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

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DOE Annual Merit Review (AMR)

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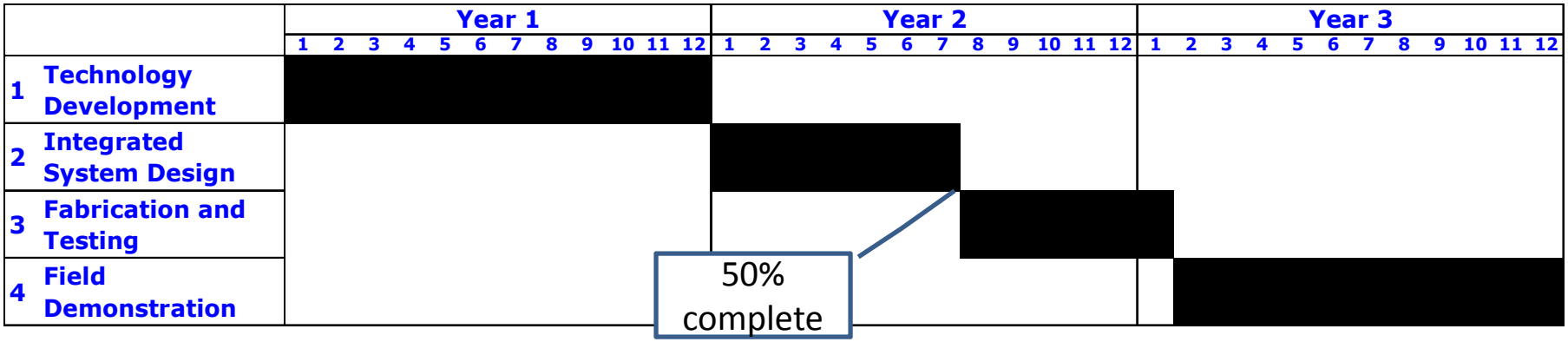
Project Overview

Timeline: July 2007-August 2010



Challenges/Barriers

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

Project Partners

- Intelligent Energy-Dr. Durai Swamy (PI)
- California Polytechnic University, Pomona
- University of South Carolina
- Sandia National Laboratories

Budget

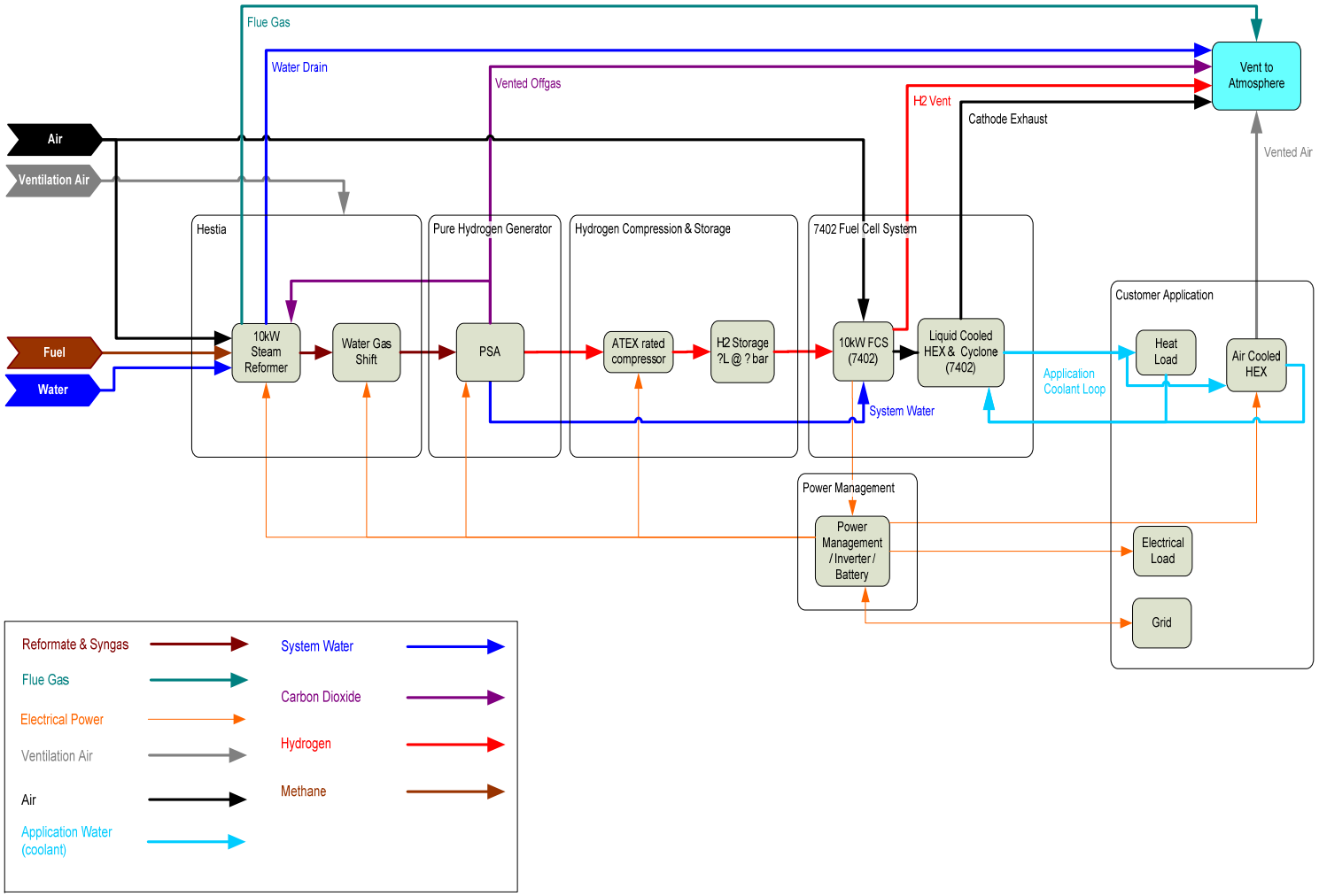
- Three year, $4.38 million program, 50% DOE cost share
- Funding received in FY 08 = $459,533
- Estimated funding for FY 09 = $ 955,101

