DOE Hydrogen Program

Low-cost Co-Production of Hydrogen and Electricity

Fred Mitlitsky

Bloom Energy Corporation

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Project ID
#FC_46_Mitlitsky

Overview

Timeline

- Contract signed: November 13, 2006
- Contract end date: December, 2009
- To date: 65% complete

Budget

- Total project funding: $4,973,601
  - DOE share: $2,480,000
  - Contractor share: $2,493,601
- Funding received in FY08: $933,153
- Estimated FY09 funding: $1,435,838

Barriers addressed

- Distributed hydrogen production from natural gas: purity, volume, cost
- Fuel Cells: durability, performance, cost

Partners

- Bloom Energy: Planar SOFC system, hydrogen testing, and project management
- Udelhoven Oilfield System Services, Anchorage, AK: General Construction
- H2 Pump LLC, Latham, NY: Equipment
- Giner Electrochemical Systems, LLC, Newton, MA: Equipment
- Univ. of Alaska, Fairbanks, AK: Independent Validation

Objectives

Overall	• Demonstrate cost-effective, efficient, reliable and durable planar solid oxide fuel cell (PSOFC) systems 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
2008	• Complete site construction • Install, commission & remotely operate PSOFC system • Hydrogen pump production system build, test & optimization • Combined PSOFC & hydrogen production system testing • Partial pressure swing adsorption (PPSA) prototype design • Hydrogen cost analysis using the DOE H2A model
2009	• Complete PSOFC system demonstration • Complete hydrogen production demonstration • Complete PPSA build, test & investigation • Complete cost and economics analysis

General Approach

- Build and test a planar solid oxide fuel cell electricity generating system that runs on natural gas
  - One year operating demonstration at commercial site
- Evaluate hydrogen production systems
  - Select one option for in-system demonstration
  - Procure, integrate & test
- Demonstrate PSOFC co-production of electricity and hydrogen
- Independent, third party validation (University of Alaska, Fairbanks)
- Economic analysis

Tasks

1. Site selection, design & build
2. Design integration of hydrogen production module with PSOFC
3. H_2 Pump, PSOFC system builds & in-lab testing
4. PSOFC in-field demonstration

   Hydrogen production demonstration
5. Decommissioning

Technical Accomplishments/Progress/Results

- Alaska site build completed with partners
  - Udelhoven Oilfield System Services
    - PDC Engineering
    - Johnson Controls
  - Chugach Electric Cooperative
  - Enstar Natural Gas
  - City of Anchorage
- PSOFC system installed and operational – key metrics achieved
- Full scale hydrogen pump integrated with PSOFC
  - Commercial anode exhaust hydrogen separation and recycle solution chosen (H2 Pump) for integration & testing with PSOFC
- Partial pressure swing adsorption (PPSA) design & prototype testing in parallel (Giner)
- Hydrogen cost analyzed using the DOE H2A model

