Status of the Acumentrics SOFC Program

Dr. Norman Bessette

SECA Annual Workshop

Philadelphia, PA.

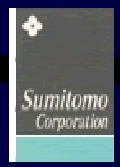
September 12, 2006

Outline

- Overview
- Cell Technology
- Bundle Testing
- Generator Developments
- Power Electronics Advancements
- Cost Estimate
- SECA Phase I Machine Performance

Acumentrics Corporation

Strategic Partners



GENERAL DYNAMICS
Strength on Your Side™

ChevronTexaco
Technology Ventures
Connecticut Innovations, Inc

Morgan Stanley

Northeast Utilities System

- *~ 67 Employees*
- *Manufacturing since 1994*
- *Based in Westwood, Mass.*
- *~40,000 sq. ft facility*
- *Completed Equity Financing on July 24, 2006*
- *Profitable for the past 12 months*
- *Critical disciplines in-house*
  - Electrical Engineering
  - Mechanical Engineering
  - Chemical Engineering
  - Thermal Modeling
  - Ceramics Processing
  - Manufacturing
  - Sales & Marketing
  - Automation
  - Finance

Acumentrics

Battery based UPS

500Watts - 20kWatts

Uninterruptible Power Supplies for Harsh Environments

Industrial-UPS®
Commercial

Rugged-UPS®
Military

Features:

- Sealed electronics
- Able to withstand vibration
- Unity power factor input
- Wide input 80VAC - 265VAC
- Isolated 120 / 240VAC output
- Hot swap battery case
- Parallelable to 20 kWatts

Field Demonstrations

- Operable on propane and Natural Gas
- Grid-tie and grid independent operation
- Cogeneration capable.
- Operating now for over 1500 hours each

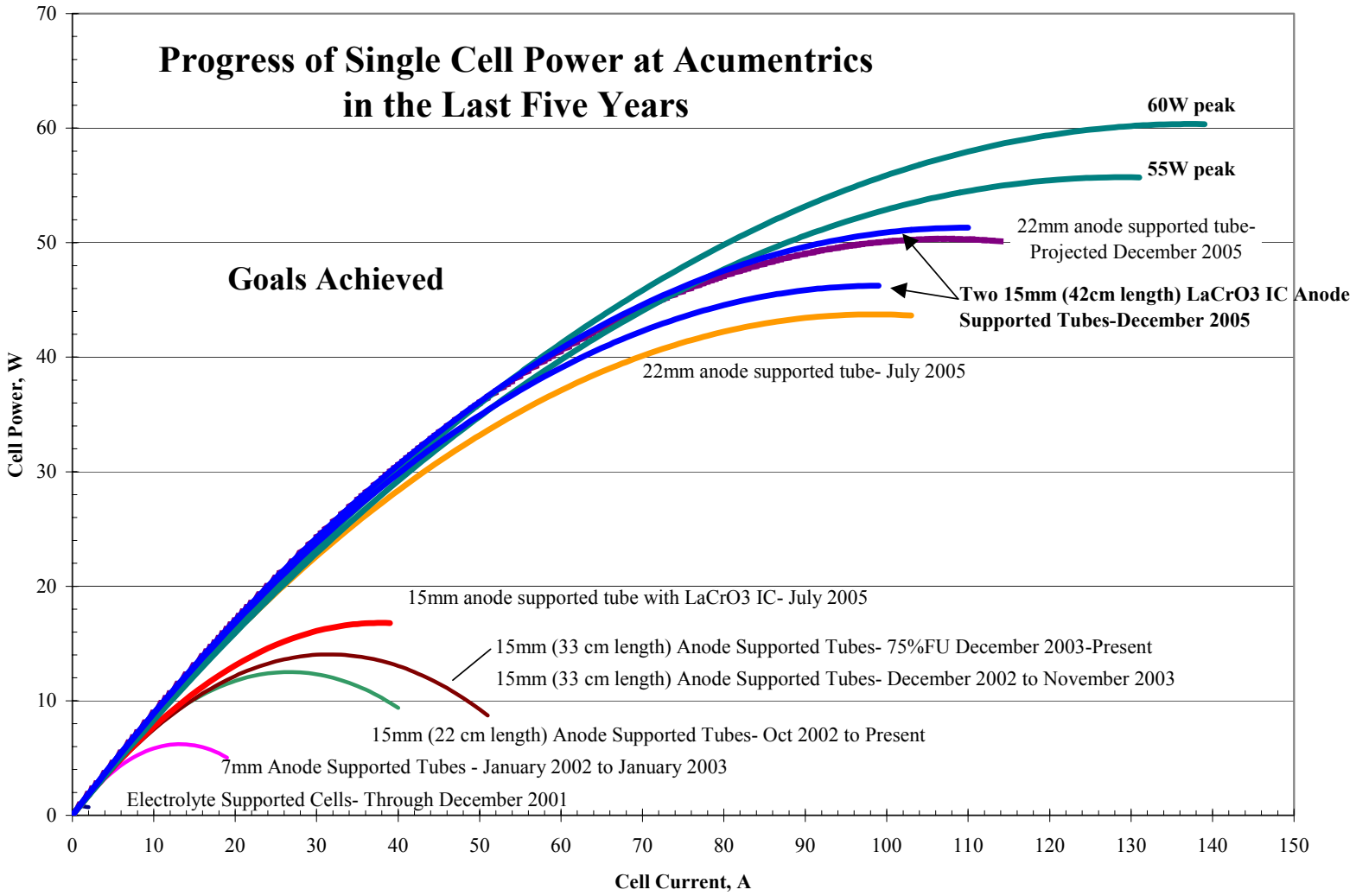
SECA Product Objectives

- Culminate in a 5-10kW modular stack capable of meeting a number of market requirements.
- Widen our fuel choices.
- Build upon our knowledge of “ruggedized” products for harsh environments.
- Allow for modular build up to the 100kW class size.
- Allow for integration with military towable power units in the 5-20kW size.

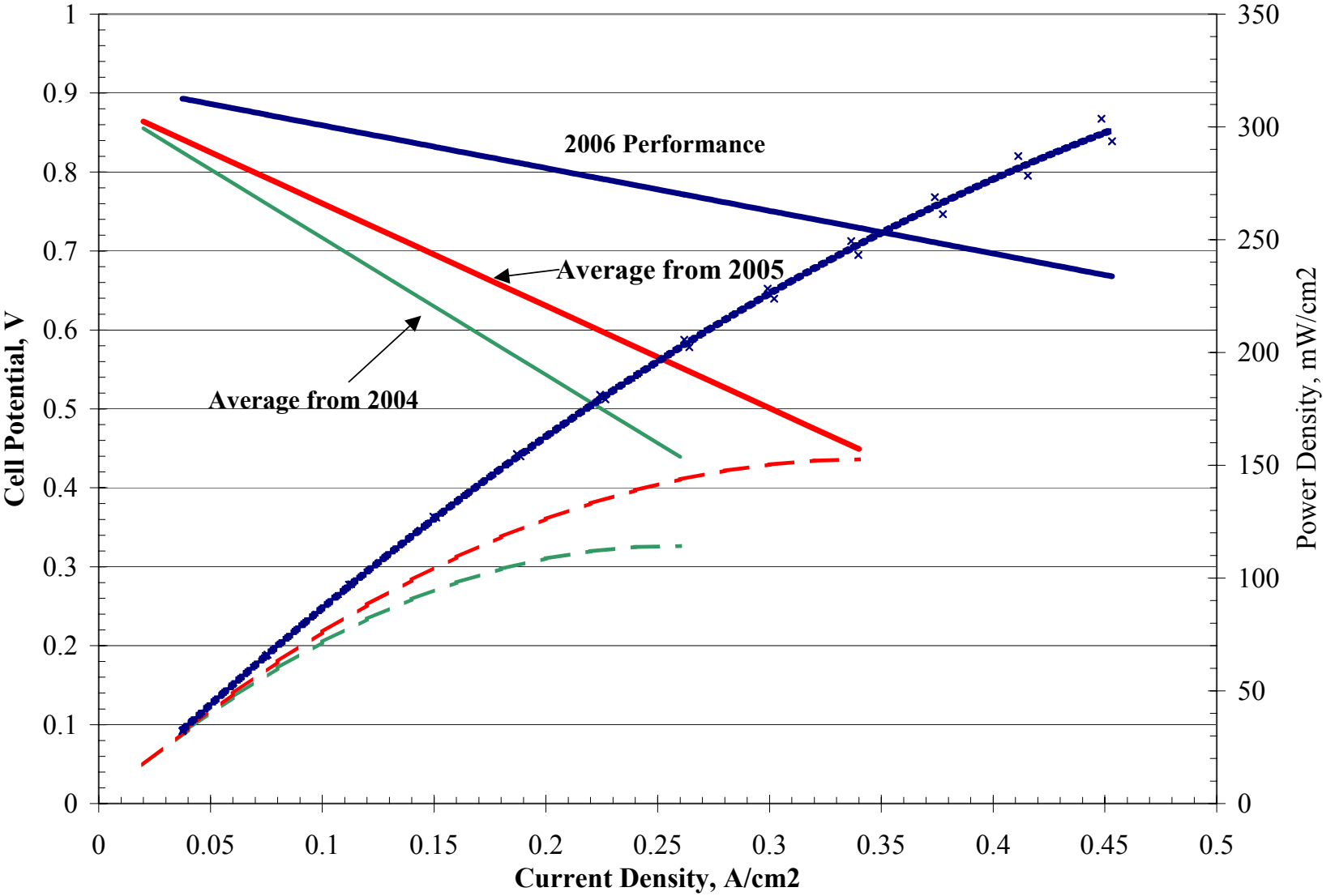
Cell Technology

- Work has remained focused on improving the power per cell while decreasing degradation.
- Power improvements have been realized by increasing the number of power take-offs as well as improving the conductivity along the cell length.
- Previous Improvements of 80-100% have been implemented into generator designs including the SECA Phase I Unit.

