2010 DOE Hydrogen Program Annual Merit Review

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

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FC 031

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Contents

Overview

Budget

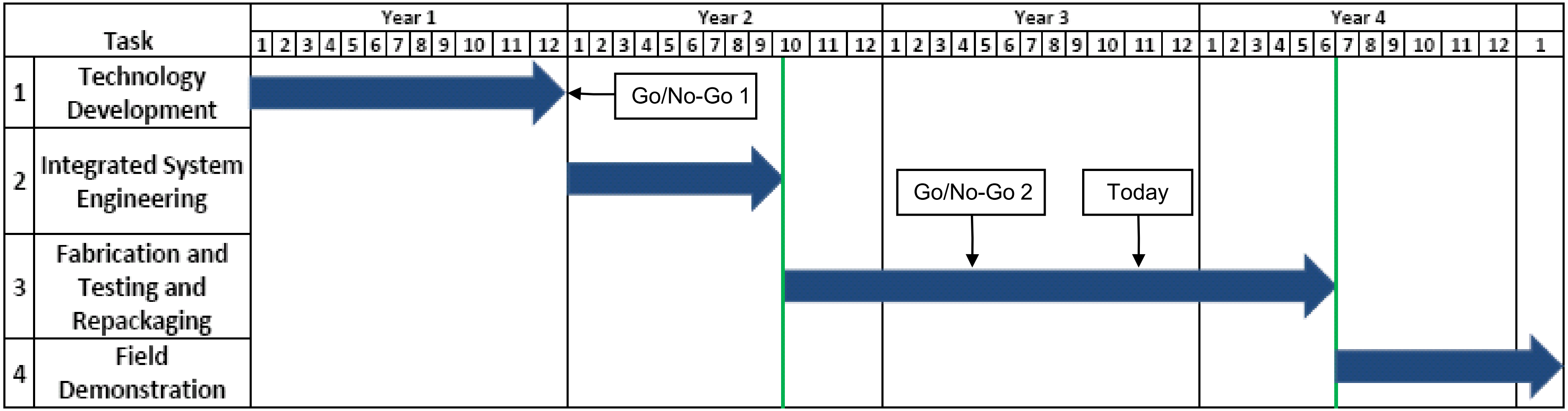
- Four year, $4.82 million program, 50% DOE cost share
- Funding received in FY08=$459,533
- Funding received in FY09=$1,131,060
- Funding estimated in FY10=$599,407

Project Partners

- California Polytechnic University, Pomona-materials development, modeling and AER bench testing
- University of South Carolina-AER modeling
- Sandia National Laboratories-systems modeling
- Intelligent Energy Ltd.- development and supply of fuel cell system

Overview

Timeline: July 2007-August 2011 (project 70% complete)



Challenges

	DOE 2011 Target
Electrical Efficiency	**40%**
Overall Efficiency	**80%**
Durability	**40,000 hrs**
Capital Cost	**$750/kW**

Relevance

- **Project- To Develop a High Efficiency 10kW PEM Fuel Cell CHP System and Demonstrate in IPHE Country (UK) Outside of the US**
- **Project Objectives for 2009-2010 to Meet DOE Targets**

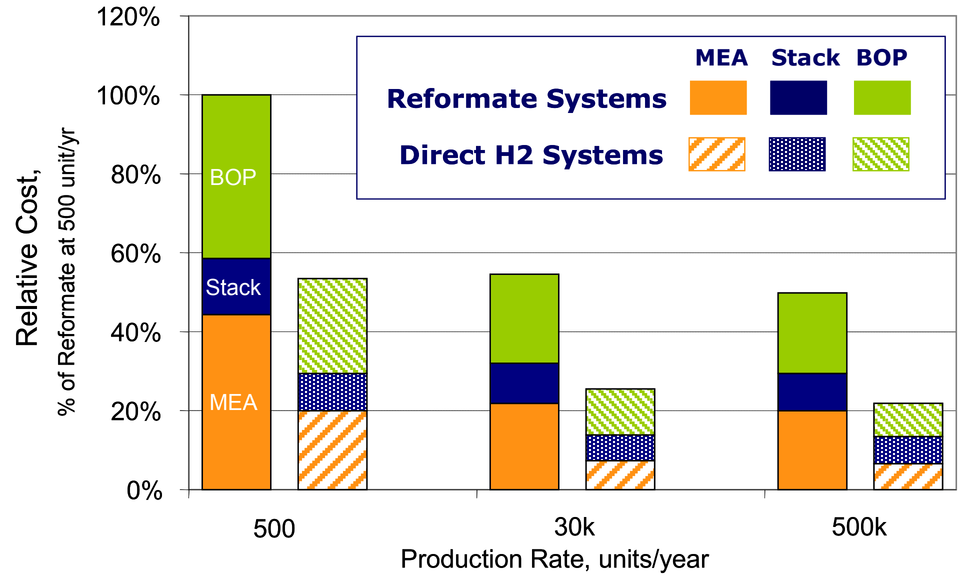
DOE 2011 Target	Project Objectives	2009-2010 Objectives
40% electrical efficiency	**40% electrical efficiency**	**Build, test and validate high efficiency (AER) fuel processor bench-scale rig**
80% overall efficiency	**>70% efficiency**	**Build, test an integrated CHP system with multiple thermal recovery streams**
40,000 hours durability	**40,000 hours durability**	**24hours/day stack testing**

