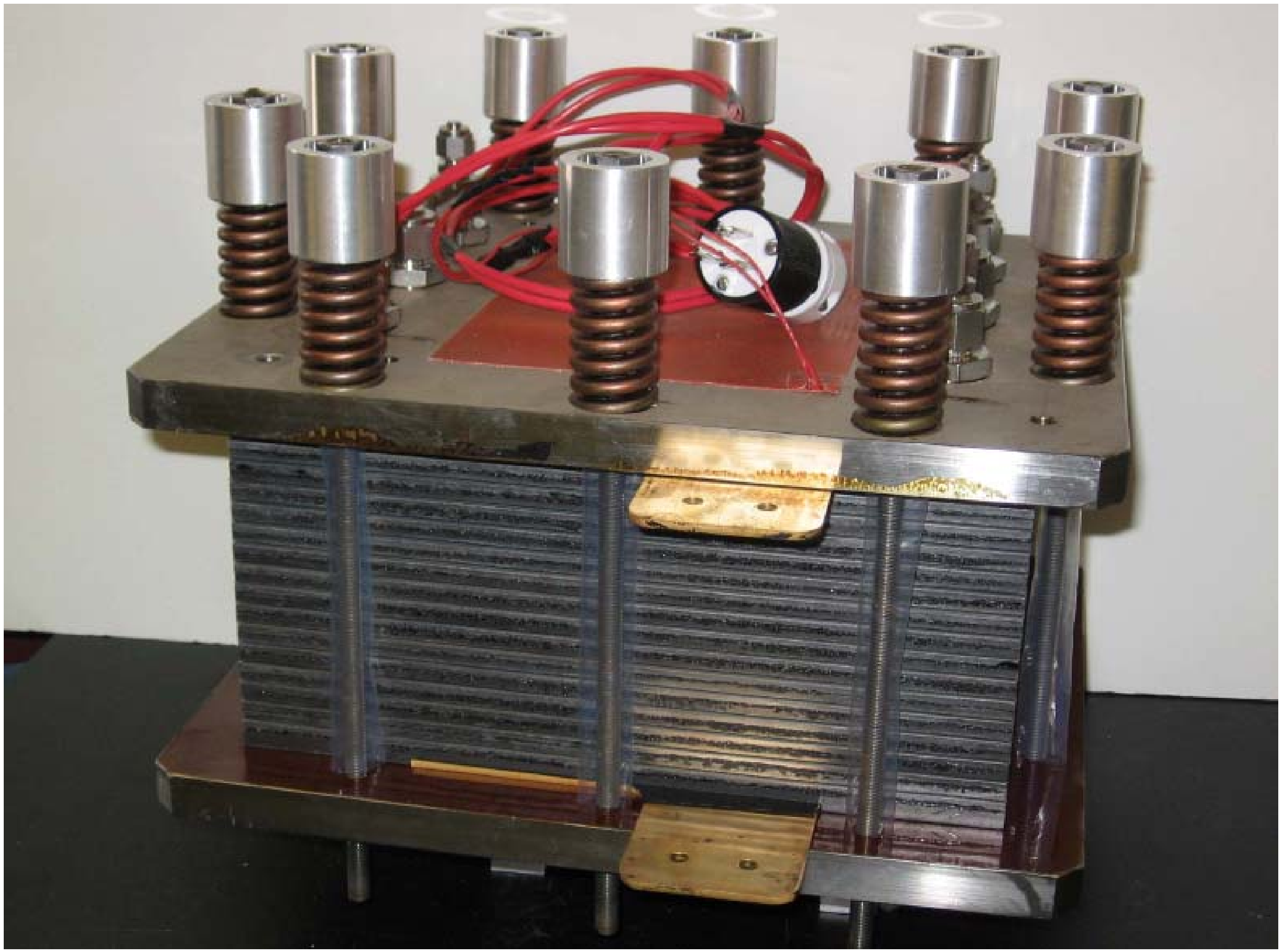
Alaska Project Hydrogen Pumping

(Hydrogen delivered for use outside the PSOFC system)



Hydrogen pump prototype

Purchased for test and evaluation



Future Work

- Build a PSOFC generating facility for Alaska installation
- Validate hydrogen pump prototype unit
  - Stand alone *and* integrated into PSOFC system
- Procure hydrogen pump production unit for Alaska installation
  - Validate in stand alone mode *and* integrated into PSOFC system
- Site design, engineering and construction
- Finalize hydrogen safety plan
- 2008 system demonstration readiness
- Complete economic modeling

Summary

- Bloom Energy PSOFC technology has logged over 8000 system hours (as of 4/6/07) as part of the DOE/EERE Chattanooga Fuel Cell Demonstration Project
- An engaged commercial demonstration partner and a technically challenging site in Alaska has been selected
- Down selected hydrogen production solution: will progress with a hydrogen pump
- At 20% complete, this project is on budget and on schedule

Additional Slides

History of Hydrogen Pumping

1962-66	Hydrogen pumping observed as a fuel cell failure mode during Gemini program.
1972	Hydrogen expansion cell (reversed hydrogen pumping) demonstrated (energy recovery and flow control).
1973	Proposal to NASA to use hydrogen pump to separate H_2 from N_2+H_2 mix.
1980-82	First product use. NASA / Air Force. Hydrogen pump to keep H_2 bubble away from water inlet side of electrolyzer. (Operated thousands of hours without failure.)

History of Hydrogen Pumping (continued)

1980	GE paper on uses of hydrogen pumping (separation including natural gas).
1985-90	NASA. Zero gravity phase separator. Hydrogen pump to remove H_2 from H_2-saturated water. ~3000 hours operation.
1995	NASA. CH_4+O_2 production on Mars. Process using hydrogen pumping to remove H_2 from CH_4+H_2O+H_2 stream. ~1000 hours operation.
2002	Fuel cell anode exhaust hydrogen separation and compression to 100 psig differential (100 cell stack demonstrated for over one year without detectable degradation).

PEM History With High Differential Pressure

Date	Application	Membrane Differential Pressure	Endurance Run
Early 70's	NASA O_2 compressor	2950 psi; one cell test with 5000 psi D/P	
Early 70's	Aircraft O_2 generator	350 psi D/P	
Early 70's	Military space – energy storage regenerative fuel cells	550 psi D/P	
Early 70's	Navy electrolyzer (basis of Proton Energy product kick-off)	200-400 psi D/P	➢100 mm cell hrs ➢40,000 stack hrs
Late 80's / Early 90's	Rocket propellant generator	1000 psi D/P	
Mid 90's	Virginia-class submarine O_2 generator	750 psi D/P; one stack test with 1000 psi D/P	>25,000 stack hrs
Late 90's	Aircraft O_2 generator	2000 psi D/P	>20,000 stack hrs