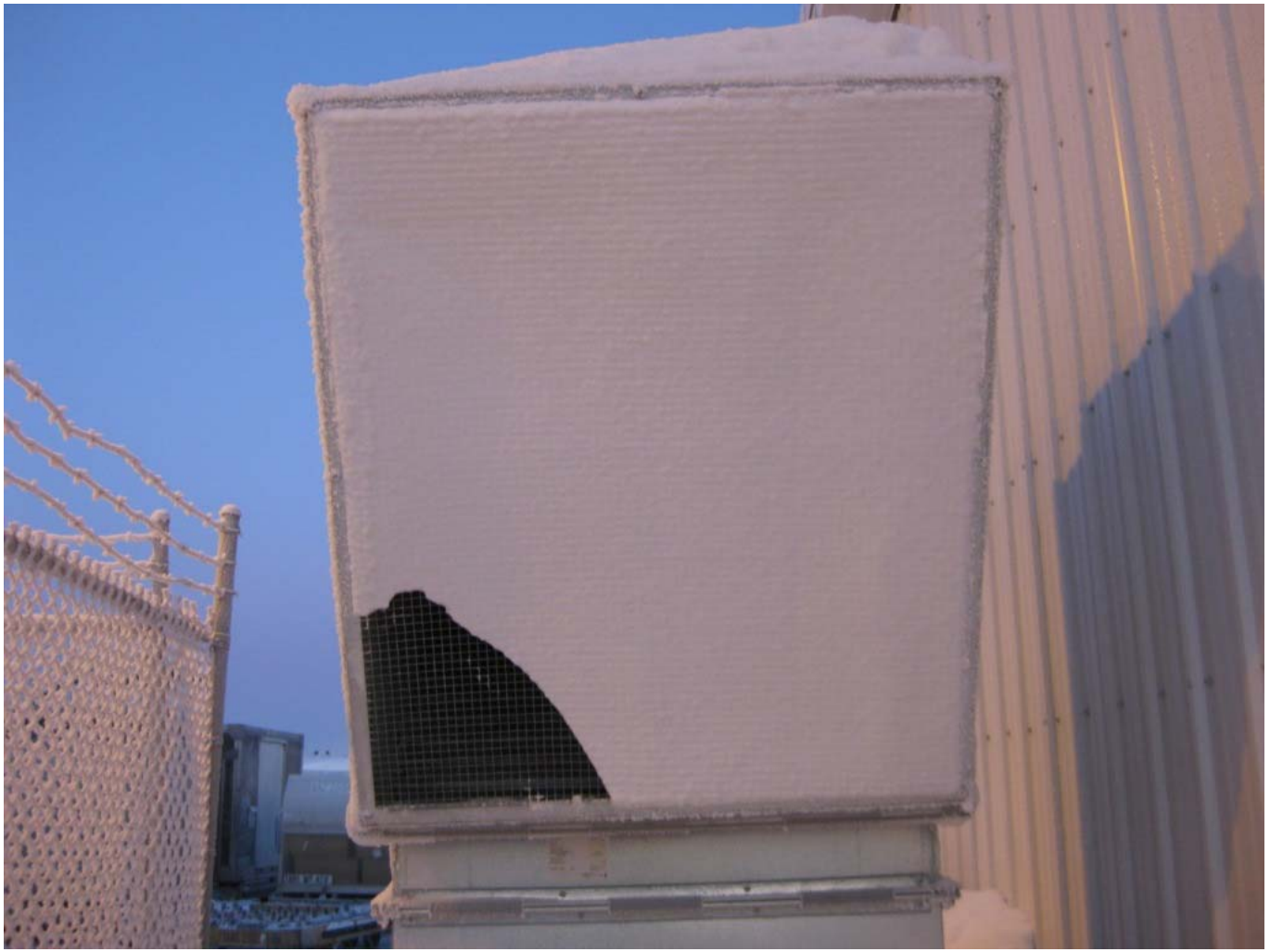
PSOFC Field Demonstration: Site Build

Electrical/Gas Inputs, Air Outputs

Building Air Handling Unit

Air Intake

Air Handling Unit Inlet with Hoarfrost



PSOFC System Operation Objectives

- 25 kW power
- Operation on natural gas
- Operate at 480V
- Grid parallel operation
- Remote monitoring
- 70% uptime over one year demonstration
- 45% peak net electric efficiency in electric-only mode

25kW PSOFC System 1C
Operating Statistics

25kW Operation	System 1C	
Average AC Efficiency	45.9	%
Peak AC Efficiency	51.1	%
Total Energy Output	48004	kWhrs
Total Fuel Consumption	10351856	L
Peak AC Power	25.9	kW
Hrs On-Site	2191	Hrs
Uptime	2178	Hrs
Load Hrs	2166	Hrs
Availability On Load	98.9	%
Availability at 20.0kWac+	93.6	%
Grid Faults	4	
System Faults	3	

-Ship 11/16/08 -Start 12/3/08 -Run data through 3/5/09

25kW PSOFC System 1D
Operating Statistics

25kW Operation	System 1D	
Average AC Efficiency	46.1	%
Peak AC Efficiency	48.9	%
Total Energy Output	47538	kWh
Total Fuel Consumption	10183941	L
Peak AC Power	25.4	kW
Hrs On-Site	2191	Hrs
Uptime	2182	Hrs
Load Hrs	2177	Hrs
Availability On Load	99.4	%
Availability at 20.0kWac+	93.2	%
Grid Faults	3	
System Faults	3	