- **Cost-saving approach**
  - High efficiency, simple fuel processor design using "off-the-shelf" components and raw materials
  - Pure hydrogen, high efficiency PEM FCs suitable for **multiple applications**
  - Implementing a core systems engineering and subsystems integration approach
  - **Volume cost reduction strategy "design once, deploy many times"**
  - BOP simplification using fixed-orifice devices, elimination of fittings and instrumentation, etc.

Approach

- **Phased Development of an Open Architecture System with a Pure Hydrogen Interface Between the Fuel Cell and Fuel Processor**

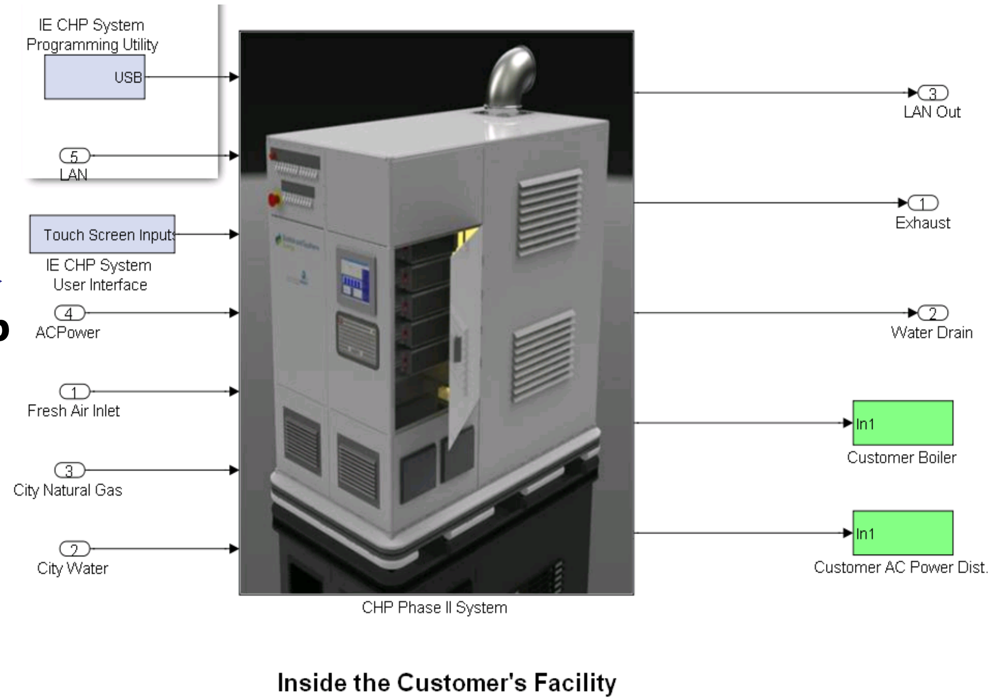
- **Advantages**
  - **Improved fuel cell performance**
  - **Increased fuel cell lifetime**
  - **Lower fuel cell cost**
  - **Smaller reformer**
  - **High fuel utilization**
  - **Simplified integration**
  - **Independent operation of fuel cell, fuel processor**
  - **"Plug and Play"**



- **Task 1**-Technology Building Blocks Development and Evaluation (EC/AC FC and SMR/MER 100% Complete-AER ongoing) **MILESTONE: GO/NO-GO #1 DECISION ACHIEVED** ✓
- **Task 2**-CHP Engineering Design and Configuration (SMR+PSA+FC 100% Complete)
- **Task 3**-CHP Prototype Construction and Validation Testing (SMR+PSA+FC 70% Complete) **MILESTONE: GO/NO-GO #2 DECISION ACHIEVED** ✓
- **Task 4**-CHP System Field Demonstration (Not Started)

