DOE Hydrogen Program

Stationary PEM Fuel Cell Power Plant Verification

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UTC Power

June 12, 2008

Project ID #

FC42

Overview

Timeline

- Start – January 2004
- End – December 2009
- Percent complete – 45%

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**
- Funding received in FY07 $1,050K
- Funding for 2008 $2,200K

Key Contributors

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

Overview: Milestone Summary

Task Number	Project Milestones	Task Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
1-2	Phase I completion	2005	2005	2005	100	Previously Reported
3	3 cell, 1000 hours with alternate UEA	7/1/07	10/31/07	10/31/07	100	>992 total hours, 1 cell removed at 780 hrs to investigate poor performance
3	30 cell with BOP, 500 hrs NWM Durability	9/30/07	9/30/07	8/31/07	100	Completed
3	30 cell & BOP, 500 hours CO & Industrial H2 robustness	11/30/07	3/31/08		100	Focus has been on the development of advanced H2-On strategies to mitigate periodic start-up/shutdown decay.
3	30 cell, 1000 hrs on alternate UEA	11/30/07	3/31/08		96	960/1000 test hours complete
3	Finalize Reformer technology feasibility study	4/1/08	4/1/08 11/31/08		10	Phase III: conceptual Reformer design & 1kW FC system reformer testing
4	Finalize Requirements for Advanced system design	6/1/07	6/1/07	6/15/07	100	Completed
4	Finalize Design	11/15/07	11/15/07	12/24/07	100	Build expected to begin in late February
4	Breadboard build, pilot production line feasibility	3/31/08	3/31/08		100	Complete, met rated power requirements
4	5kW advanced system, 500 hrs durability	5/1/08	5/1/08		0	Phase III
5	Scalable 10kW AC Demo	11/23/07	2/28/08		95	AC demonstrated. Parallel operation to be completed
5	5kW electrolyzer demo	7/30/07	3/15/08		100	First H2 produced. Commissioning completed
5	5kW FC & electrolyzer, 1000 hrs	4/1/08	4/1/08		0	Phase III
5	5kW & Reformer Demo	5/1/08	5/1/08		0	Phase III
5	5kW & Reformer, 4000 hrs	11/30/08	11/30/08		0	Phase III

