

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

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FC032

This presentation contains no proprietary, confidential, or otherwise restricted information

Acumentrics Corporation

Strategic Partners



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



- ~ 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

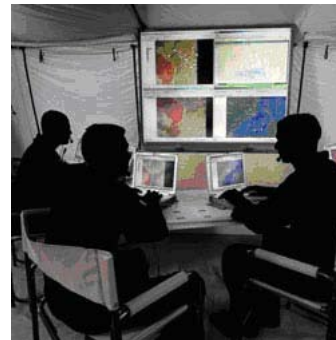
Acumentrics *Battery-based* UPS

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



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

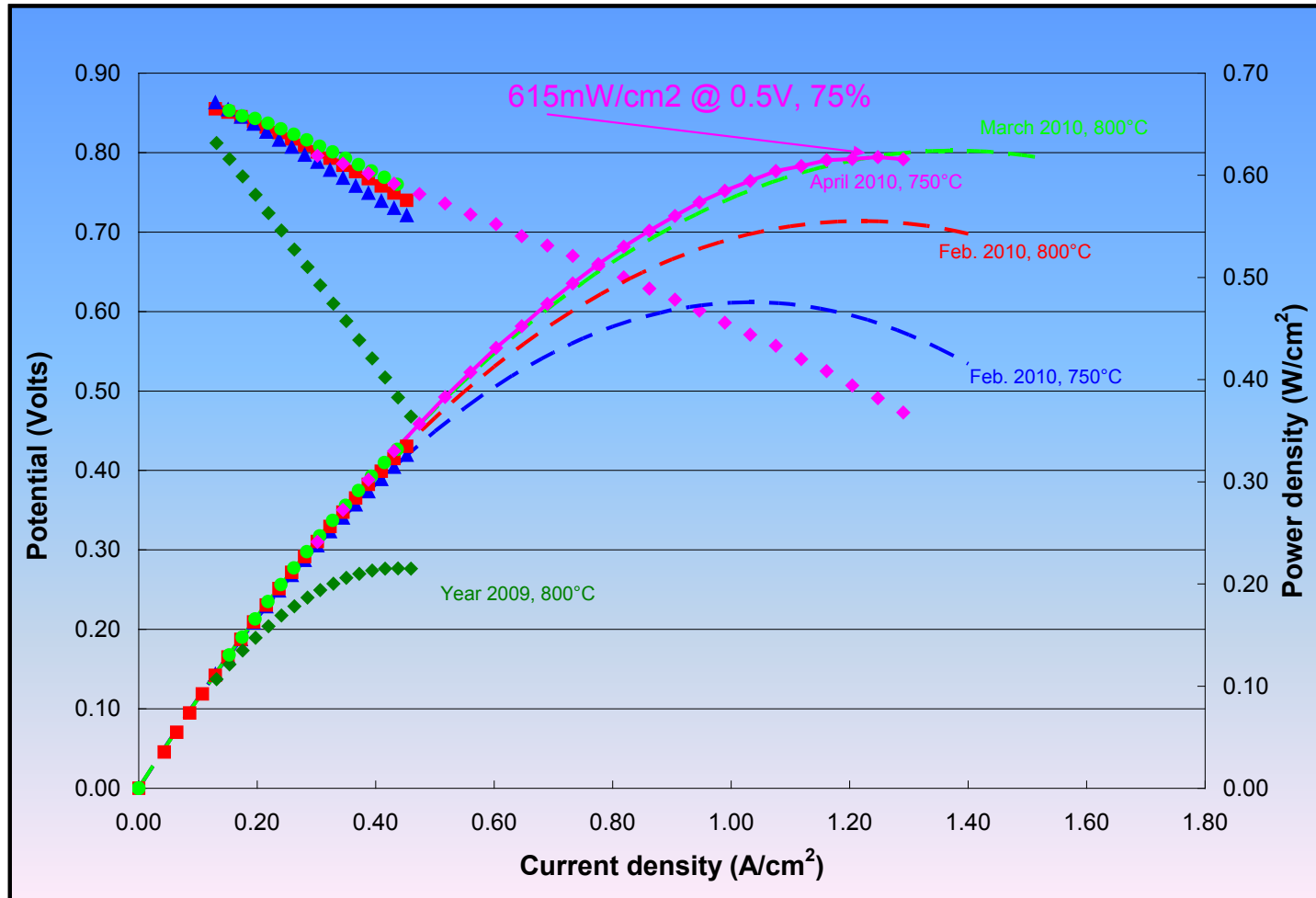
- Improve Cell Power & Stability
- Cost Reduce Cell Manufacturing
- Increase Stack & System Efficiency
- Develop ability to operate on liquid fuels (funded through ONR & DOD)
- Integrate to remote power, military, and mCHP platforms to allow short, medium, and longer term market penetrations

Technical Approach

Perfect the individual System pieces followed by optimizing their integration:

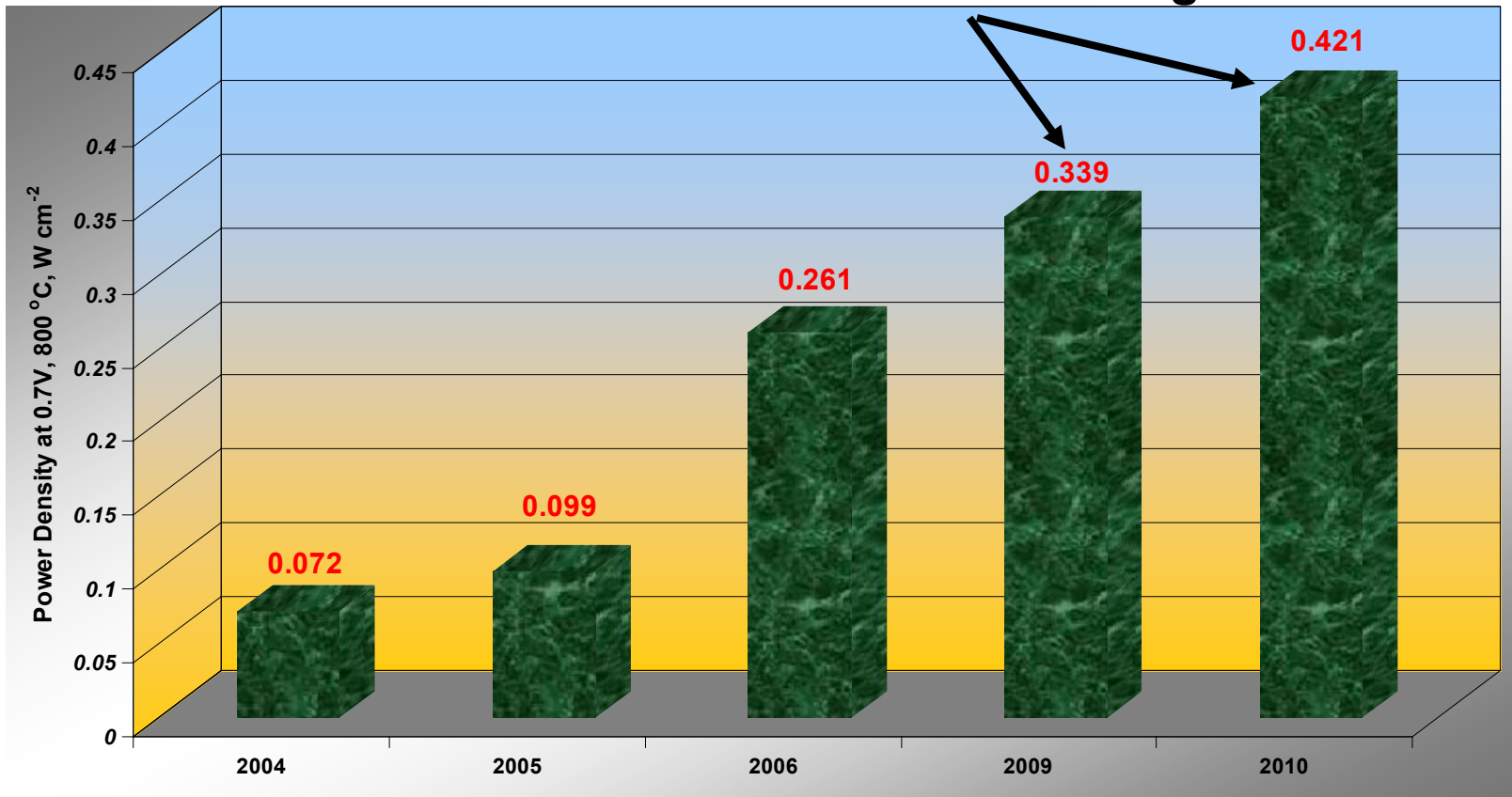
- **Cell Technology:** Improve power & stability of the cell building block
- **Cell Manufacturing:** Improve processing yield & productivity while decreasing material consumption
- **Stack Technology:** Refine stack assembly and improve heat removal and integrity while cost reducing components
- **System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

