Development and Demonstration of a New Generation High-Efficiency 1-10 kW Stationary PEM Fuel Cell Power System

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Intelligent Energy

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INTELLIGENT ENERGY
Clean fuel and power

Project FC39

Overview

Timeline

- Start: July 2007
- End: July 2010
- 25% complete by 4/08

Budget

- $4.4 million budget
  - 50% DOE cost share
- $322K received FY07
- $450K projected for FY08

Barriers

Targets	Project	DOE 2011
Electrical Eff.	40%	40%
Overall Eff.	> 70%	80%
Durability	40,000 hrs	40,000 hrs
Capital Cost	$400 / kW	$750 / kW

Partners

- Intelligent Energy, Inc. (lead)
- Intelligent Energy, Ltd.
- University of South Carolina
- California State Polytechnic University, Pomona
- Sandia National Labs

Objectives

Develop and demonstrate a PEM fuel cell based stationary power system that provides foundation for commercial, mass produced units that address identified technical barriers

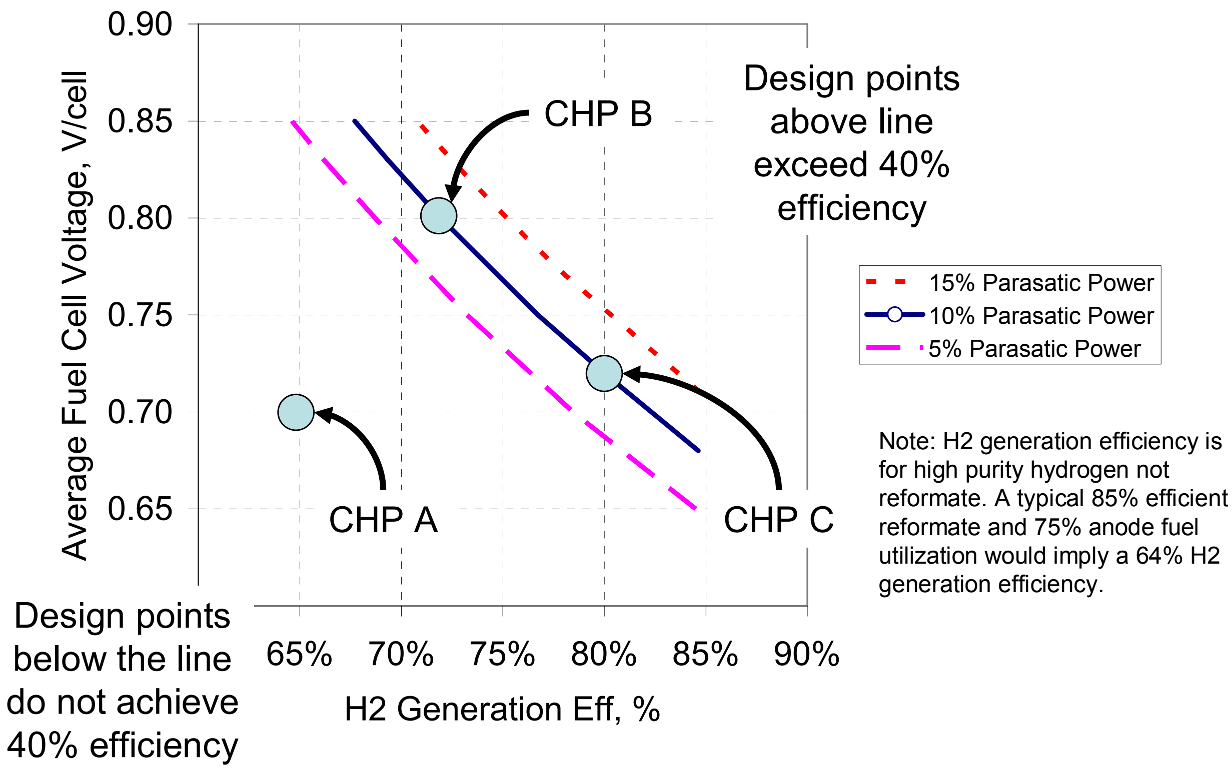
- Technical objectives
  - 40% electrical efficiency (fuel to electric energy conversion)
  - 70% overall efficiency (fuel to electric energy + usable waste heat energy conversion)
  - Potential for 40,000 hour life
  - Potential for $450/kW
- Topic 7A – International Partnership for a Hydrogen Economy (IPHE)
  - Engage international partners
  - Demonstration phase in an IPHE country other than USA

Milestones

Month/Year	Milestone or Go/No-Go Decision
July 2007	Contract signed and project launched
January 2008	Milestone: Evaluation of adsorbent materials for use in adsorption enhanced reformer completed; initial tests with high pressure membrane reformer completed
July 2008	Go/No-Go Decision: Validation of hydrogen generation and fuel cell performance improvements demonstrating the viability of achieving a 40% electrical efficiency for the system will be complete. A Go decision will be followed by proceeding to development and testing of a prototype PEMFC power system.

