Stationary PEM Fuel Cell Power Plant Verification

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UTC Power

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Project ID #
FC_26_Strayer

Overview

Timeline

- Start – January 2004
- End – December 2009
- Percent complete – 60%

Barriers

Commercial Viability of PEMFC for stationary applications

- Product Cost
- PEMFC Durability
- PEMFC Field Robustness

Budget

- Total project funding
  - DOE share - 11,357K
  - Contractor share - 10,422K
- DOE Funding for 2009 - $955K

Key Contributors

- UTC Power- Lead

Key non-cost share suppliers

- Houston Advanced Research Center – Test services
- US Hybrid – Power conversion
- TDI – Power electronics
- Avalence - Electrolyzer

Relevance - Program Metrics

Parameter	Metric	Demonstration	Result
Rating	5kW, applicability up to 200 kW range power plants	Test (5kW)	5kW powerplant constructed with rated power up to 40C @1000 meters. Scalability in 5kW building blocks feasible for AC and DC applications. Design is scalable to larger power applications
Efficiency	>35 %	Test	@5kW net on Pure Hydrogen: Fuel Cell System without power conditioning: 51% Advanced system with power conditioning: 45%
Primary Fuel	Hydrogen from various sources including feasibility for hydrocarbon reformate	Test, Analysis	Study for natural gas, LPG, propane underway.
Emissions	As good as or better than U.S. requirements	Test	Zero emmissions. Hydrogen concentration in exhaust is less than 25%LFL under all operating conditions. Not yet analyzed for reformer based system.
Operation	Start time < 30 minutes, All U. S. weather conditions	Test	Demonstrated start time is 15 seconds (Hydrogen based system). Not yet analyzed for reformer based system.
Durability	Design goal: ≥15,000 hrs (ultimate application goal ≥40,000 hr) Demonstrated requirement: 1,000hrs, ≥1 year replacement interval	accelerated component and cell stack testing	5kW baseline powerplant unit has accumulated 3500hrs with <10uV/hour of non-recoverable performance decay.
Mean Time Between Forced Outages (MTBFO)	≥2,000 hours with long term goal of 5,000 hours	Test, statistical analysis	Reliability model projects 1800 hours and testing is ongoing to increase the projection.
Maintainability	Web based remote control, diagnostics	Test	Demonstrated remote monitoring, control with both modem or ethernet capability.
Use of thermal energy	Integration with liquid desiccant	Study	Completed
Grid Interconnectivity	Any US grid with minimal equipment	Demonstration Test, UL 1741 assessment	AC 120VAC single phase demonstrated AC grid connect inverter under development for demonstration in 2009.
High availability & multiple grid connections	Increased availability of power plants & demonstrated grid connections on feeder lines; suitability for backup power application.	Demonstration Test, modeling, and statistical	Baseline 5kW powerplant demonstrated 99.6% availability over 1500hrs