Cell Performance Progress

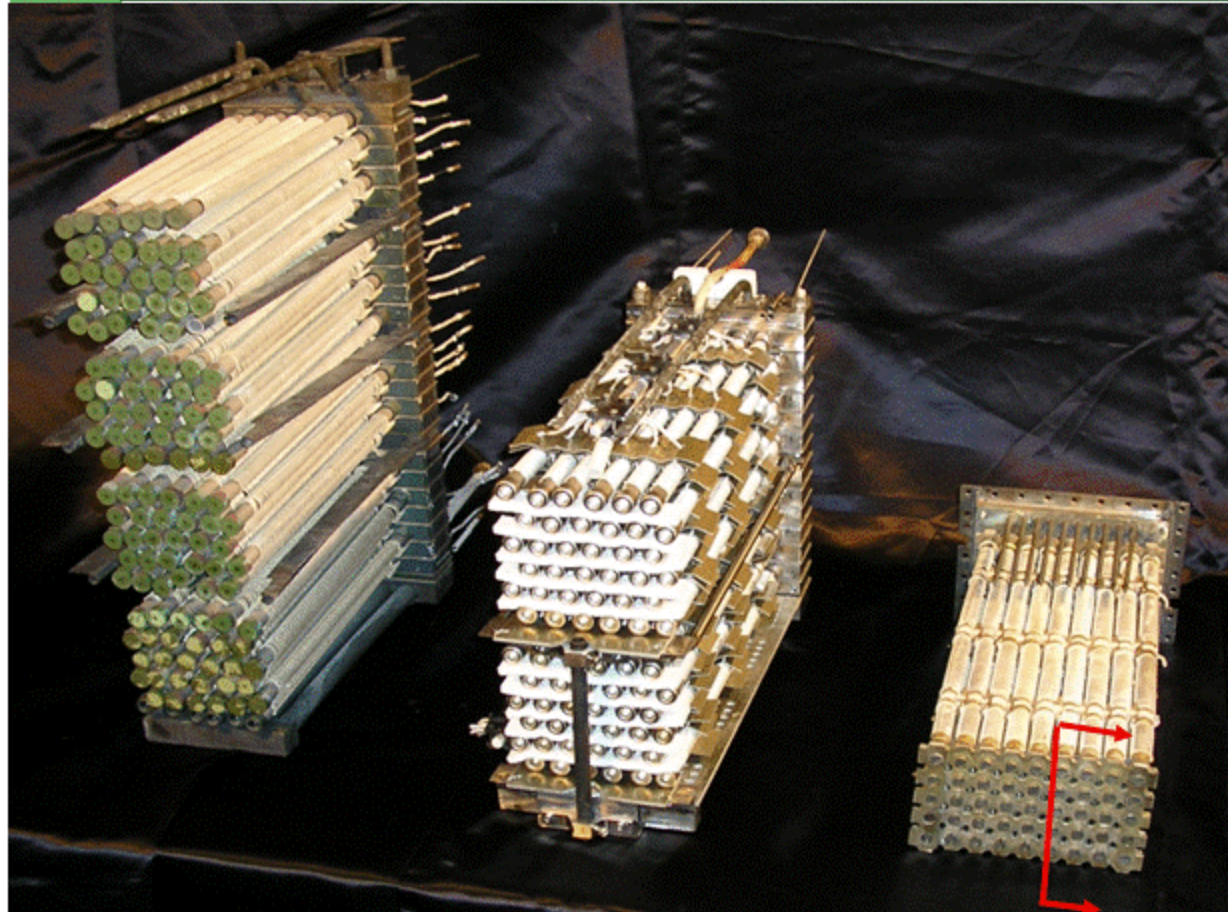


Cell Performance Progress

24% Gain Since 2009 Meeting



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!**

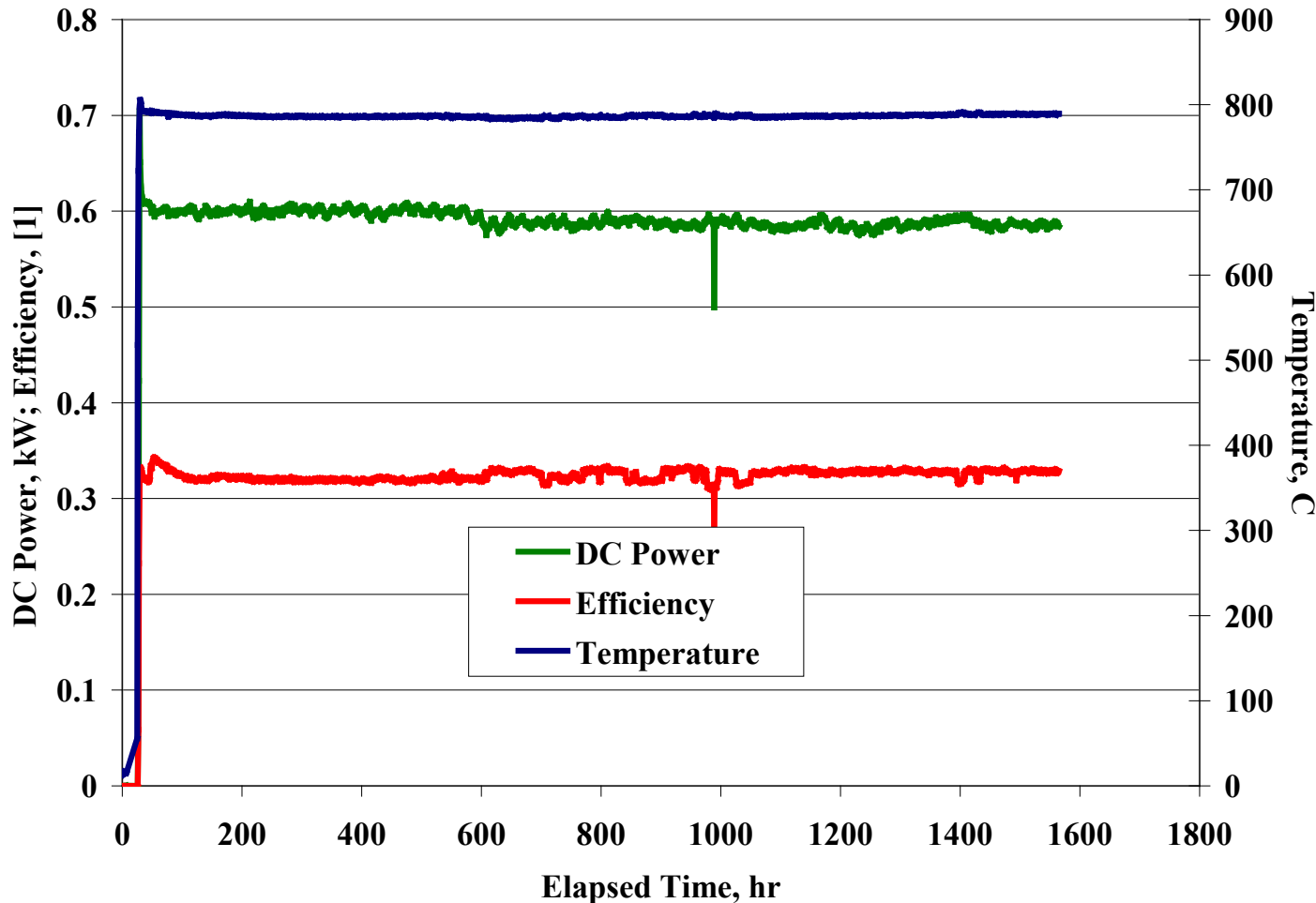