Approach

Open architecture – high purity hydrogen interface between fuel cell, fuel processor



- Increase cell voltages
- Increase hydrogen generation thermal efficiency
- Decrease parasitic loads

Approach

Fuel cell stack and system

- Improved flow field design
- Fluid flow modeling
- Advanced MEA design
- Diffuser optimized for water management
- Advanced bipolar plate materials
- Reduced air pressure requirements
- Pressed plate architecture to address cost
- Optimized air delivery design
- Optimized power management design & configuration

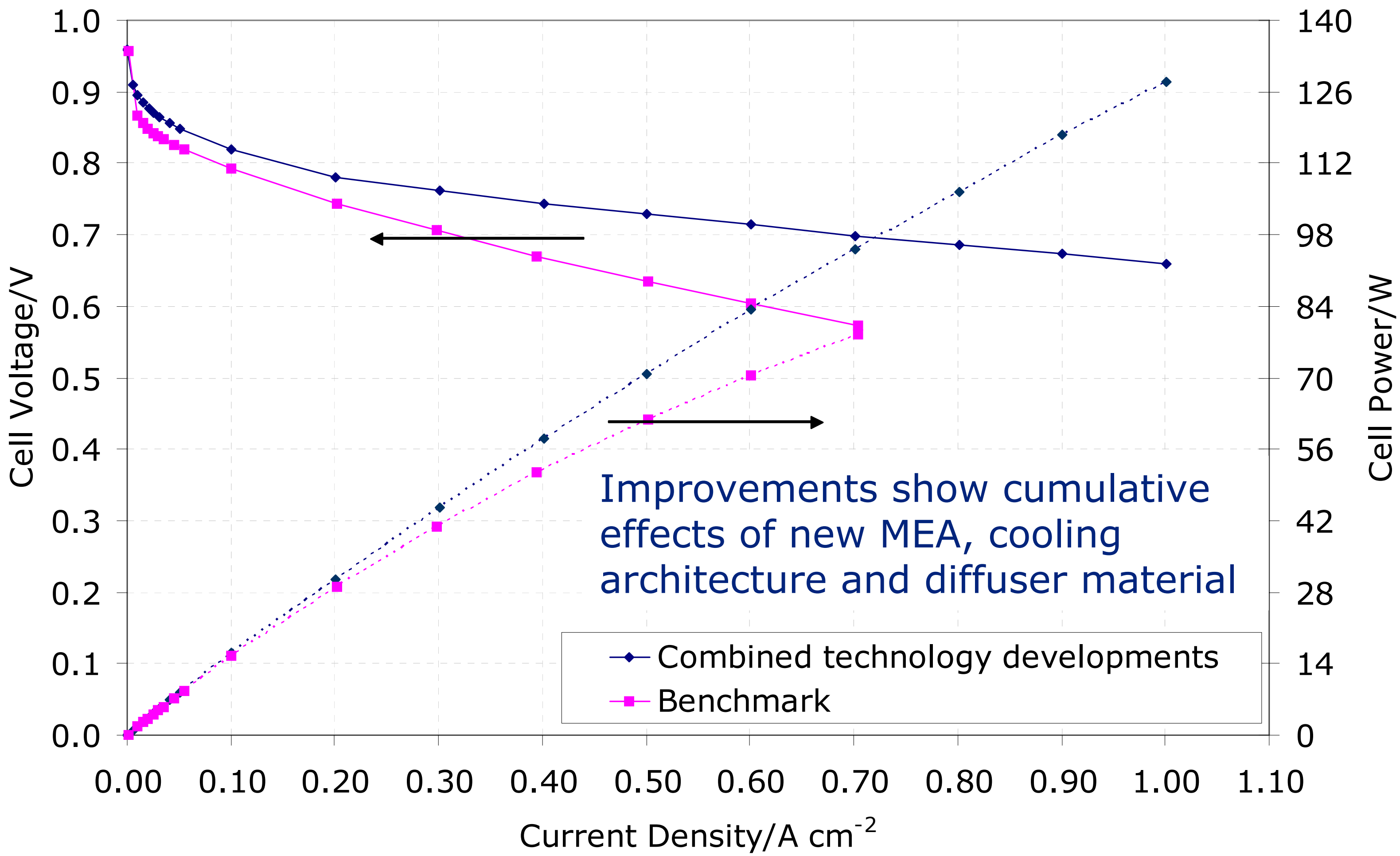
Hydrogen generation

Ethanol reforming - Two platforms in development

- MesoFuel advanced membrane reactor (< 2 kWe)
  - Increase reactor pressure
  - Thermal integration improvements
- Hestia with rapid cycle PSA (> 2 kWe)
  - With 100mV fuel cell voltage improvement, efficiency target can be reached with optimization of current Hestia design
  - With 20mV fuel cell voltage improvement, efficiency target can be reached with integration of CO_2 adsorption (AER) into Hestia process