Approach

- Model-based systems engineering using industry standard software
  - **Address trade-offs for optimization at both subsystem and system level**
- End-to-end system integration with prototype test and validation unit (SMR + PSA 2009/10)
  - **Real data for model inputs**
  - **Automated controls development**
  - **Multiple level safety systems**
- CE certification (SMR + PSA 2010/11)
  - **Addresses safety and manufacturab**
- Pure hydrogen PEM FC
  - **Addresses durability**
  - **Addresses high electrical efficiency**
  - **Addresses lower costs**



- Low cost, highest efficiency hydrogen generator will plug into existing architecture (AER 2012/13-ADDITIONAL FUNDING REQUIRED)

CHP Technical Accomplishments

1. Detailed engineering completed in June 2009

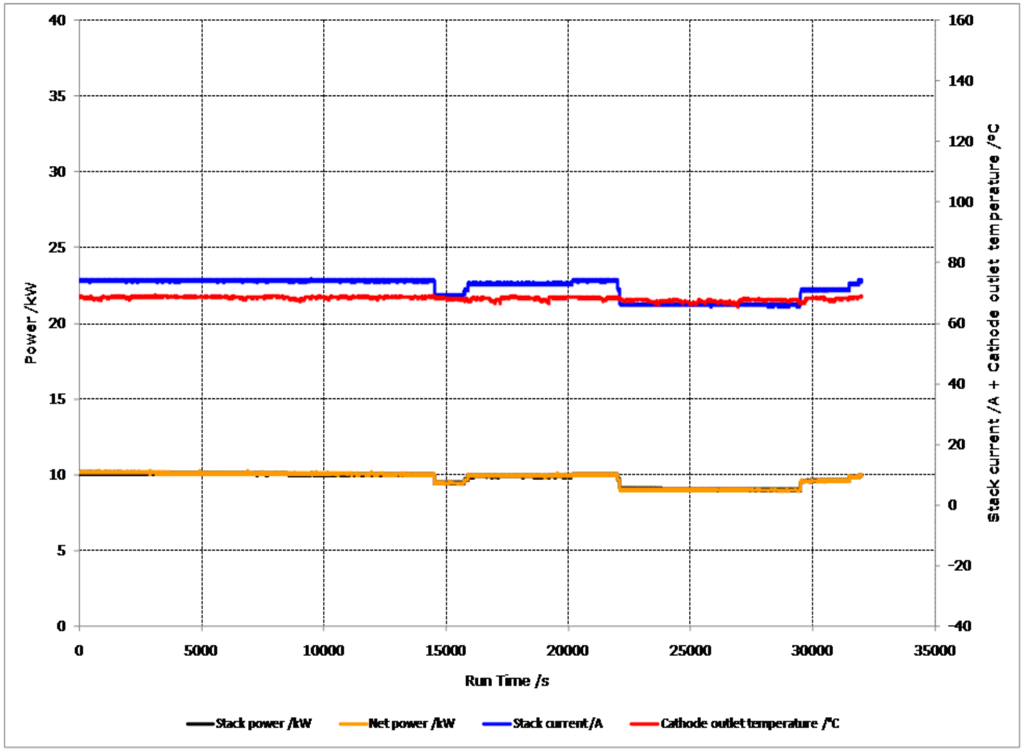
2. Construction and shakedown tests completed in October 2009