Objectives

- Develop and demonstrate PEM fuel cell based 1-10 (kWe) stationary combined heat and power system that provides the foundation for commercial mass-producible units that address the identified technical barriers
- Technical
  - 40% electrical efficiency (fuel to electric energy conversion)
  - 70% overall efficiency (fuel to electric energy conversion + usable waste heat energy conversion)
  - Potential for 40,000 hour life
  - Potential for $450/kW
  - System demonstration in IPHE country
- Topic 7A-International Partnership for a Hydrogen Economy (IPHE)
  - Engage international partners
  - Demonstration phase in an IPHE country other than the USA

Approach

- Process Flow Diagram



Approach

- CHP System
  - Open Architecture: High purity H_2 interface between fuel cell and fuel processor
  - Heat recovery from fuel cell, combustor flue and synthesis gas

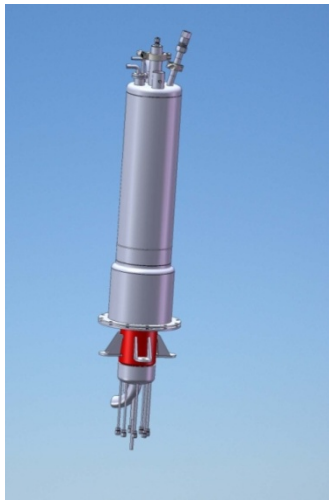
Electricity Produced, (kW)	Cathode Off Gas Heat (kW)	Synthesis Gas Heat (kW)	Flue Gas Heat (kW)
10	5-13.9*	2-3	2-3

  - Lowering of parasitic power requirement-IMPROVES EFFICIENCY
  - Water recovery from fuel cell (cathode off-gas), flue gas and synthesis gas

*depends on application and/or modeled assumptions

Approach

- Hydrogen Production Subsystem
  - Integrate improved H_2 generator/rapid cycle PSA
  - Demonstrate the platform using natural gas to align with IE commercial program with Scottish and Southern Energy Ltd.
  - Validate continuous H_2 production using AER for future coupling to CHP prototype and/or deployed systems-HIGHEST EFFICIENCY ENABLER
  - Simplified low cost-to-manufacture reformer design (T3) with expected increase in efficiency