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

Fundamentals

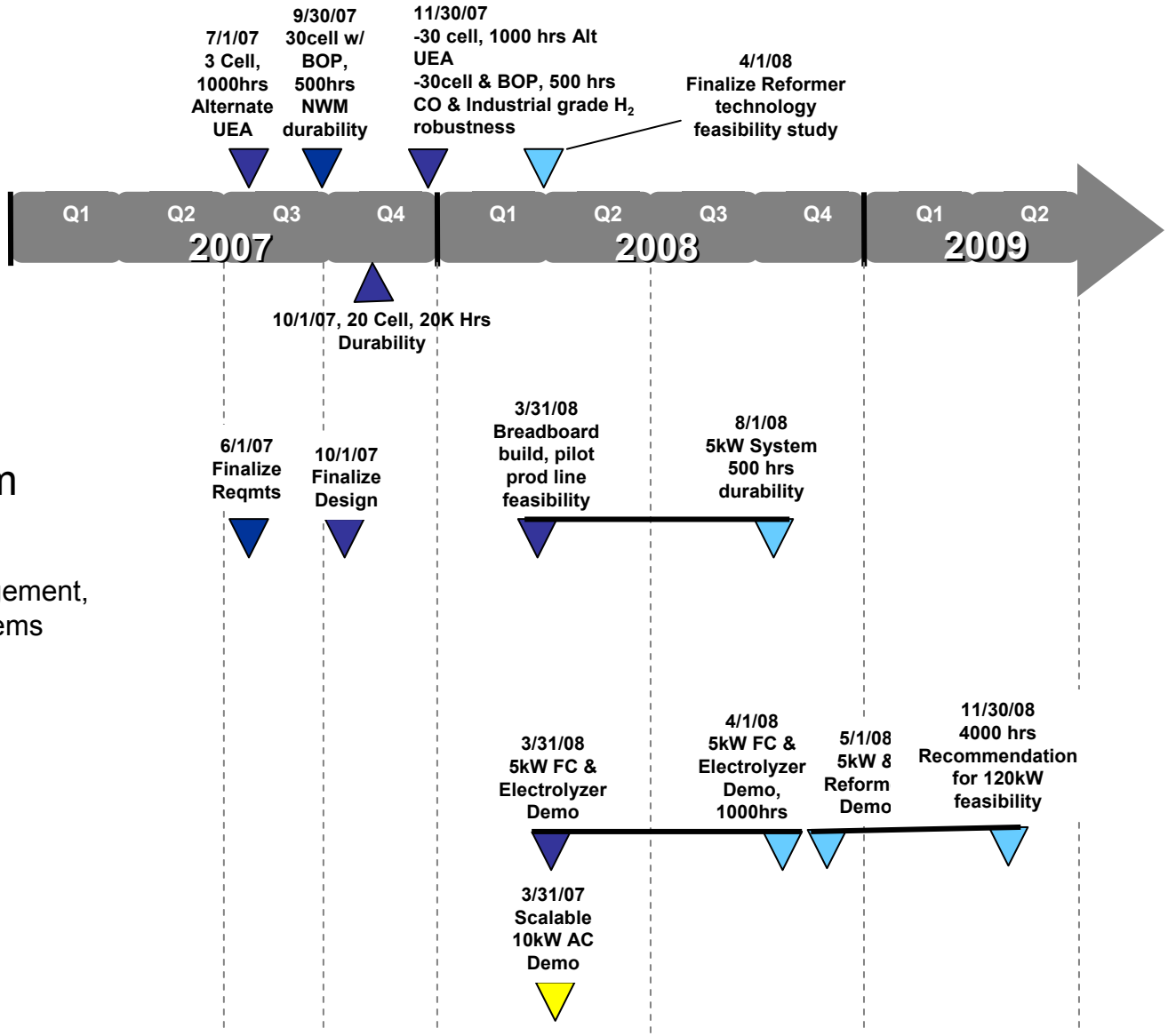
CSA Durability, Cost & Operability

Advanced System Integration

Cell stack, thermal management, fuel & air processing systems

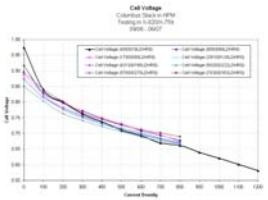
Demonstration

Scalable 5kW, Flex H_2 source (electrolyzer, reformer)