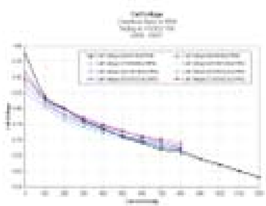
On target

Complete

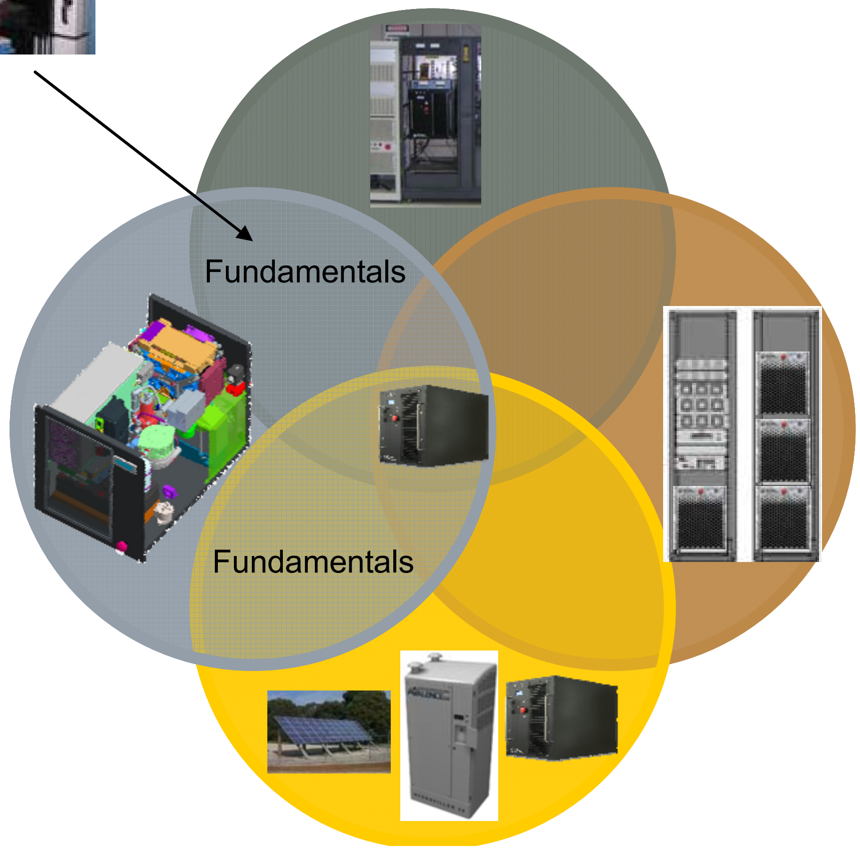
Objectives

1) **Evaluate the operation of a 150 kW natural gas fueled PEM fuel cell.**
2) **Assess the market and opportunity for utilization of waste heat from a PEM fuel cell.**
3) **Verify the durability and reliability of low cost PEM fuel cell stack components.**
4) **Design and evaluate an advanced 5 kW PEM system.**
5) **Conduct demonstrations of PEM technology with various fueling scenarios.**
6) **Evaluate the interconnection of the demonstration 5 kW powerplants with the electric grid.**

Approach: 5KW Technology Platform



Fleet: Prove Durability



Advanced System

Improve commercial viability and field readiness

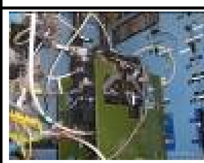
Flexible Output
Demonstrate AC output, building block power architecture & Grid Connectivity

Flexible Fuel Source

Reformer, Electrolyzer

Accomplishments – Fundamentals

Low Cost CSA Development & Verification Summary

Product	Photo	IR (mV/100masc)	mV @ 1000 mA/cm^2	OCV (mV)	Falloff Time (min)	Recoverable Decay (uV/hr)	Non Recoverable Decay (uV/hr)
5kW PEM CSA Spec		<15	>600	>898	>1	<70	<21
Baseline UEA (30-Cell CSA)		13	628	945	4.7	457	
Alternate UEA-1 30 cell, 500 hrs		10.2	570	979	9.04	226	47
Alternate UEA-2		8	642	982	>10	239	<21 (682 Load hours)
33-Cell stack with Alternate UEA-2		12	654	>970	7.9	616 (1000 hrs)	29