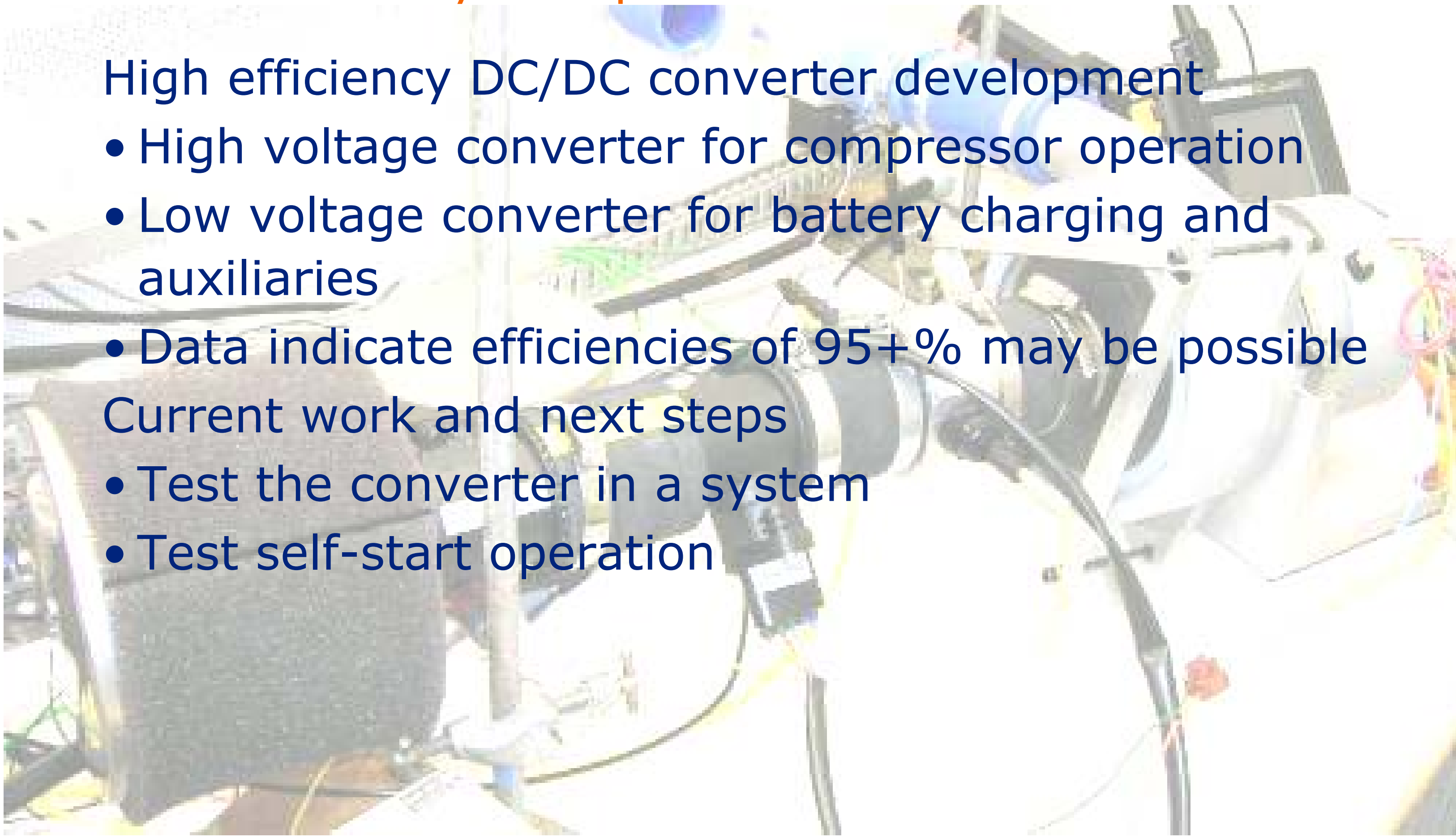
Technical Accomplishments

PEMFC – single cell performance improvements



Technical Accomplishments

PEMFC – reduced system parasitic loads



High efficiency DC/DC converter development

- High voltage converter for compressor operation
- Low voltage converter for battery charging and auxiliaries
- Data indicate efficiencies of 95+% may be possible

