Development of a Low Cost 3-10kW Tubular SOFC Power System

Norman Bessette

Acumentrics Corporation

June 10, 2010

FC032

Acumentrics
Trusted Power Innovations

Acumentrics Corporation

Strategic Partners

GENERAL DYNAMICS
Strength on Your Side™

U.S. Department of Energy
Energy Efficiency and Renewable Energy

ARISTON

ONR
Science & Technology

ChevronTexaco
Technology Ventures

SECA

MASSACHUSETTS
TECHNOLOGY
COLLABORATIVE

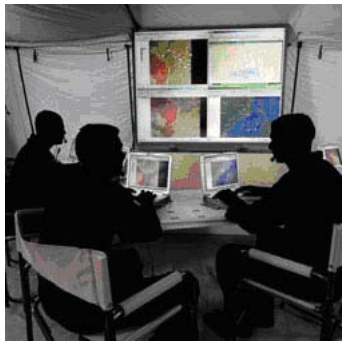
Sumitomo
Corporation

MiSource

Northeast
Utilities System

- *~ 95 Employees*
- *Manufacturing since 1994*
- *Based in Westwood, Mass.*
- *~40,000 sq. ft facility*
- *Critical disciplines in-house*
  - Electrical Engineering
  - Mechanical Engineering
  - Chemical Engineering
  - Thermal Modeling
  - Ceramics Processing
  - Manufacturing
  - Sales & Marketing
  - Automation
  - Finance

Acumentrics *Battery-based* UPS



Uninterruptible Power Supplies for Harsh Environments

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

Acumentrics
Trusted Power Innovations

Solar Flare Tests RUPS at 170˚F for 16 hours

General Atomics SkyWarrior

Overview

Timeline

- Project Start: 4/1/2008
- Project End: 9/30/2011
- Percent Complete: 60%

Budget

- Project Funding
  - DOE Share=$11,692,737
  - Contractor=$3,897,579
- Funding Received
  - $6,695,325

Barriers

- Cell Power Density
- Stack Power Density
- Cell Cost Reduction
- System Cost Reduction
- System Efficiency
- Lifetime

Objectives

- Improve Cell Power & Stability
- Cost Reduce Cell Manufacturing
- Increase Stack & System Efficiency
- Develop ability to operate on liquid fuels (funded through ONR & DOD)
- Integrate to remote power, military, and mCHP platforms to allow short, medium, and longer term market penetrations

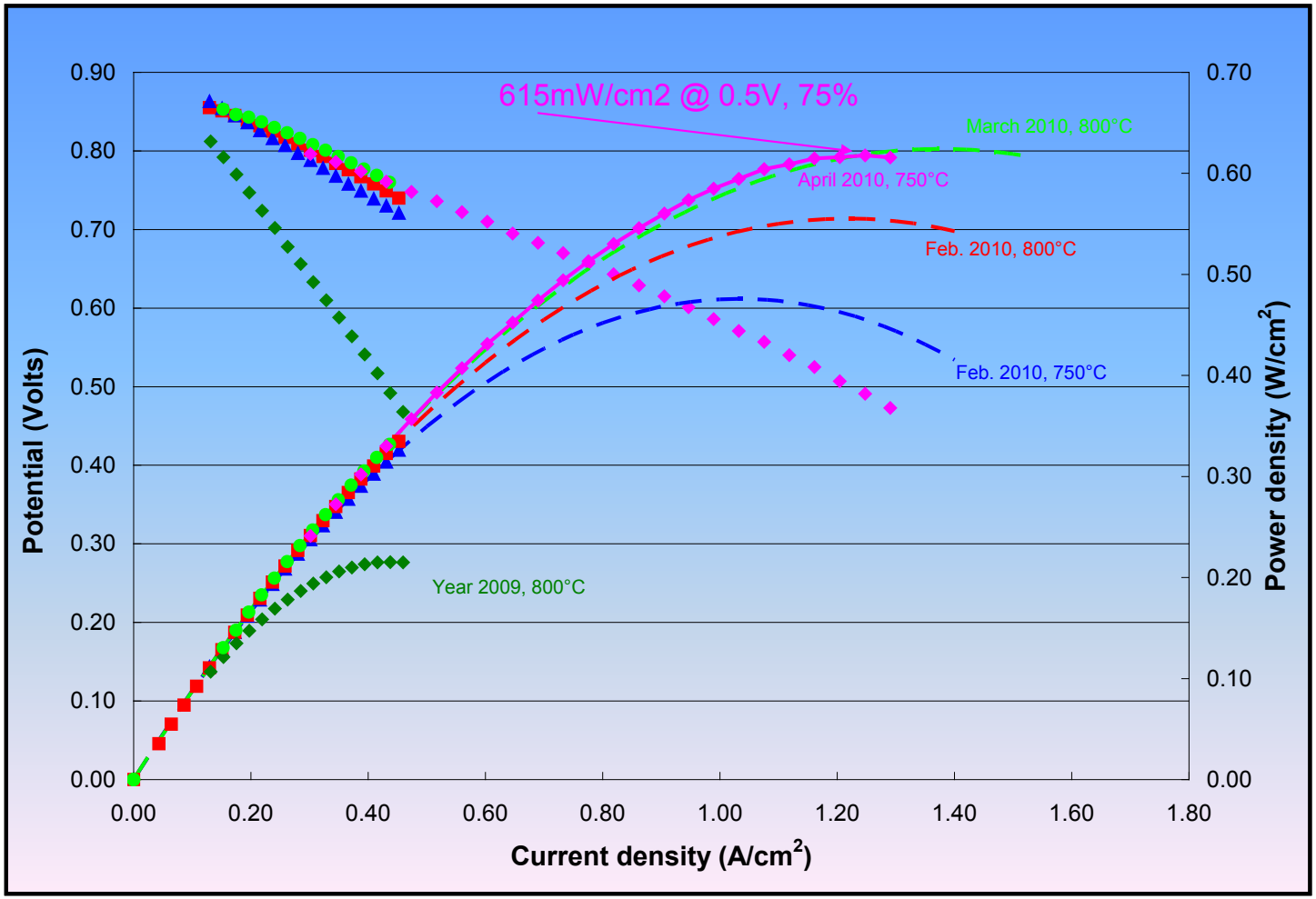
Technical Approach

Perfect the individual System pieces followed by optimizing their integration:

- **Cell Technology:** Improve power & stability of the cell building block
- **Cell Manufacturing:** Improve processing yield & productivity while decreasing material consumption
- **Stack Technology:** Refine stack assembly and improve heat removal and integrity while cost reducing components
- **System Performance:** Develop simplified controls and BOP to allow for a reliable, highly efficient unit.