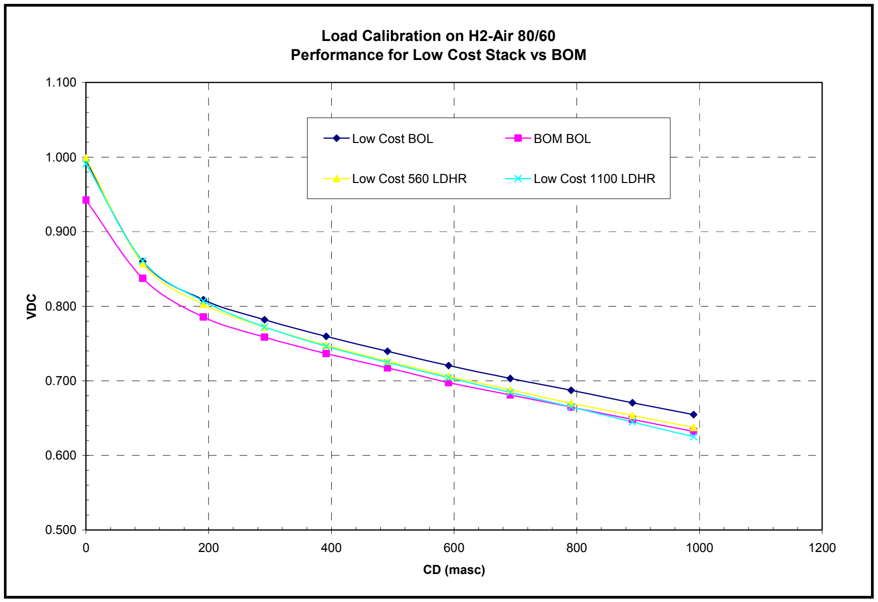
Accomplishments – Fundamentals

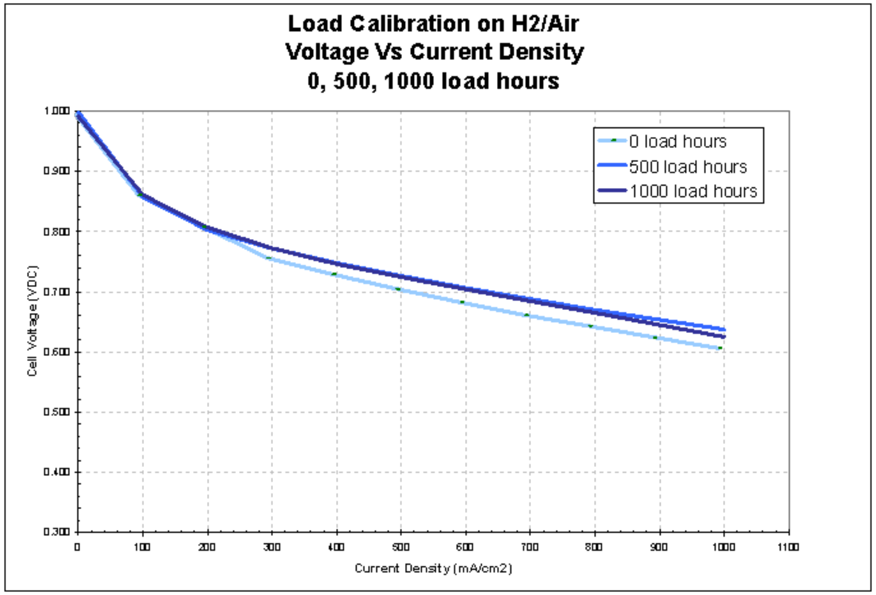
Low Cost Cell Stack (33 Cell)

- Stack Configuration
  - Water transport plates with optimized coolant channels
  - Alternate UEAs

- Objective:
  - Acceptance testing (simulated powerplant operation)
  - Constant current hold to >1000 hours before insertion into powerplant.

Accomplishments – Fundamentals





Low cost cell stack demonstrated performance equivalence with baseline design.

No degradation observed over initial 1,000 hours of endurance testing.

Accomplishments – CSA performance

Validation Cell Stack shows good performance at 1000 hours

Test	**BOL Baseline Cell Stack**	**Low Cost Cell Stack 1000 LDHRS**
IR (mV/100mA)	12	N/A
Falloff (min)	8.5	>10
OCV (mV)	963	993
Perf. @ 1000mA/cm^2 (mV)	645	625
Air U Response @ 600, 800, 1000 (50-70%)	20, 16, 25	24, 45, 57
Recoverable, Non-Recoveravle Decay (uV/hr)	457(60LDHRS)	616, 29

Fundamentals: Low Cost CSA Summary

- IR, OCV, Falloff time, and Conductivity have exceeded program requirements

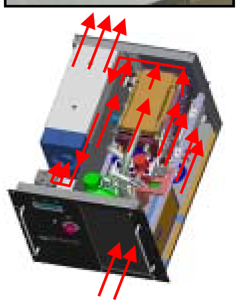
- Performance at $1A/cm^2$ is close to minimum criteria
  - Some air sensitivity at high current densities after 1000 hours.