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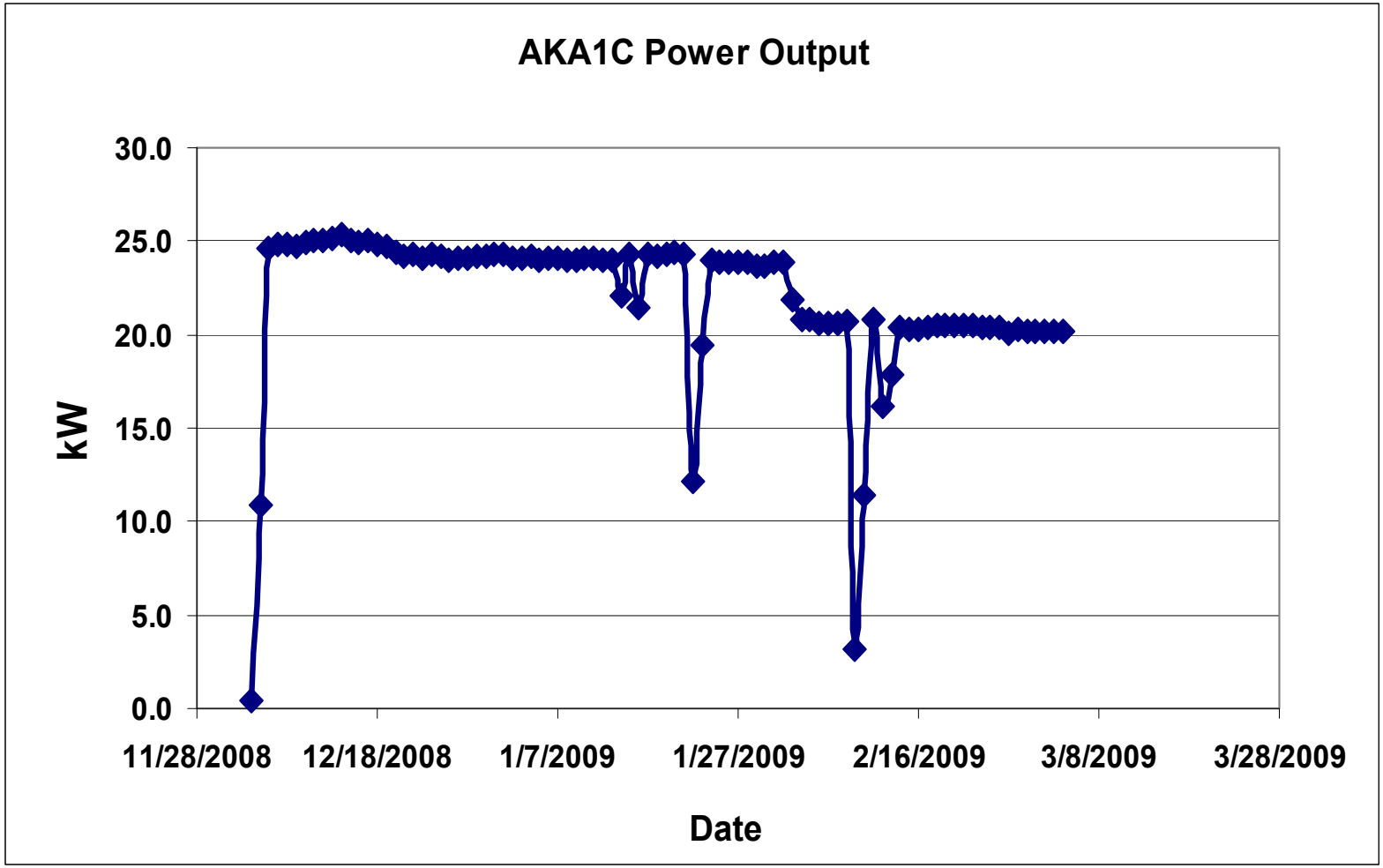
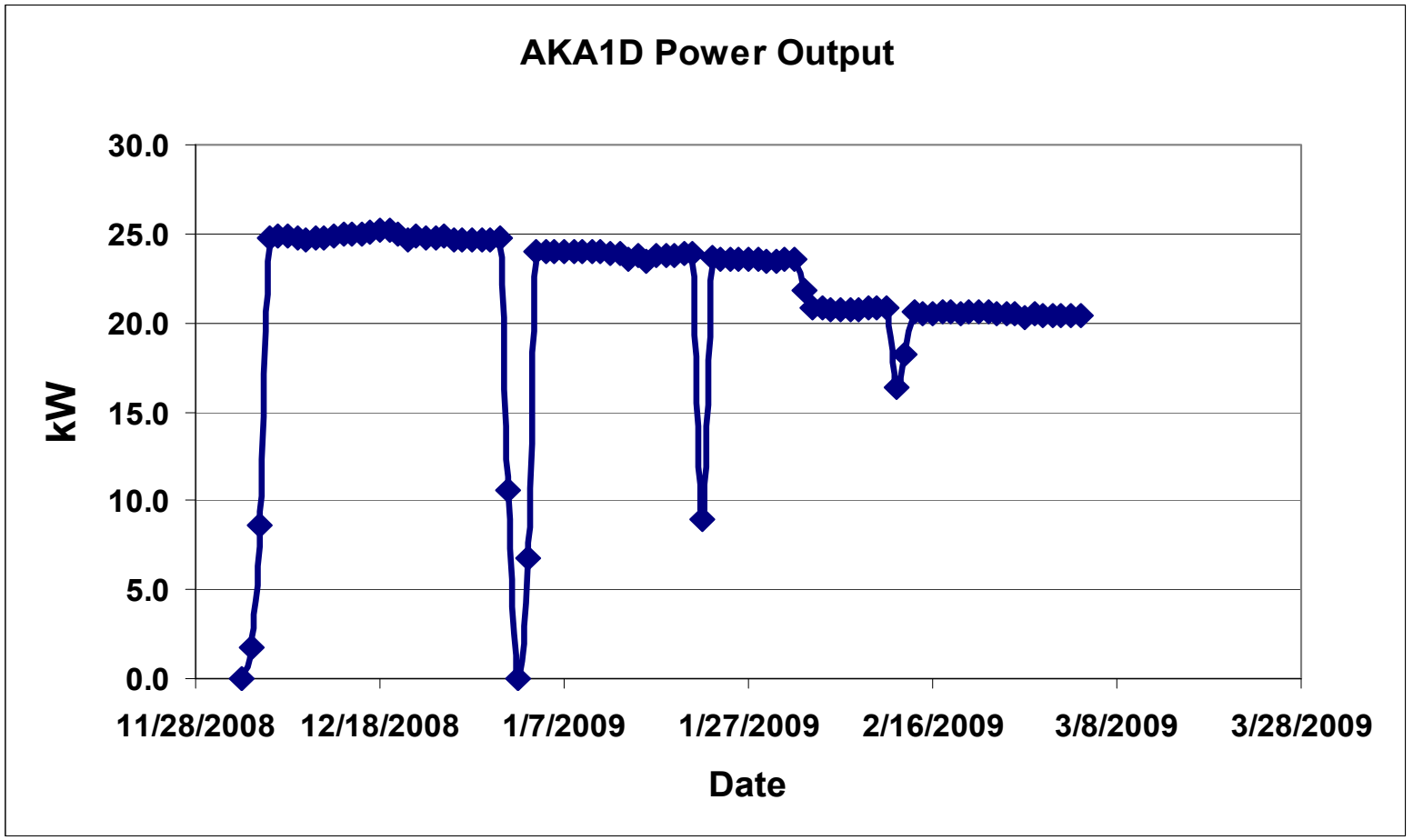
System 1C Power Output