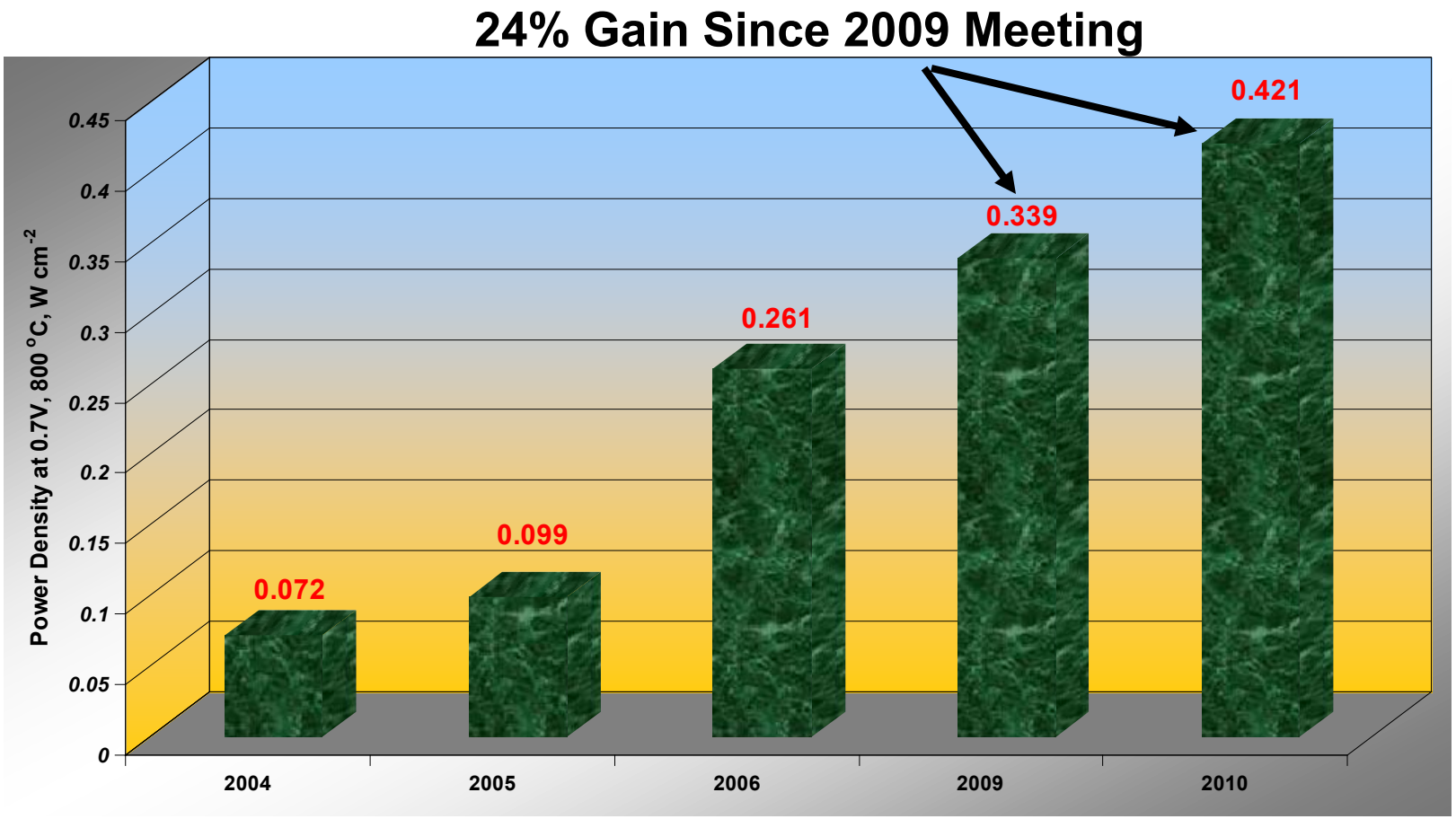
Acumentrics
Trusted Power Innovations

Cell Performance Progress

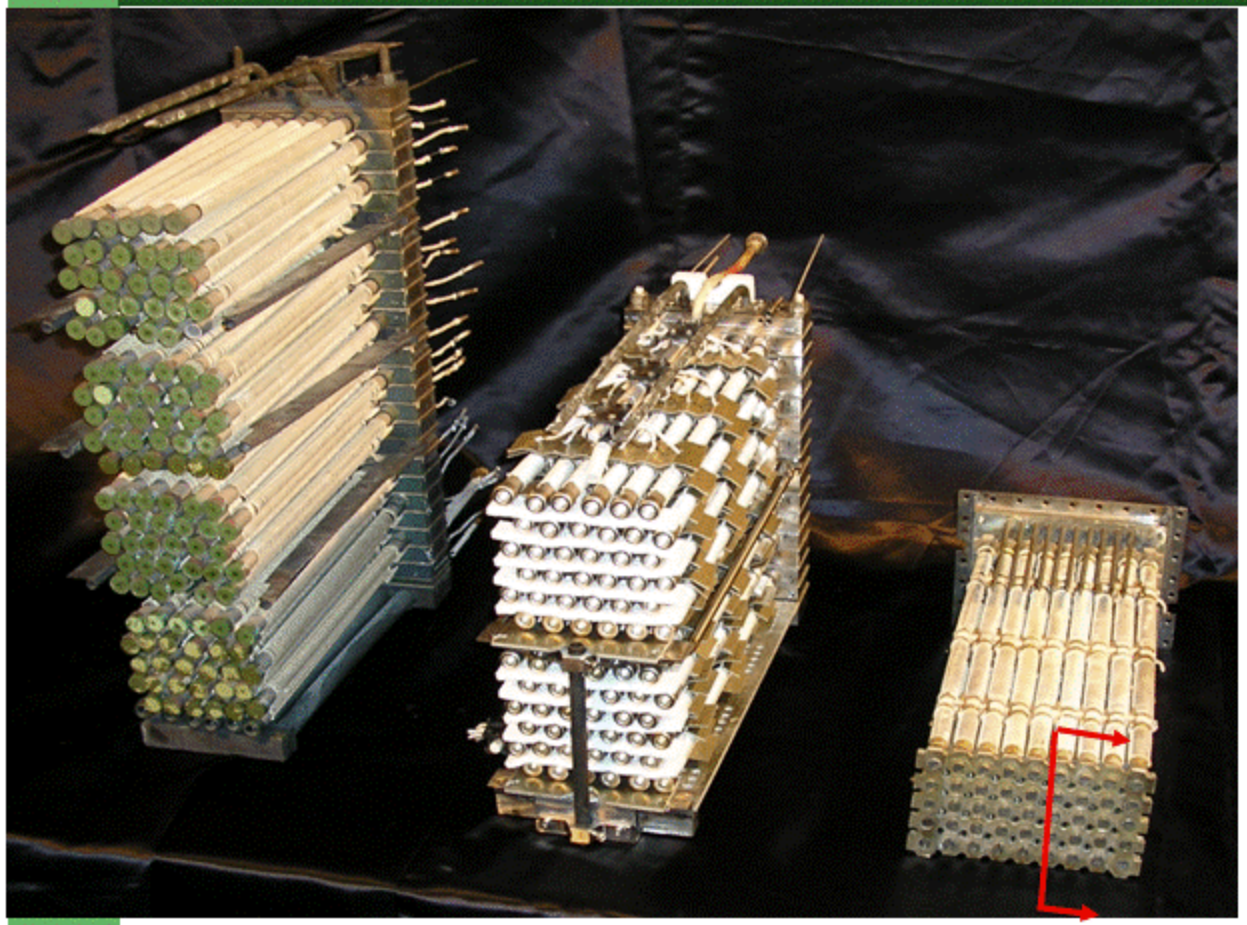


Acumentrics
Trusted Power Innovations

Cell Performance Progress



Stack Size Reduction



No. of tubes-1.25 kW
2004 – 126 tubes
2006 – 72 tubes
2009 – 45 tubes
2010 – 20 tubes
55% reduction since 2009 meeting!