Completion at risk
Completion on target
Completed
Phase III

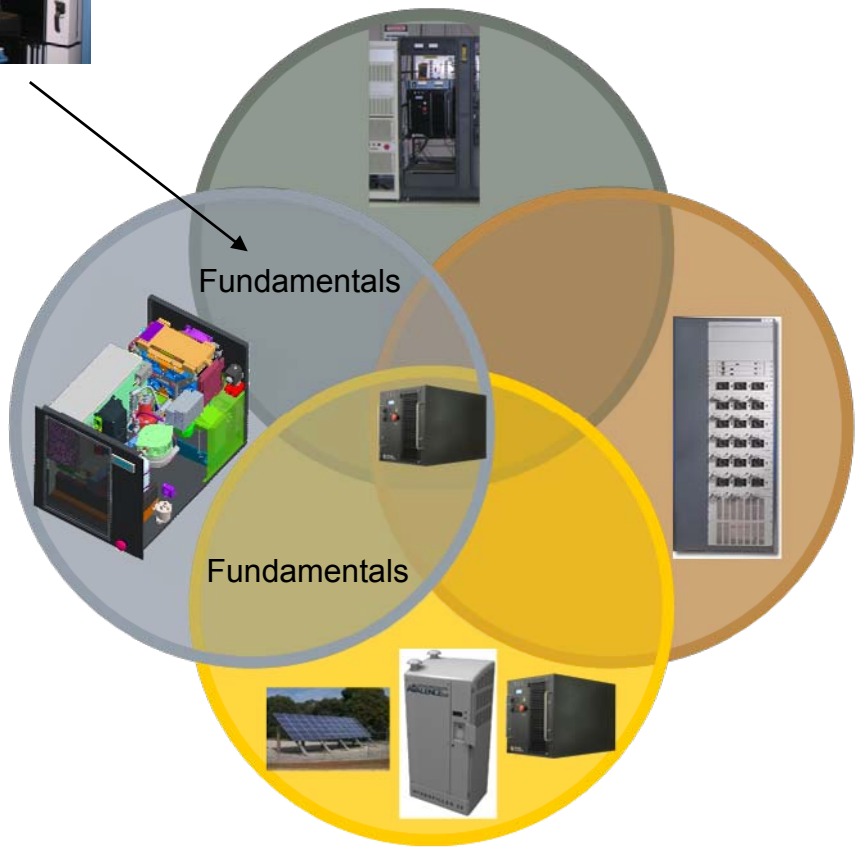
Approach: 5KW Technology Platform



Advanced System

Improve commercial viability and field readiness

Fleet: Prove Durability



Flexible Output

Demonstrate AC output, building block power architecture & Grid Connectivity

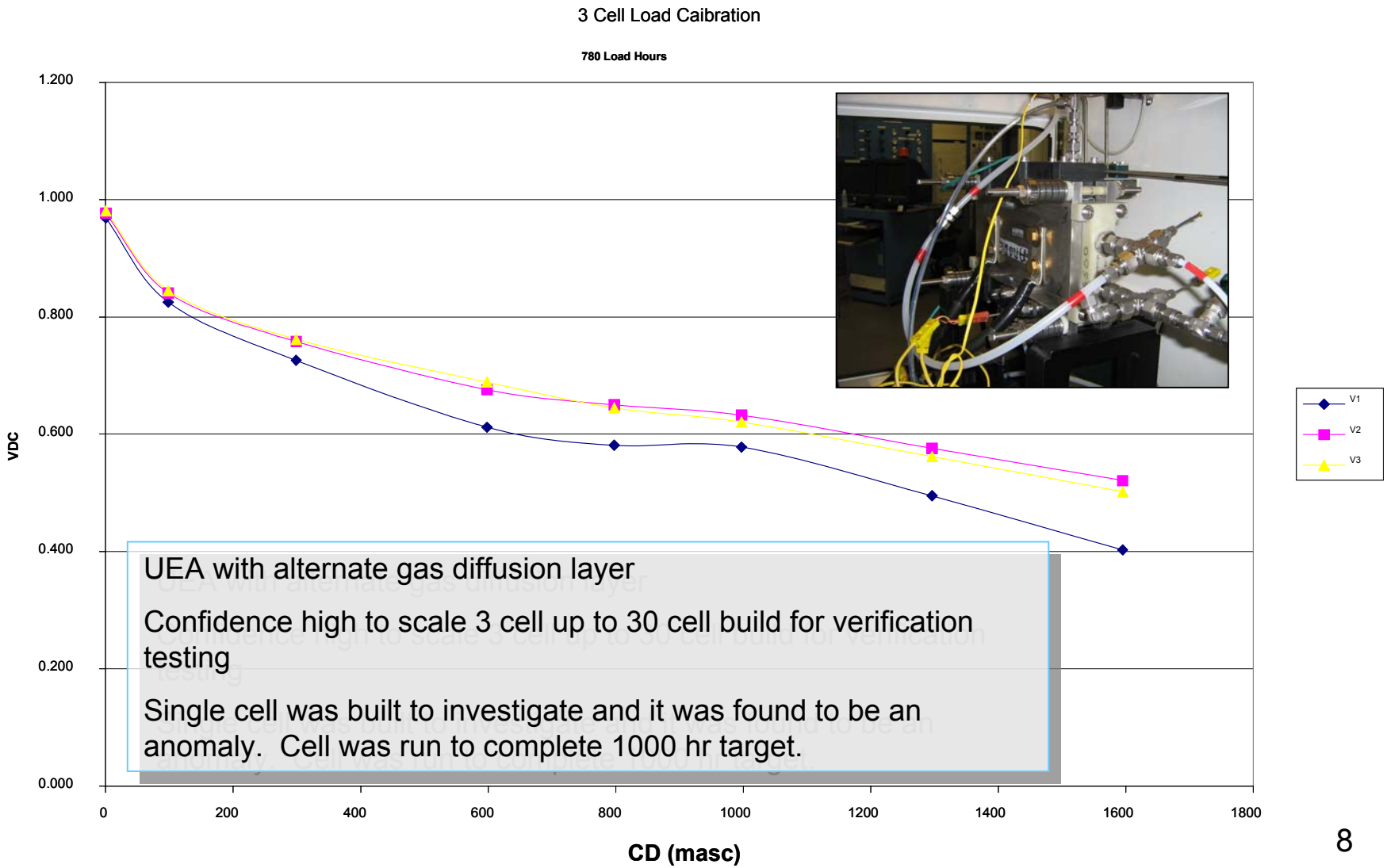
Flexible Fuel Source

Reformer, Electrolyzer

Enabling Fundamental Technologies

- Low cost durable membrane (ALTERNATE UEA)
- Evaporative cooling (NWM Durability)
- Field robustness – H_2-On Mitigation