Run data 12/3/08 through 3/5/09

System 1D Power Output



Run data 12/3/08 through 3/5/09

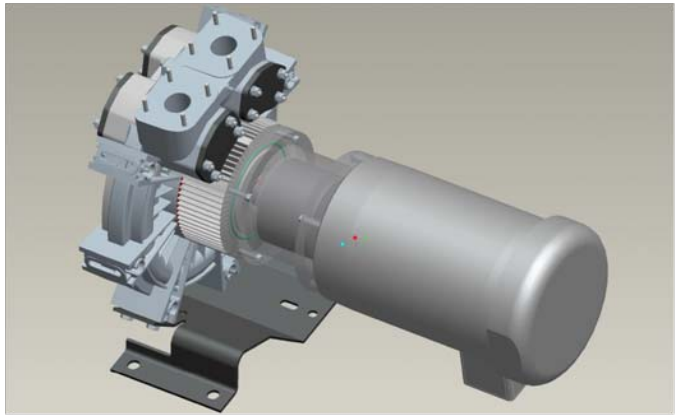
Fault Analysis

- Six service calls 12/3/08 - 3/5/09
- #1 fault condition: Anchorage weather
  - Water pump & water flow meter: not rated for <0C
  - Building thermal control shutdown when air intake clogged with hoarfrost
- Components upgraded
  - Power electronics
  - Mass flow controller
  - Anode recycle blower

Blower Studies

- Blower research and development to improve system efficiency and reliability through reduction of parasitic losses and simplified installation

- Development of anode recycle blower capable of high temperature ambient/media
  - Hydrogen
  - Carbon Dioxide
  - Steam
  - Carbon Monoxide