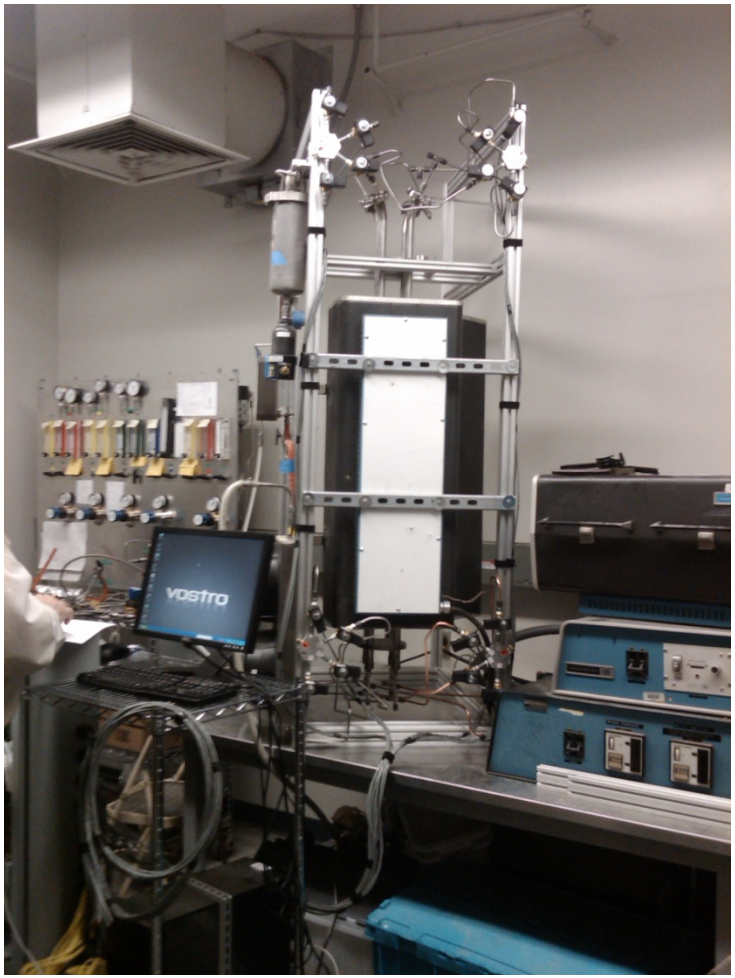


Approach

- Fuel Cell Subsystem
  - 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

Accomplishments Since Last AMR

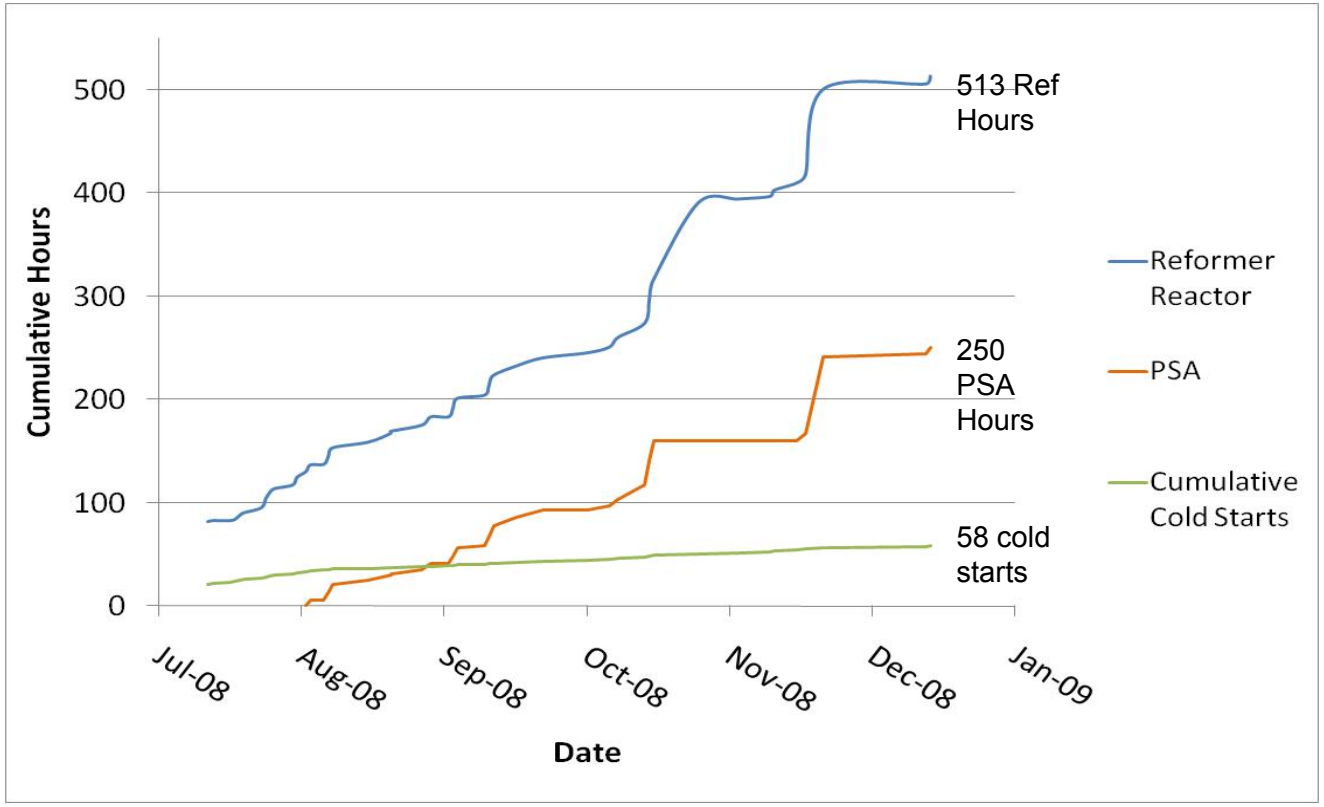
- AER
  - Multiple tube cyclic continuous hydrogen production test rig ready for operation*



*Single tube feasibility test data presented in last AMR

Accomplishments Since Last AMR

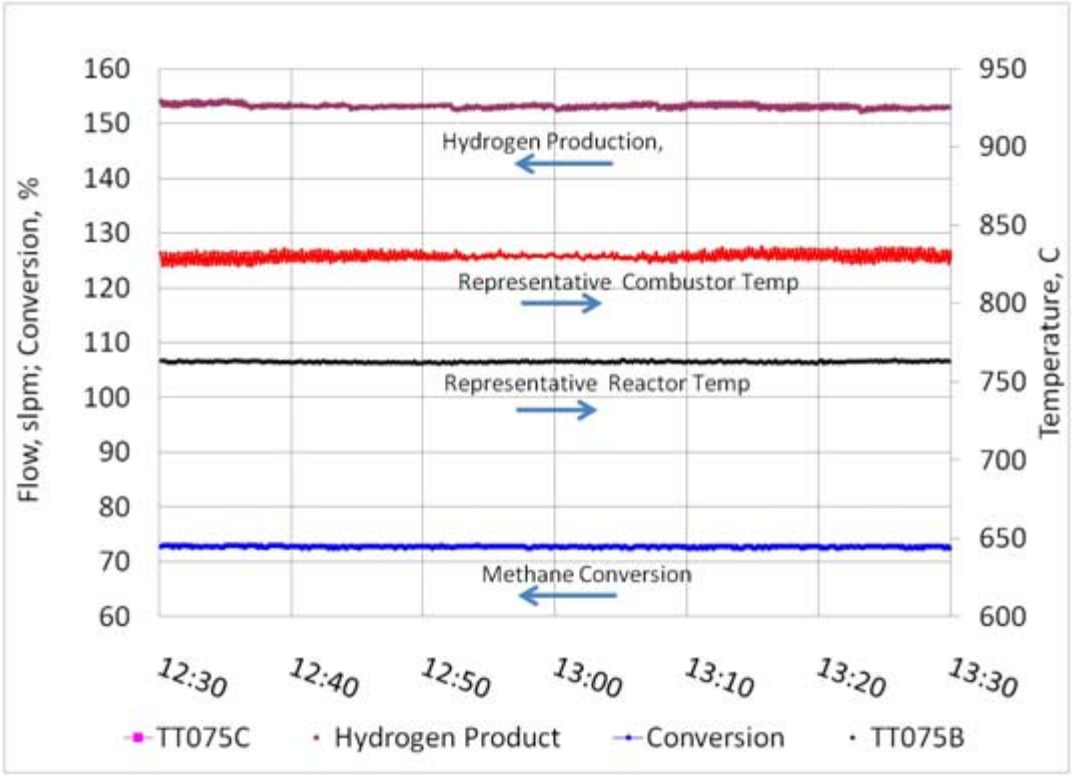
- Hydrogen Production Subsystem
  - 513 Hours of Testing



Accomplishments Since Last AMR

- Hydrogen Production Subsystem
  - Repeatable production runs at > 65% thermal efficiency*