Fundamentals: Alternate UEA (3 Cell)



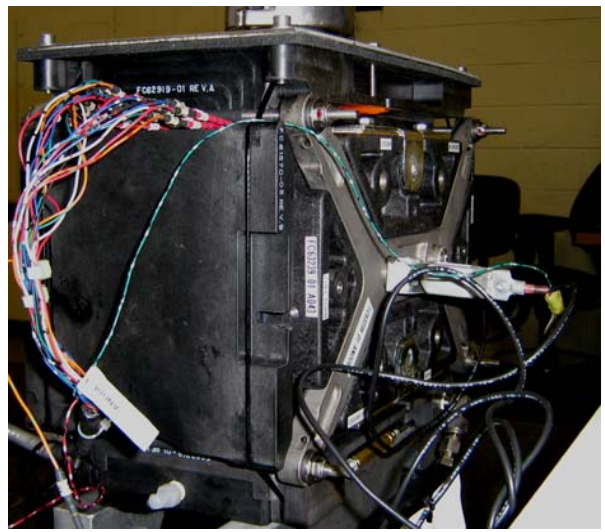
UEA with alternate gas diffusion layer

Confidence high to scale 3 cell up to 30 cell build for verification testing

Single cell was built to investigate and it was found to be an anomaly. Cell was run to complete 1000 hr target.

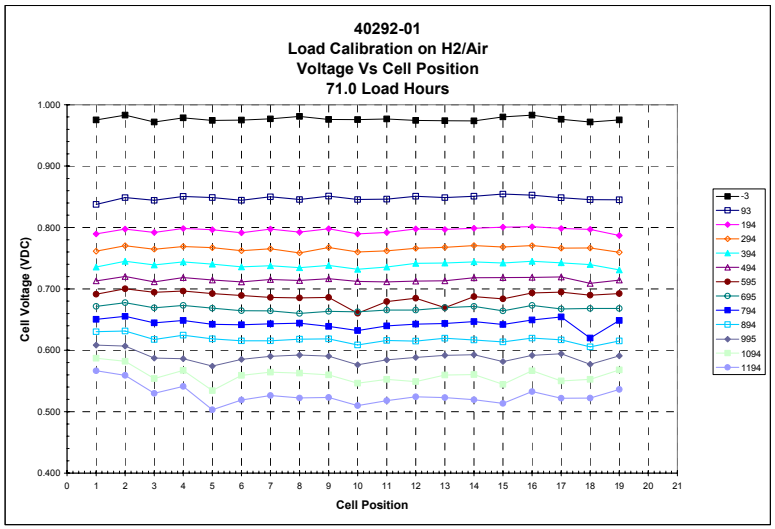
Fundamentals: Alternate UEA (30 Cell)

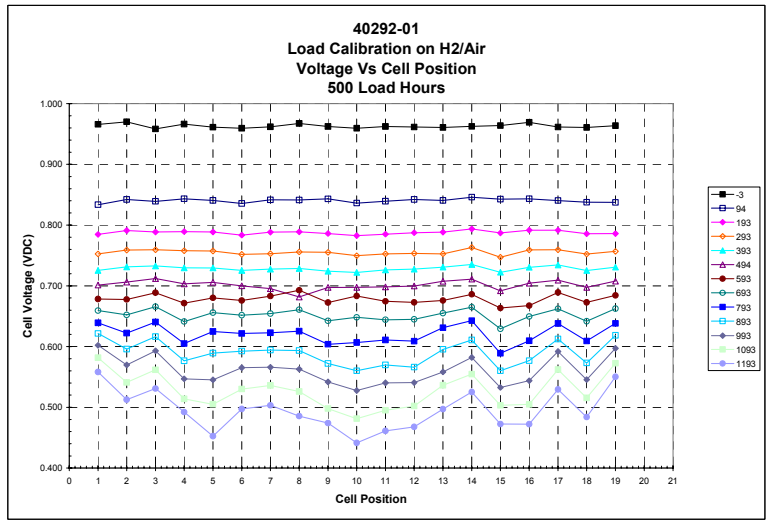
- Stack Configuration
  - Molded water transport plates
  - JM UEAs
  - 2 Pass Fuel, 1 Pass Air



- Objective:
  - Acceptance testing (low coolant flow, evaporative cooling mode)
  - Constant current hold to >1000 hours

Fundamentals: Alternate UEA (500 hrs)