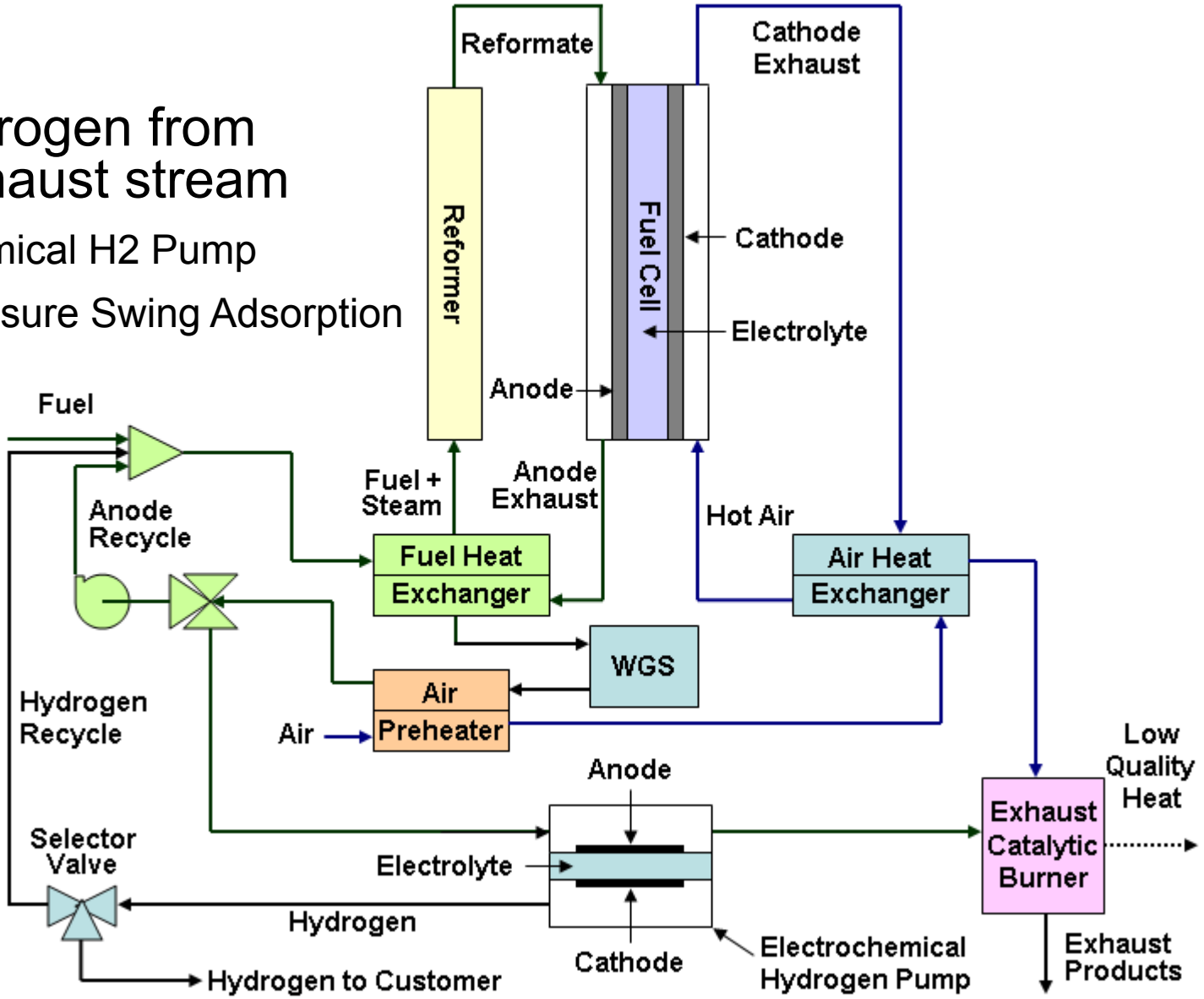


- Started with a commercially available air blower
  - Collaboration with vendor and their local university
  - Applying CFD to develop a series of modifications to make it suitable for operation as an anode recycle blower

Low-Cost Co-Production of Hydrogen and Electricity

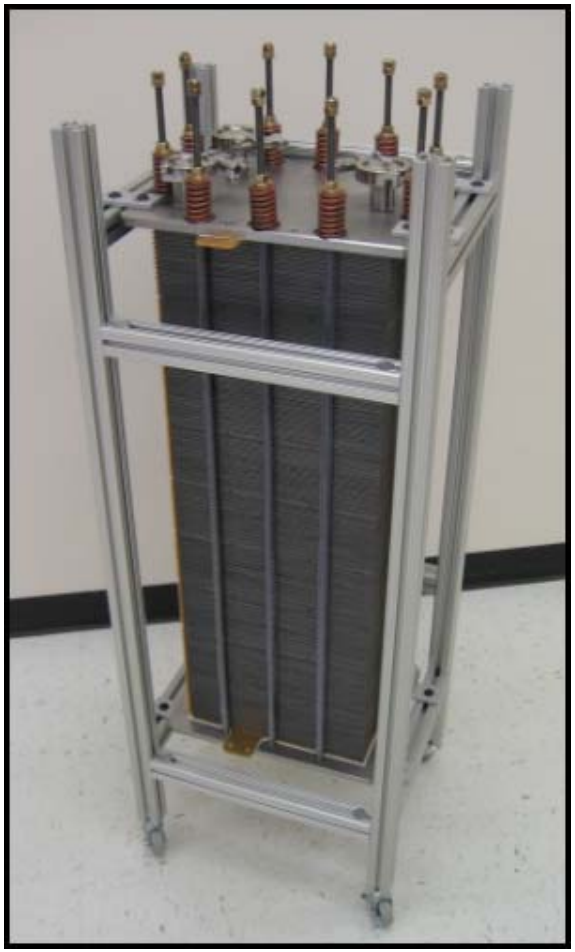
Purify hydrogen from anode exhaust stream