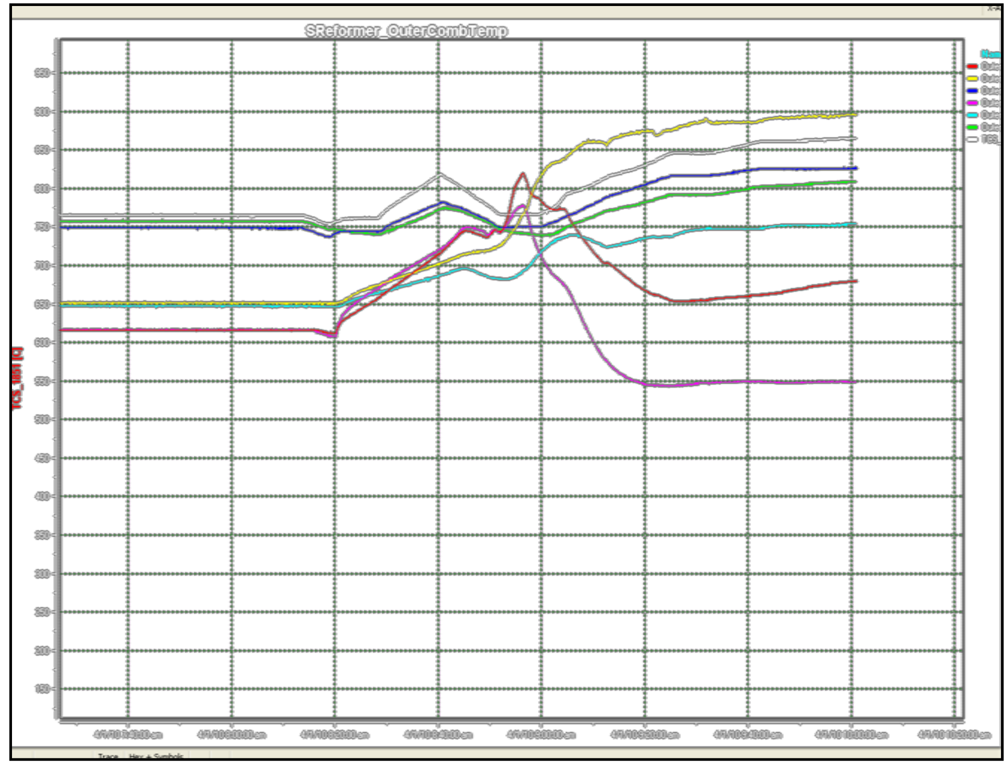
3. First power production achieved in November 2009

4. Automated combustor startup and full system safety shutdown implemented in February 2010
5. System in Continuous Operation Since March 2010

Over 1500 hot hours achieved on fuel processor: 3X improvement over Year 1/Task 1 unit