Advanced System

- Characterize technical and commercial gaps vs. market requirements
- Benchmarking
- Development progress

Advanced System Improvement Goals

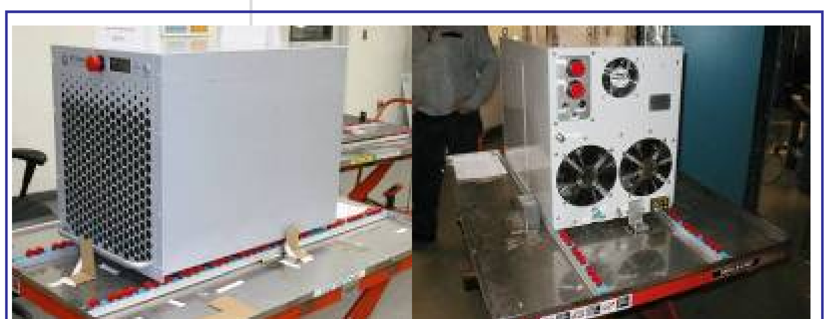
	Power Output (kW)	Water Balance (deg C)	Altitude (m x 100)	Lifetime (yrs)
Requirement	**5**	**40**	**18**	**10**
Current Design	4.25	28	1	10
Projected	5	40	18	15



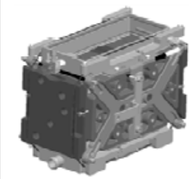
High Efficiency Power Conditioning

Increased HEX

Improved Air flow



Advanced Low cost CSA



Increased membrane durability

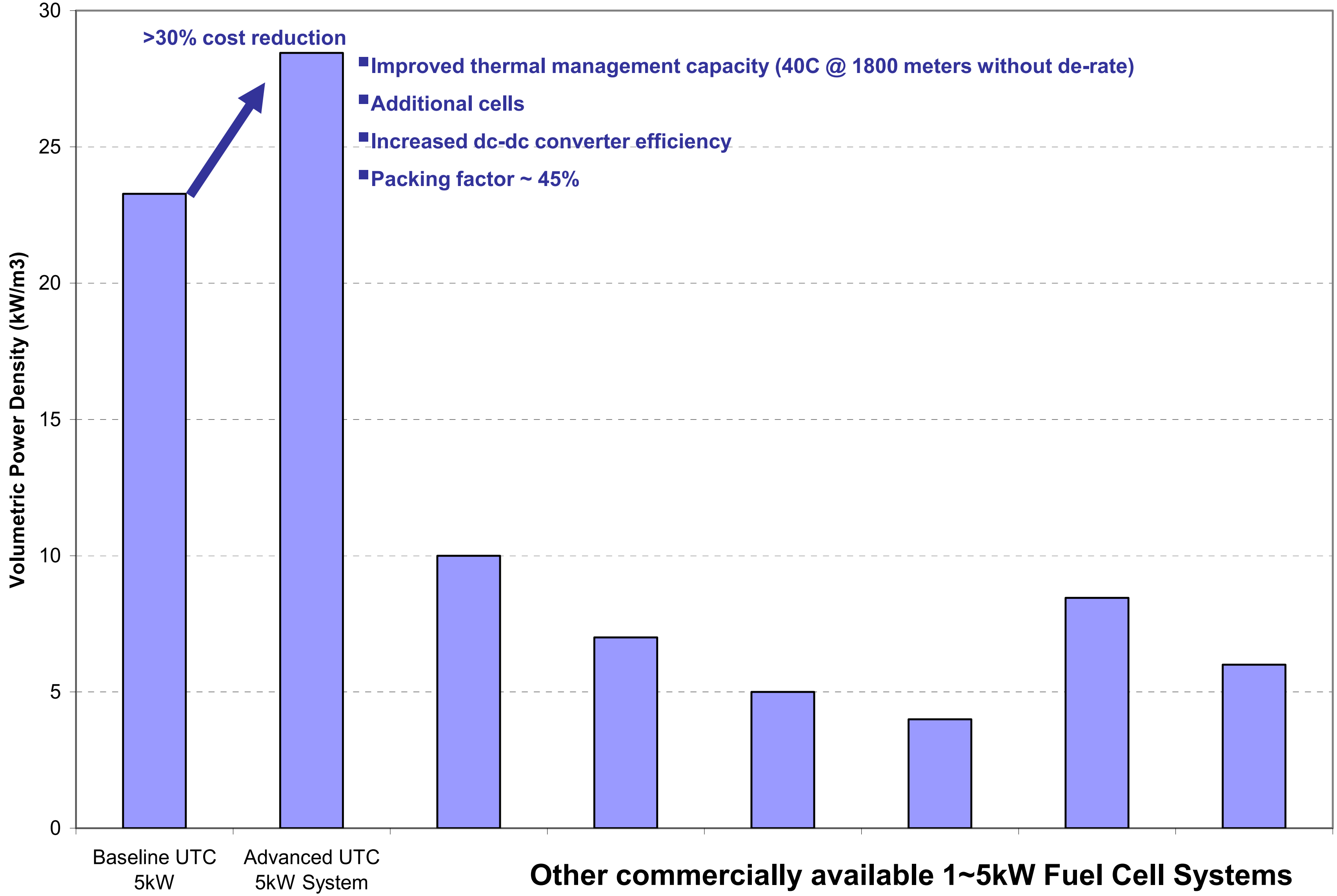
Advanced System Simplification

Design for Mfg & Assembly

Targeted VA/VE

System simplification Component Reduction

Advanced System Accomplishments - Benchmarking