Therm Eff.	Load	Time	H20/C	Supp Fuel
	slpm			slpm
65.24	69.5	9/24/2008 16:27	2.86	0
64.94	69.4	9/24/2008 17:29	2.87	0
65.47	69.8	9/30/2008 17:11	3.08	5.3
65.65	69.5	10/1/2008 11:20	3.04	5.3
65.85	70	10/1/2008 13:30	3.13	0
65.21	61	10/1/2008 15:00	3.26	4.6
65.07	70	10/2/2008 11:41	3.04	5
65.27	60.7	10/2/2008 16:00	3.01	6
65.32	62	10/2/2008 17:40	2.91	7



Data from 10/1/2008

* $n = H_2\ Q_{out} / CH_4\ Q_{in}$

Accomplishments Since Last AMR

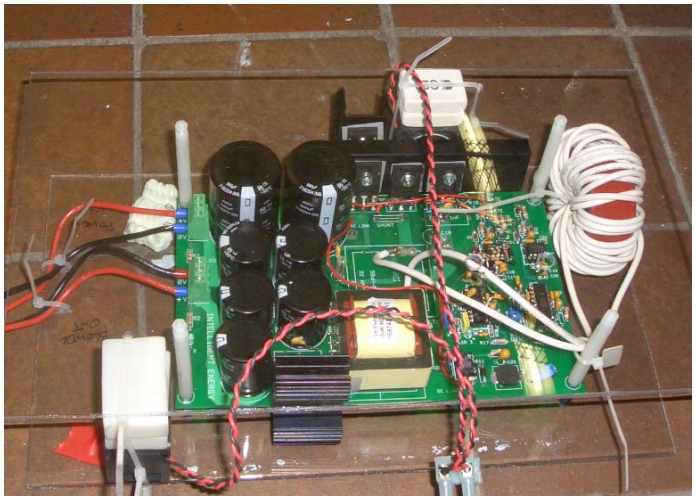
- Hydrogen Production Subsystem
  - Achievement of >69% thermal efficiency
  - Validation of water-gas shift reactor and catalyst

	Date	CO to Shift	CO out shift	Thermal Efficiency
		%, dry	% dry	%
Previous Shift Reactor	10/2/2008	13.3	3.6	65
New Shift Reactor	10/28/2008	11.5	1.5	69

WGS reactor and catalyst allow for heat recovery from exothermic process (favored by low temperature) and increases H_2 yield

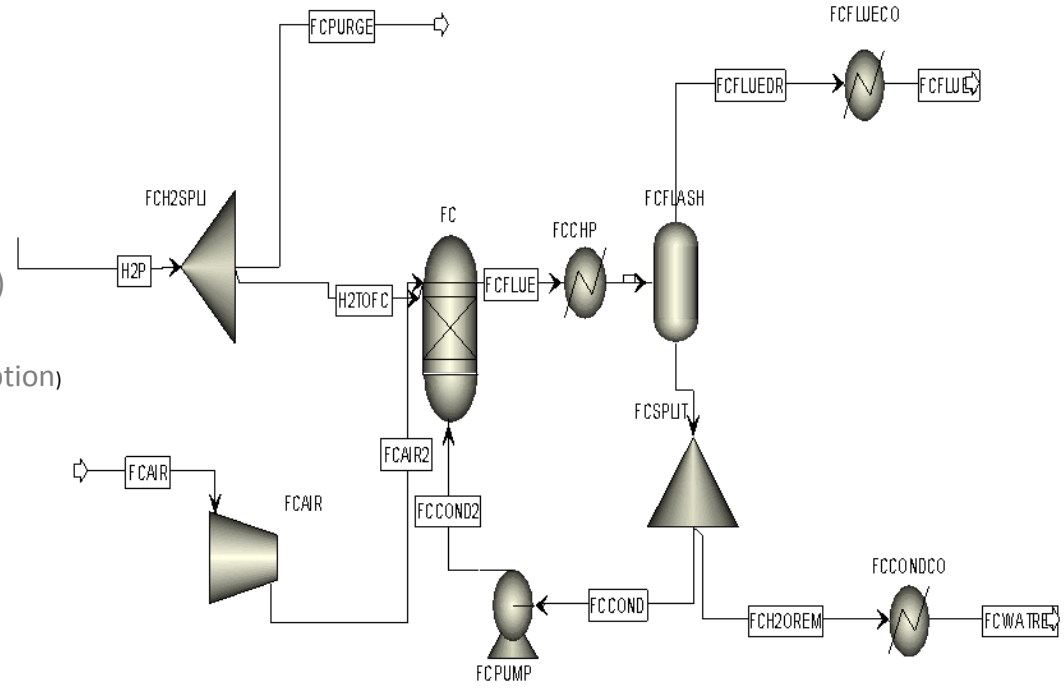
Accomplishments Since Last AMR

- Fuel Cell Subsystem
- Work has previously been done with two efficient prototype DC-DC converters, one to generate high voltage compressor power, and the other to generate low voltage controls power.
- These have now both been packaged into to a near final form



Accomplishments Since Last AMR

- Fuel Cell Subsystem
  - Aspen Model
- Assumptions
  - System input: 0.84 kg H_2/hr
  - 5 % split rate
  - FC outlet T = 60 C
  - Water cooled to 50 C and recycled (Assumption)
  - Lambda ~2
  - Rejected air and water cooled to 25 C (Assumption)
  - Estimated 2 kW in parasitic power loss
  - 10 C water cooling in flash vessel (heat loss assumption)



Accomplishments Since Last AMR

- Fuel Cell Subsystem
  - Testing to 500 hrs (1000 hrs to date)