CHP Technical Accomplishments



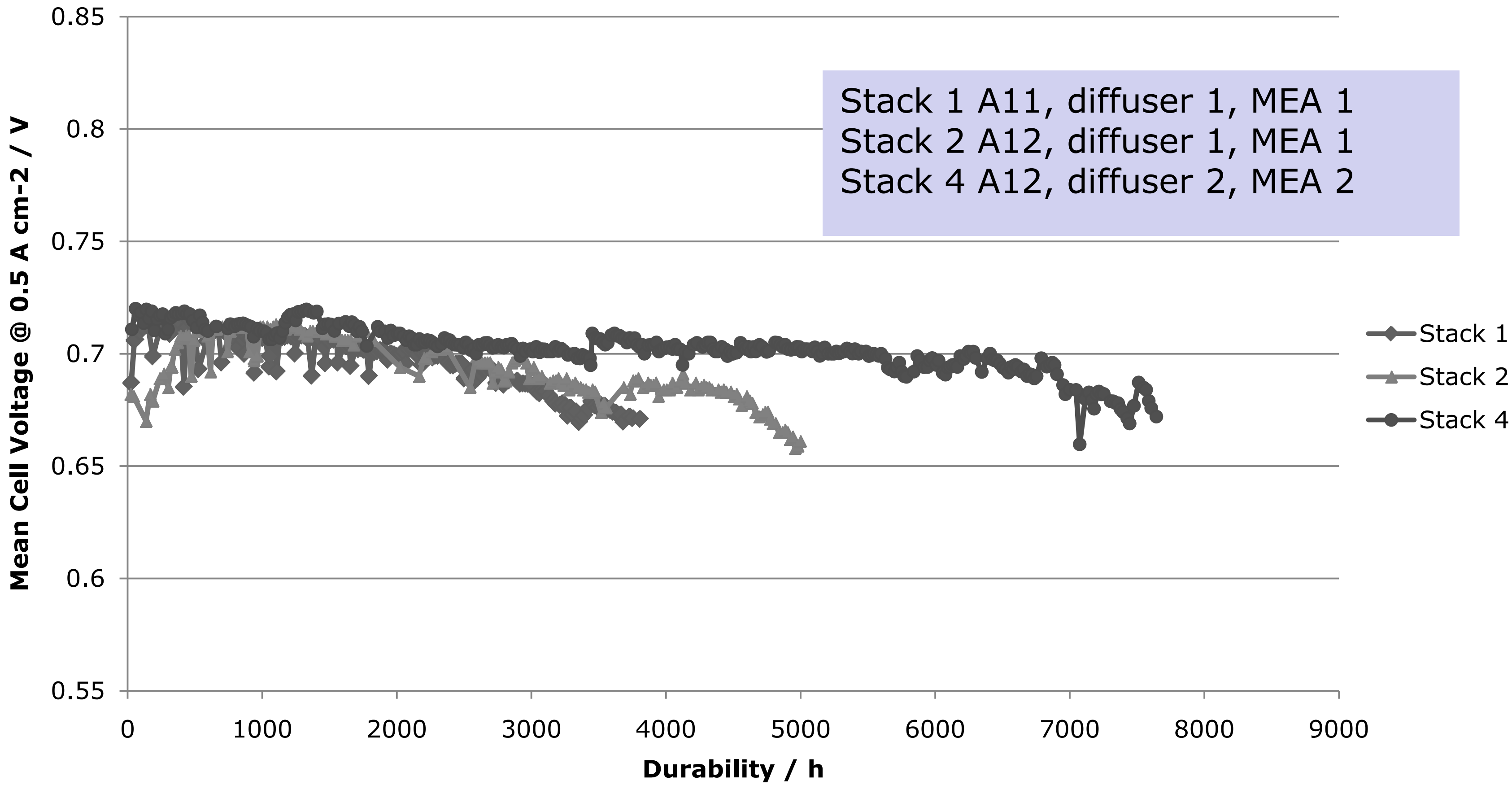


- •FC in CHP system running-10 hour data set
- •Expected power output was attained