Product	IR (mV/100mA)	mV @ 1000mA/cm^2	OCV (mV)	Falloff Time (min)	Conductivity (uS)
Target	<15	>600	>898	>1	<1
Alt UEA	10	~570	978	9.8	0.40
Baseline UEA	13	593	945	4.7	6.55

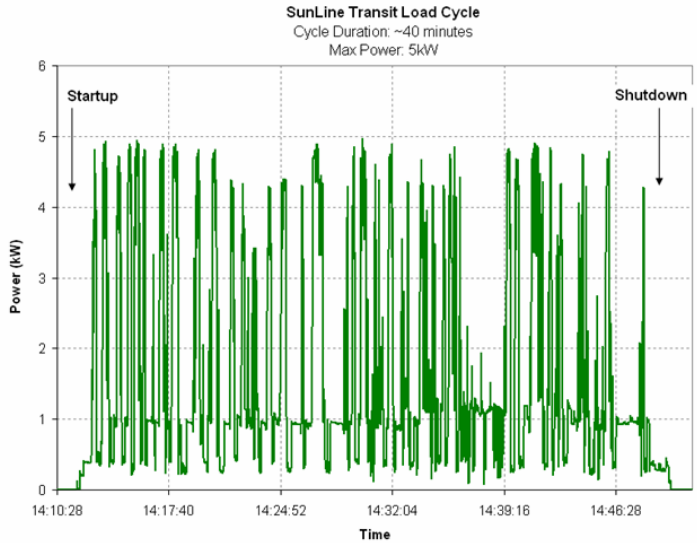
Fundamentals: Alternate UEA Summary

- IR, OCV, Falloff time, and Conductivity have exceeded program requirements
- Performance at 1A/cm^2 is close to minimum criteria
  - Expected to improve with optimized cathode flow fields
- Recoverable decay will sustain 8 hours of backup power
- Non recoverable decay will be assessed at the next load cal (500 hour point)

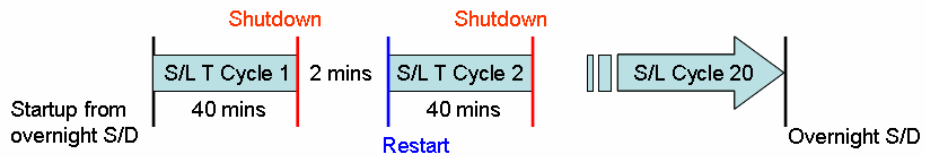
Fundamentals: NWM Durability

Start/Stops	Load Hours	Test Description
291	129	20BSS, Load Calibrations
162	70	FUDS, HWFET Cycles
797	501	Sunline Transit Cycles
Rework for Installation in X-909		
250	300	Sunline Transit Cycles
Total		
1500	1000	

NWM Durability Unit



Durability Test Protocol:

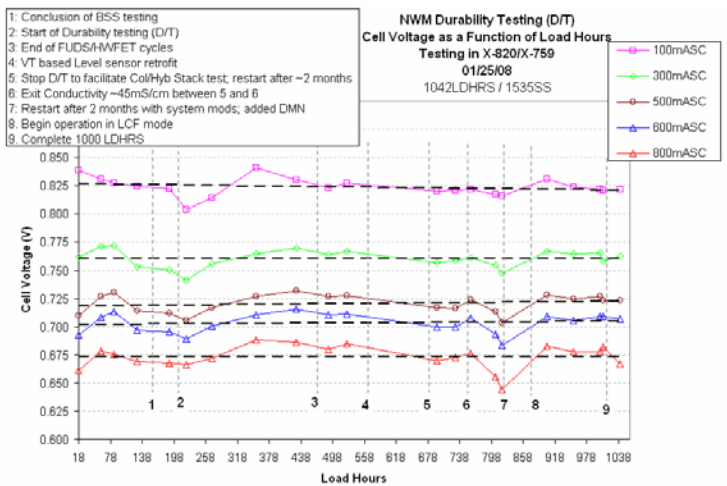


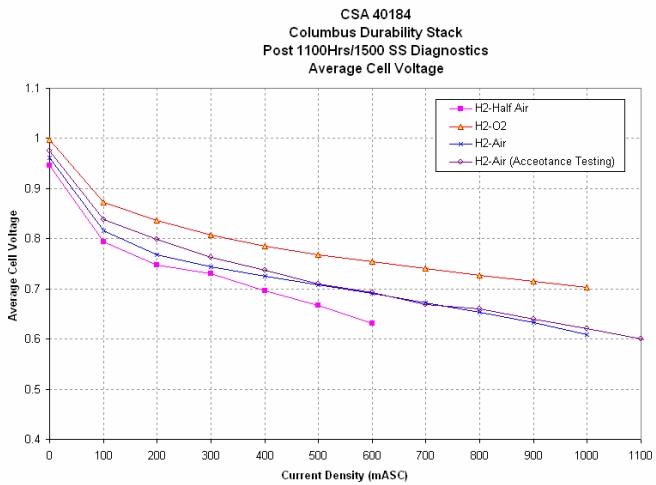
Result

- Completed 1000LDHRS and 1500S/S running durability load cycles in NWM mode

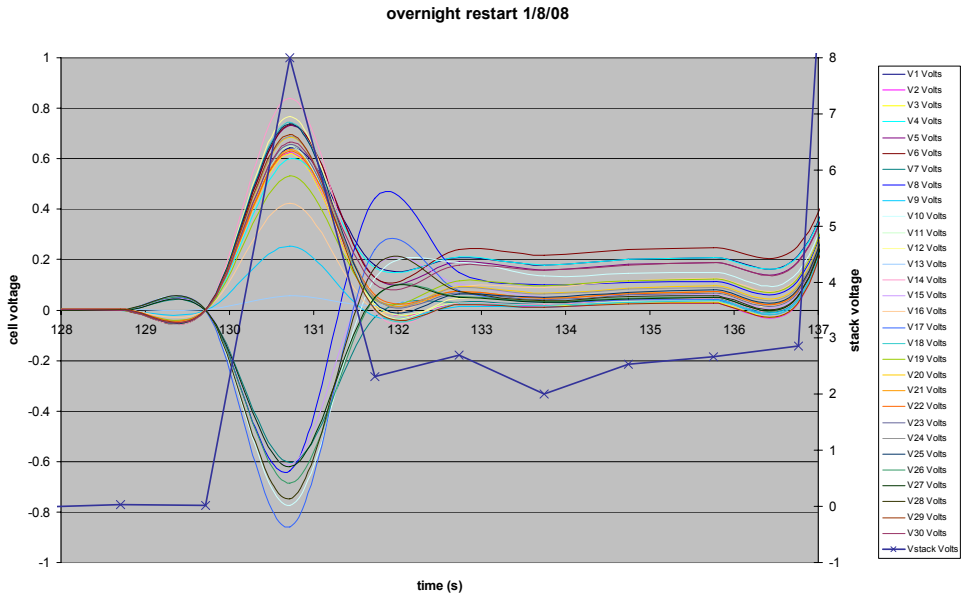
Fundamentals: NWM Durability Summary

- Completed 1000LDHRS and 1500S/S running durability load cycles in NWM mode
- Overall average decay was ~20mV over 1007HRS/1520SS.
- End cells had 30% higher decay than U107 cells
- A large portion of the decay is expected to be S/S decay as quality of H_2-On on the unit was not fully mitigated
- LCF mode coolant clean-up and reduction in the number of S/S cycles helped to recover/sustain performance loss