- Electrochemical H2 Pump
- Partial Pressure Swing Adsorption



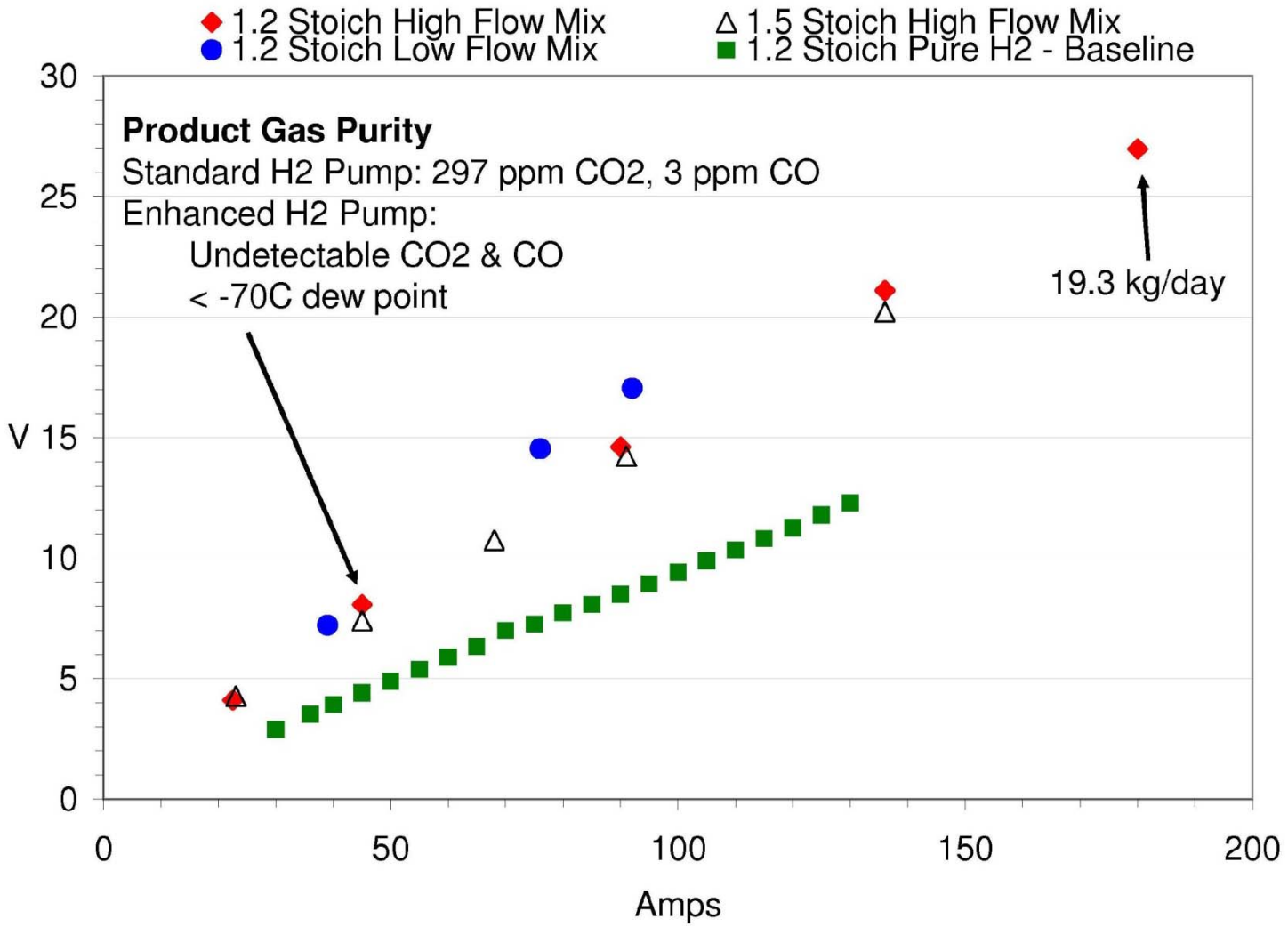
25kW PSOFC Demonstration with H2 Pump

- Two operational modes
  - Hydrogen recycle
  - External hydrogen delivery
- SOFC operation at 95% fuel utilization in recycle mode
- 2000 hours test duration, with < 5% performance degradation of hydrogen production (19 kg/day max production)



H2 Pump with 120 cell stack
Operating temperature: 150C – 180C
Product hydrogen pressure: <5 psig

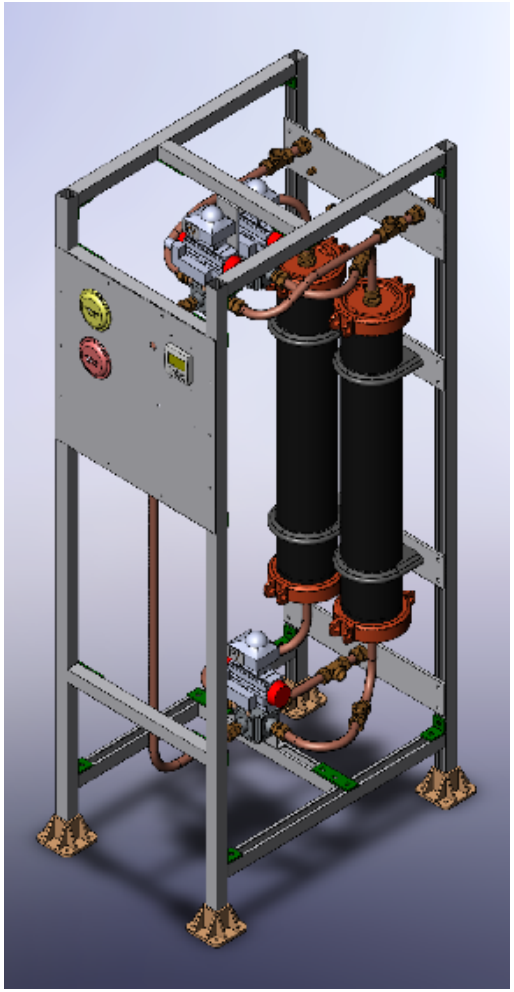
H2 Pump Test Demonstrated 19kg/day & High Purity



- Improved plumbing, preparation & measurement capability are needed to demonstrate hydrogen purity exceeding six 9's