Reformer from a "hot-idle" to steady-state hydrogen in one hour

Integrated system built and tested
Milestone #2 achieved

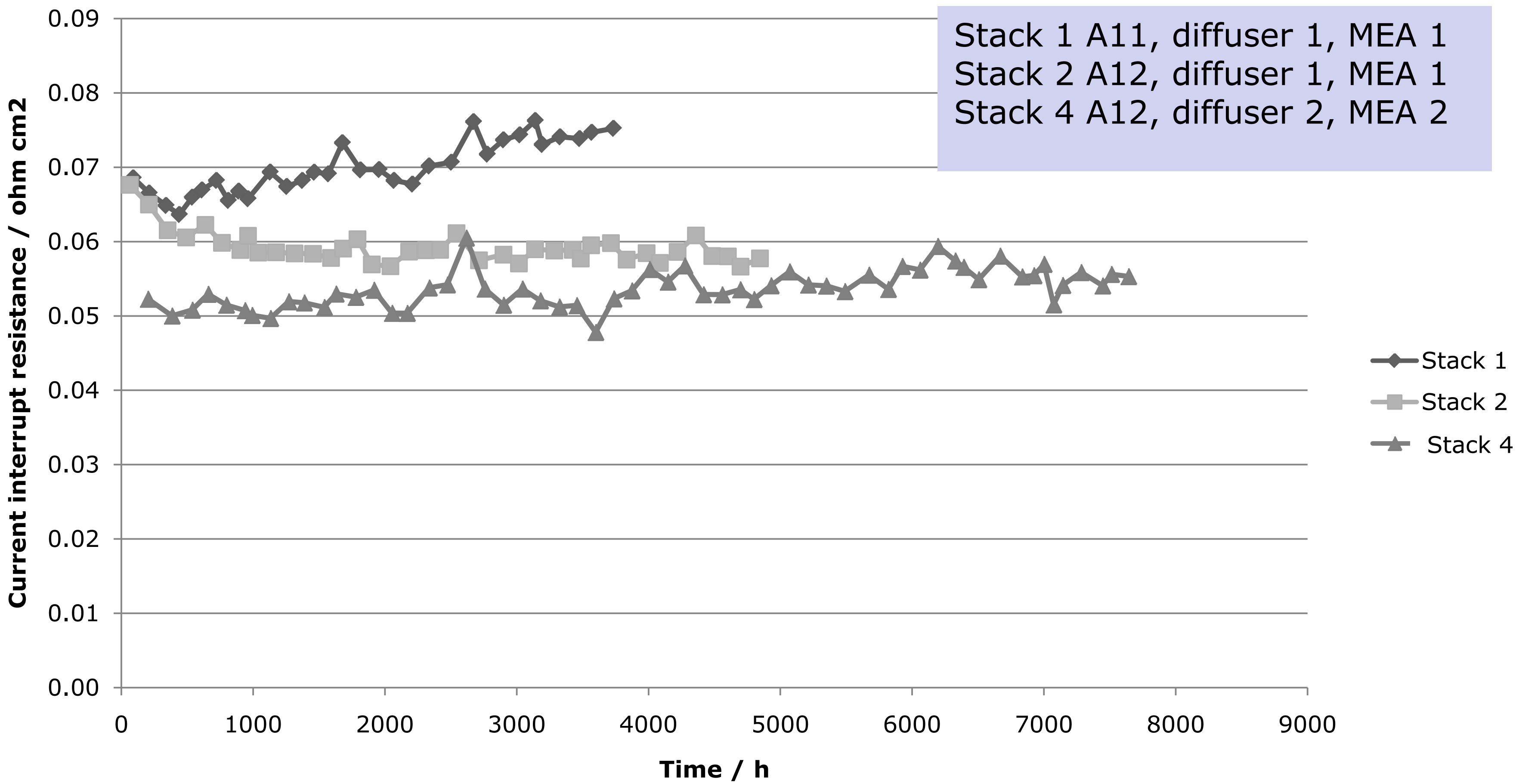
CHP Technical Accomplishments



Bench Test-20 cell stack durability at 0.5 A cm^{-2}

- **Cycle: 10 hours at 100A + diagnostics +thermal cycle [75C-25C-75C] + shutdown/start up +excursion to 200A**
- **~ 6% degradation after 7000 hours [stack 4]-2011 DOE target is 4.9% for 7000 hours**
- **Durability extended from ~3500 hours to ~7000 hours over course of program**

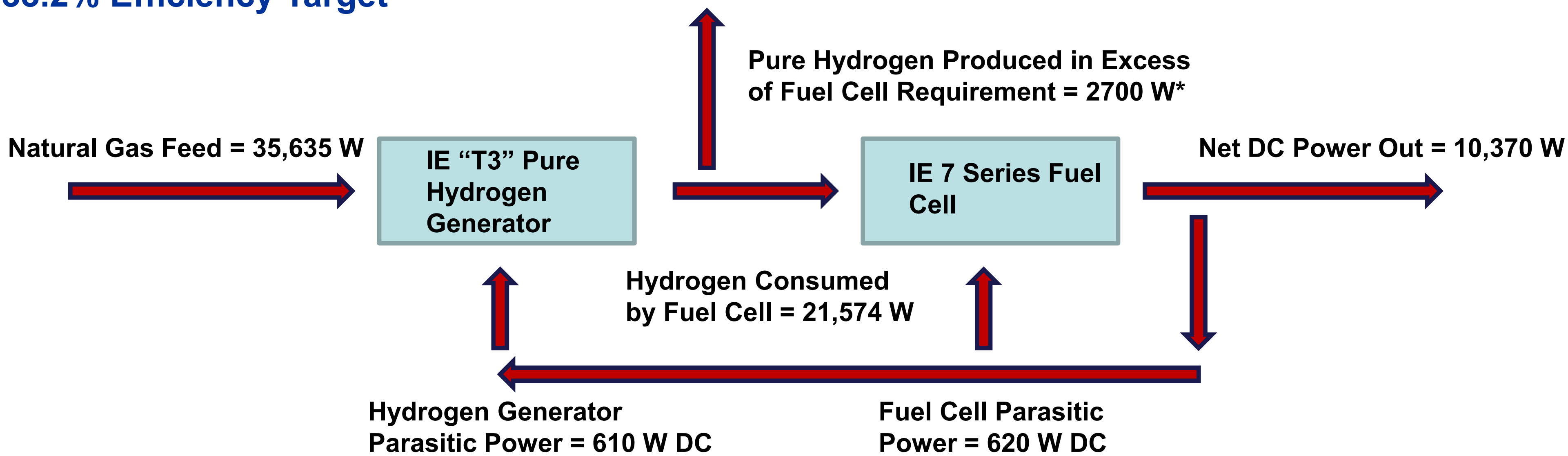
CHP Technical Accomplishments



Bench Test-Current Interrupt Resistance

CHP Technical Accomplishments

System Has Exceeded 10 kW Net Electric Power Output Target and is Approaching Expected 33.2% Efficiency Target



Chemical Efficiency of Natural Gas to Hydrogen = (21574 + 2700) / 35635 = **68.2%**
Chemical Efficiency of Fuel Cell = (10,370 + 610 + 620) / 21574 = **53.4%**
DC Power Delivery Efficiency = 10,370 / (10,370 + 610 + 620) = **89.4%**