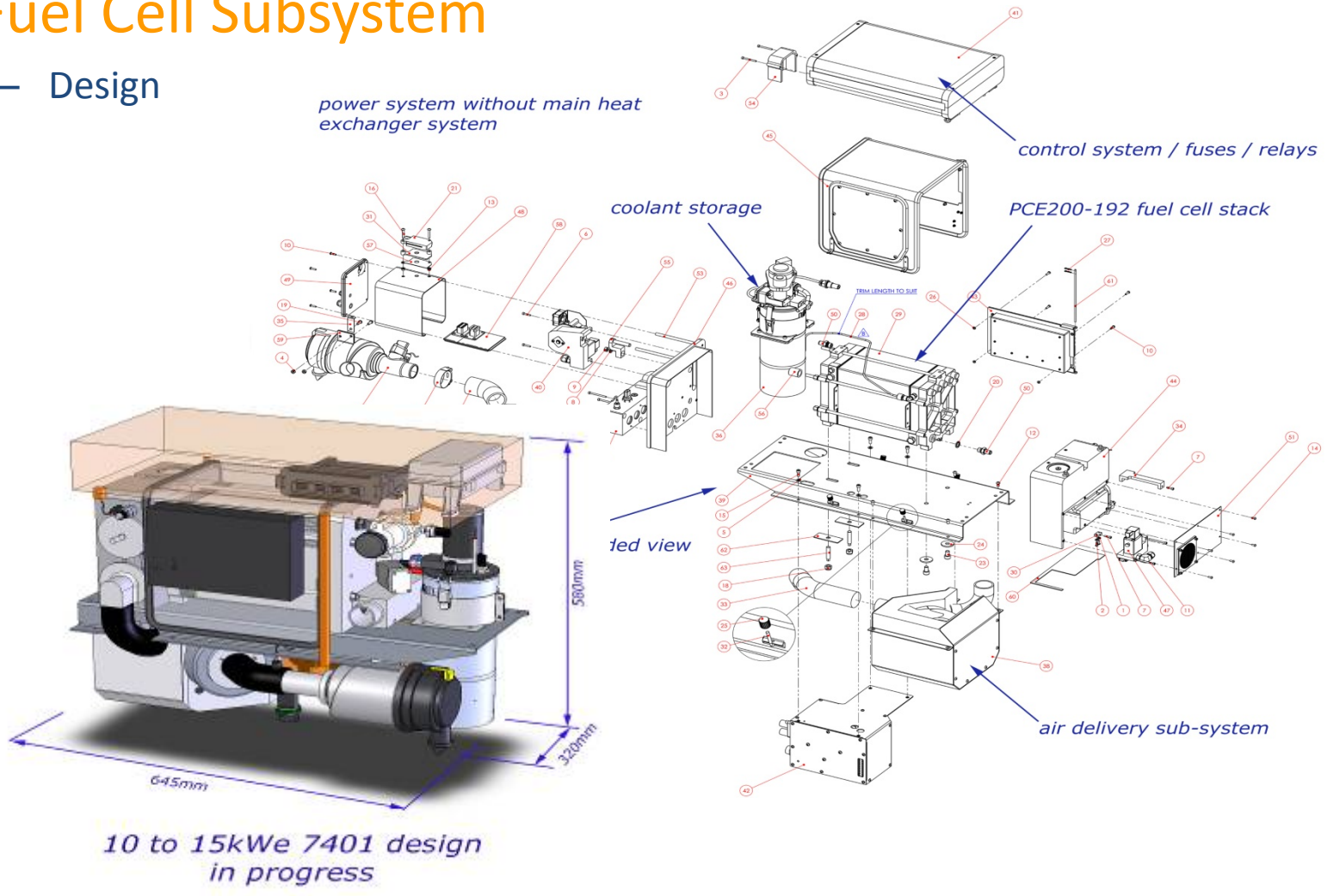
Accomplishments Since Last AMR

- Fuel Cell Subsystem
  - Testing to 500 hrs

Infant Mortality Failure Modes	Root Cause	Design fix
1: Failed compressor		
This system was fitted with a Varex compressor. This type of compressor performed well in early prototype systems but proved to have a short life when running past 200 hrs.	Vane tip wear	Replaced with high speed centrifugal type compressor which do not have close tolerance tip clearance and utilise high speed air bearings.
2: Air box gasket moved		
Air leaks were found during testing	Gasket face too small	Sub-system design modified and gasket eliminated.
3: Purge valve failure		
High flow of gas detected in the purge line. The rubber seat fitted to the purge valve was found to be damaged.	Damaged sealing surface as supplied	Purge valve manufacturer changed.
4: Compressor vibration		
The replacement Varex compressor began to exhibit high noise from the drive end.	Rotor needle roller bearing failure.	Future designs use a high speed centrifugal type compressor which do not have close tolerance tip clearance and utilise high speed air bearings.
5: Water flow meter failure		
The water flow meter is submersed in the catch pot (as designed). The test was shut down due to low water flow. Inspection showed that the water flow meter had failed.	Water ingress into the flow meter processing electronics.	Component was replaced, examined and sent to manufacturer for further inspection