Full Sized PPSA Prototype Build

- 25kW sized PPSA unit from Giner expected Q2 ‘09
- No water gas shift required
- Low parasitic electrical power
- Anode exhaust to be separated
  - Flow rate: 99 slpm
  - Temperature: 30C
  - Supply pressure: 5 inches water column
  - H_2 (29.3%), CO_2 (66%), H_2O (3.4%) & CO (1.3%)
- PPSA effectiveness
  - 80% fuel recovery (CO, CH_4, H_2)
  - 95% CO_2 separation



H2 Cost Analysis Using DOE H2A Model

	Original Proposal (BE model)	Current Analysis (H2A Model)
Installed Capital Cost	$1,500 / kW	$1,500 / kW
Overall **System** Efficiency	56%	56%
Net **Electrical** Efficiency	33%	33%
NG Cost	$8 / mmbtu	AEO 2007
Capacity Factor	90%	98%
H2 / Year	50,192 kg	54,656 kg
Electrical Output	200kW	200kW
Delivered cost of H2/gge	**$4.82**	**$4.53**

BE & H2A models are very consistent; differences are in assumed capacity factor

H2 Cost Analysis Adding Value of Electricity

	Original Proposal (BE model)	Current Analysis (H2A Model)
Delivered cost of H2/gge	$4.82	$4.53
Value of Electricity	$0.12 / kWh	$0.12 / kWh
Electrical output	1,576,800 kWh / year	1,716,960 kWh / year
Value of annual output	($167,360)	($182,240)
H2 / Year	50,192 kg	54,656 kg
Value of Electricity / kg H2	($3.77)	($3.77)
H2 cost, net/gge @ 300 psi	**$1.26**	**$0.97**

Projections are consistent with DOE delivered cost of H2 goals

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Future Work

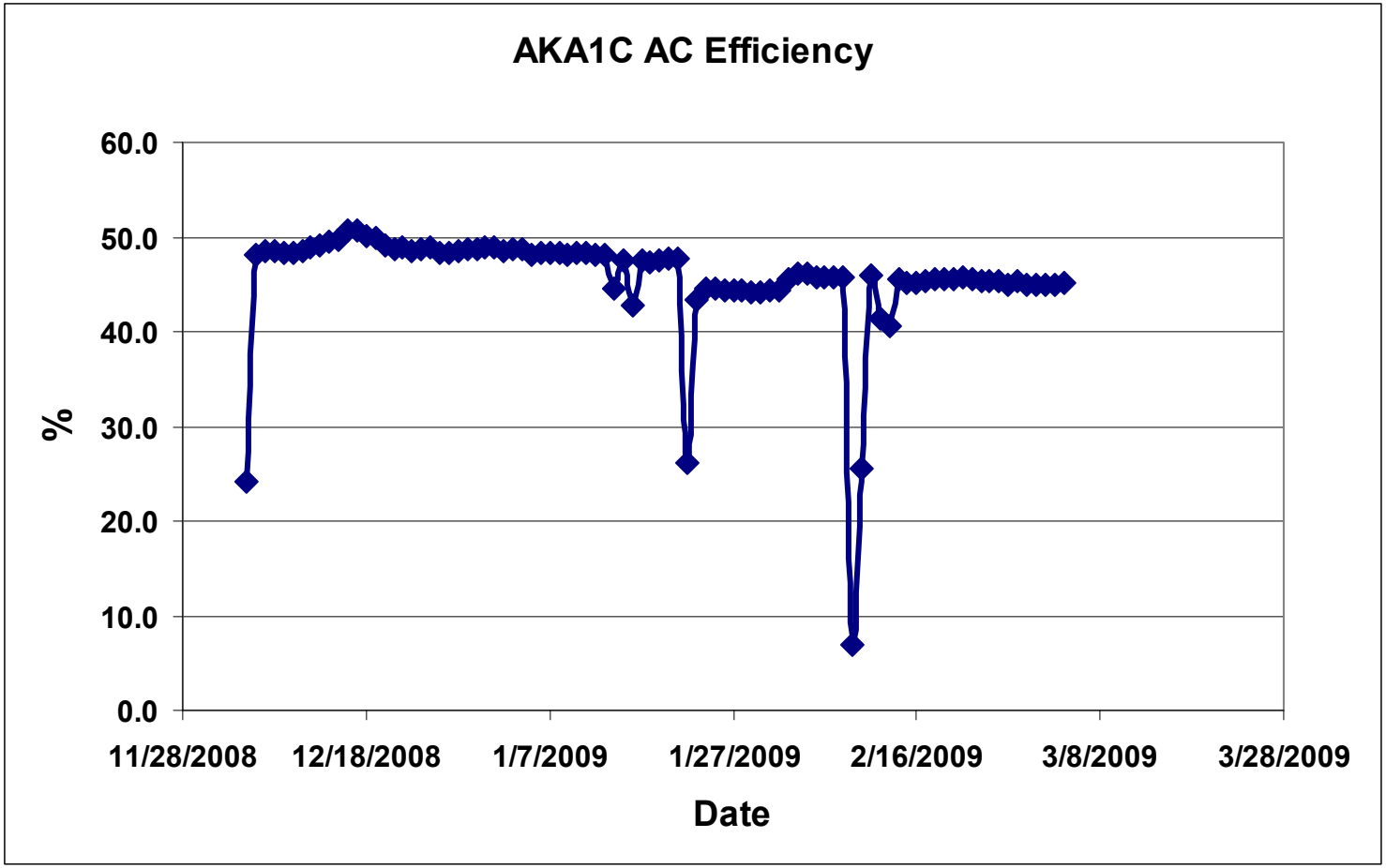
- Complete one year demonstration of PSOFC system
- Complete demonstration of co-production of electricity and hydrogen
  - Complete PSOFC & H2 Pump 2000 hour test
  - Third party validation of volume & purity
- Complete PPSA prototype test
- Complete cost modeling