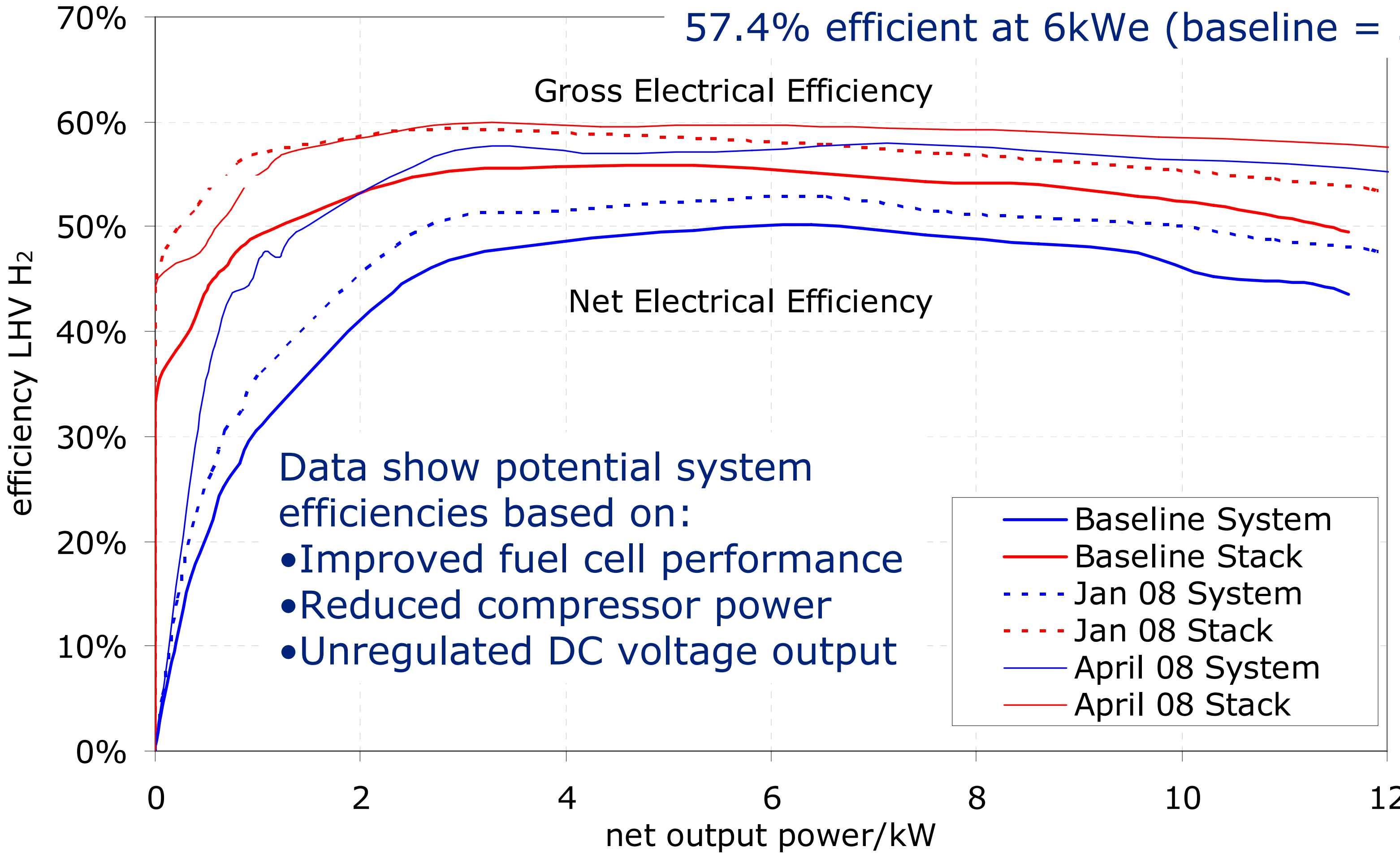
Current work and next steps

- Test the converter in a system
- Test self-start operation

Technical Accomplishments

PEMFC – forecast fuel cell system performance improvement

57.4% efficient at 6kWe (baseline = 50%)



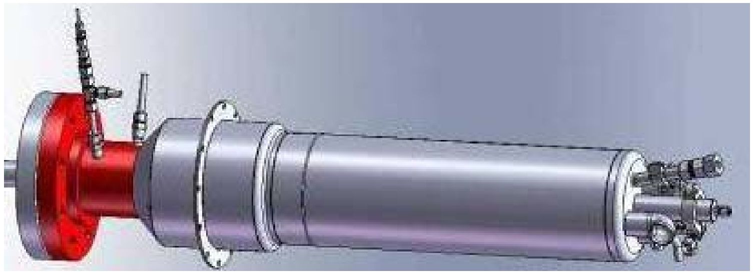
Data show potential system efficiencies based on:

- Improved fuel cell performance
- Reduced compressor power
- Unregulated DC voltage output

Technical Accomplishments

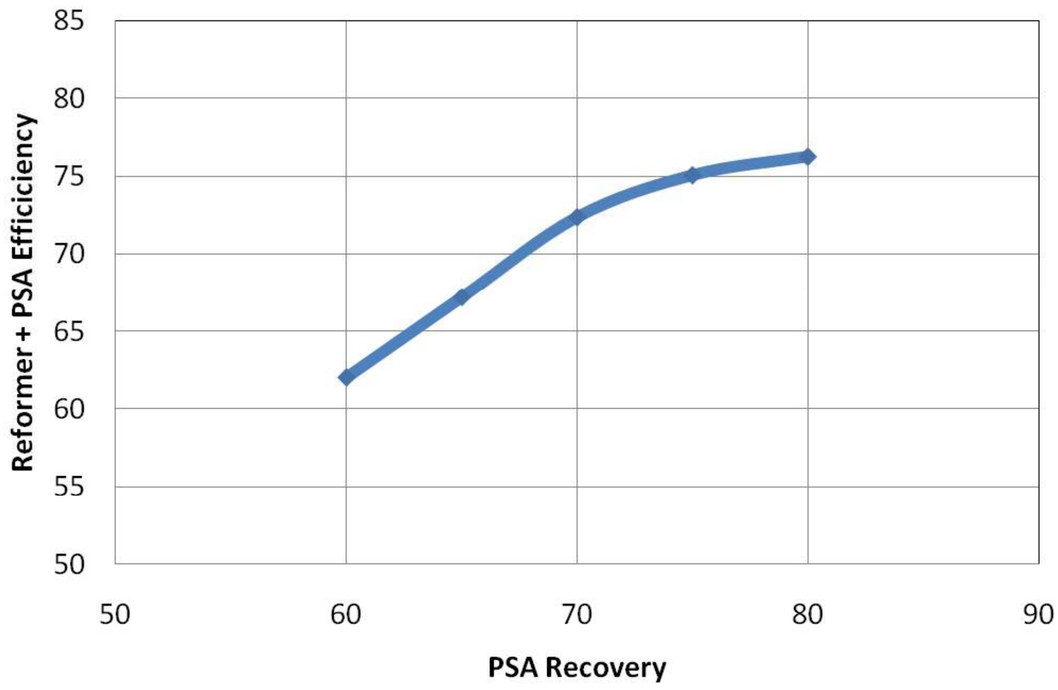
Hestia reformer - new reactor design

- Designed for ease of manufacture, assembly
- Reduced pressure drop across combustor/flue gas path
- Enhanced thermal integration
- Streamlined balance of plant
- Increased operating pressure / H_2 recovery
- Status
  - Fabrication, assembly completed fall 2007
  - Testing initiated December 2007
  - Initial ethanol tests performed January 2008
  - Preparing for next phases of tests April 2008