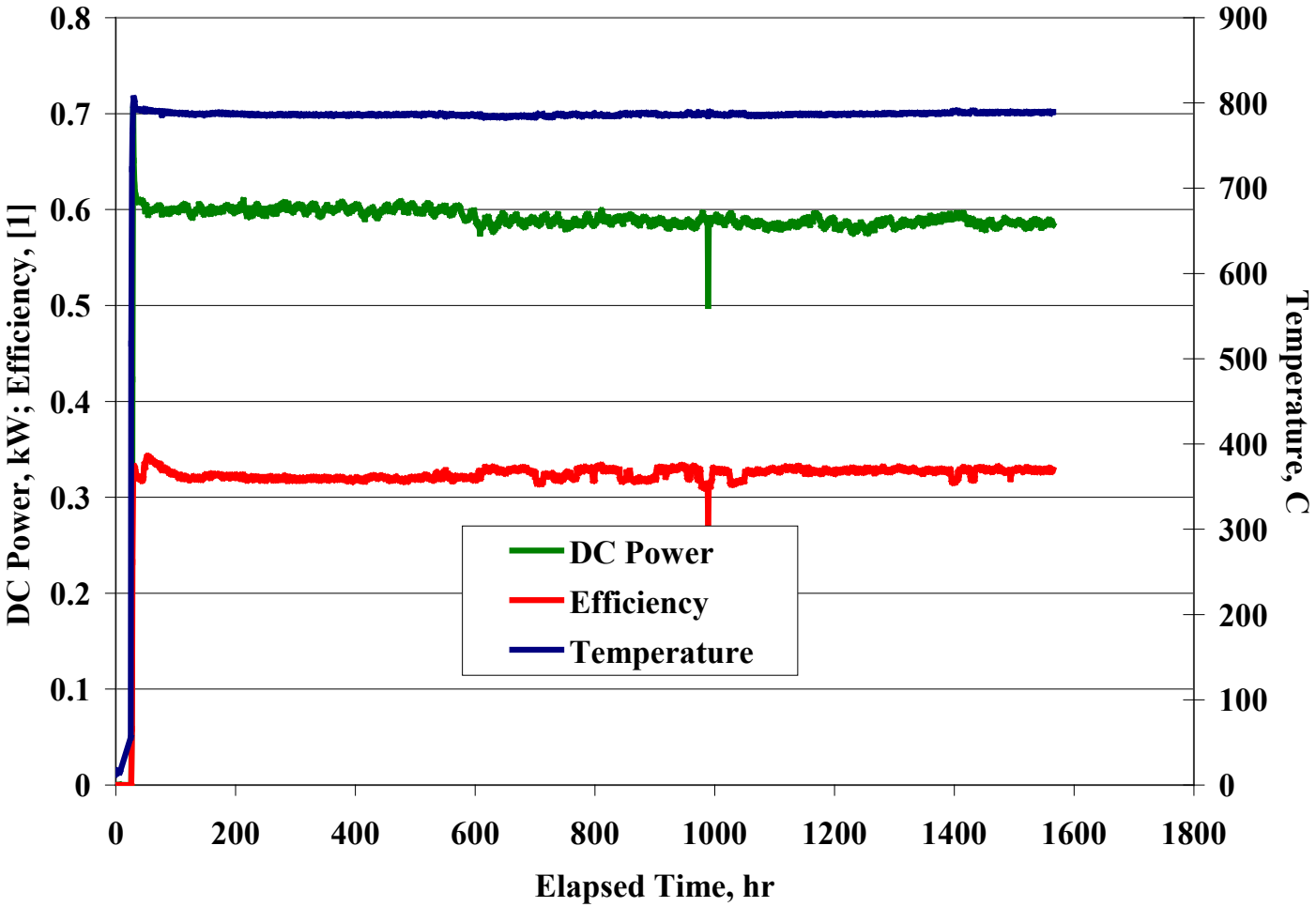
Weight reduction (total):
75% from 2004-2009
90% from 2004-2010
Additional 15% or ~13lbs since 2009 meeting!

Volume reduction: 33% 2009-2010

EERE Funded Program Status

- Achieved passage of BP1/BP2 “Go/No-Go” test in June 2009
- Demonstrated over 40% net AC on both steam reformed & advanced generator systems
- Significantly increased power per cell.
- Reduced operating temperature by 100C and potential for 200C
- Developed reduced recuperator cost and flexible design through this program and DOE Heat Exchanger SBIR.