Acumentrics Progress

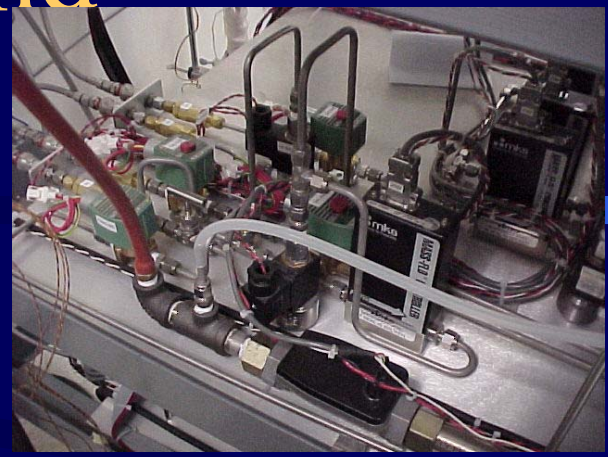


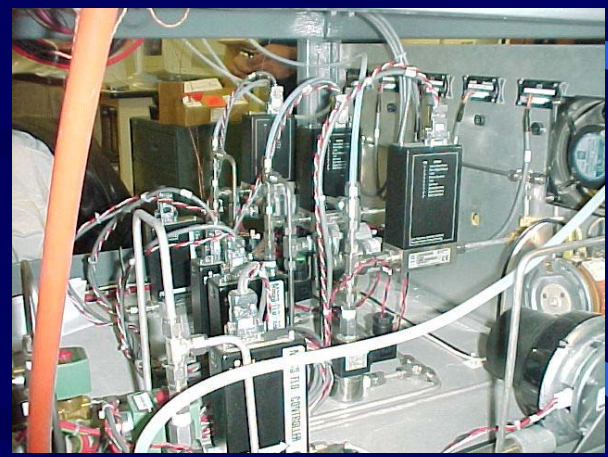
Comparison of Performance



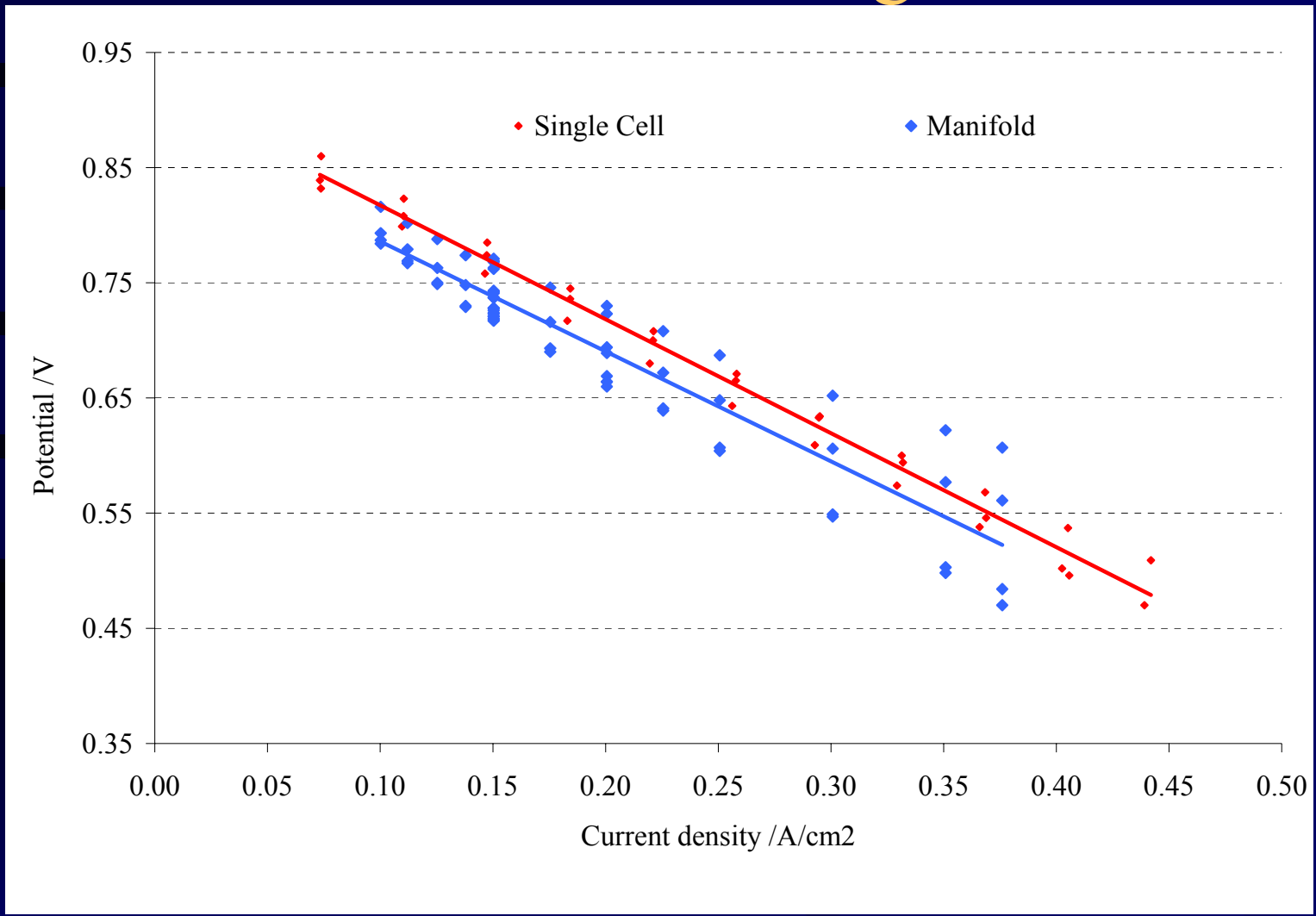
CPOX Test Stand

- Fuel+air or H_2 capabilities
- Controlled through a series of valves and MFCs
- Can adjust for actual O_2 and CH_4 contents to deliver known fuel quantities
- Added safety features of pressure and temperature E-Stops