(Configured as standalone stationary power system: includes thermal mgt, power conditioning, startup battery)

Advanced DC/DC Converter

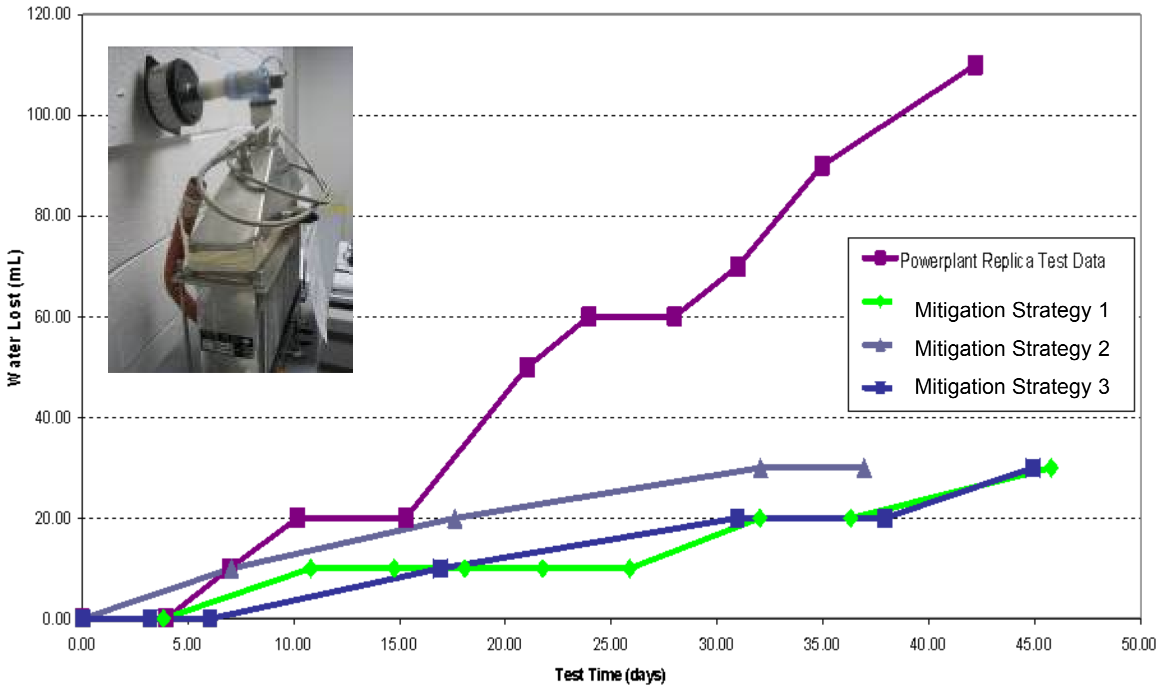
- Improved efficiency, control, and value.
- Combined multiple functions to lower assembly cost.
  - Provides power to the load and powerplant parasitic power.
  - Integrated Start-stop decay mitigation system.
  - Voltage and Current Sensing for both the Fuel Cell and Energy Storage System.
- Demonstrated CAN communication
  - Lowers wire harness costs and complexity.
  - Controller I/O reduced enabling lower cost controller.
- Demonstrated distributed control algorithms
  - E.g. Send set points from the controller rather than actual control signals.