Goal: 1500hr operation with <1%/500hr degradation rate

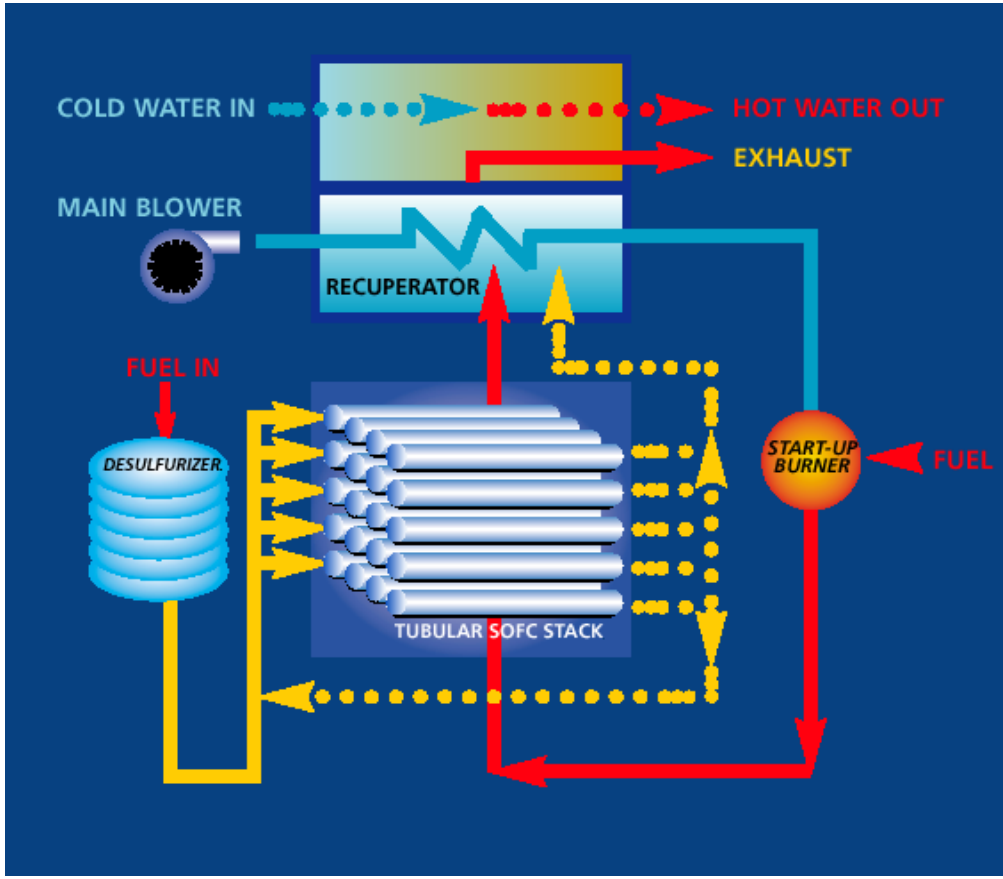


Setup:
1kW nominal
-Previously had ~473hrs operation
-Hour-averaged data shown

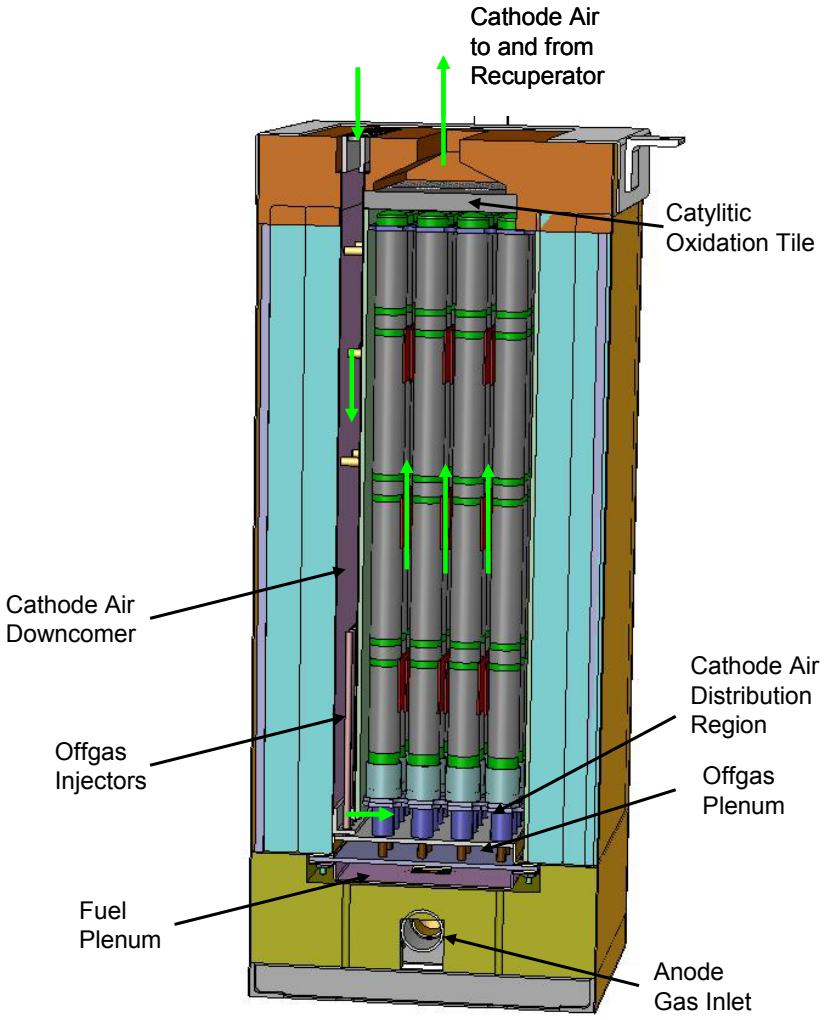
0.9%/1000hr
(0.7%/1000hr counting starting hours)

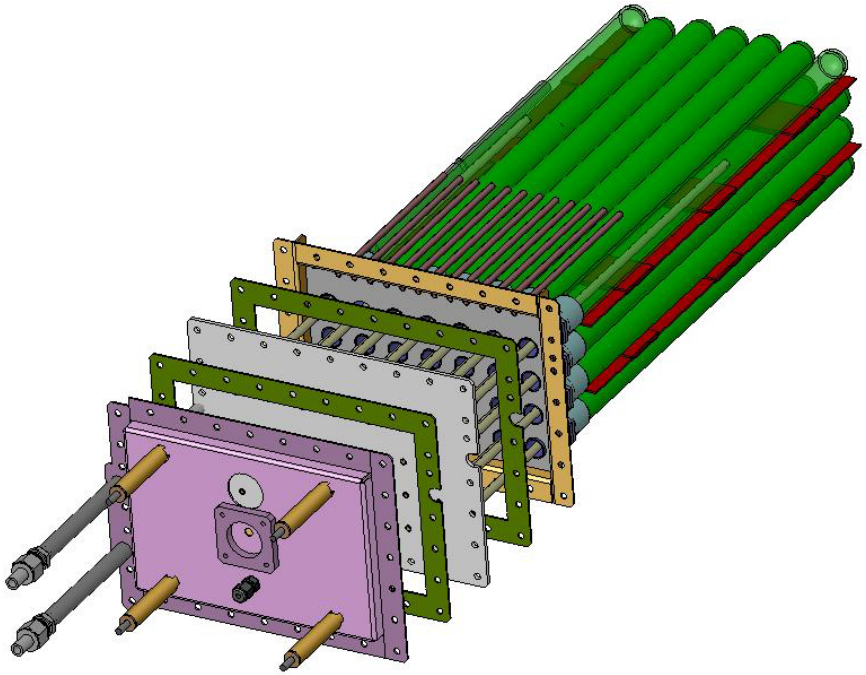
System Operation

- Tubular Cells
  - Inherent strength and tolerance to rapid temperature change
- High Operating Temperature (800 C)
  - Internal fuel reforming and cogeneration opportunity
- Standard Manufacturing Process
  - Low capex
- Standard Components
  - Standard HVAC balance-of-plant components
  - Leverage 12 years DC/AC conversion experience