Technical Accomplishments

Hestia reformer – initial results



- New reformer reactor has been tested as standalone system, using simulated PSA off-gas as heat source
- Results to left show expected H_2 generation efficiency based on reformer test results + potential PSA recoveries

Technical Accomplishments

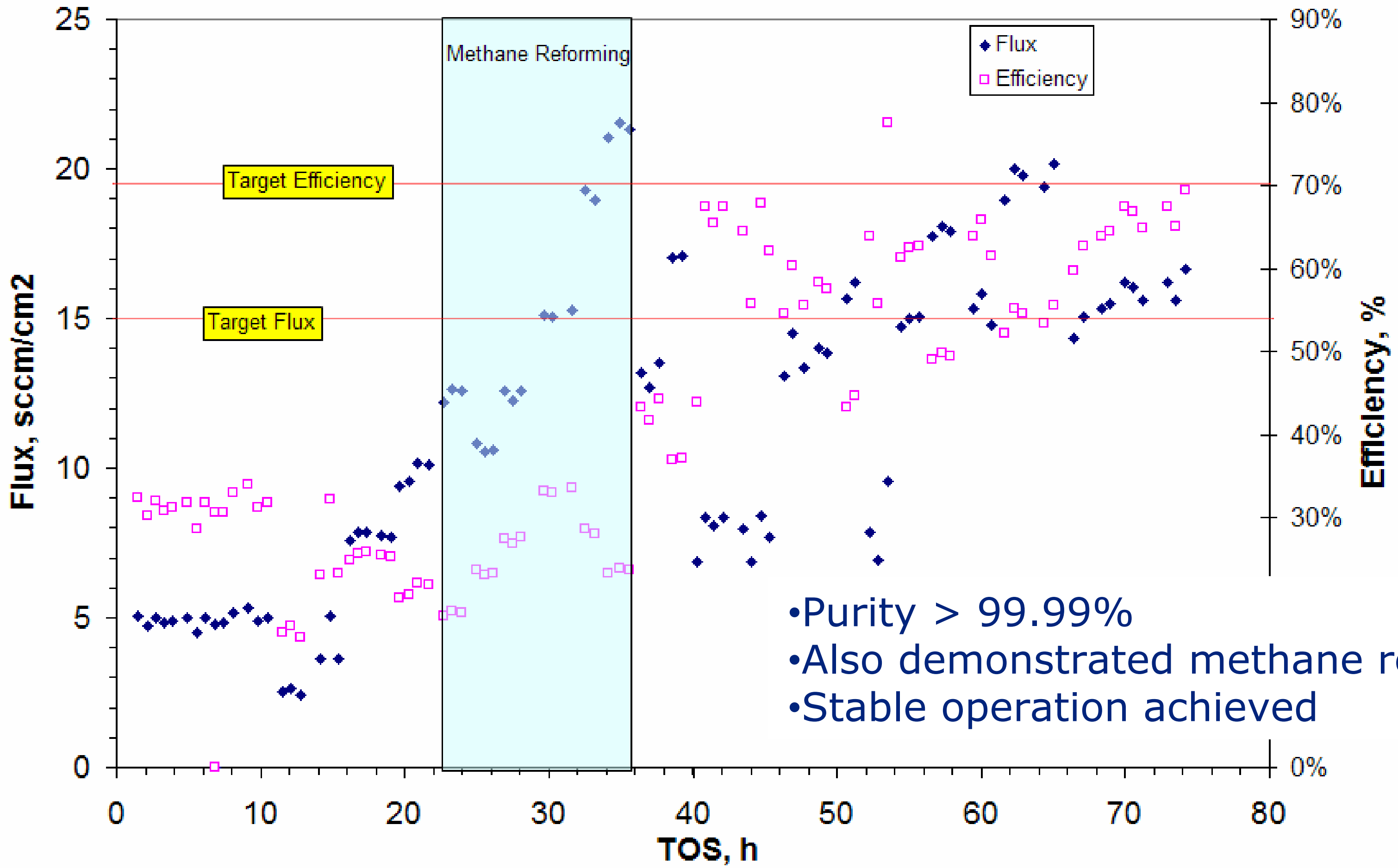
Meso reformer – performance mapping of single module completed

Metric	Target	Status (4/15/08)
H_2 purity	> 99.9%	> 99.9%
Thermal efficiency	> 70%	65 - 67%
H_2 production, slpm	5-6 (10 module)	0.6 @ 65 - 67% efficiency (single module)
H_2 flux, sscm/cm^2	15-20	15-17