End – to – End Efficiency = 68.2% * 53.4% * 89.4% = 32.6%

*** Hydrogen generator operated higher than FC need: optimization and load profiling work is continuing**

CHP Technical Accomplishments

	Expected Initial Performance @ 10kW	Achieved@ 11kW	Expected Target With Optimization
Pure Hydrogen Produced (SLPM)		135	
Natural Gas Fed to Reformer (SLPM)		54	
Natural Gas Fed to Combustor (SLPM)		6.3	
Hydrogen fed to Combustor (Proxy for PSA off-gas) (SLPM)		5	
Fraction of Natural Gas Power Converted to Pure Hydrogen*	72%	68.2%	73.5%
Fuel cell Gross power (W)		11540	
Hydrogen Consumed by Fuel Cell (SLPM)		120	
Gross Efficiency of Fuel Cell	53%	53.4% ✓	55%
Fuel cell parasitic power (W)	720	620 ✓	600
Hydrogen production parasitic power (W)	850	610 ✓	700
Percentage of DC Power Available to Customer		89.4%	
End-to-End Electrical Efficiency (Electricity Out / LHV Fuels In)	33.2%	32.6%	36.2%
Thermal Power Recovered from Hydrogen Generator (W)**	4200	2732**	5000
Thermal Power Recovered from Fuel Cell (W)	4200	6640 ✓	5000
End-to-End Thermal Efficiency		30.1%	
Overall Combined Heat and Power Efficiency	61.1%	60.8%	>71.5%

- *Hydrogen generator efficiency below expectation due to natural gas (rather than PSA off-gas) firing of the combustor
- *We expect to be firing the combustor using off-gas, and to achieve efficiency targets in May
- **Heat exchanger replacement and insulation measures will be taken in coming months
- Elements of the system are already achieving modeled predictions

AER-Boosting H_2 Generation Efficiency

Uses medium temperature (475-550C)and hydrotalcite for CO_2 capture with FC cathode and anode off-gases for regeneration

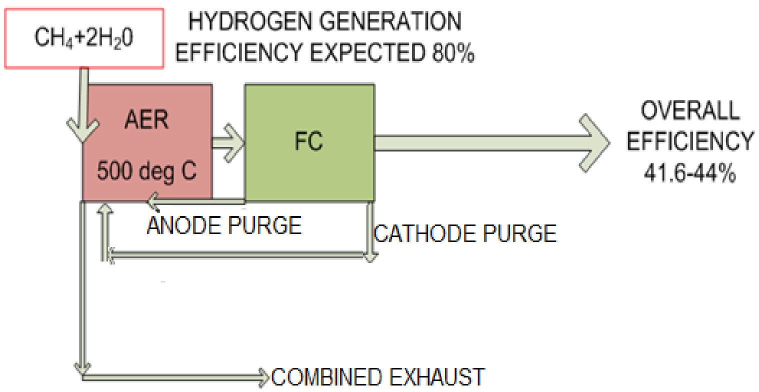
Objective This Year: Continuous H_2 Production

Higher Efficiency

- Lower Rx Heat (140 kJ/mol)

- No Water Gas Shift or PSA-lower cost

- Low pressure operation–lower parasitic losses



Four tube (2” diameter x 48”) reactor beds, cyclically operated at Cal Poly Pomona

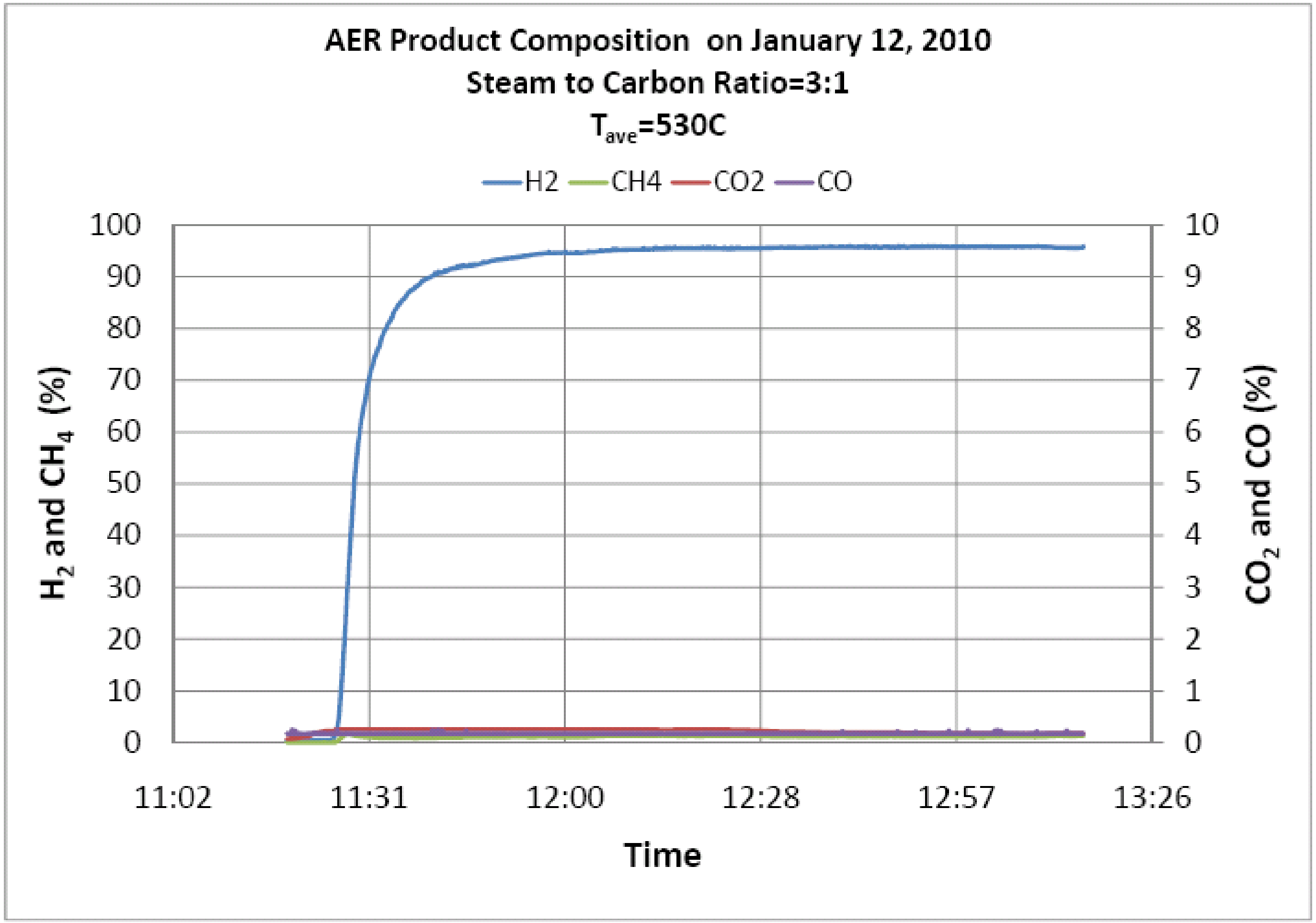
$$CH_4 + 2H_20 \rightarrow CO_2(\text{Adsorbed}) + 4H_2$$