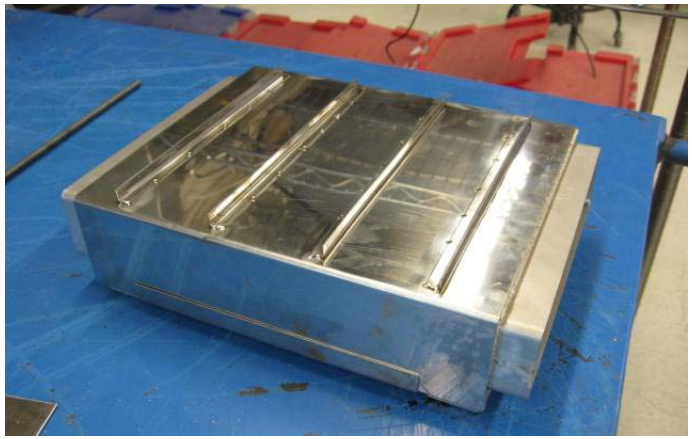
Stack Design





Recuperator Reductions

- 300 cu. in.
- 17.8 lbs

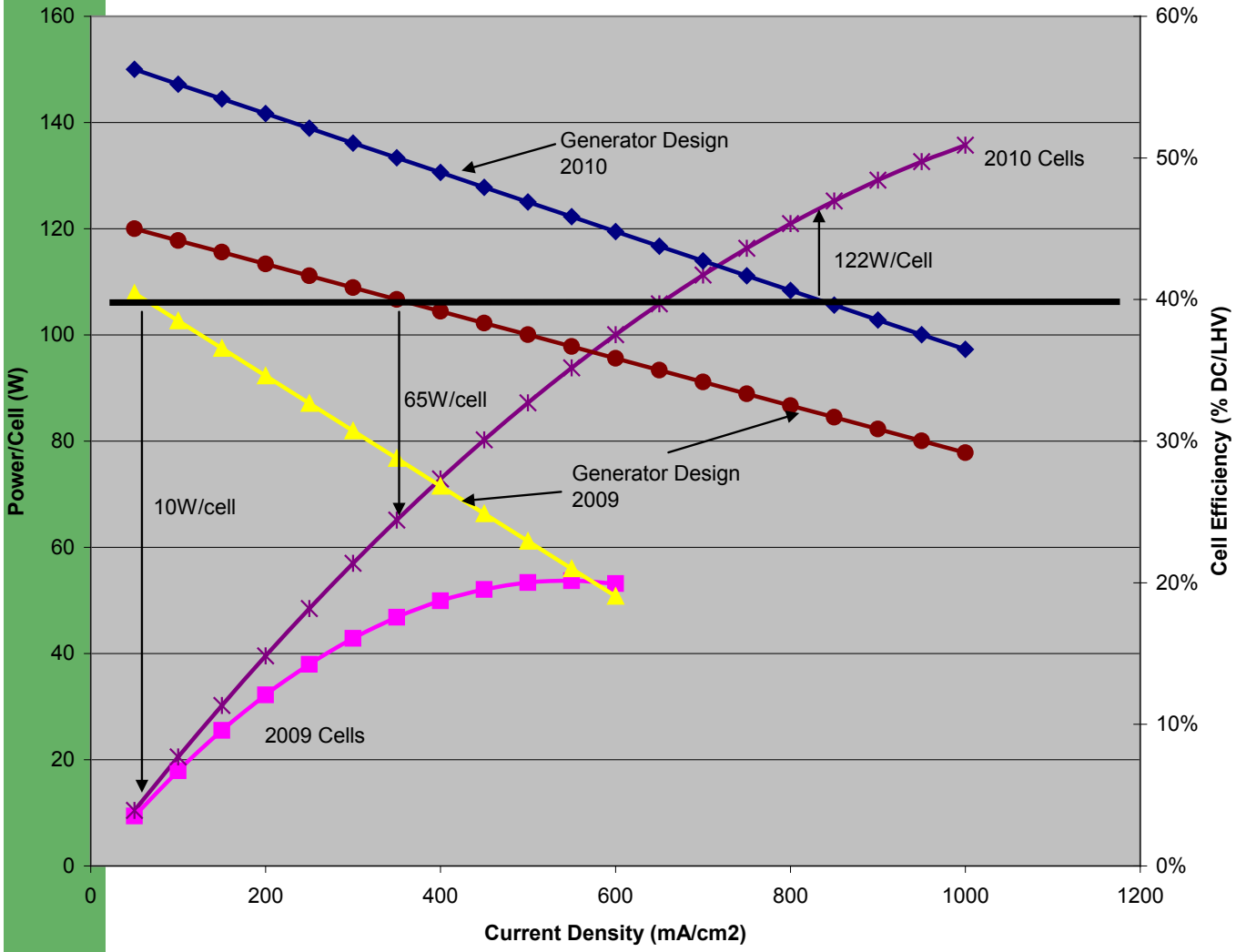


- 100 cu. in.
- 3.8 lbs

REQUIREMENTS

- Exhaust Inlet Temperature: 850 - 950C
- Air Outlet Temperature: 725 - 800 C
- Effectiveness: >85%
- Total Pres Drop: 1250 Pa
- Equal Air & Exhaust Flows
- Air Flow – 150 Slpm/ kWe
- 100,000+ Hours & Hundreds of Thermal Cycles

Improvements in Generator Design



Latest Cell Design

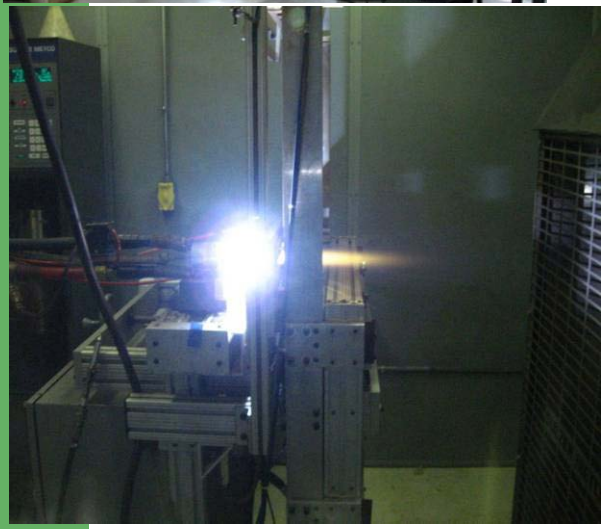
6x decrease in cell count at 40% efficiency

Latest Generator Design

2x decrease in cell count for 40% efficiency

Fuel Cell Manufacturing

Isostatic Press



Plasma spray

Automated dip-coating

- Facility Capable of >300kW/yr
- Cell Cost down 55% since 2009 review
- Down 67% material, 45% labor
- Cell Power up >100%/cell

Automated Cathode Coating

High Temperature Firing

Relevance to EERE Stationary Milestones

	2008 Status	2012	2015	2020	Acumentrics Present Status
Electrical efficiency at rated power	34%	40%	42.50%	45%	35-40%
CHP energy efficiency	80%	85%	87.50%	90%	85%
Factory cost	$750/kW	$650/kW	$550/kW	$450/kW	
Transient response (10%- 90% rated power)	5 min	4 min	3 min	2 min	<3 min
Start-up time from 20°C ambient temperature	60 min	45 min	30 min	20 min	25 min
Degradation with cycling	< 2%/1000 h	0.7%/1000 h	0.5%/1000 h	0.3%/1000 h	<1%/1000h
Operating lifetime	6,000 h	30,000 h	40,000 h	60,000 h	>5000h
System availability	97%	97.50%	98%	99%	99%

- Efficiency proven over 40% on stack. Demonstrate system in 2010/2011
- CHP efficiency of 85% proven on 1kWe wall hung systems
- Demonstrated start-up and load transients as part of ONR liquid fuels testing
- Latest generation systems operated with stacks over 5000hrs and total system tests over 8000hrs