T = 575 – 640 C
P_{feed} = 70 – 175 psig
P_{prod} = 5 psig – 500 mbar
S/C = 4.5

Technical Accomplishments

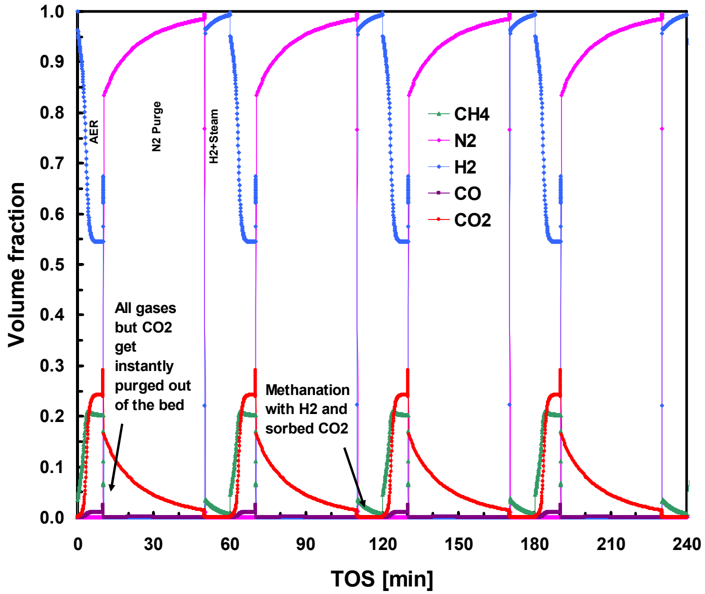
Meso reformer – summary of flux and efficiency

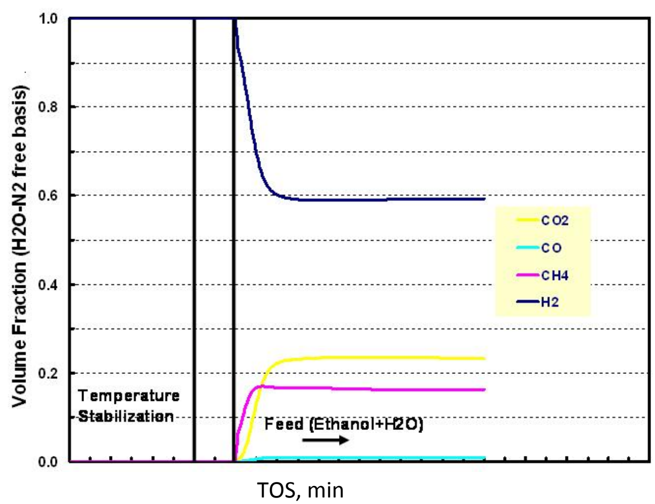


- Purity > 99.99%
- Also demonstrated methane reforming
- Stable operation achieved

Technical Accomplishments

AER – dynamic model for AER process steps (U South Carolina)





PSA model adapted to PSA model adapted to include reforming reactions

Model has informed experimental apparatus designs

- Bed sizing
- Cycle times
- Temperatures
- CO_2 breakthrough
- Purge gas requirements

Status: Calibrating model with experimental results. Model breakthrough times are similar to test data

– include reforming reactions

– Model has informed experimental apparatus designs

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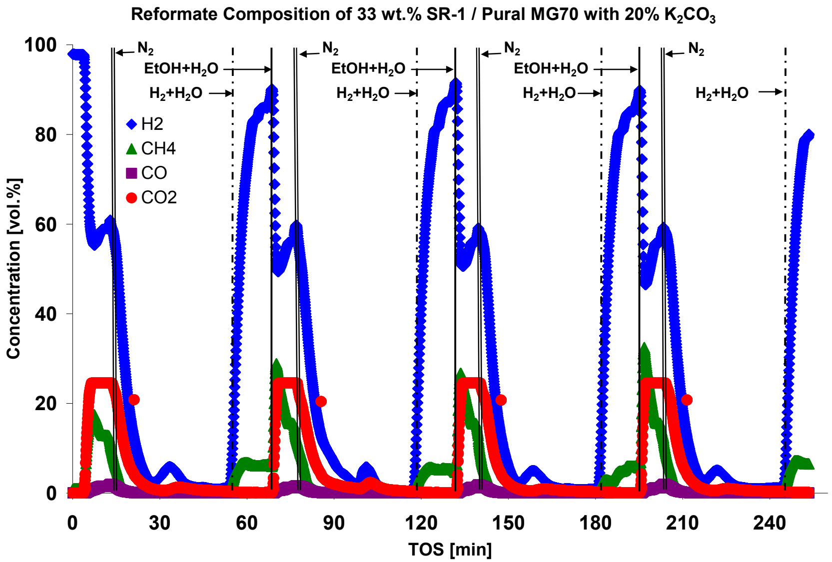
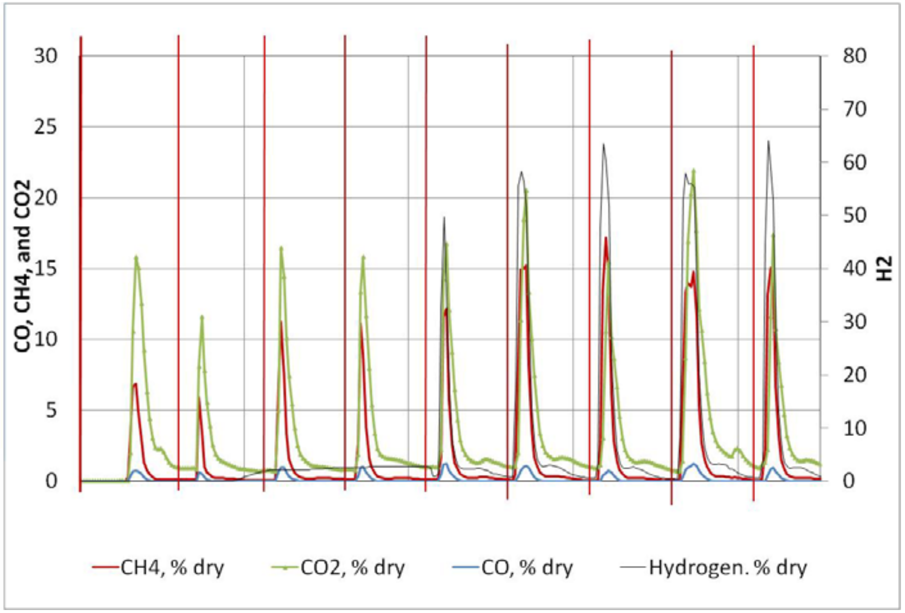
Technical Accomplishments