Weight reduction (total):
75% from 2004-2009
90% from 2004-2010
**Additional 15% or ~13lbs
since 2009 meeting!**

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



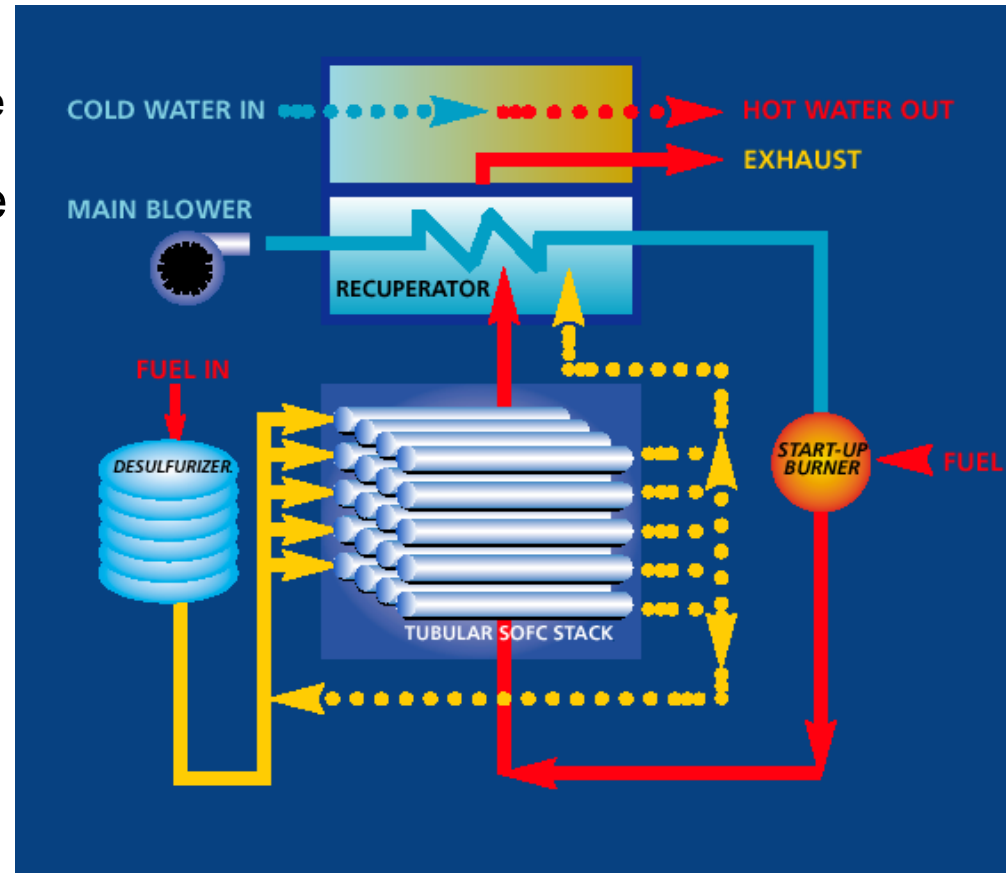
Setup:

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

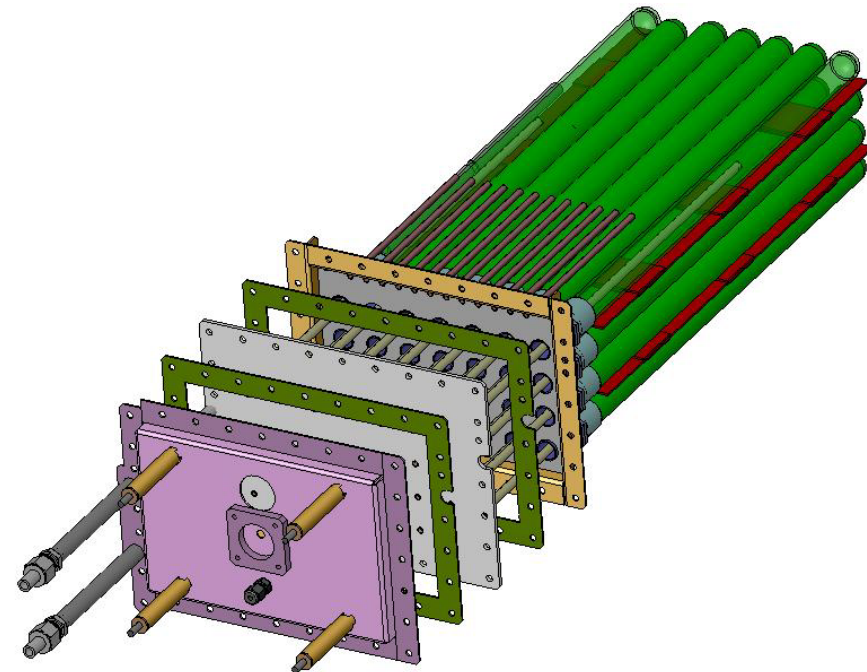
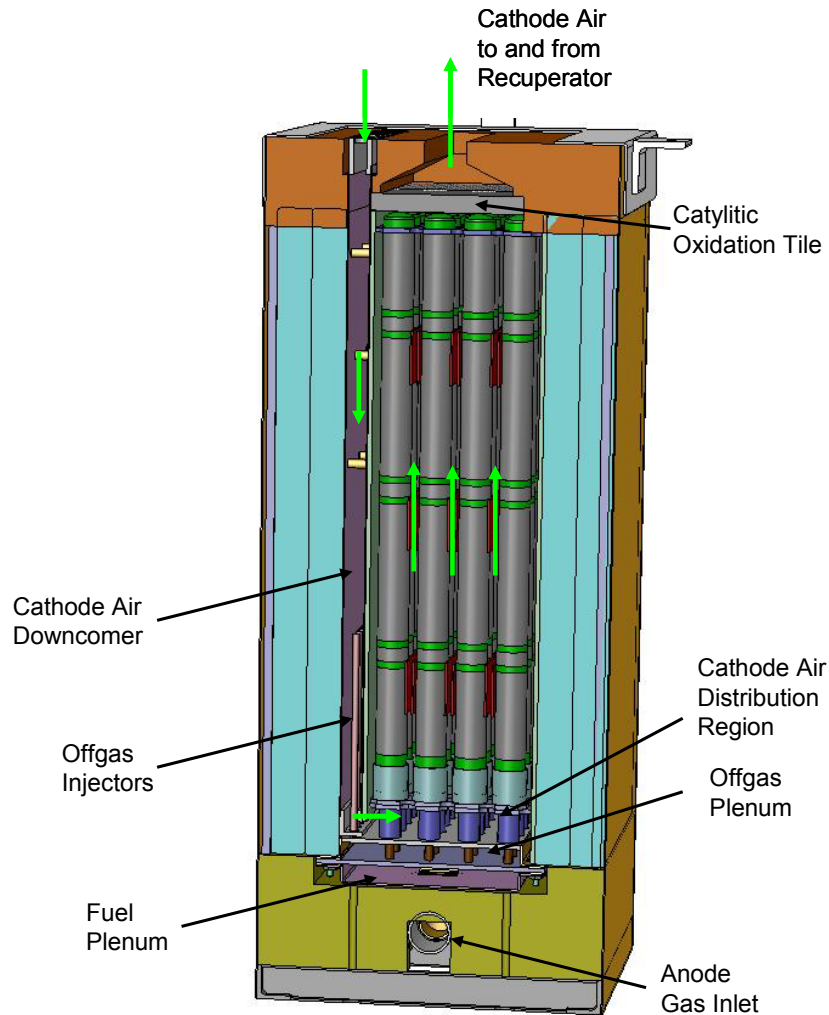
0.9%/1000hr
(0.7%/1000hr
counting
starting hours)