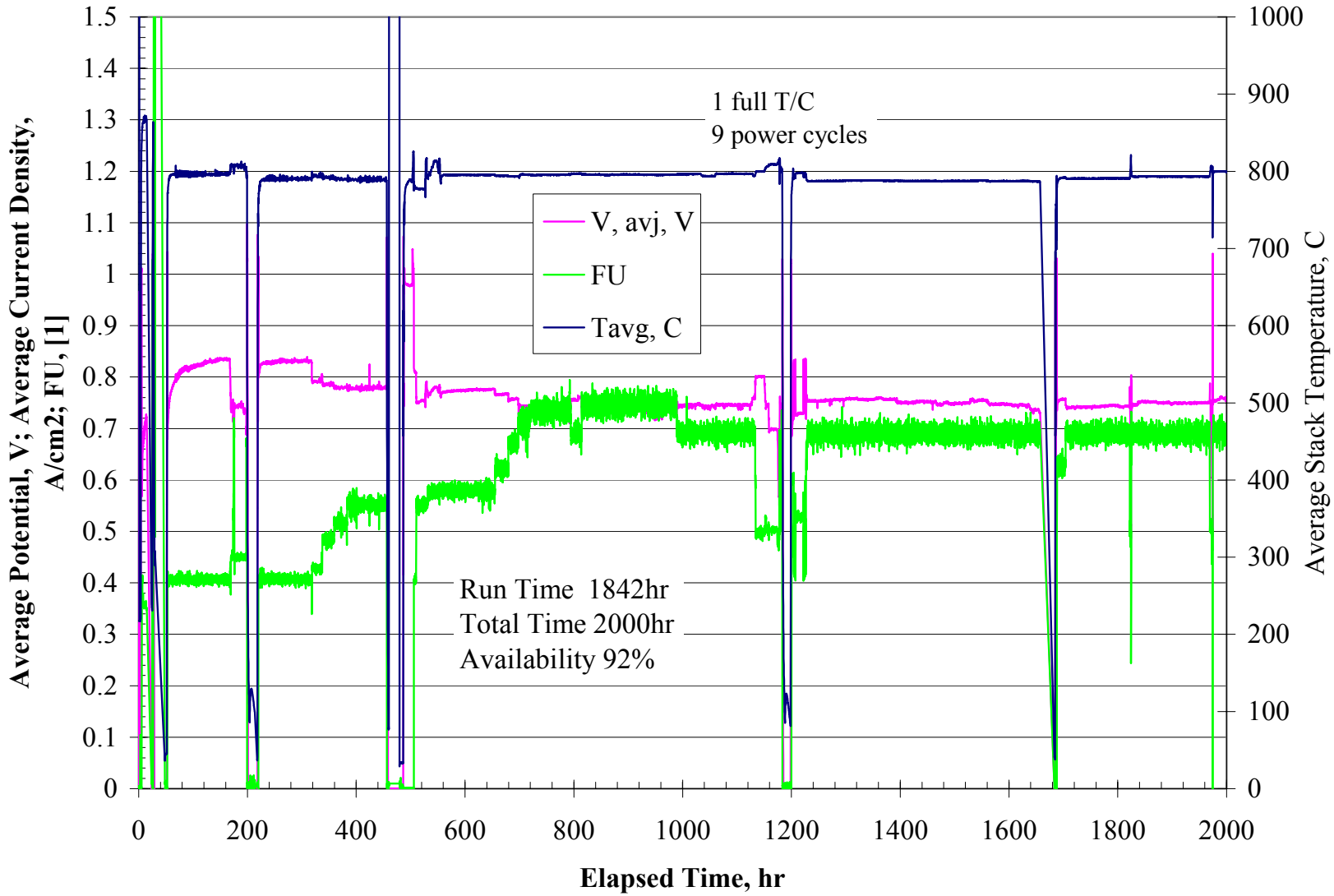




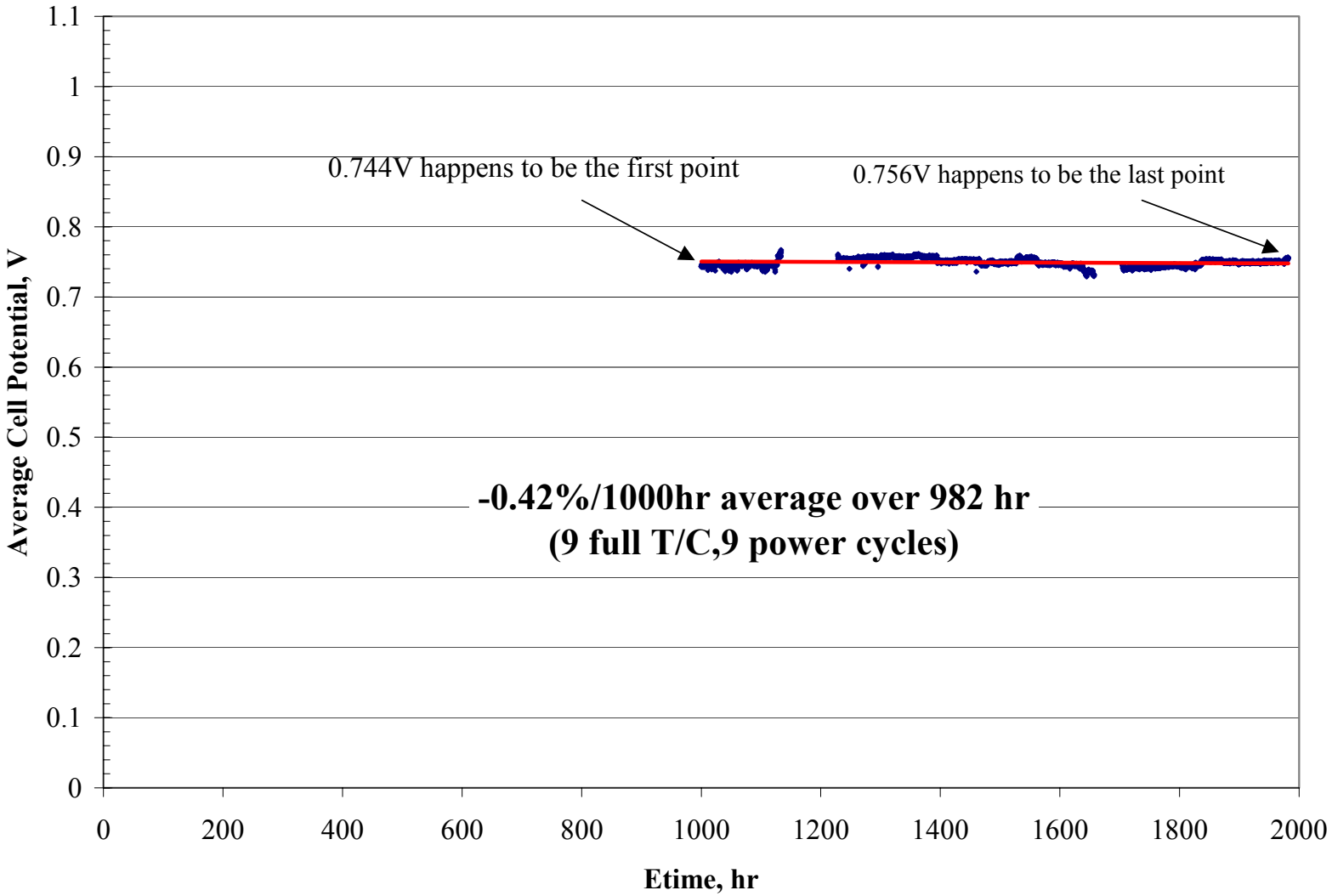
Comparison of CPOX Test Stand and Bundle Testing



3 IC Bundle Test



Degradation of 3 IC Bundle Test



Bundle Test Highlights

- Hit effective **35.7% efficiency** at 75%FU, ~3000WDC generator equivalent
- Realized a peak power of **~7.6kWDC** on a generator basis before losses
- **92% availability** through **2000hrs** total run time
- **7 full thermal cycles** including SECA requirement, **9 power cycles**
- Degradation rate over 982hrs operation at 70%FU, 1 additional thermal cycle, 9 power cycles- **-0.42%/1000hr** by best fit.

Generator Cost Reductions

- Work has focused on four major areas:
- Recuperators- metallic and ceramic
- Fuel Recirculation Systems
- Liquid Fuel Reforming
- Air/Fuel Metering

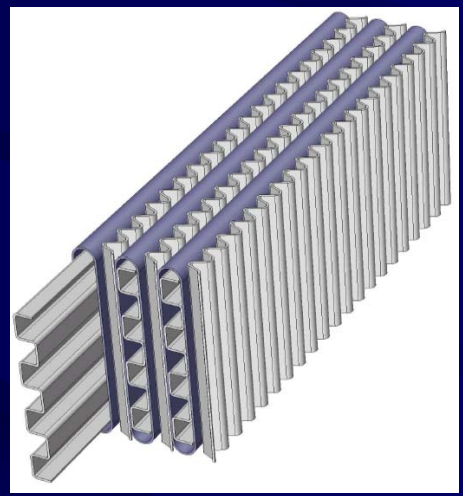
Recuperator Development

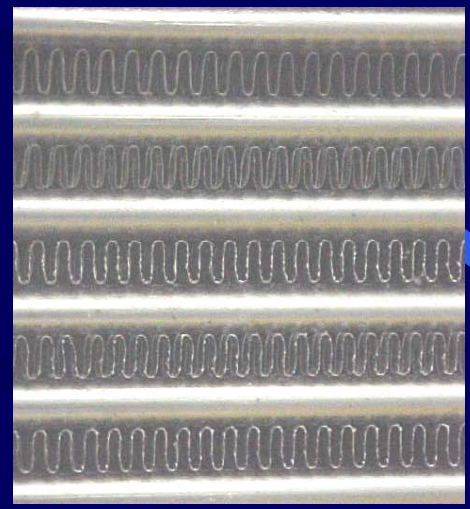
- Full scale metallic and ceramic recuperators tested
- Metallic units are quite effective (82-90%) but oxidation resistance and life are a concern
- Ceramic units have been proven to survive but the effectiveness has been lower (65-75%) than metallic units.
- 80+ Effectiveness required
- Hybrid Solutions are being investigated.

Recuperator Types

Bent Tube

Fin Core

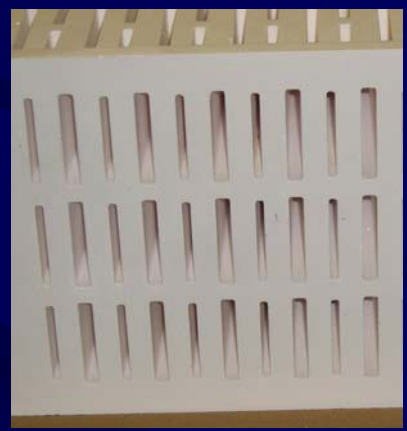




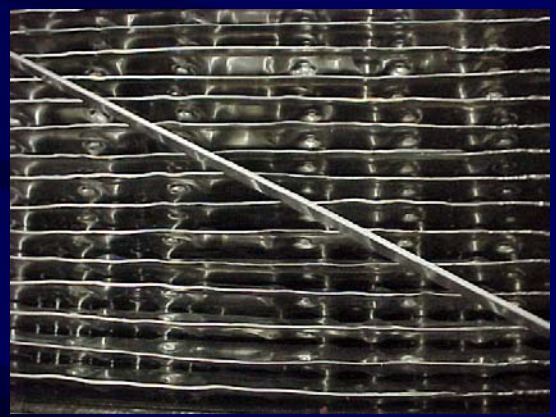
Recuperator Types

Counter-flow

Ceramic



Recuperator Types

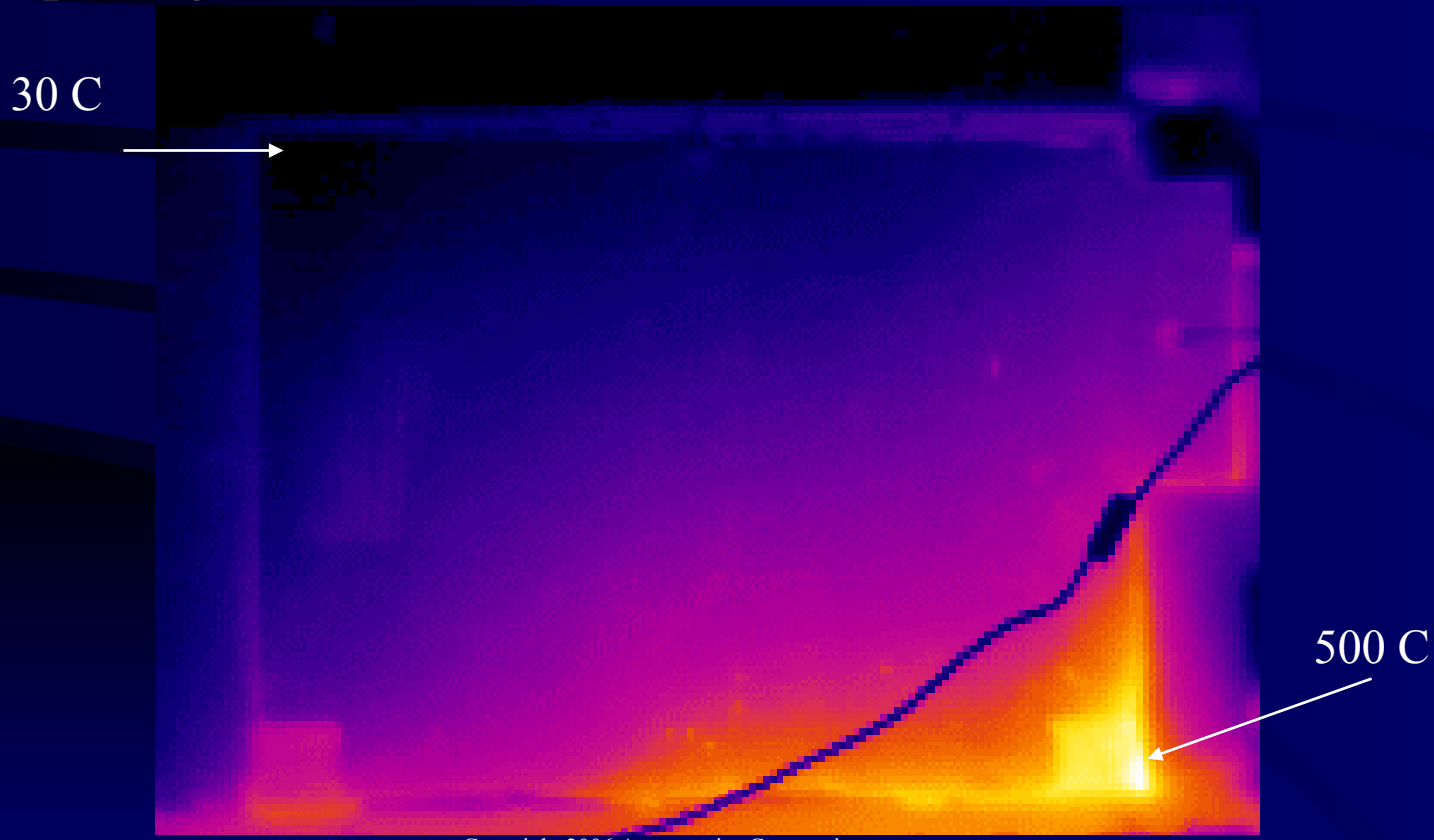


Folded Sheet

- Simple construction
- Counter flow
- Zero Leakage
- Low Pressure Drop

Folded Sheet Recuperator

- Skin temperature indicates flow short circuiting
- Need to optimize aspect ratio
- Additional area can be obtained by decreasing sheet spacing – 4 versus 6.5 mm