AER –experimental proof of concept



The above chart demonstrates four consecutive AER cycles successfully demonstrated on small reactor with ethanol-water mixture (S/C=6, 70 psig)

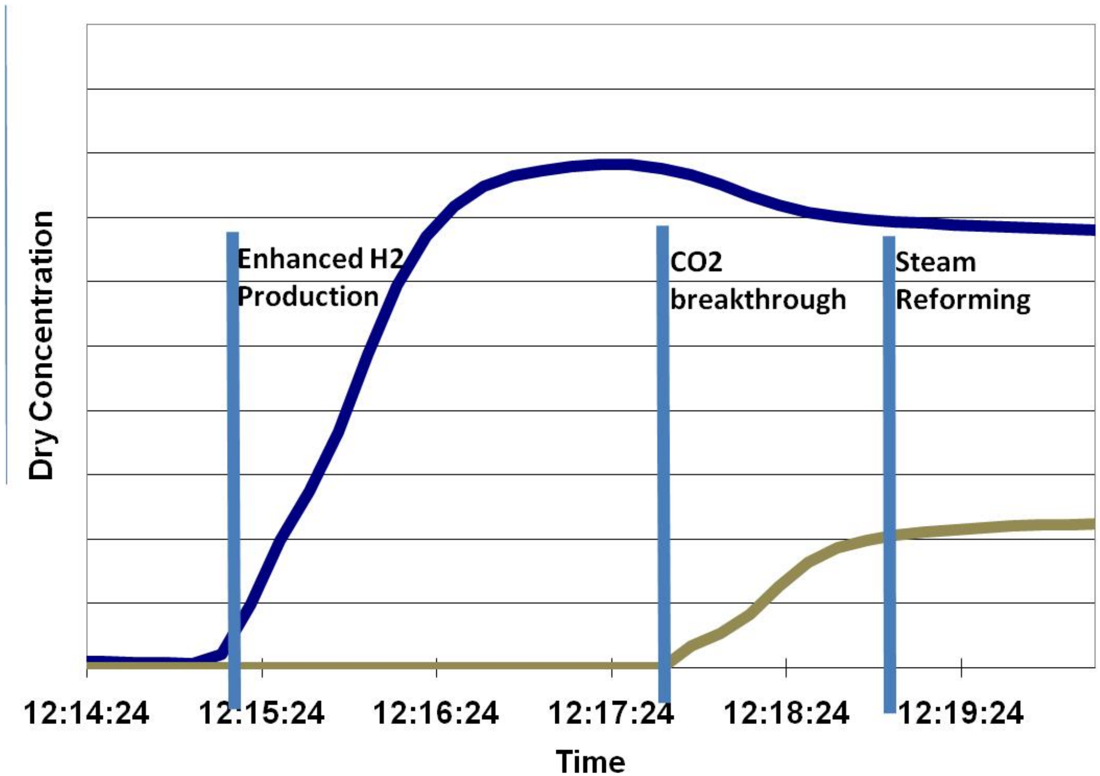


- Chart shows consecutive cycles with Ethanol on larger reactor (S:C =4.5)
- Table below is total cycles on larger reactor through May 2008

AER Flow	Number of Cycles
EtOH	44
CH4	20
CO2	66

Technical Accomplishments

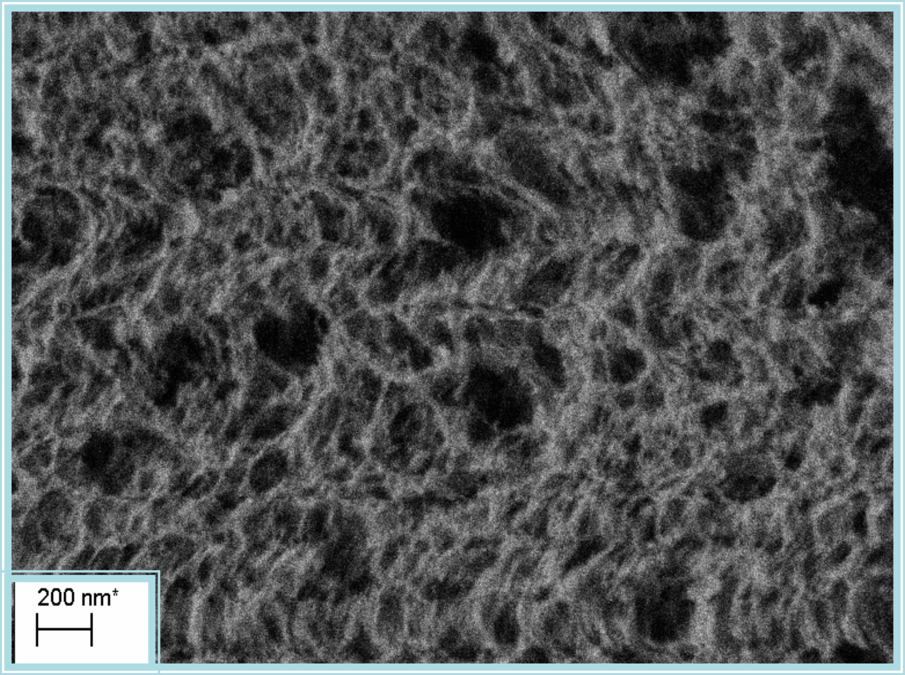
AER – full scale experimental results with integrated combustor