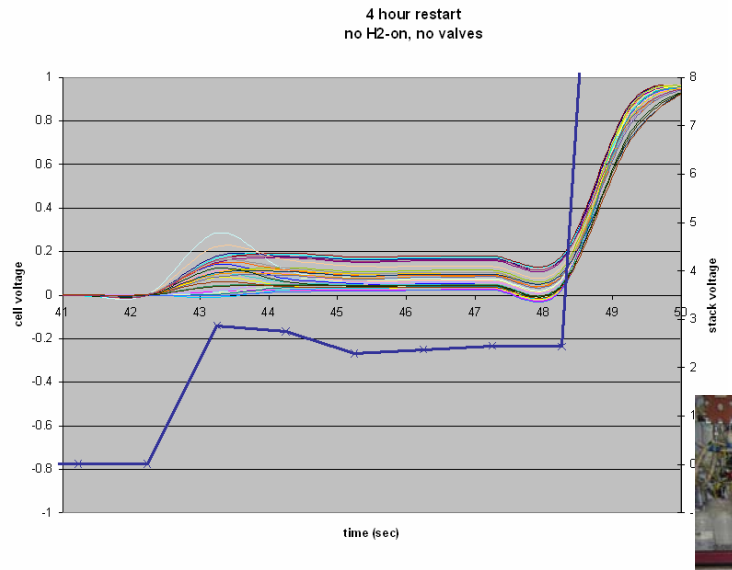
Fundamentals – Startup decay

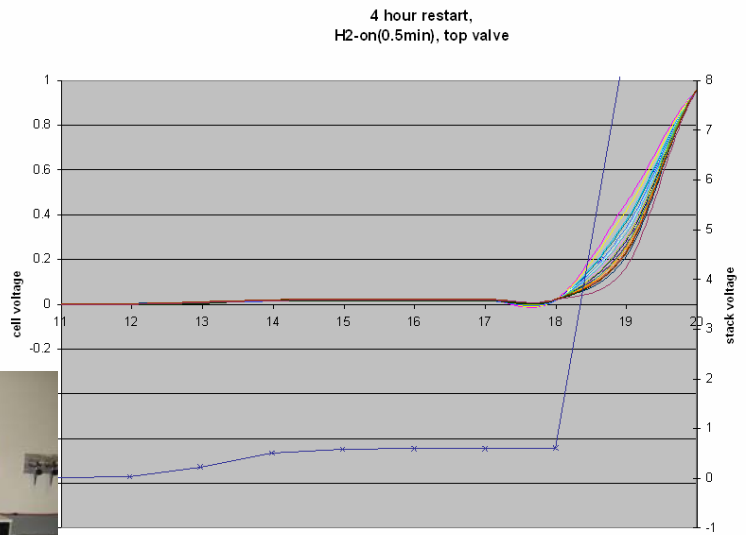


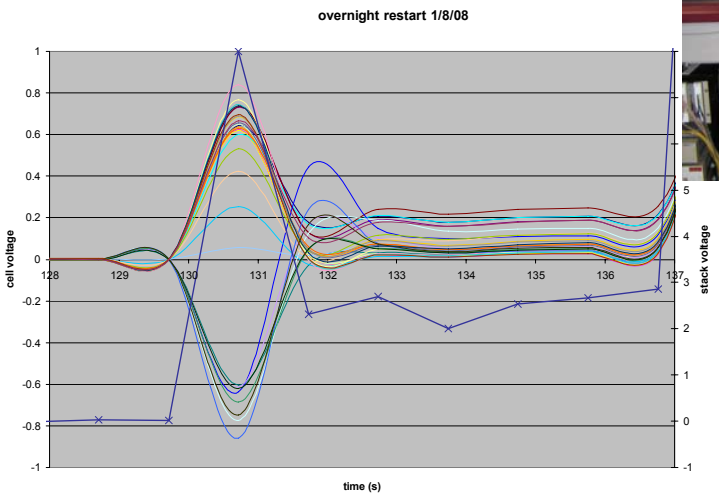
- **Current H2-On mitigation strategies were not sufficient to fill the system with enough hydrogen to provide satisfactory start voltage profile in an overnight test.**

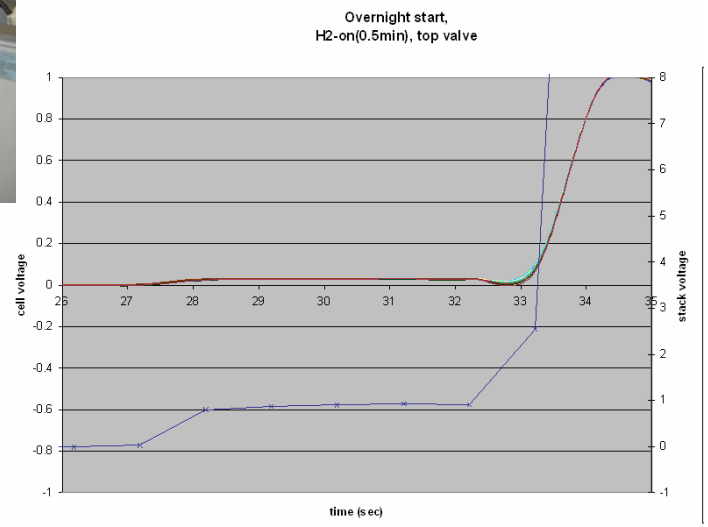
- **Baseline system showed noticeable hydrogen escape in 4 hours and by 17 hours (overnight 5pm-9am) hydrogen completely escaped out and the system was filled with ambient air.**