Acumentrics
Trusted Power Innovations

Products

Remote Power System Specifications

500 W DC / Load following capability / Natural Gas, propane fueled

Electrical Efficiency of 20-35%

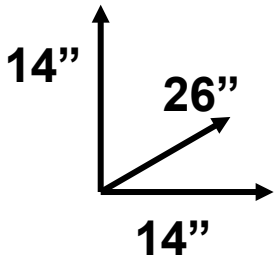
Previous Generation

Size: 22” x 22” x 33”, 220lbs, 9.2ft3

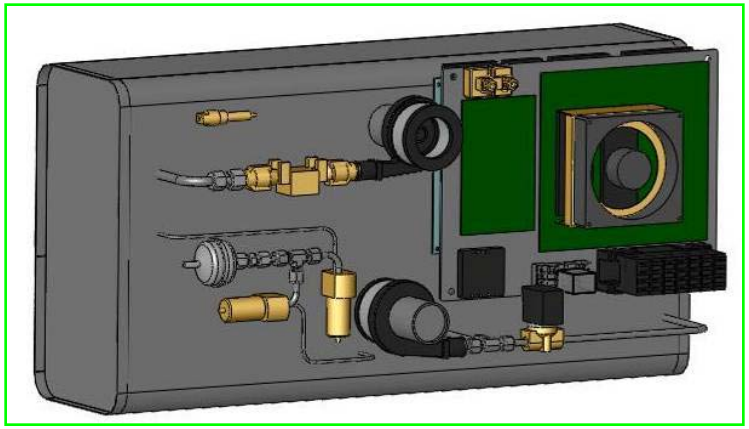
68% weight reduction