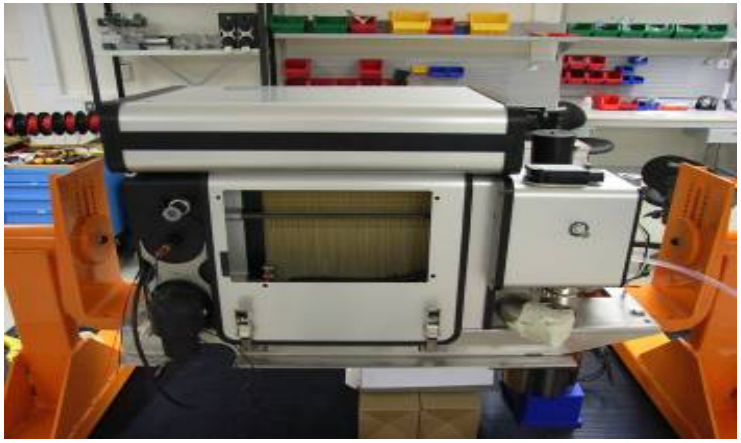
Accomplishments Since Last AMR

- Fuel Cell Subsystem
  - Design



Accomplishments Since Last AMR

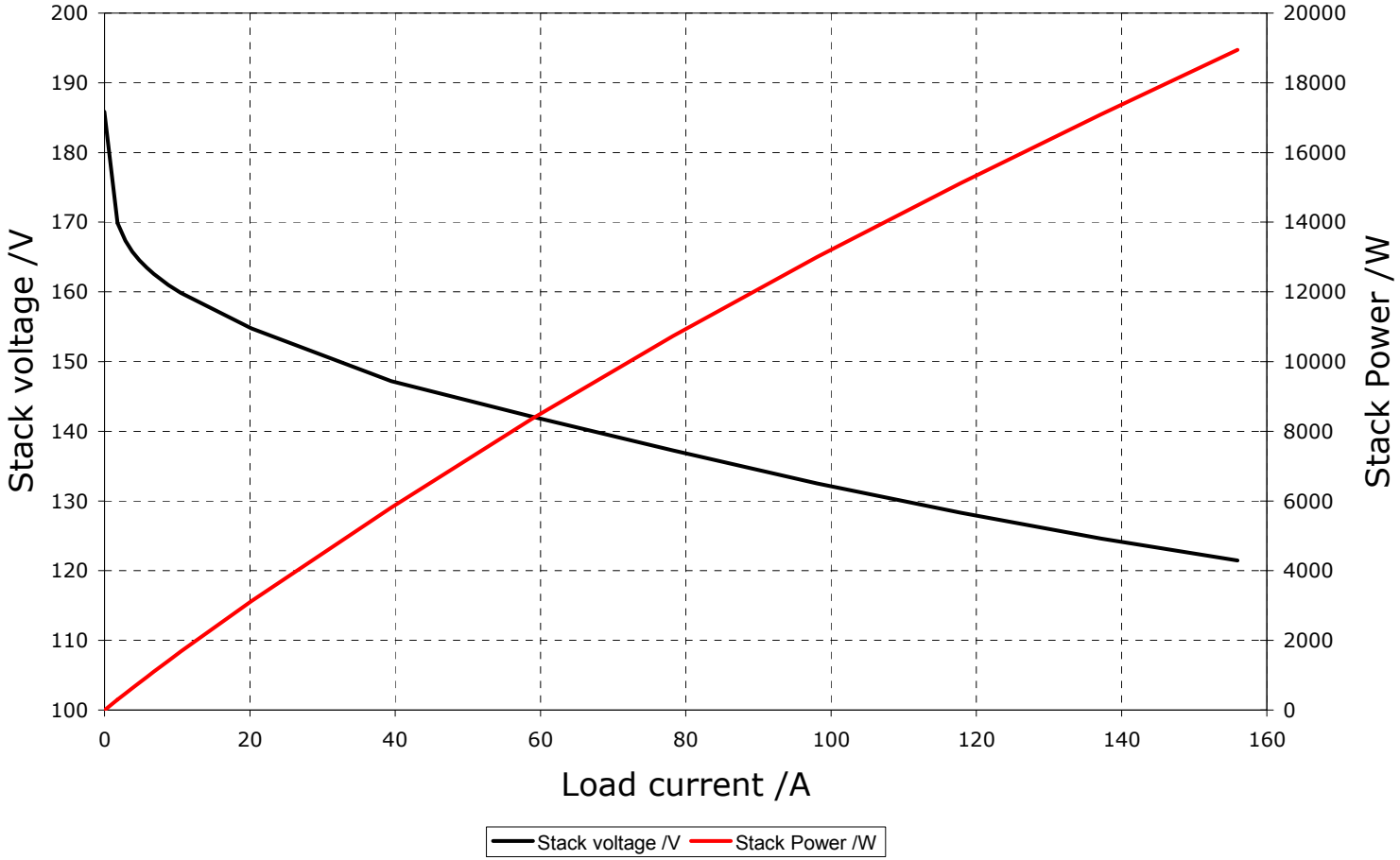
- Fuel Cell Subsystem & Test Station
  - Built



- FC (7402)
- Test Rig
- System Tested
- Shipping to US in March 09

Accomplishments Since Last AMR

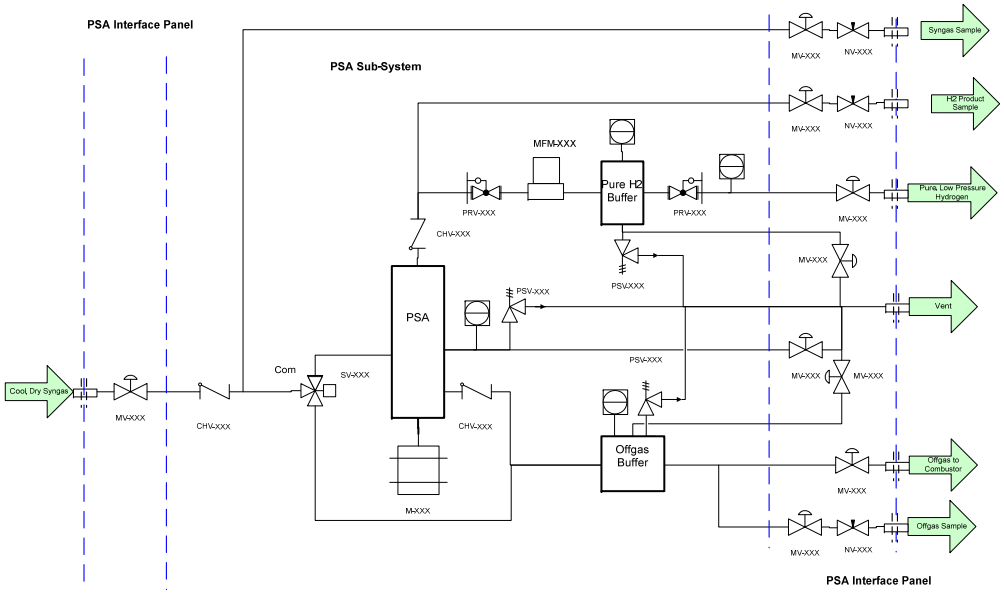
- Fuel Cell Subsystem
  - Polarisation Post-"ruggedization" Testing