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



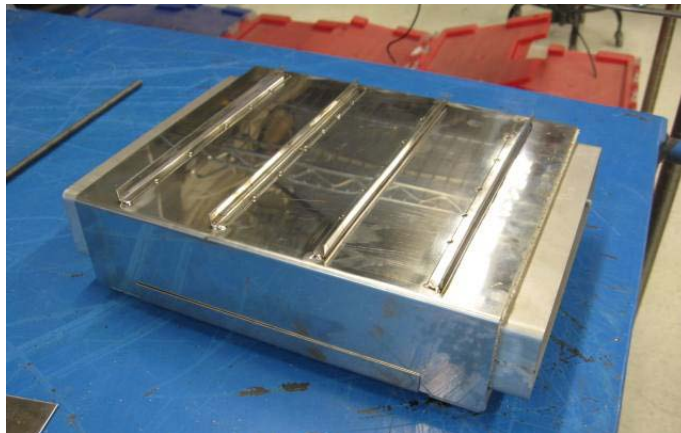
Recuperator Reductions



- 300 cu. in.
- 17.8 lbs

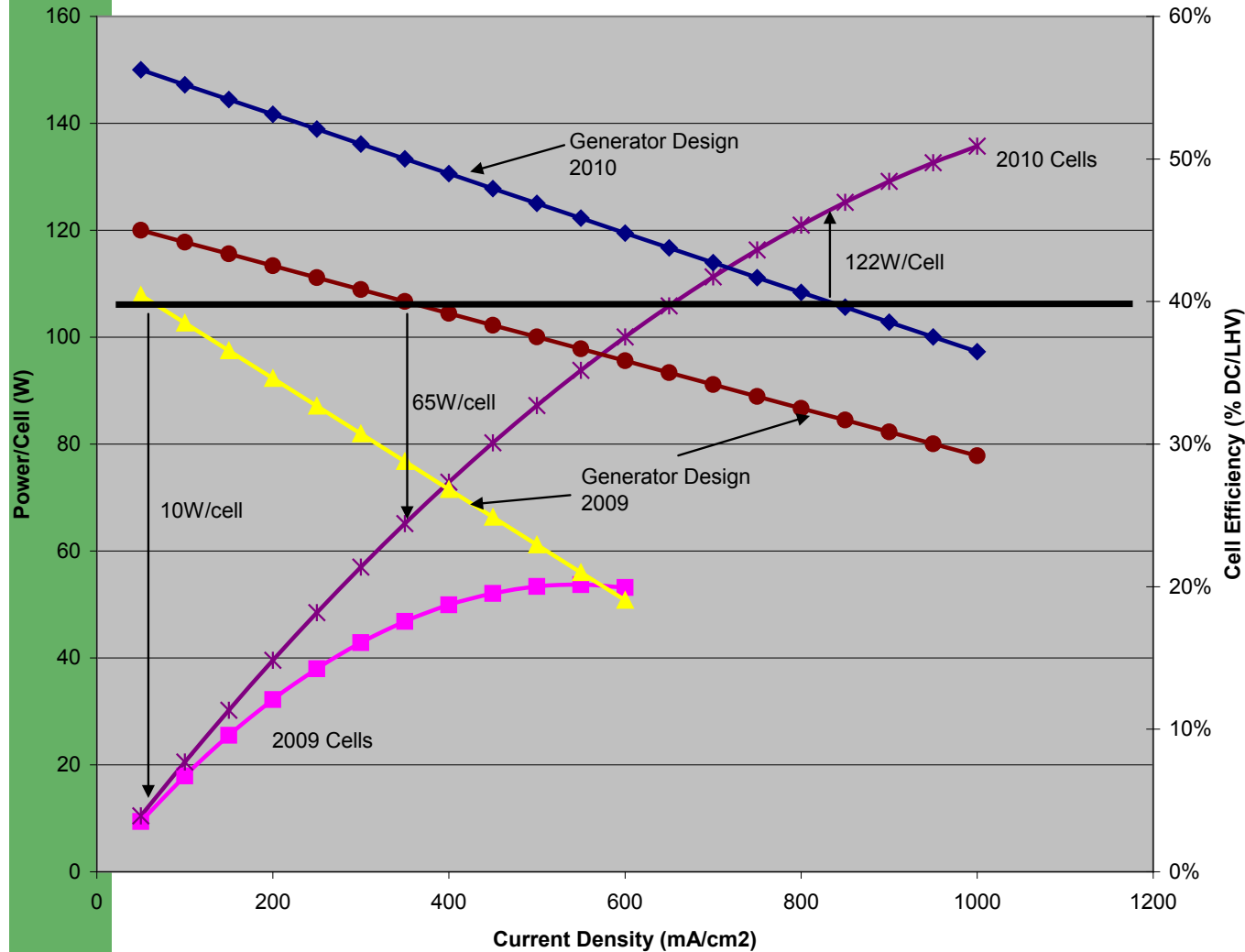
REQUIREMENTS

- 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



- 100 cu. in.
- 3.8 lbs

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

Automated Cathode Coating

Isostatic Press



Automated dip-coating



Plasma spray

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



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