Hybrid Advantages

DOE SBIR "Hybrid Ceramic/Metallic Recuperator of SOFC Generators"

Metallic

Advantages

- Manufacturability
- Extended Surface
- Compactness
- Thermal Shock

Disadvantages

- High Cost
- Fouling/Oxidation

Ceramic

Advantages

- Low Cost Materials
- High Temp Stability
- Single Casting

Disadvantages

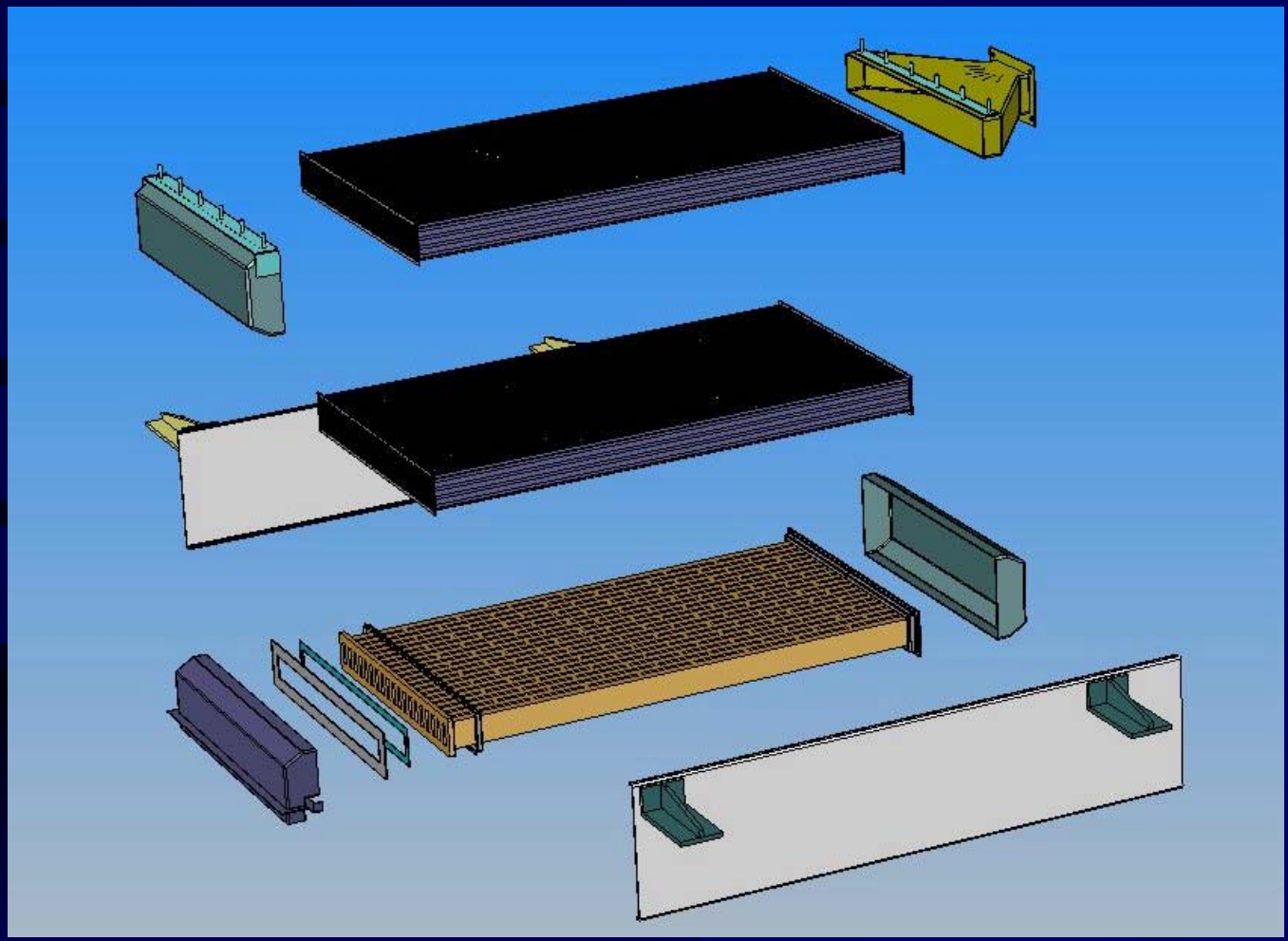
- Thermal Shock

Hybrid

Advantages

- Low Cost Materials Throughout
- Modular Manufacture
- Temperature Gradients on Ceramic are Reduced
- Materials Optimized for Temperature
- Thermal Expansion Unrestrained

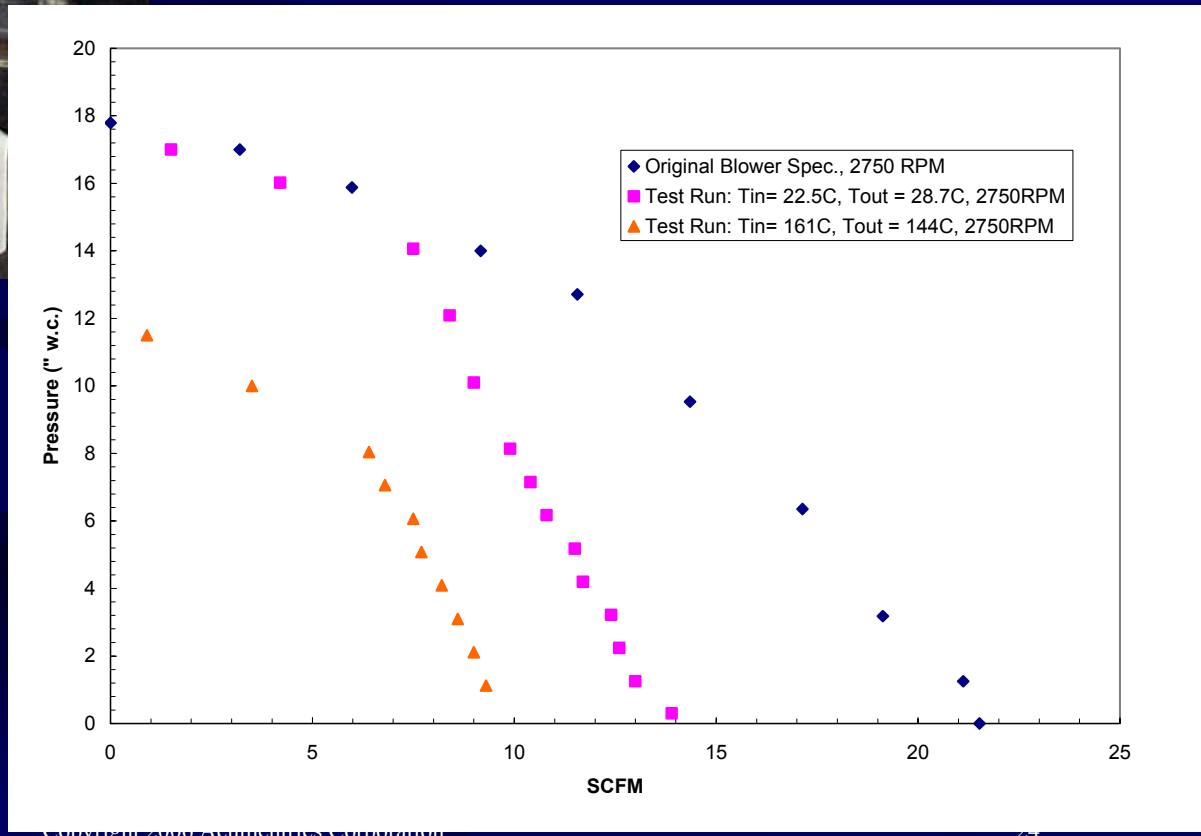
Hybrid Recuperator



Recirculator Design

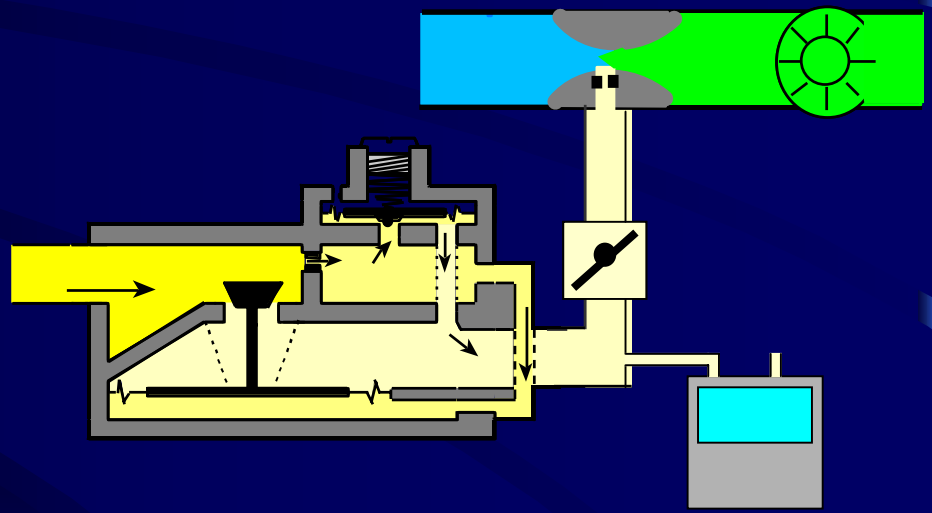
- Need to move to steam reforming for efficiency gains necessary for Phase II targets.
- The preferable design does not require high pressure gas
- Hot offgas recirculator is considered best long term option for integration with the natural gas infrastructure.
- Last report period, the recirculator design was discussed.
- During this period, Acumentrics has focused on stack testing for efficiency and stability.