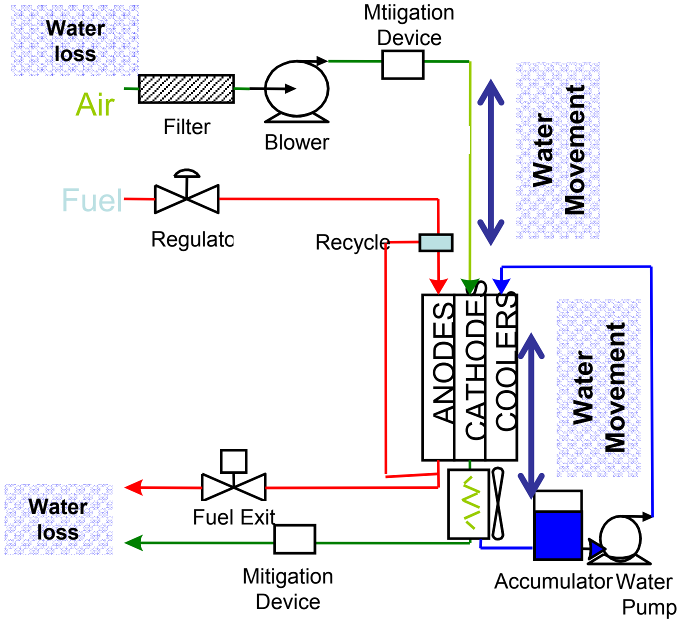
Future Work:
•Grid Connect DC/DC and DC/AC Version

Grid Connect – Integrated Inverter

- Study completed for commercially available options & application process to commission grid connect units in the field
- Requirements developed for advanced 5kW PCS variant for AC output & grid connectivity
- AC version developed under separate UTC Power-US Hybrid collaboration
- Integrated 220/110 VAC version of the power conditioning system to be built for breadboard powerplant demonstration.

System Water Management





Issue - Water Management in all stationary operating modes:

- Maintaining Water Balance & System water management for field robustness is key issue for fuel cells.
- Fuel cells have shown start up times on the order of 8-10 minutes after periods of inactivity due to CSA dry-out.
- Water storage and management of system hydration is vital to maintain cell stack hydration for field robustness. If water storage is lost, the fuel cell will fail to start.

Result

Mitigation Strategies 2 & 3 enable the system to meet storage requirements and 30second system startup time metrics for fuel cells in stationary applications.

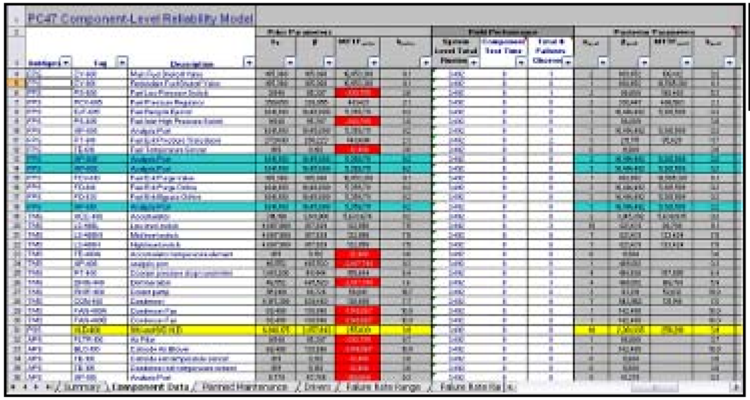
Demonstrations

- Baseline 5kW system endurance testing at Houston Advanced Research Center (HARC)

- Field demonstrations

- Flexible fuel source (High Pressure Electrolyzer, Reformer)

Demonstrations – Reliability Modeling



Projected System MTBF	1,363
Projected System Availability *(per allocated components model)*	97.8%
Allocated Risk Percentage - Failure Rate & Failure Cost	**80.0%**

low		high	
627	hours	3,223	hours

Component & System data

Component bench testing

3.0 Verification Testing	
3.1	Material Testing
3.2	Component Bench test
3.2.1	Cathode Blower Endurance Test
3.2.2	TMS Pump Endurance Test
3.2.3	CVS Fan Endurance Test
3.2.4	TMS Bench Testing
3.2.4.1	TMS performance & pressure drop test
3.2.4.2	TMS Fan Endurance Test
3.2.5	Reliability Analysis (Weibull?)
3.3	Power Plant Durability Test
3.3.1	4000 hr endurance hold
3.3.2	Start-stop durability
3.3.3	CSA Dryout test
3.4	CSA Testing
3.4.1	Single cell endurance test
3.4.2	33 Cell Endurance test
4.0 Powerplant Validation Testing	
4.1	Power plant field fleet testing