Products



Remote Power System Specifications

500 W DC / Load following capability / Natural Gas, propane fueled
Electrical Efficiency of 20-35%

Previous Generation

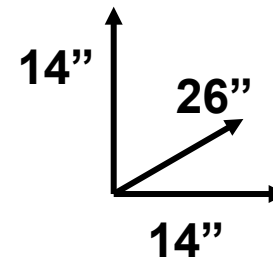
Size: 22" x 22" x 33", 220lbs, 9.2ft³



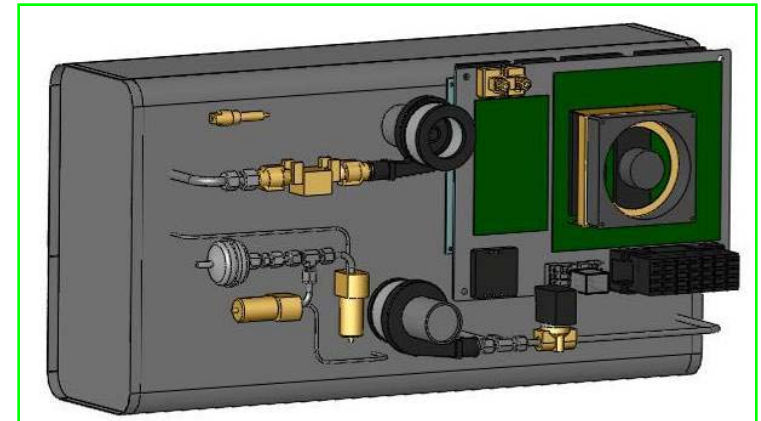
68% weight
reduction

70% weight
reduction

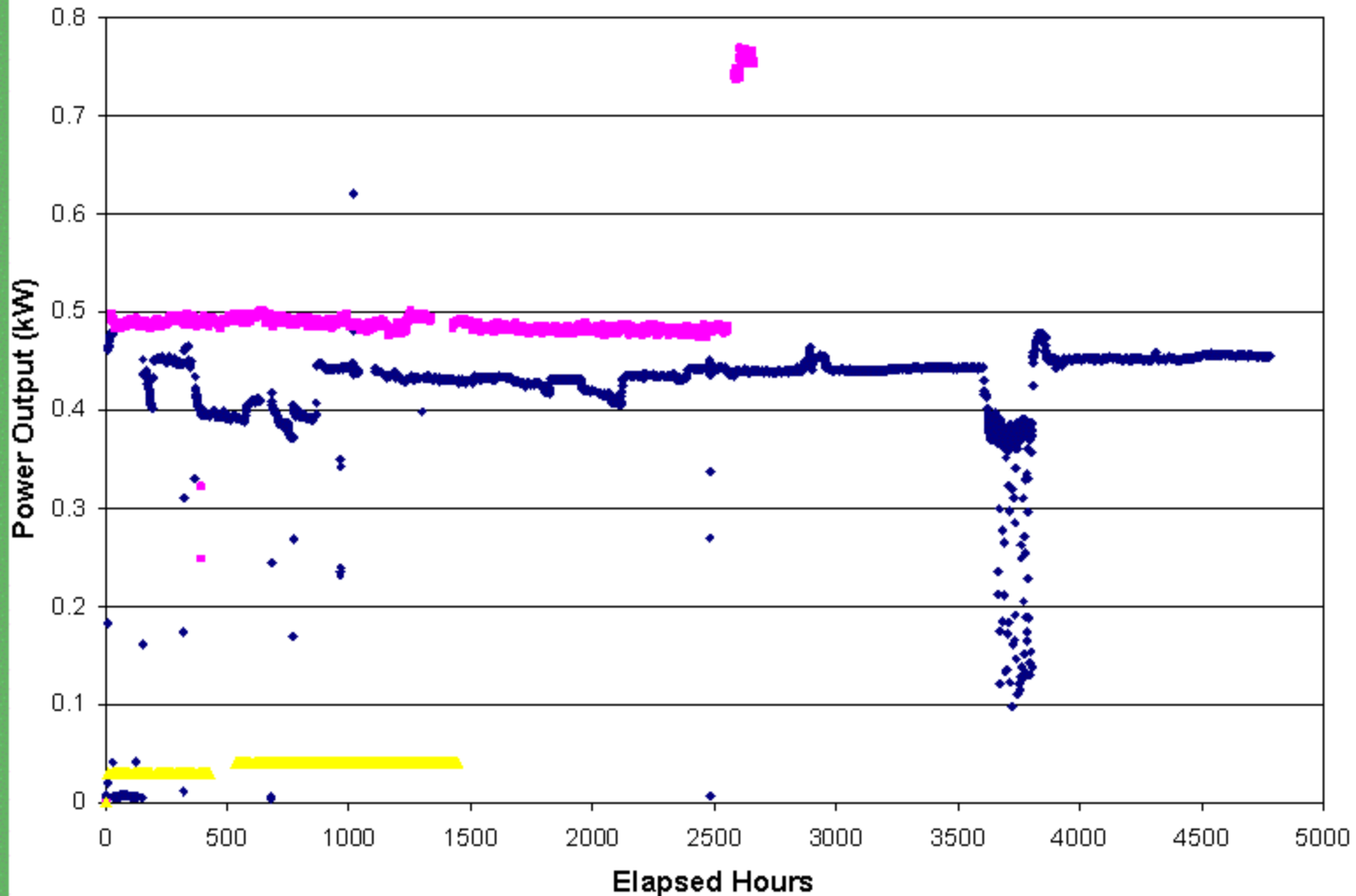
Present Generation



2.9ft³
60-70lbs



Remote Power Unit Stability

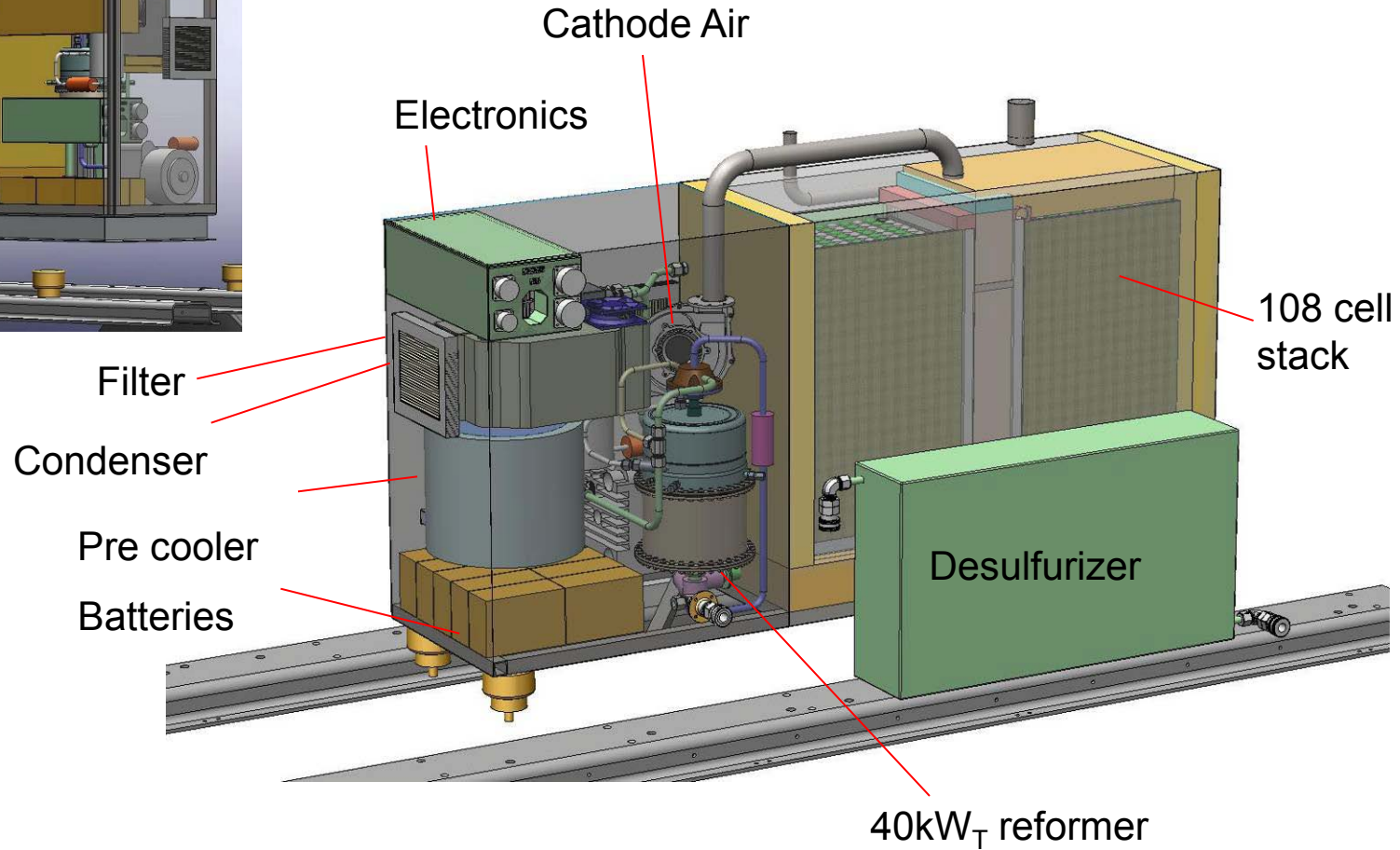
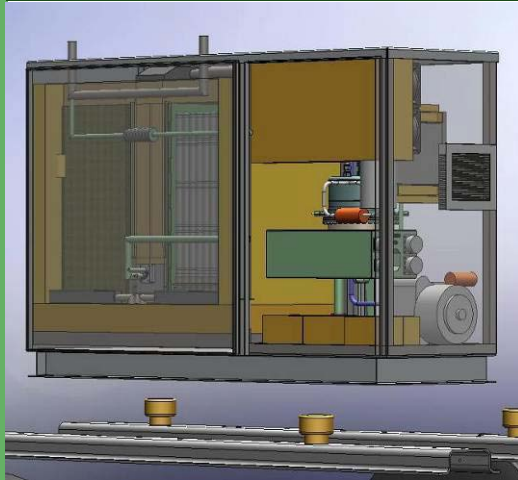