Recirculator Test Setup

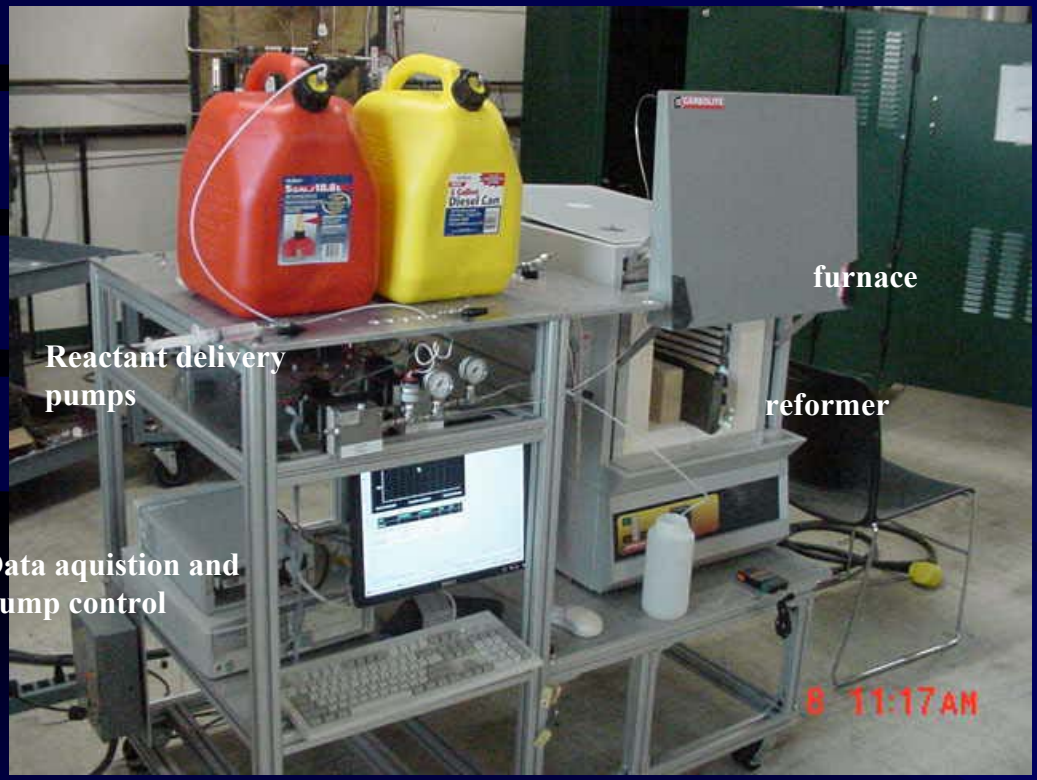


Anode Air/Fuel Control

- Challenges:
  - Flow metering (Fuel:air mix to required resolution & accuracy)
  - Fuel flow control (stable, proportional over flow range)
- Solution: Pre-mix pneumatic system common to most home heating systems



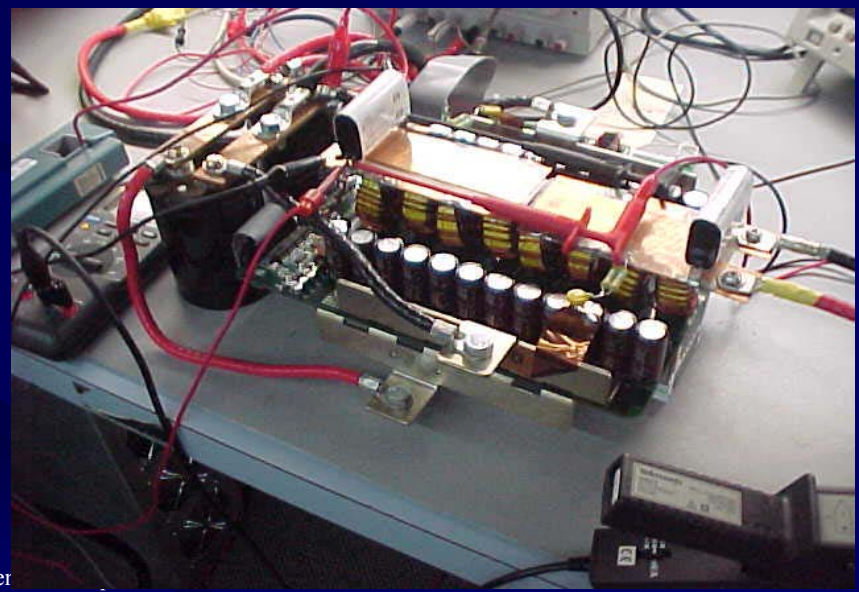
Diesel Reforming



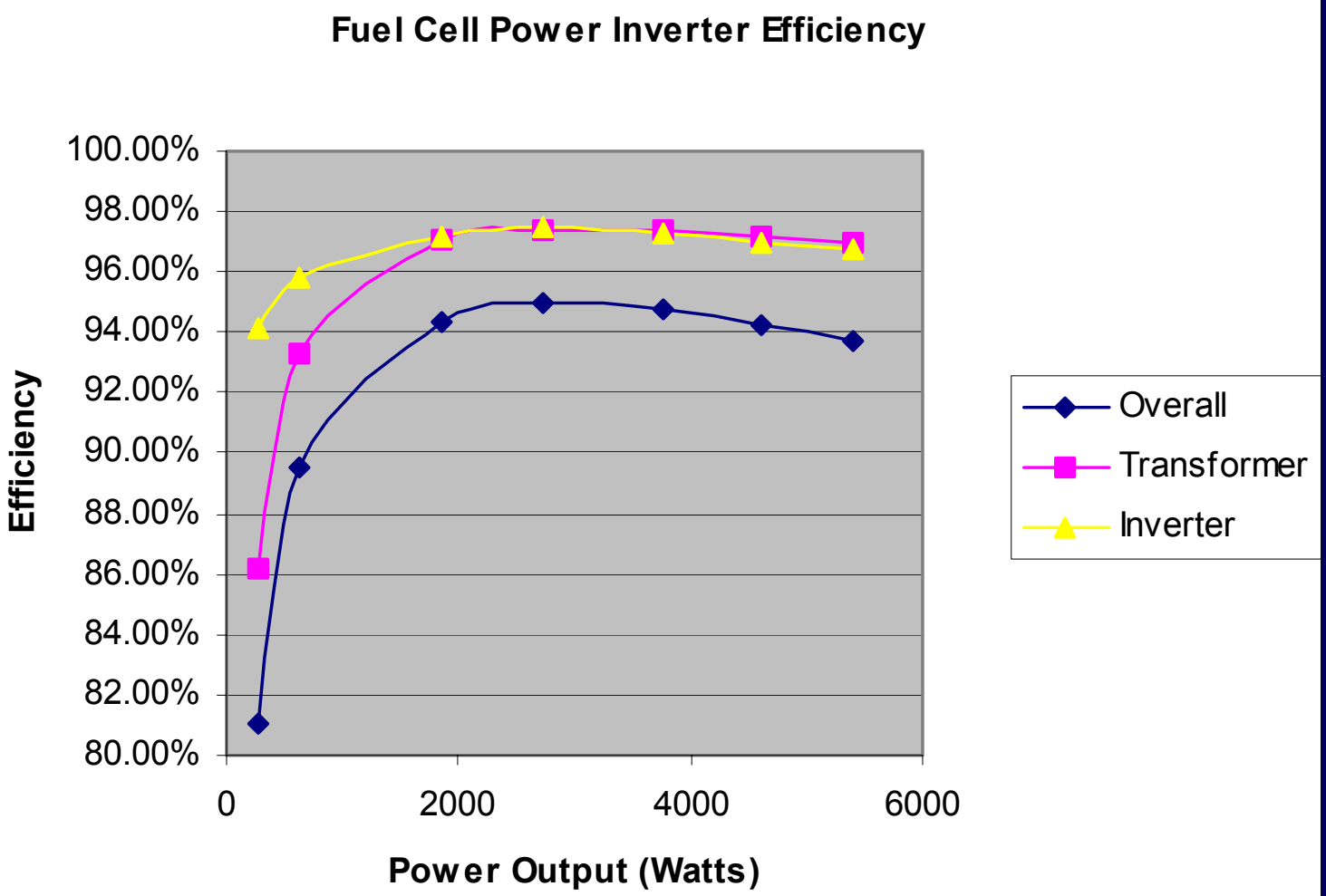
- Test reformer Capable of providing 5kW diesel reformate.
- Test configuration and shakedown complete.
- Completing gas composition mapping over output range
- Will be linked to previously described Bundle Tests.

Low Voltage Inverter Development

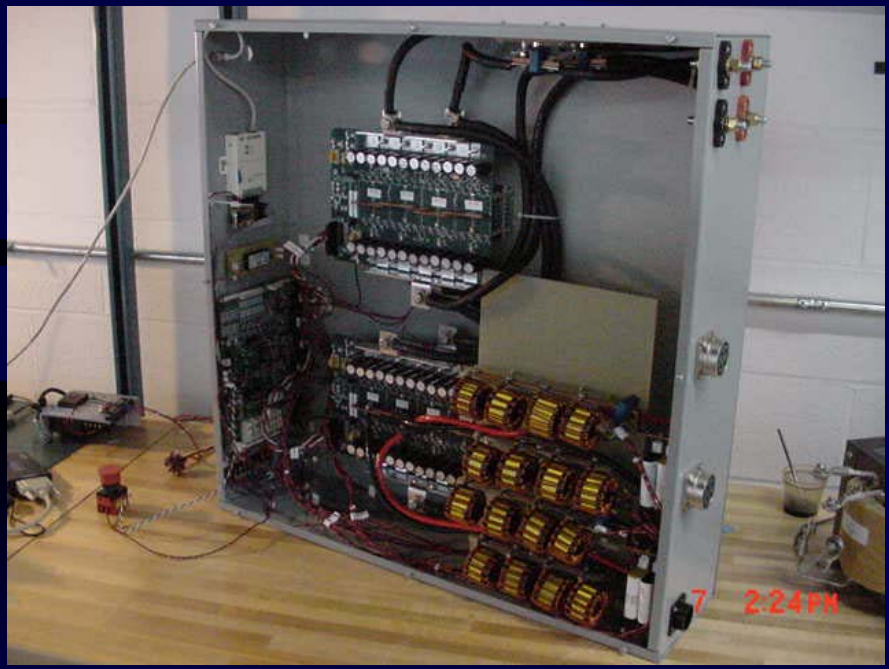
- A DC/DC converter was developed early Phase I.
- Interleaved buck – boost topology of 6kW Capacity
- This DC/DC topology has been configured into a dual inverter.
- An interleaved topology and high frequency MOSFETs greatly reduce output filter requirements and cost.