AER Technical Accomplishments

- Four tube, cyclical reactor test rig operated
- (1-2 LPM hydrogen continuous production rate)

Primary Experimental Parameters	
Variable	**Range of Values**
Bed Temperature	**475°C to 550°C**
Feed Rate	**0.01 to 0.025 mol/min**
Steam to Carbon Ratios	**2:1 to 4:1**
Catalyst to Sorbent Ratio	**1:10 and 1:4**
Supplementary Experimental Parameters	
Carbon Source	**Ethanol, LPG, Methane**
Cycle Times	**72, 96, 120, 144 and 168 seconds**
Tubes in Cycle	**Three tubes or four tubes**
Steam Cleaning Time	**10 and 20 seconds**

AER Technical Accomplishments



Continuous hydrogen production at low temperature with >95% purity achieved: progress since last year

AER Technical Accomplishments

- Summary
  - High purity hydrogen production achieved
  - Over 350 hours on test rig: 0 hours last year
  - Materials stability indicated
    - >2,500 process cycles switching from production to regeneration back to production
  - Process simplicity demonstrated (automated operation with PLC and timed solenoid valves-single operator)

Homogenous catalyst/sorbent extrudate

After slight discoloration with no conversion deterioration or breakage

Adsorbent and Catalyst Before

Technology Transfer

- Joint venture with Scottish and Southern Energy
- System installers subcontractor Logan Energy
- Site modeling and controls subcontractor Element Energy
- Inverter development in collaboration with NEDAP

Future Work

- (2010) System optimization (SMR+PSA+FC) and redesign to accommodate future plug-in AER fuel processor*
- (2011) Six month field demonstration in IPHE country (UK)**
- (2011/12) AER fuel processor scale up and testing (further funding required)

Demonstration site in UK under construction-August 2010 completion

*Milestone #3
**Milestone #4

Summary

- **2009/10 integrated CHP system built and tested**

>30% electrical efficiency achieved **>1900 hot hours operation**

>9.3kW waste heat recovery achieved **4 of 8 metrics achieved**

- **2009/10 AER bench-scale hydrogen production**

High purity **Less expensive materials**

Adsorbent stability indicated **Higher efficiency over SMR+PSA**

- **2010/11 Model based system engineering of Beta demonstrator to assess trade-offs and improve efficiency**

Target of 36.2% projected efficiency attainable (SMR+PSA +FC)

50 % size reduction

Grid-tied, CE marked demonstrator

- **2012/13 integrated AER+FC CHP system with 40% electrical efficiency, ~$750/kW, path to 40,000 hours durability-Additional funding required**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