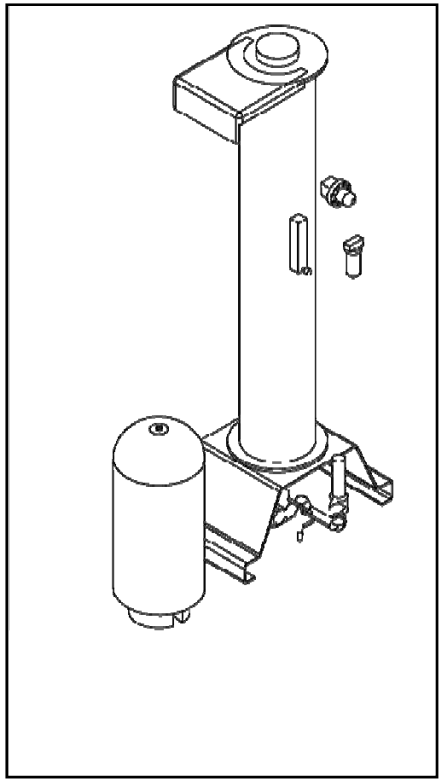


Accomplishments Since Last AMR CHP System Design

- Hydrogen Production Subsystem
  - PSA Subsystem

CE certified PSA* integrated into CHP system

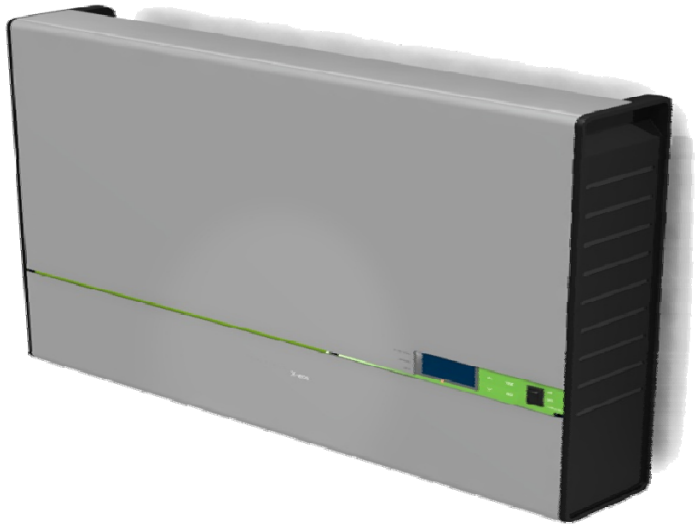




*supplied by QuestAir

Accomplishments Since Last AMR
CHP System Design

- Electrical and Grid Interconnection
  - The NEDAP Altrium Mygrid system currently under consideration
  - This is a modular system that allows different energy sources (e.g. wind, battery, fuel cell, solar cell and generators to be mixed and managed)
  - This existing modules for battery and solar form a solid basis for a FC input module
  - Output modules are rated at 5kW and two could be used for 10kW single phase, and three for 10kW three phase.
  - Fuel cell input modules are required and battery module would give additional capability



Accomplishments Since Last AMR
CHP System Design

- Safety Assessment

  Codes & Standards Review for CE Marking

Certification Strategy Compiled

Step 1: Risk Assessments & FMEAs
Step 2: Directive Compliance Review

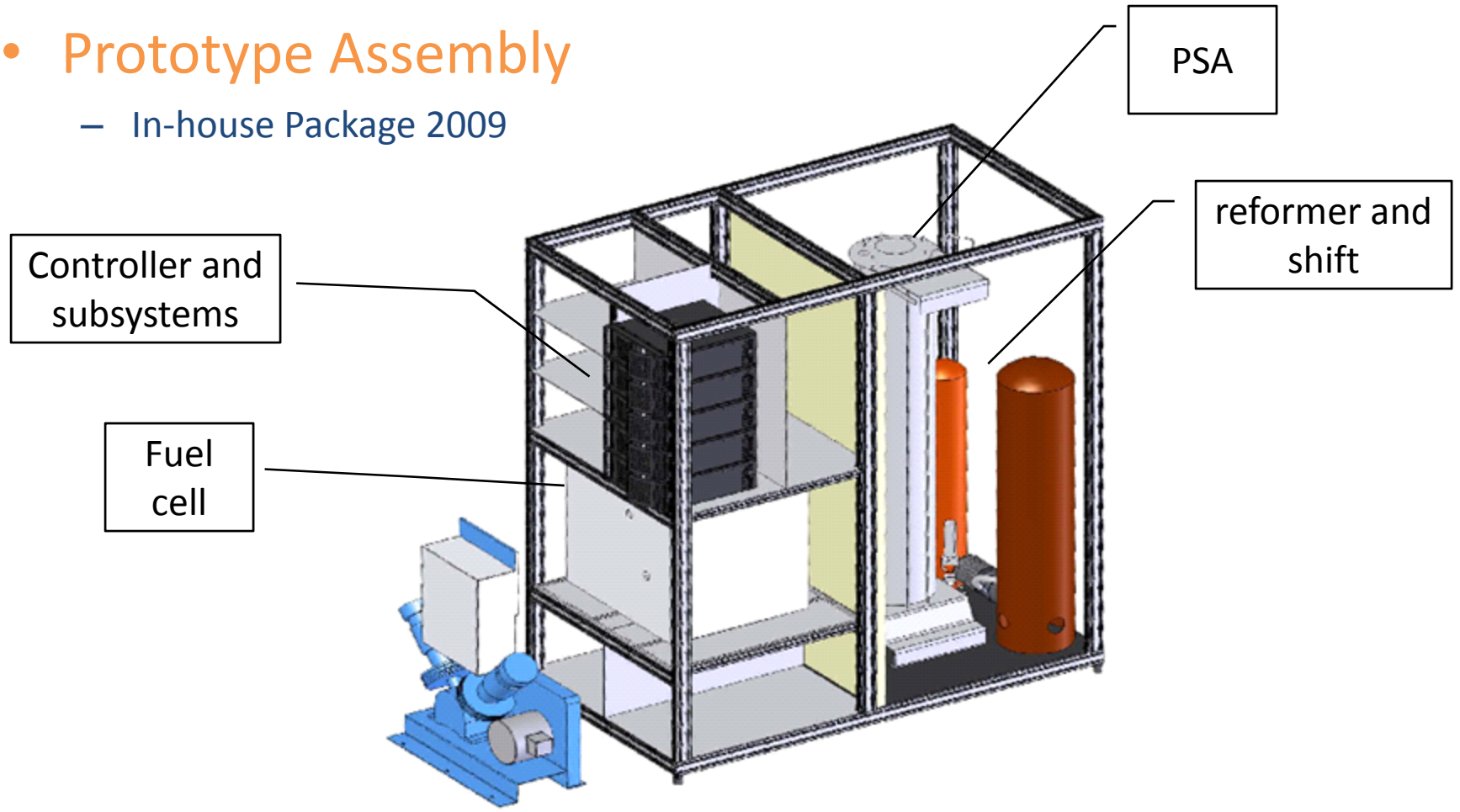
ATEX - Designed for equipment to be placed in explosive atmospheres
GAD - Gas Appliances Directive
PED - Pressure Equipment Directive
LVD - Low Voltage Directive
EMC - Electromagnetic Compatibility Directive
MAC - Machinery Directive (covers rotating appliances)