SECA Inverter Efficiency



SECA inverter



- Two independent dual inverter assemblies (4 total)
- 220V AC split phase
- 5kW steady, 10kW peak
- Dual DC sources: SOFC & battery
- Battery inverter is bi-directional
- Grid-tie & anti-islanding under development.
- Undergoing fabrication & Test.

SECA Cost Estimate

- Cost estimate was performed during August 2006.
- The simulation was based on the SECA Phase I machine manufactured at 50,000 units/yr.
- Raw material costs provided to all SECA teams were utilized.
- Total Capital Equipment Required was ~$40M
- Total Resulting Capacity was ~300MW

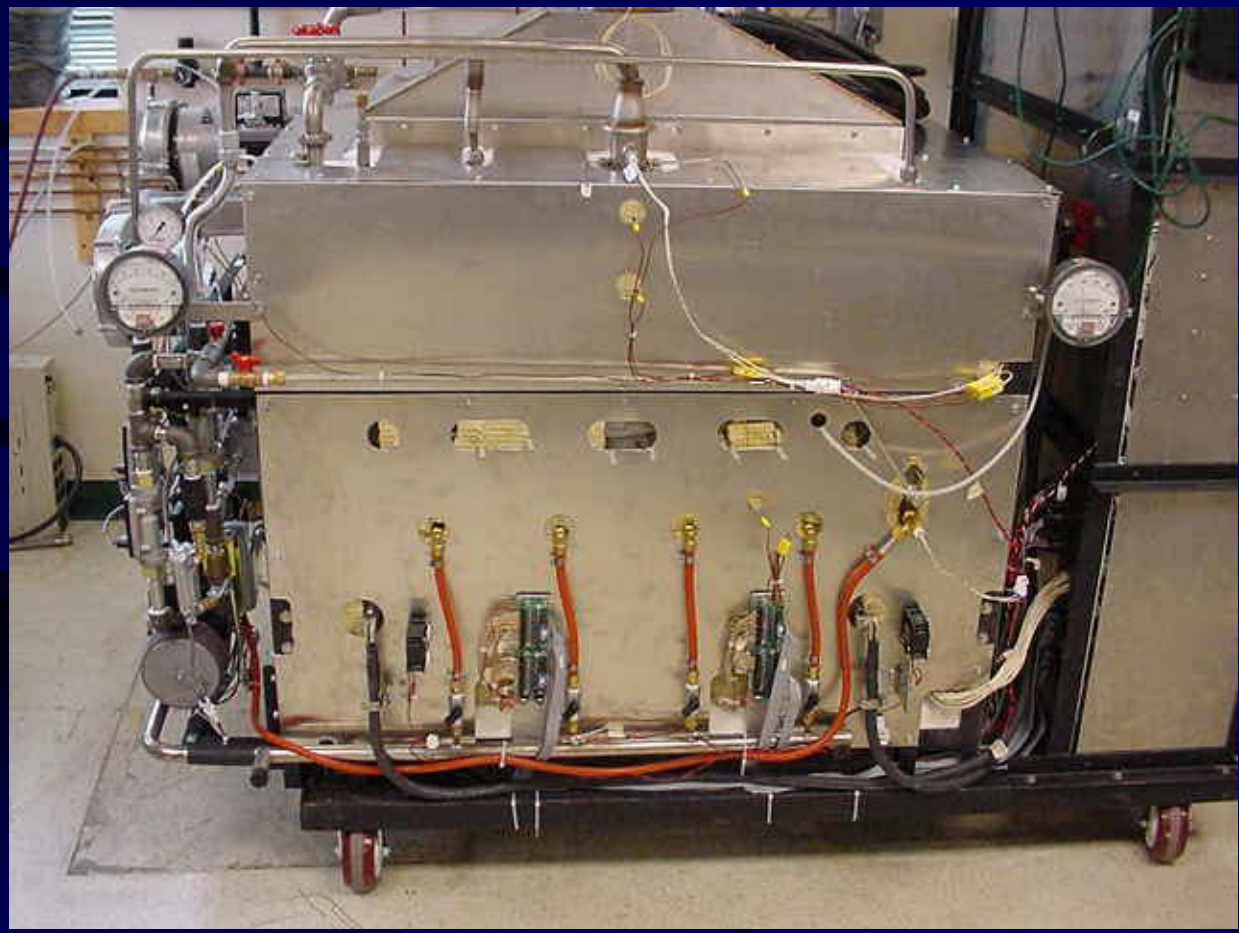
SECA Phase I Cost Estimate

- Total machine cost of $4156/unit
- Cost/kW = $681.

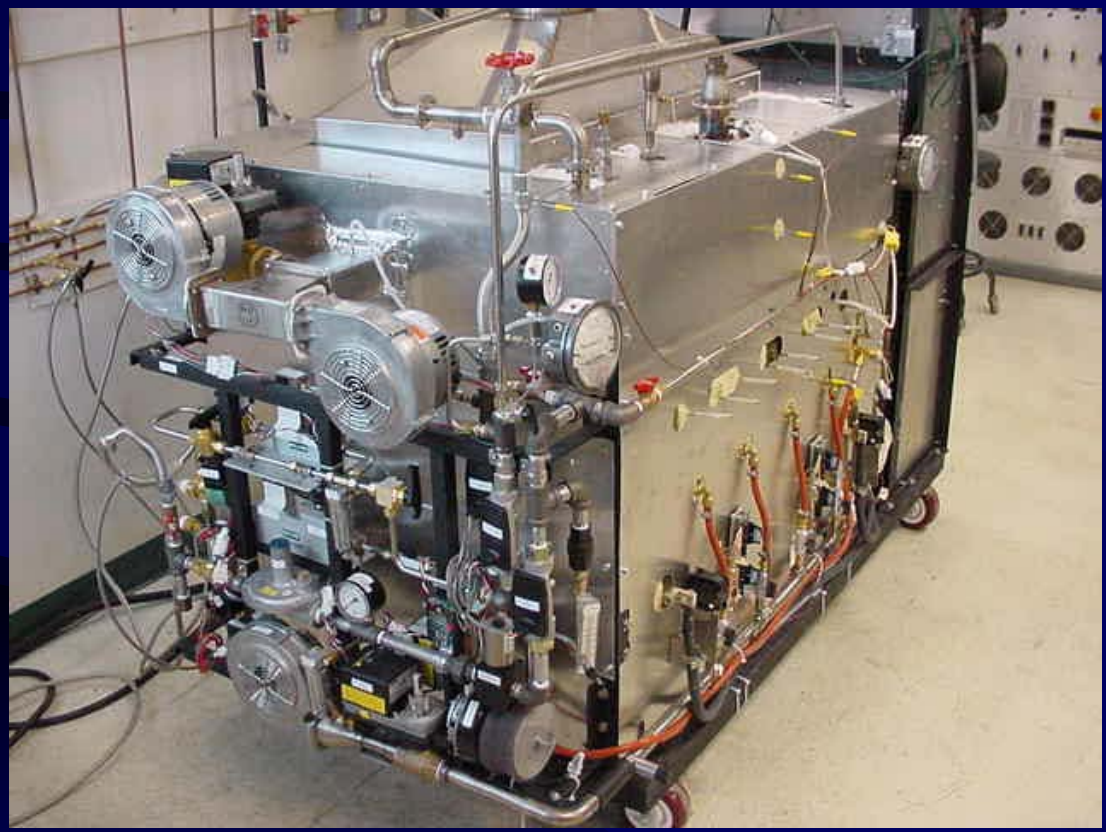
SECA Phase I Machine

- The SECA Phase I machine was built in May/June 2006
- Latest Generation Multi-IC cells were used.
- Used Latest Control boards and DC/DC high efficiency converter developed in Ph I.
- Operated on CPOX fuel stream.