70% weight reduction

Present Generation

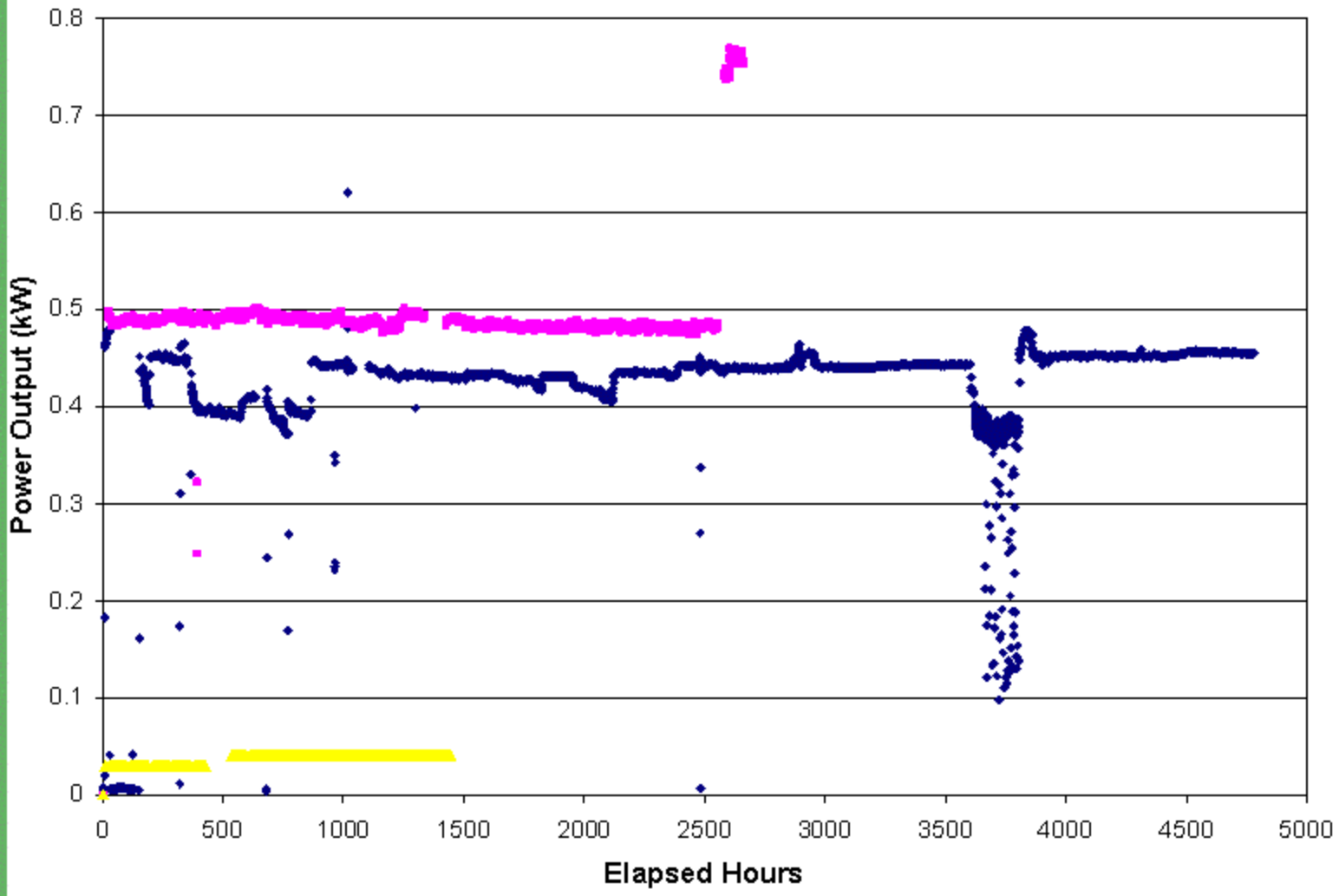


2.9ft^3
60-70lbs



Acumentrics
Trusted Power Innovations

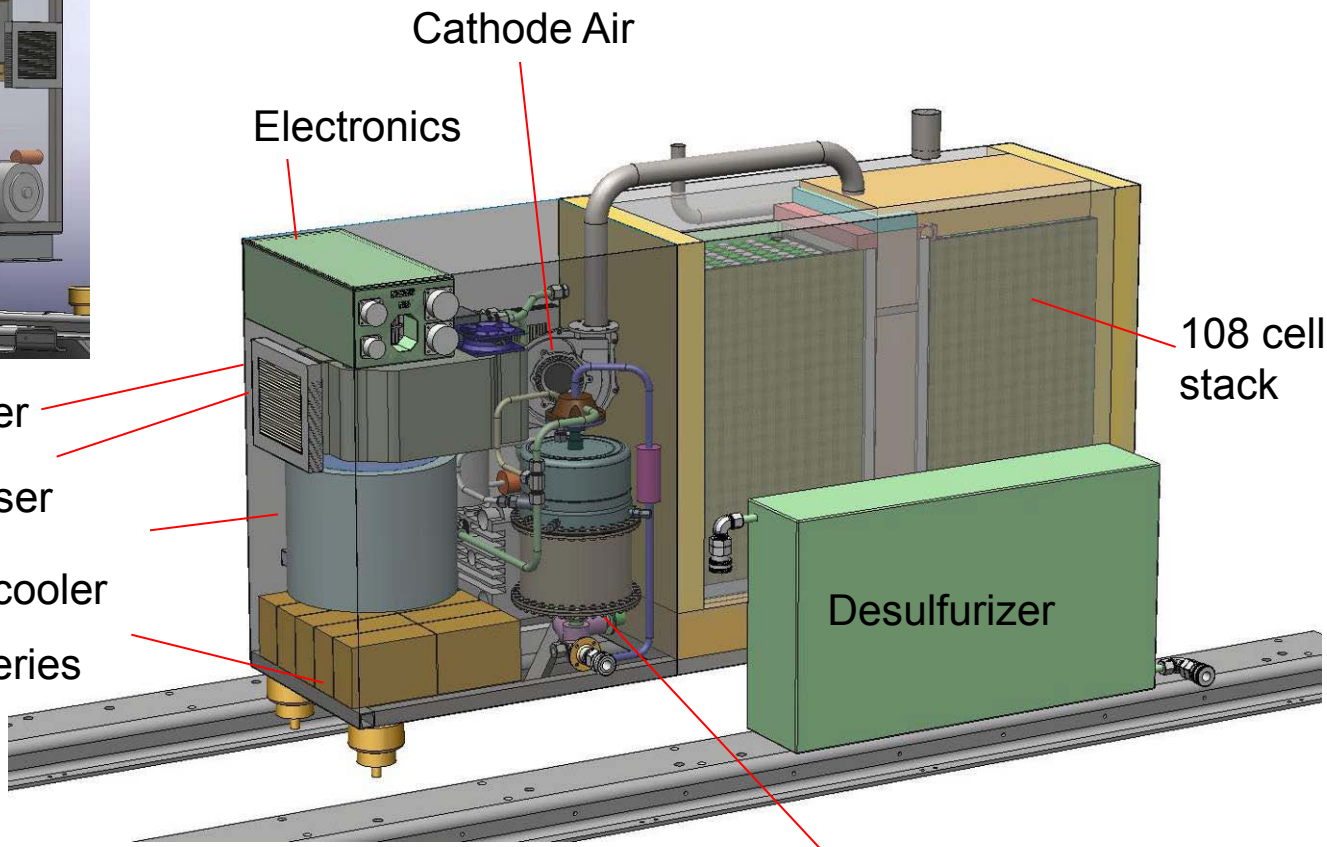
Remote Power Unit Stability



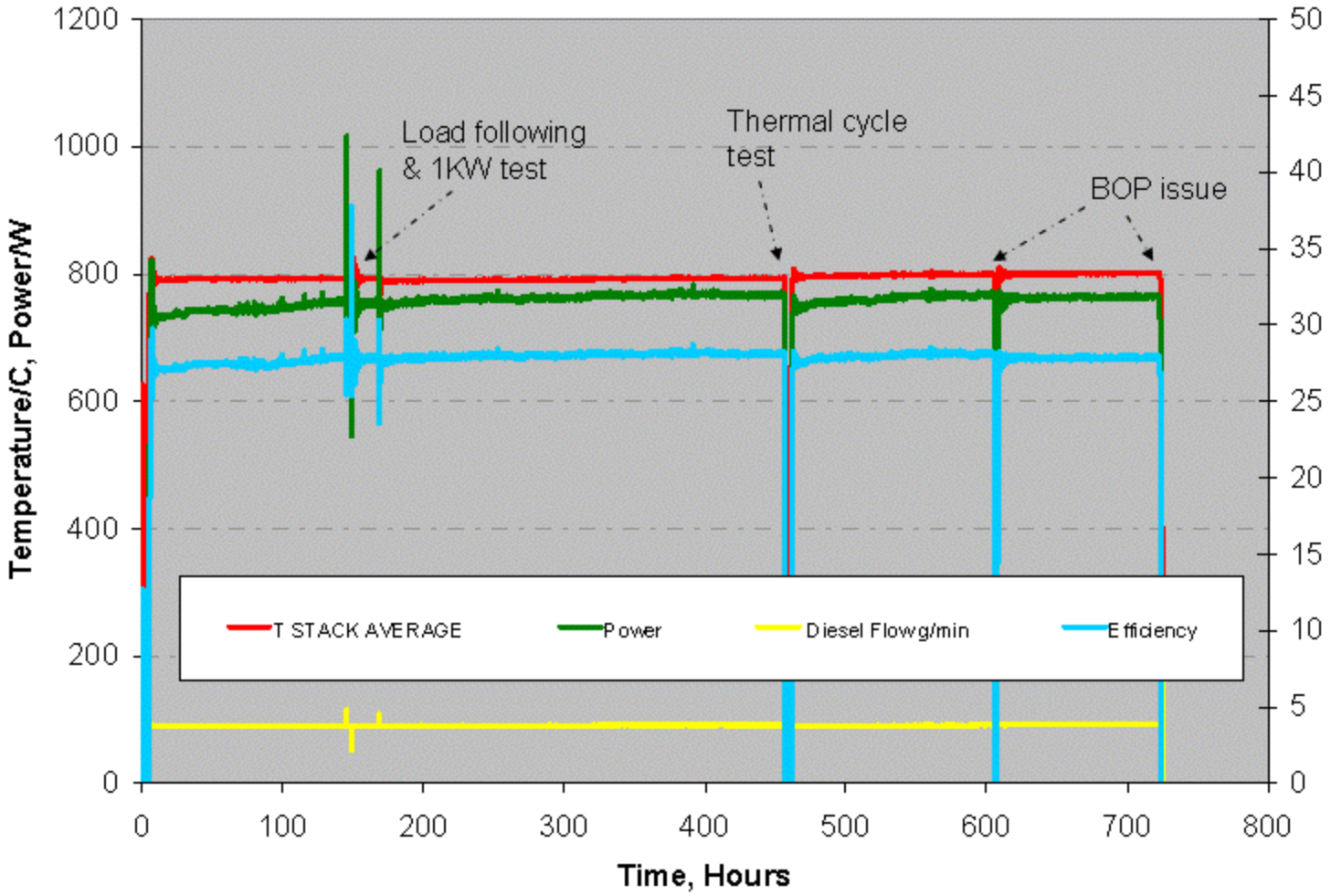
Environmental Testing

- Operating at various ambient temperatures up to 45 degrees C >5000hrs.