Environmental Testing

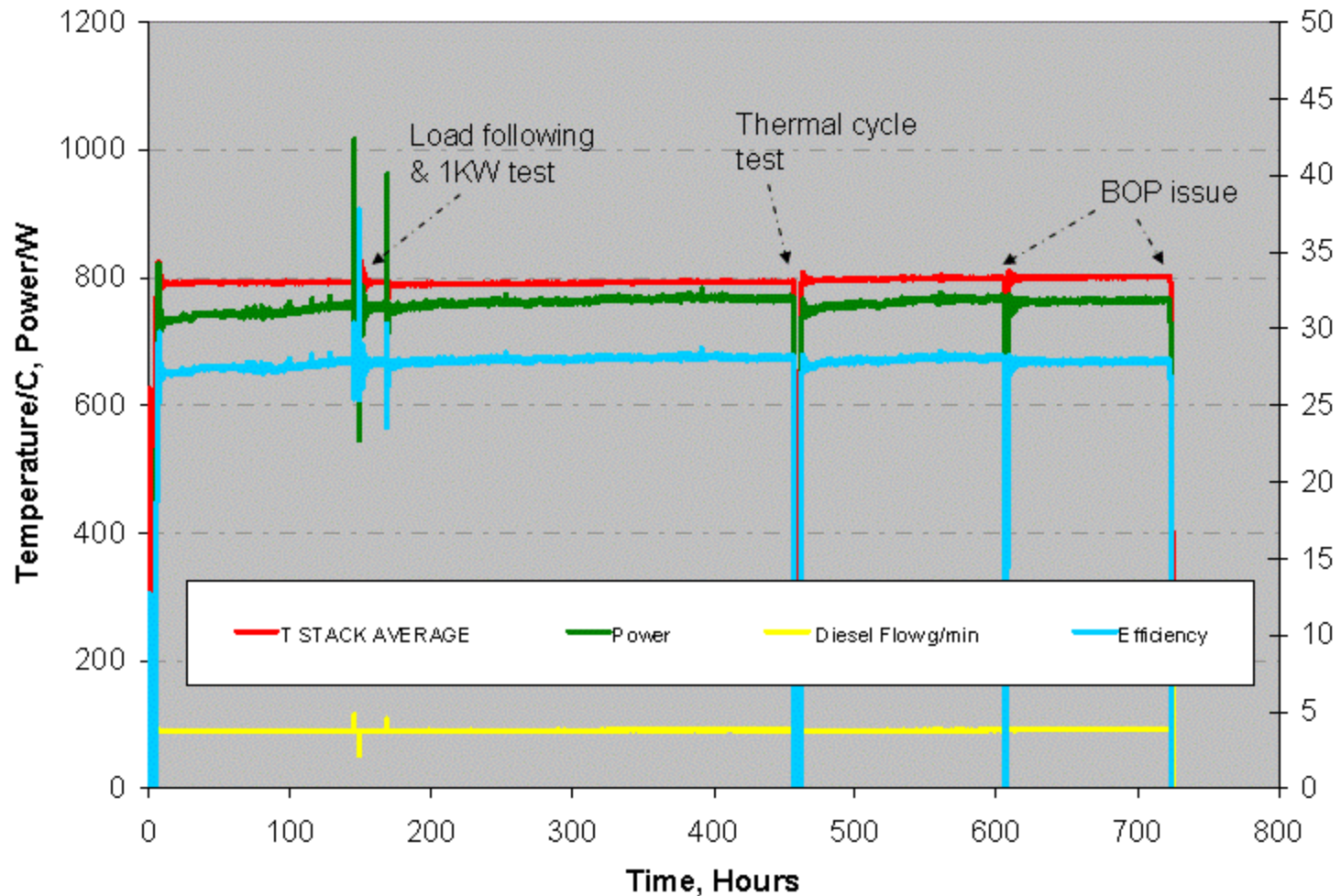
- Operating at various ambient temperatures up to 45 degrees C >5000hrs.



JP-8 Fueled 10kW Generator

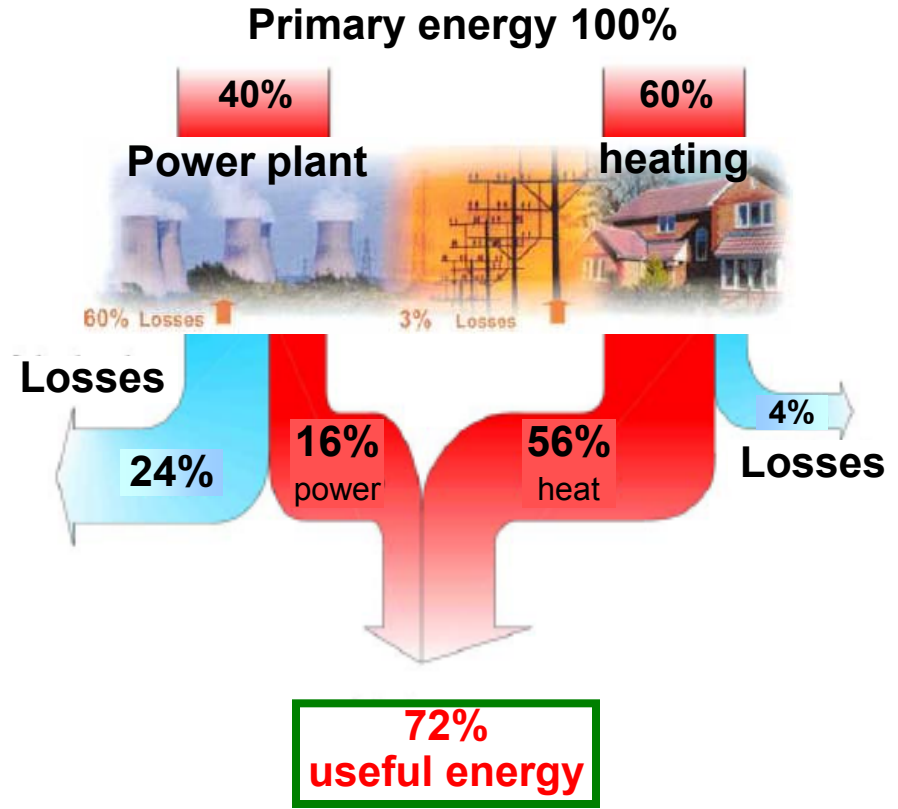
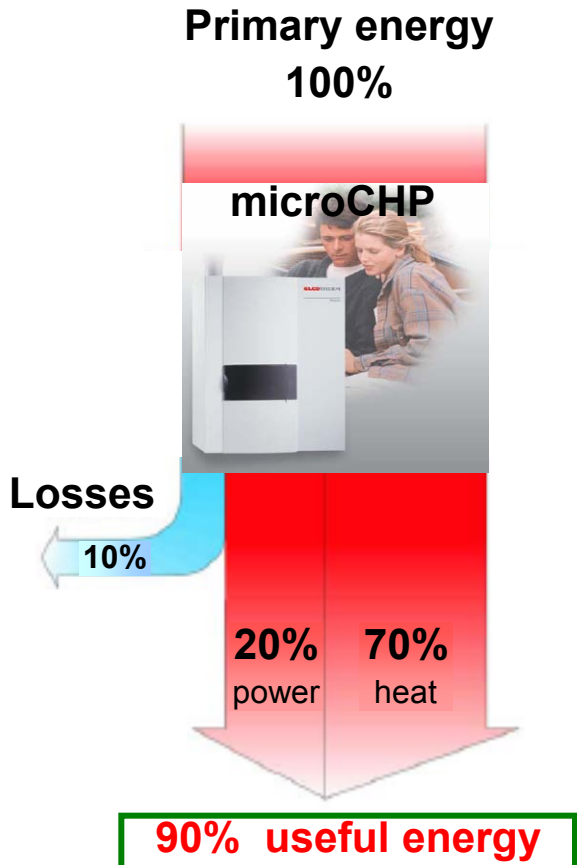