Baseline & Advanced Powerplant Field Demonstrators

Demonstrations: 5kW Baseline System Endurance Testing

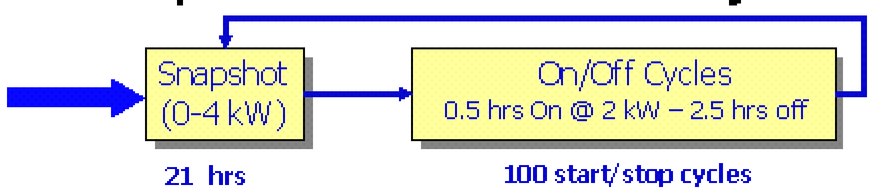
Phase I Testing Completed under non-DOE program:

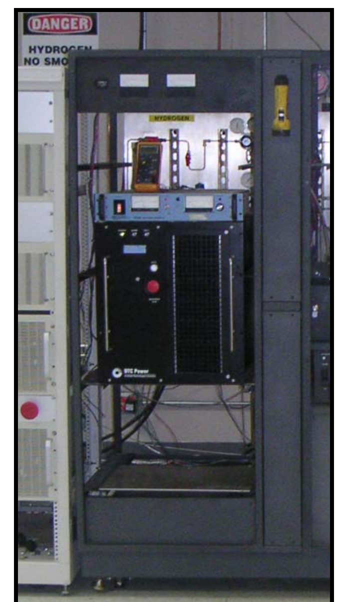
- Continued endurance hold at 2kW net power until 2500 hours
- At 1500 hours: Average efficiency = 42%, Availability = 99.6%

Phase II Testing in progress under DOE program:

- >8100 Kilowatt hours, >3500 Load hours, and >450 Starts

Phase 2 test plan: 12 months on/off cycles





Field Rooftop Installation

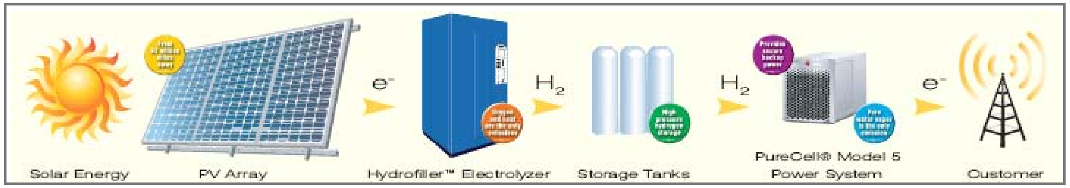
Application: supply emergency backup power to security and emergency response radio repeaters.

•Fully Installed on roof in December 2008.
•Hydrogen fuel supplied by solar powered Avalence electrolyzer.

Field Demonstrations

	No. of units
1. AT&T	(1)
2. Deutsche Telekom North America	(1)
3. Greensburg FEMA Shelter	(3)
4. SeeWind Design	(1)
5. Southern California Edison	(1)
6. Down-selection in Q209	(2)

Demonstrations: Flexible fuel source



- **Initial Operation to 2300 PSI without a compressor completed.**
- **Phase III to complete 3,000 PSI Hydrogen production (recent retrofit with new higher pressure membranes).**
- **Reformer concept study is underway**