SECA Phase I Machine



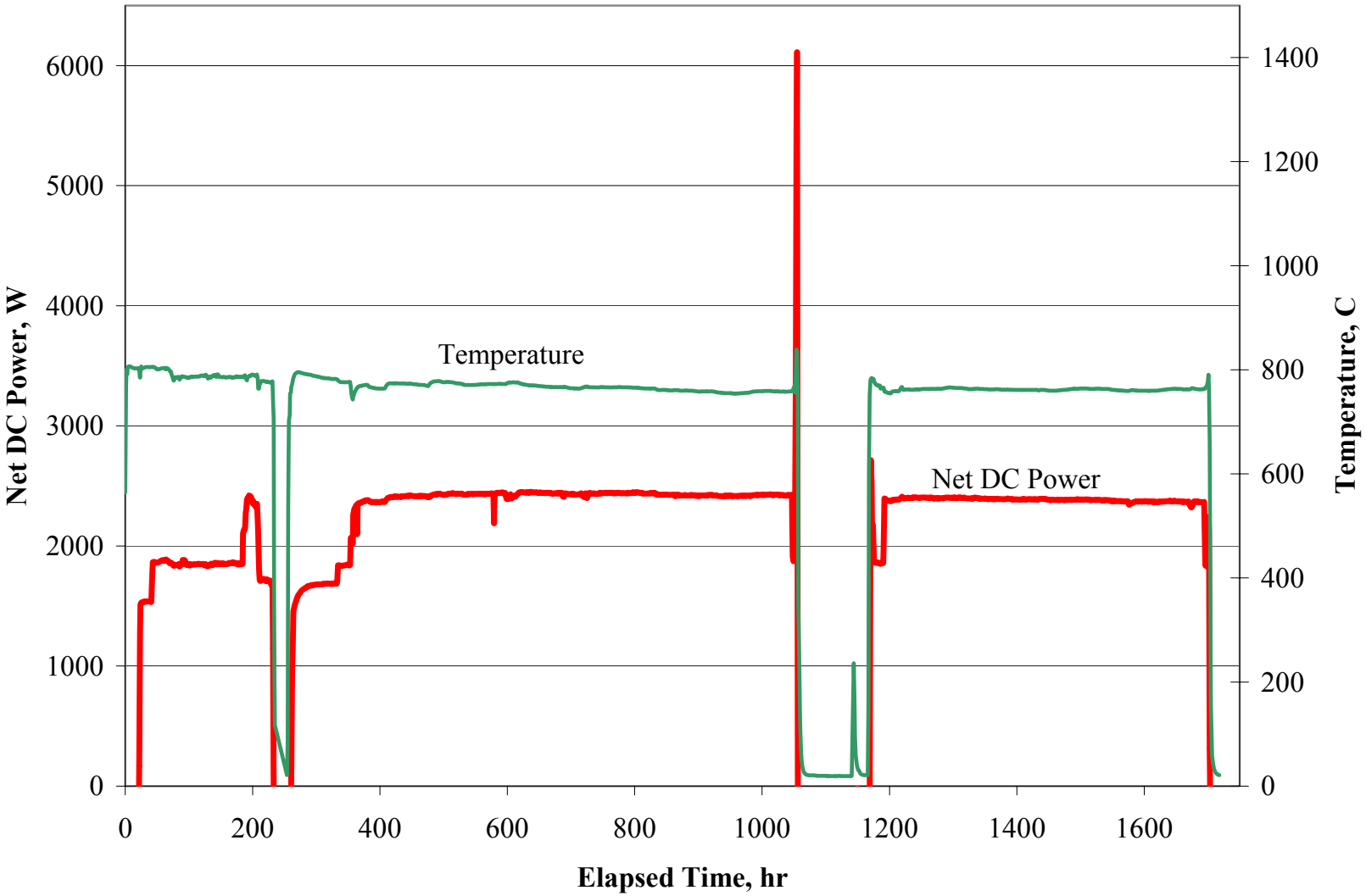
SECA Phase I Machine



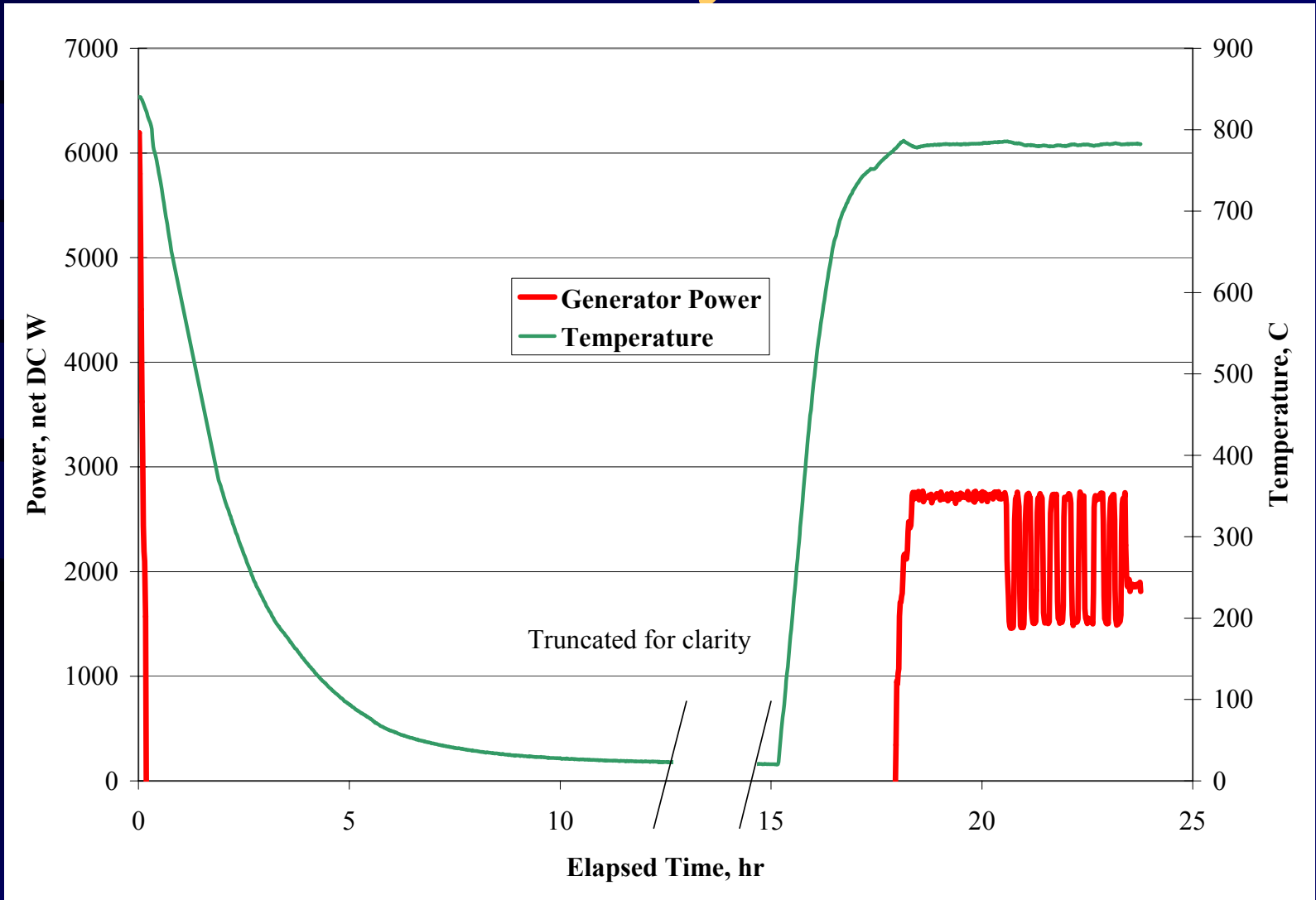
Scheduling

Event	Expected	Actual
Startup	6/22/06	6/27/06 (-5 days)
Finish 1000hr run	7/31/06	8/9/06 (-9 days)
Peak power	8/1/06	8/10/06 (-9 days)
Start 500hr run	8/4/06	8/16/06 (-12 days)
Complete Test	8/25/06	9/06/06 (-12 days)