Supplemental Slides

Photograph by R. Clucas, courtesy Alaska Volcano Observatory, USGS

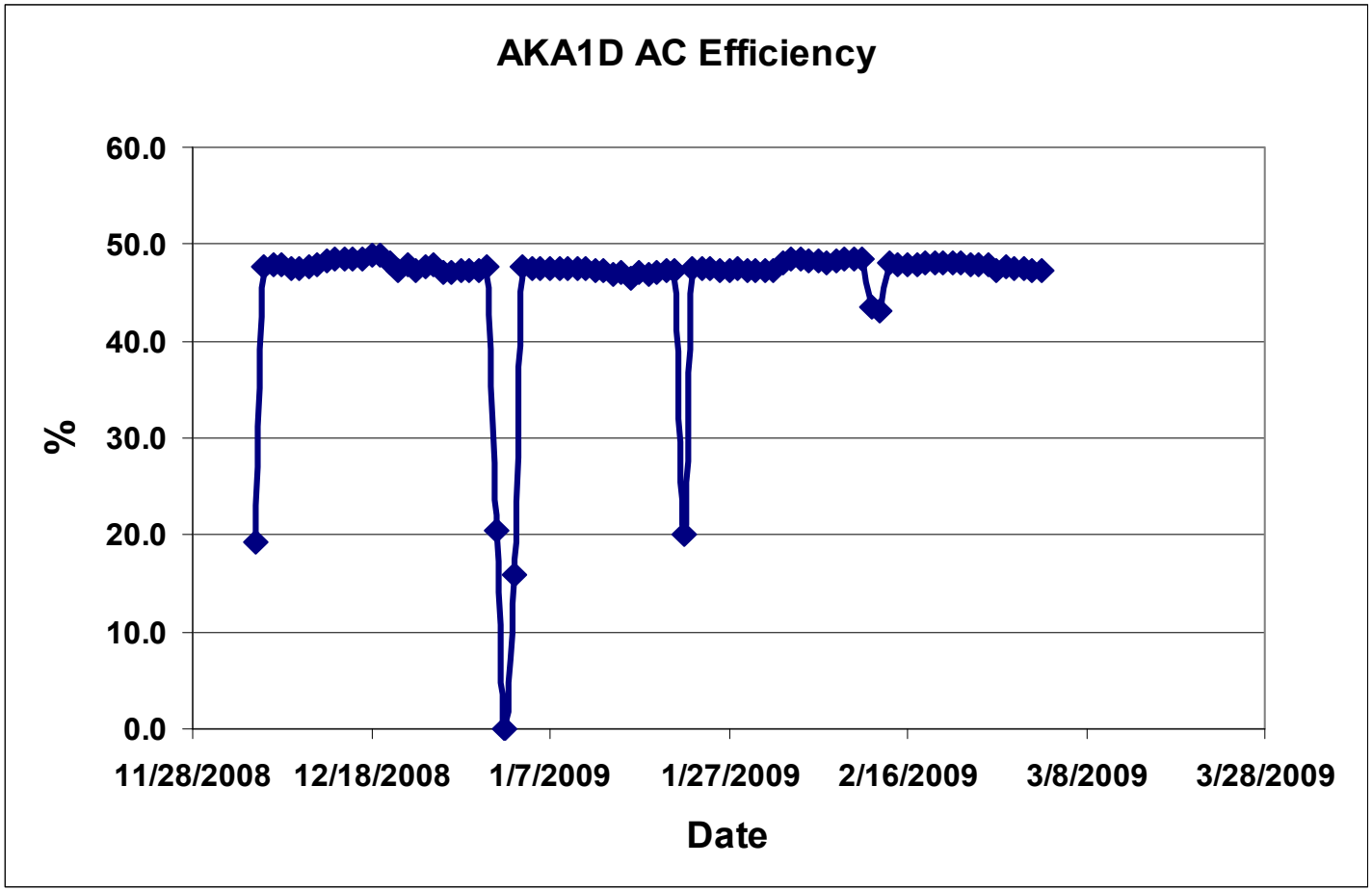
Mt. Redoubt volcano eruptions shutdown Anchorage Airport in March 2009

System 1C Efficiency



Run data 12/3/08 through 3/5/09

System 1D Efficiency



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