JP-8 Fueled 10kW Generator



Operational Stability on Liquid Fuel



mCHP vs. power plant and (condensing) boiler

Acumentrics

microCHP
simultaneous power and heat production

Primary energy
100%

Losses
10%

20% power

70% heat

90% useful energy

Primary energy 100%

40% Power plant

60% heating

Losses
24%

16% power

56% heat

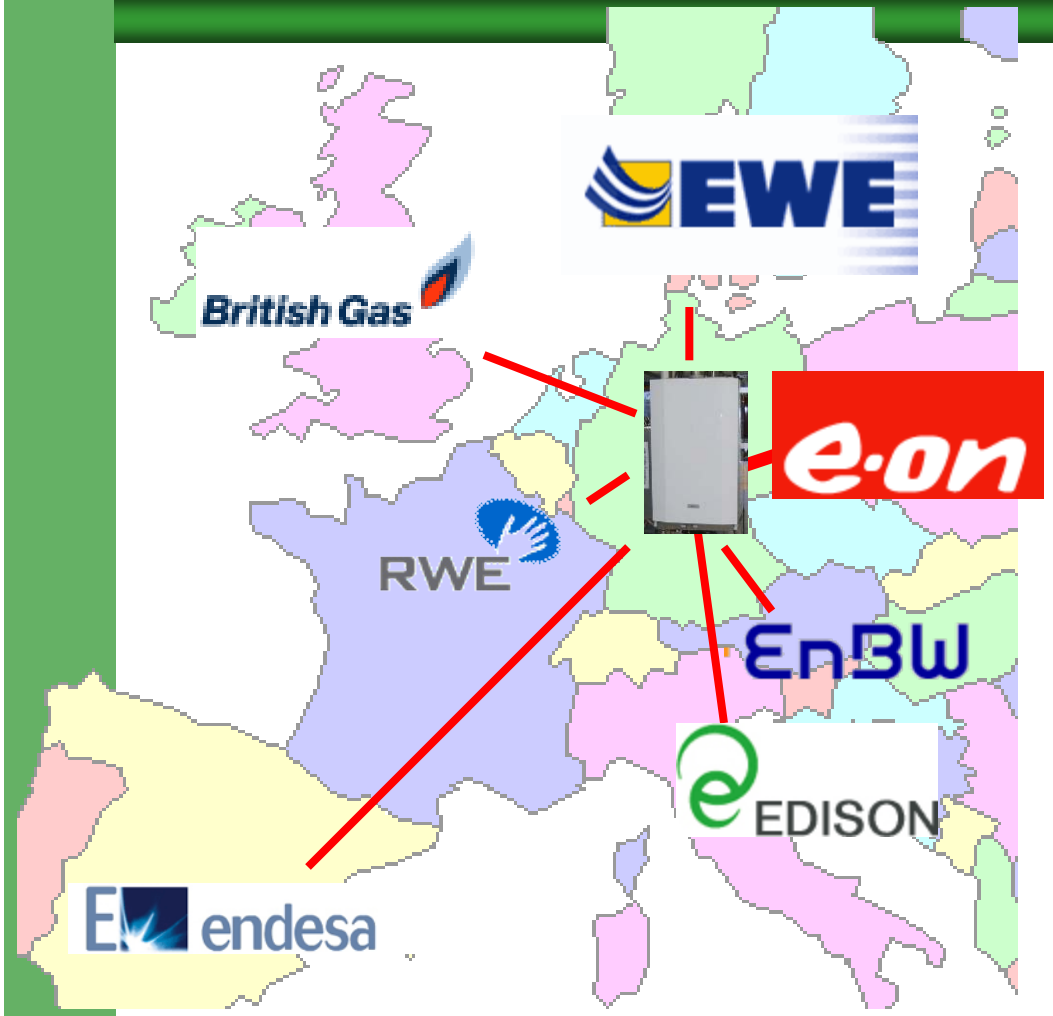
4% Losses

72% useful energy

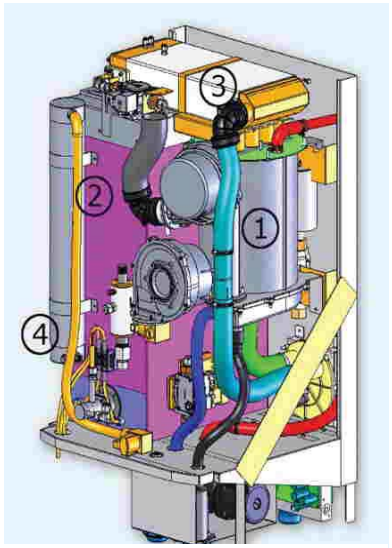
Common technology
separate power and heat production

= 10 – 25% lower primary energy consumption
= 10 – 25% lower CO_2 emissions
= 10 – 25% lower energy cost

1kW Home CHP Appliance



- 25% energy savings
- Demo with major European utilities
- Follow-on work under EFESO program
- Need to integrate latest Cell technology



1 Booster Boiler
2 Fuel Cell Stack
3 Exhaust Heat Exchanger
4 Fuel desulfurizer

ARISTON

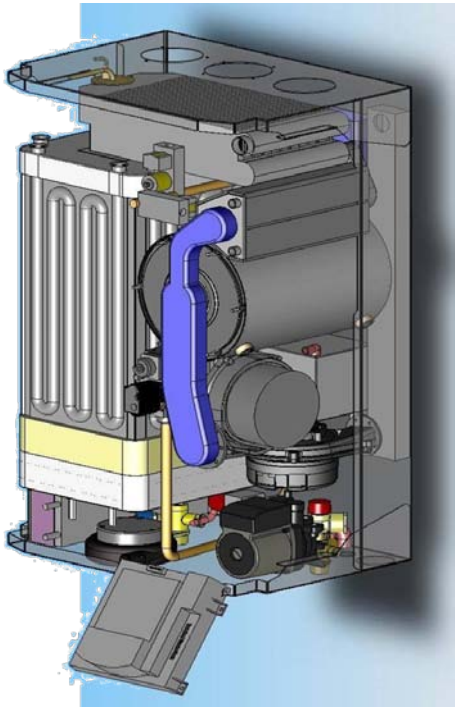
Collaborations - EFESO Program

Enviromentally Friendly Energy from Solid Oxide fuel cell

- Italian government program granted to Ariston thermal group and 15 partners including Acumentrics.
- Acumentrics is the first foreign company to be issued an Italian government grant for a green energy program
- Heavily dependent upon the previous and future support of the U.S. DOE.
- Three year, $1.1M program culminating in a 1kWel and 2.5kWel mCHP prototype.
- Brings in key technology contributors on inverters, balance of plant components, testing labs/Universities and certifying bodies

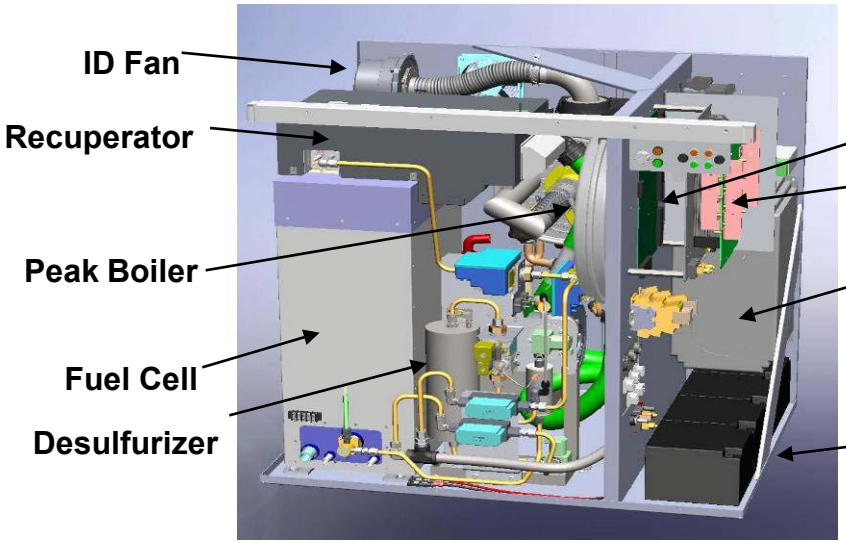
Ariston Wall Mounted mCHP

- One kilowatt unit with 20 kW thermal boiler
- Huge achievement to meet space and weight requirements
- 80-90% total efficiency, 33”x22”x18”
- 180lb total, 100lb FC sys



mCHP Appliance

- 2kW Electrical/30kW thermal
- On-demand hot water
- Condensing Boiler
- 40%electrical, 85-90% total efficiency



Proposed Future Work

- Assure cell stability
  - Correlate stability vs. current density
  - Demonstrate stability over thermal cycles
- Resolve thermal issues in stack due to higher power density
  - Test improved thermal management techniques
  - Compare results of CPOX and steam reformed systems
- Continue cost reductions on each product platform
  - Continue cell manufacturing automation
  - Continue “make/buy” decisions on generator and BOP components

Summary

- Significant progress in cell power enhancement
- Advanced Cell Manufacturing automation & material reduction while increasing cell performance.
- Significant progress in stack size & weight
- Demonstrated stable system operation in real world conditions for >5000hrs.
- Defined a path to market entry for the short, medium, and long term.

Thanks to

- Reginald Tyler of the DOE-Golden Office
- Dimitrios Papageorgopoulos -DOE EERE
- Thomas Benjamin-Argonne National Laboratory
- Don Hoffman, John Heinzel, Ed House - ONR
- Ariston Thermal Group
- Technical Staff at Acumentrics