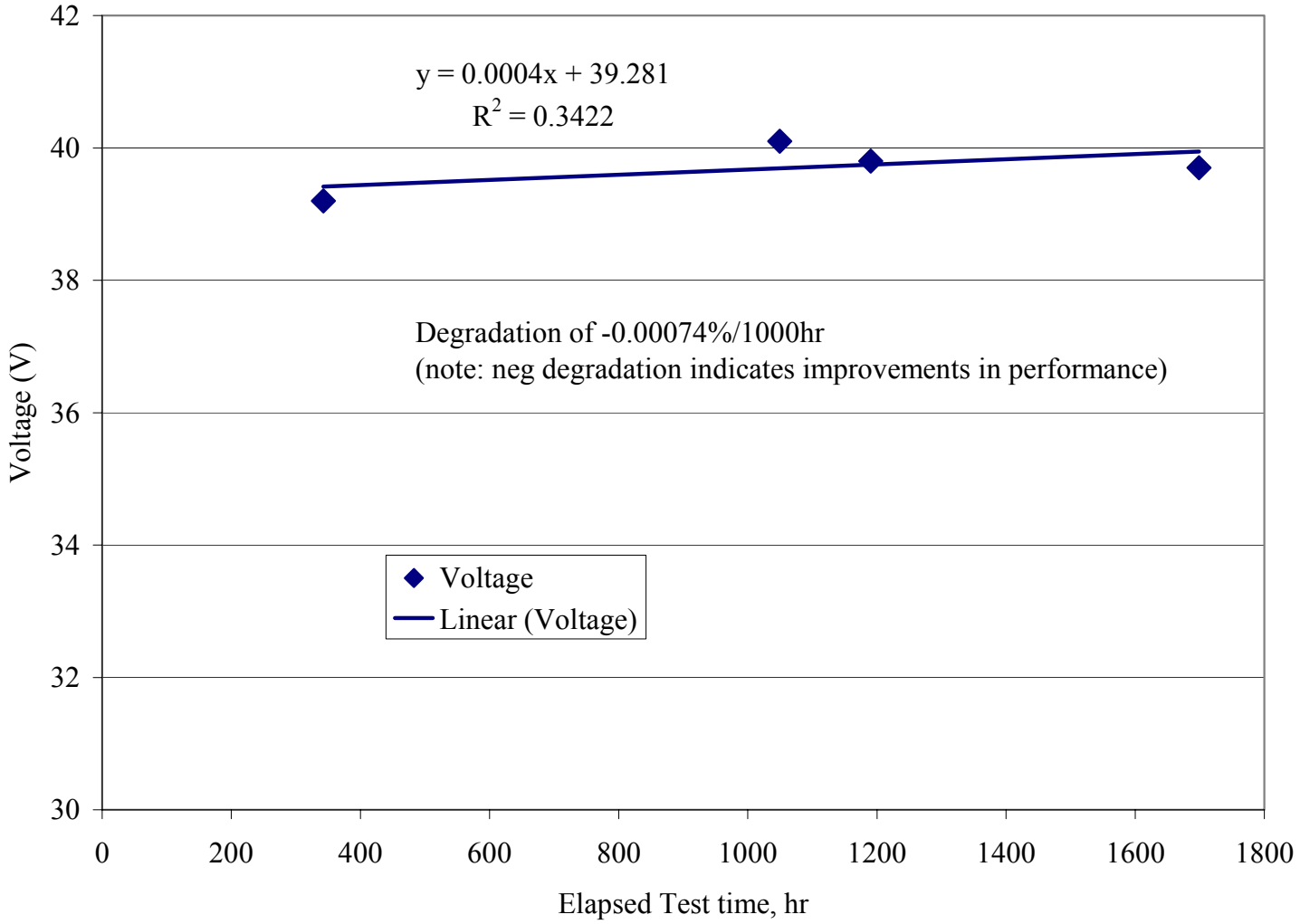
SECA Generator Run



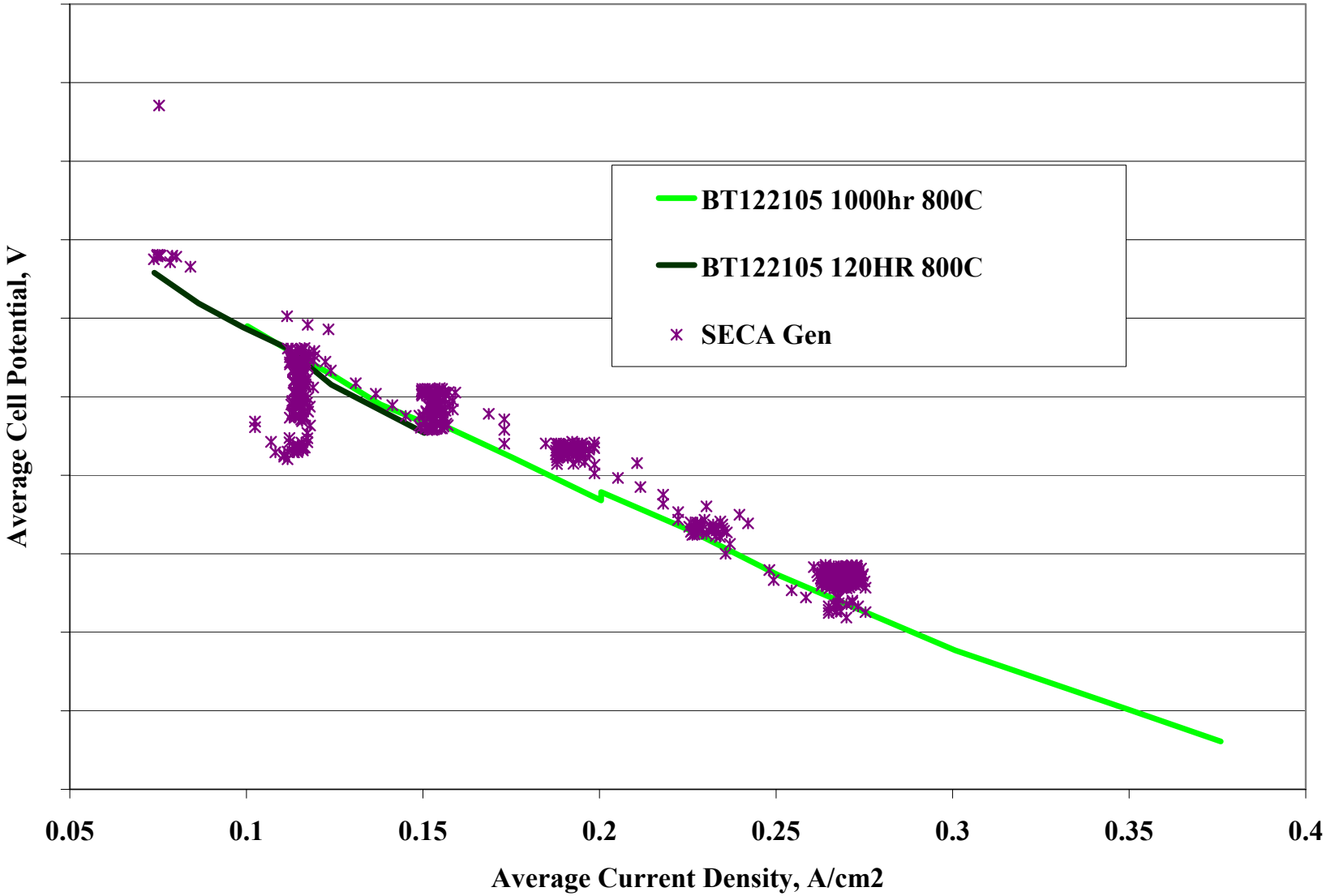
One Thermal Cycle and Nine Power Cycles



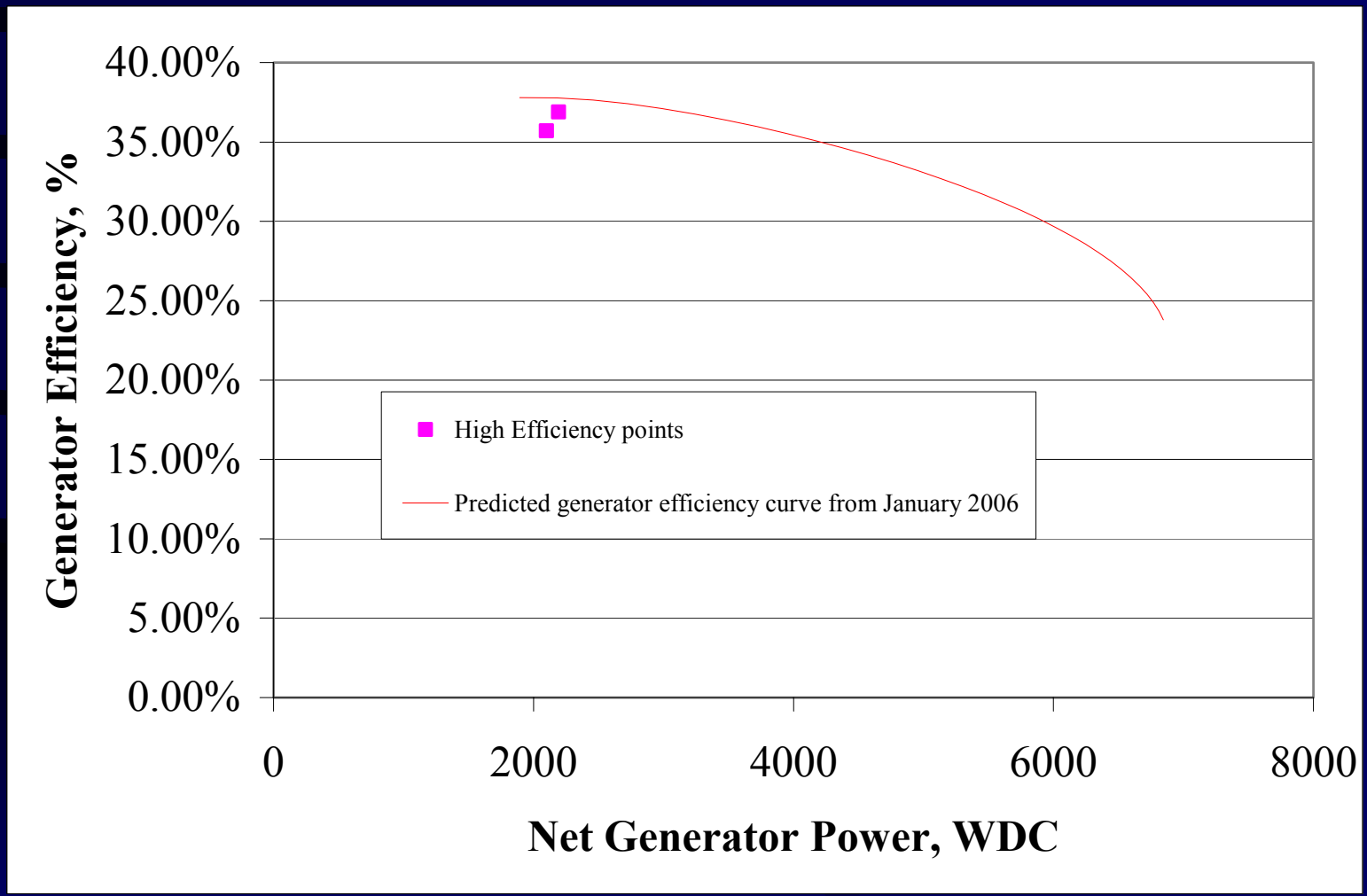
Degradation Points Taken



Generator Performance



Prediction of Efficiency & Empirical Results



SECA Generator Goals

	Goal set by SECA	Acumentrics Phase I Generator
Peak Power, net kW DC	3-10kW	
Degradation Rate %/500hr	≤2%/500hr	
Peak Efficiency, %	35%-55%	
Availability, %	>80%	
Transient Power Degradation, %	<1%	
Cost, $/kW	<$800/kW	

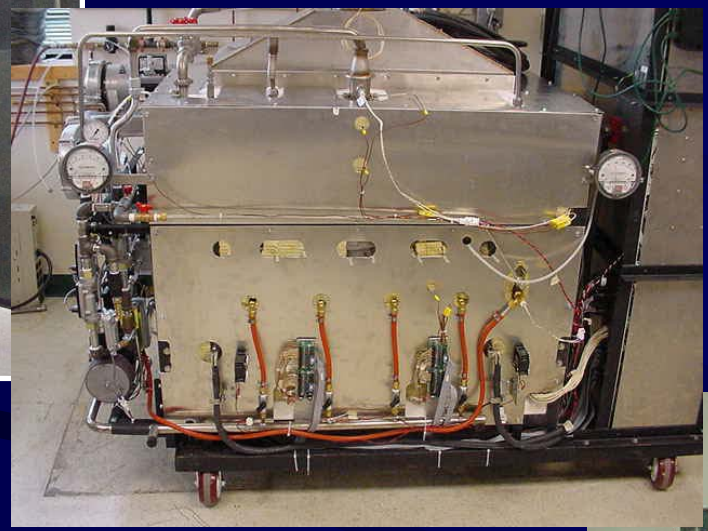
SECA Generator Goals

	Goal set by SECA	Acumentrics Phase I Generator
Peak Power, net kW DC	3-10kW	6.1kW
Degradation Rate %/500hr	≤2%/500hr	-.00035%/500hr
Peak Efficiency, %	35%-55%	36.9%
Availability, %	>80%	97.5%
Transient Power Degradation, %	<1%	0.75%
Cost, $/kW	<$800/kW	~$685/kW

Conclusions

- Completed the development and implementation of a anode supported tubular cell producing twice the power density of that available prior to SECA Phase I.
- Completed the SECA Phase I cost audit demonstrating a cost of <$800/kW (pending final audit review).
- Completed SECA Phase I testing showing power over 6kW on our 5kW class machine and demonstrating very stable performance.

Acknowledgement



Strategic Alliance Partners

National Park Service

UAF CERL EPRI

Propane Energy Research Council

Department of Energy-National Energy Technology Laboratory

Heather Quedenfeld, Project Manager