Operational Stability on Liquid Fuel



mCHP vs. power plant and (condensing) boiler

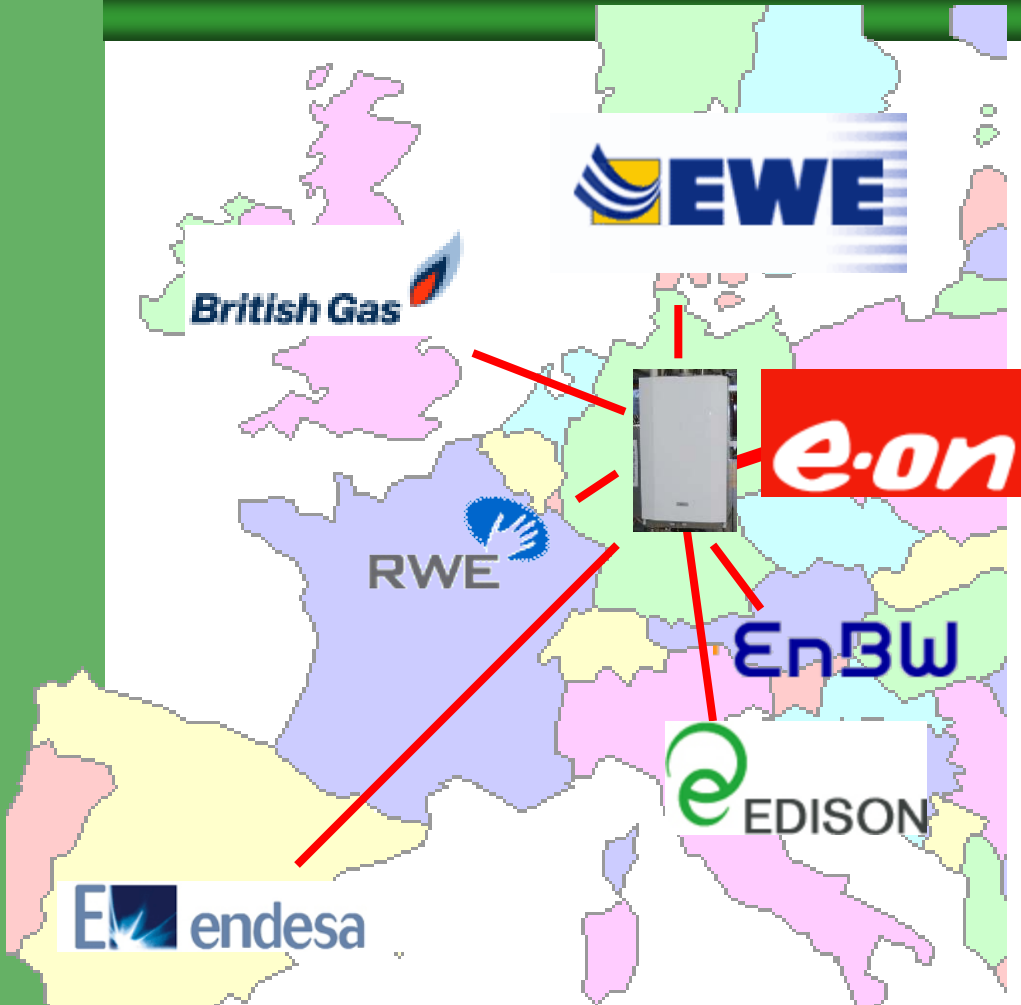
microCHP
simultaneous power and heat production



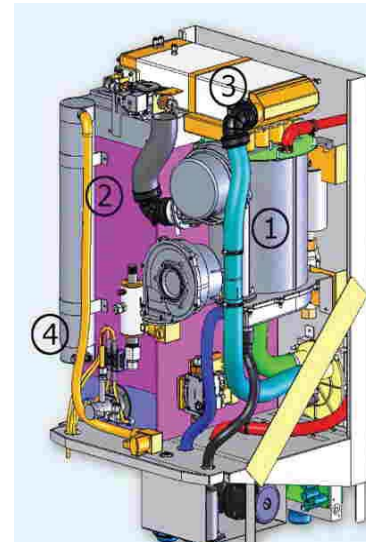
Common technology
separate power and heat production

- = 10 – 25% lower primary energy consumption
- = 10 – 25% lower CO₂ 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



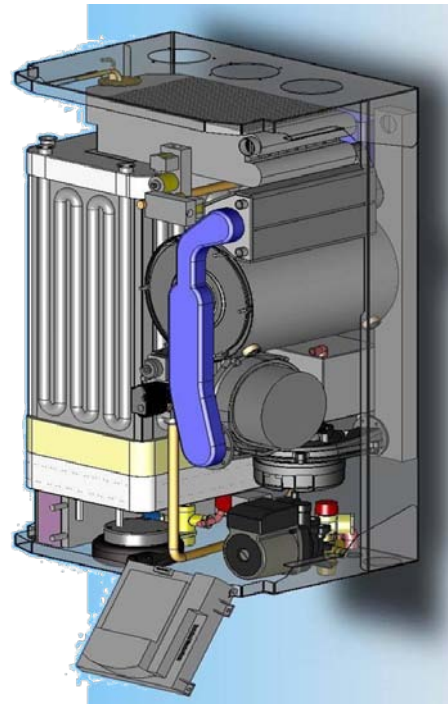
Collaborations - EFESO Program

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

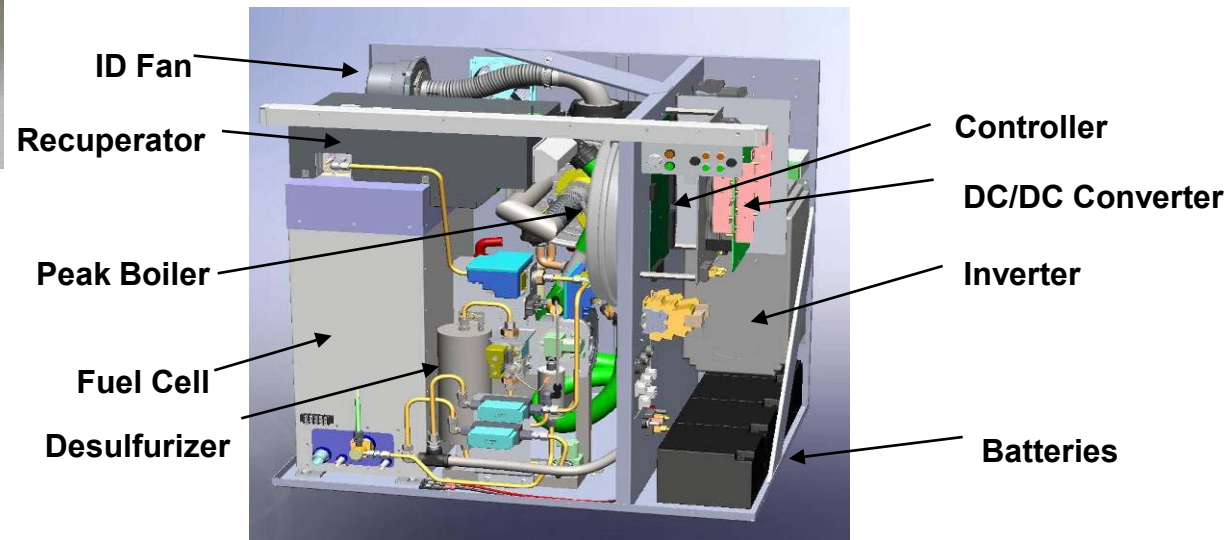
- One kilowatt unit with 20 kW thermal boiler
- Huge achievement to meet space and weight requirements
- 80-90% total efficiency, 33"x22"x18"
- 180lb total, 100lb FC sys



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
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