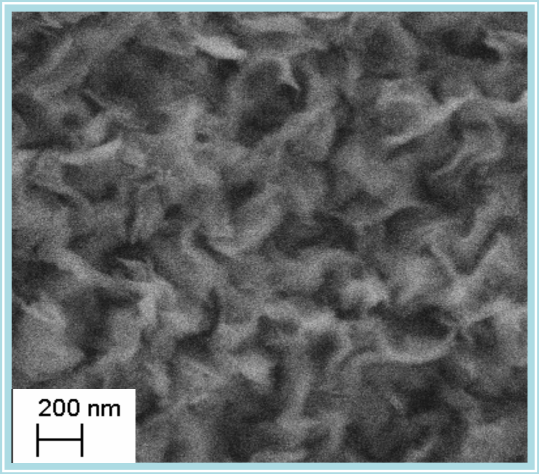
- Currently evaluating cycle timing, temperature profiles, heat balance
- Reactor and test stand specifications:
  - Natural gas or ethanol
  - 1 to 5 kWe
  - Regenerate with nitrogen, steam or other
  - All heat provided by combustion
  - Measure H_2 production enhancement as well as CO_2 breakthrough in bed

Technical Accomplishments

AER – novel adsorbent materials (Cal Poly Pomona)



- Amorphous magnesium oxide (MgO) ambigel and xerogel materials
- Significant potential for increased adsorption capacity
- Status:
  - Several batches synthesized and currently being analyzed by IE
  - Further batches planned

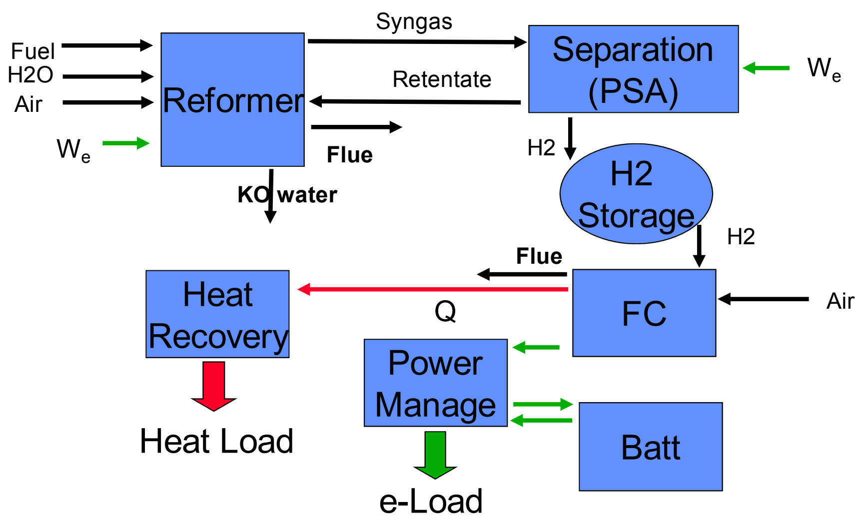


SEM of monolithic MgO aerogel (left) and xerogel (right)

Technical Accomplishments

System level performance assessment (Sandia)

- Collaboration with Sandia National Labs to assess potential performance of possible system architectures
- Part of Sandia's contribution to IEA-HIA Task 18
- Status (4/15/08):
  - Collaboration launched in March 2008
  - System model adapted to capture IE's approach
  - Initial results show 35% fuel-to-electric efficiency based on historical Hestia reformer data, new fuel cell data and parasitic power losses
- Next steps
  - Consider other system architectures
  - Continue to update models with experimental data
  - Form basis for go/no-go in July 2008



Future Work

FY08

- Go/No-Go (July 2008): Determine system architecture leading to reaching technical objectives
  - Go decision will be followed by proceeding to development and testing of a prototype PEMFC power system

FY09

- Milestone (January 2009): Complete engineering design of integrated power system
  - Milestone followed by in-house system testing
- Go/No-Go (July 2009): Validation of the prototype power system's ability to meet performance targets will be complete
  - Go decision will be followed with continuing to the field demonstration of this system

Summary

Summary of technical progress highlights

System	Baseline	Status (4/15/08)
Fuel cell system efficiency	50%	57%
Hestia hydrogen generator	Sophisticated mechanical design	Design for manufacture and assembly
Meso hydrogen generator efficiency	50%	65 – 67%
Adsorption enhanced reformer	Concept on paper	Experimental proof of concept

- Approach: Develop portfolio of technologies in Project Year 1 (Jul-07 – Jul-08) to determine best architecture for meeting DOE objectives for stationary fuel cell power
- Partners
  - IE in US (lead) & UK
  - U of South Carolina
  - Cal Poly Pomona
  - Sandia Nationa Labs
- Future work: Down-select technologies then engineer, test and demonstrate new generation PEMFC power system