FC specific: BS/EN 62282 Fuel cell modules
Reformer specific: ISO 16110pt1 Hydrogen generators using fuel processing technology
CHP- specific: CEN/CENELEC – FC gas heating appliance of nominal heat input < 70 kW (prEN 50465)

Step 3: System Conformity Review
Step 4: Testing & Notified Body Assessment
Step 5: Certification

CHP System Work in Progress

- Prototype Assembly
  - In-house Package 2009



CHP System Work in Progress

- Future CHP Package

  Field Demonstrator 2010

Plan for Remainder of Project

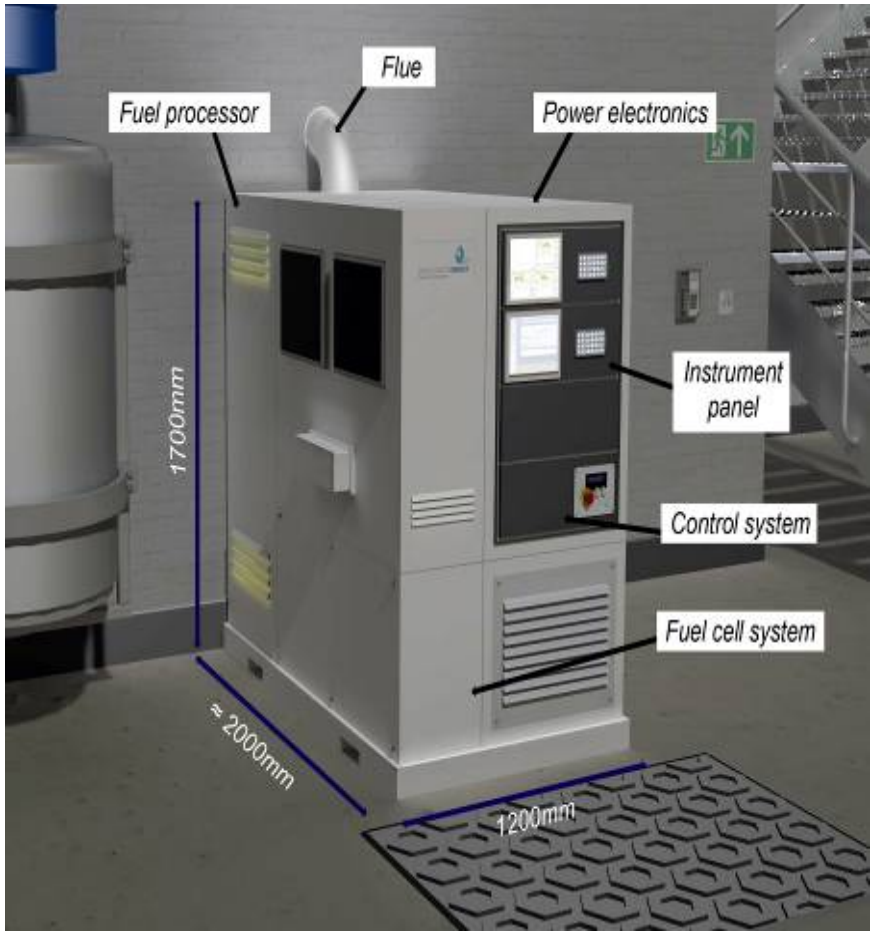
- Finalize site selection by end of Task 3
  - IE Loughborough facility
  - Scottish and Southern Energy Ltd. (Perth Scotland)
  - Work with OEMs to create smaller, less expensive components for future designs
  - CE certification

Plan for Remainder of Project

- Complete CHP prototype and witness test in Long Beach during September 2009
- Evaluate results of AER alongside T3 to select best platform for European demonstration unit that meets or exceeds project efficiency targets during Phase 4
- Continue techno-economic studies to validate cost reduction strategies

Conclusion

- Proven subsystems technology to 500 hrs
  - Identified & Mitigated Infant Mortality
  - Preparing Integration of Fuel Cell Subsystem and Hydrogen Production Subsystem
  - Prototype CHP to be commissioned during Q2-Q3 2009
  - Subsystem components fully described
  - High Level Risk analysis of main subcomponents prepared in readiness for High and Component level FMEAs in Q1 09.
  - Subsystem steady-state models
    - preliminary models ready for experimental validation

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