Future Work

Fundamentals

CSA Durability, Cost & Operability, field robustness

Advanced System Refinement

Cost Reduction

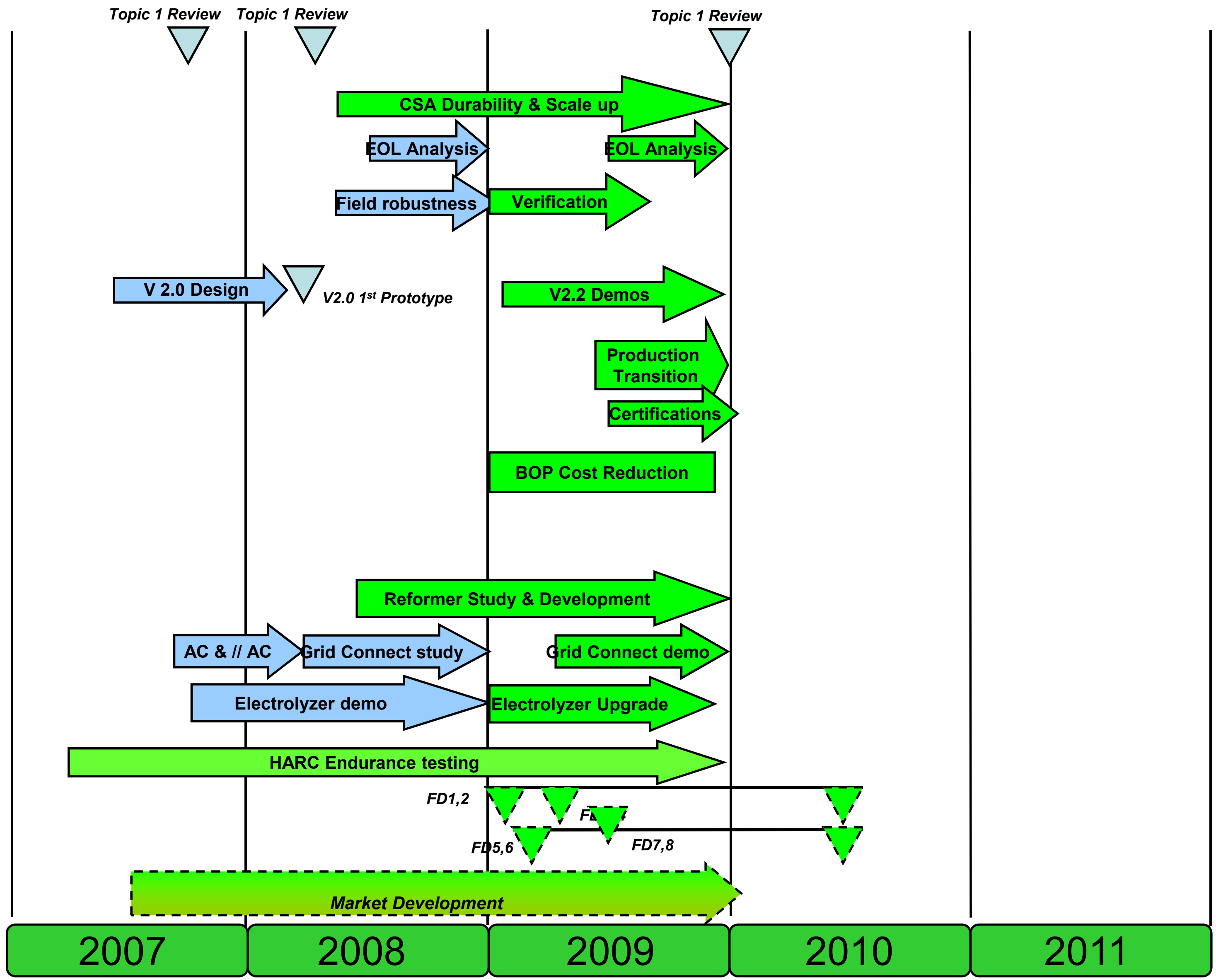
Certification

Produce field demos

Demonstrations

On-going baseline field & endurance testing

Field Demonstrations with potential launch customers



Project Summary

- **Significance:** This project continues to advance the development and demonstration of the fundamental technologies necessary to enable PEM stationary fuel cell power plants to meet the needs of stationary power applications

- **Focused Approach:** Demonstrate technology for low-cost, high durability stationary fuel cells using a 5kW system platform to verify fundamental technologies in a complete system environment. The 5kW platform is as an efficient method to evaluate and build on lessons learned during early 150kW powerplant demonstration activities.

- **Results:** This project continues to accomplish goals to further the development of fuel cell technology toward meeting the demands of stationary applications (ie. Durability, operability, cost). Accomplishing these technological achievements and further reduction of cost, size and complexity will enable commercialization of fuel cells for stationary power applications.