Fundamentals – Startup decay







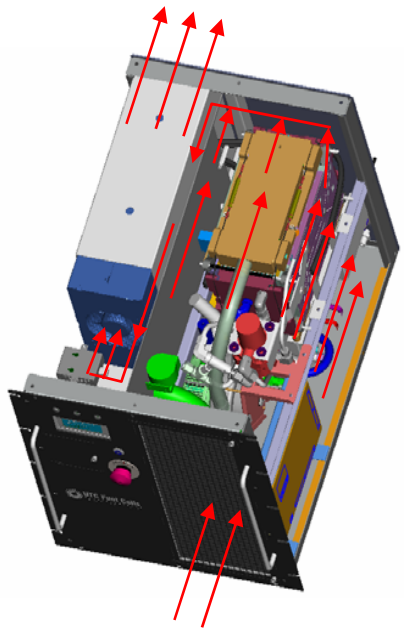


Advanced System

- Development progress
- Characterize technical and commercial gaps vs. market requirements
- Project and verify closure of performance gaps with advanced system

Advanced System Improvement Goals

	Power Output (kW)	Water Balance (deg C)	Altitude (m x 100)	Cost (000's $)	Lifetime (yrs)
Requirement	**5**	**40**	**18**	**Confidential**	**10**
Current Design	4.25	28	1	Confidential	10
Projected	5	40	18	Confidential	15

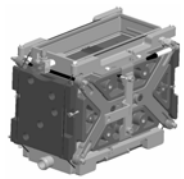


High Efficiency Power Conditioning

Increased HEX

Improved Air flow

Advanced Low cost CSA



Advanced System Simplification

Design for Mfg & Assembly

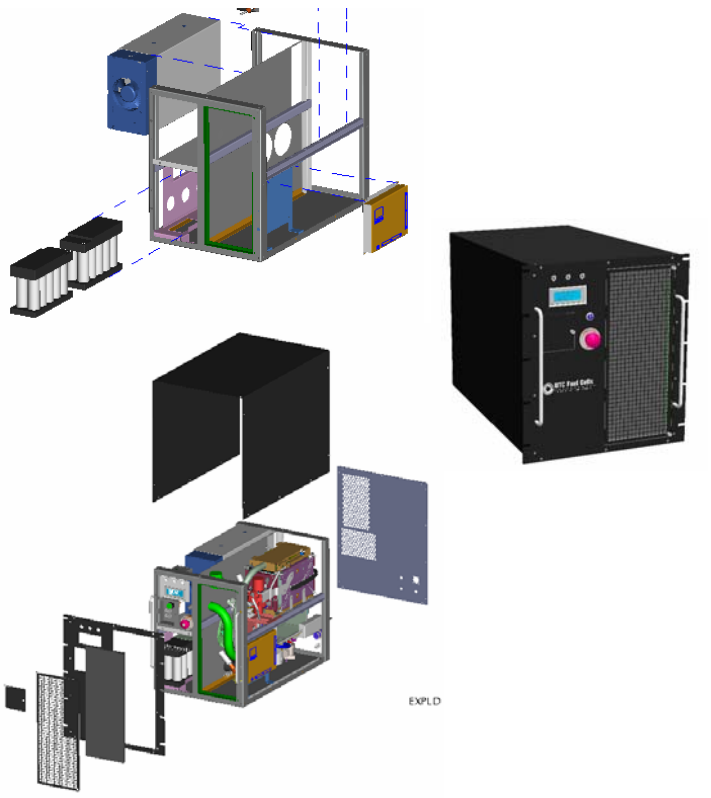
Targeted VA/VE

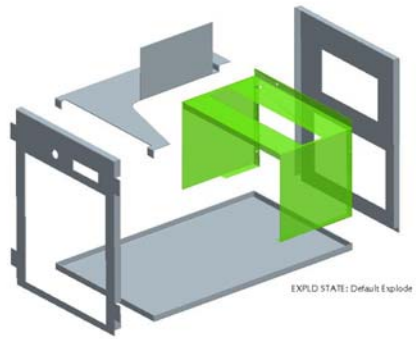
Increased membrane durability

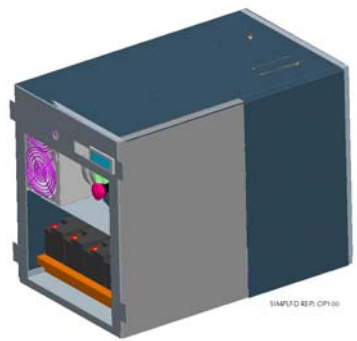
System simplification Component Reduction

Advanced System Accomplishments

Frame & Panel Approach	⇒	Frameless design
8 panels/doors, 1 frame		6 panels/doors, No frame



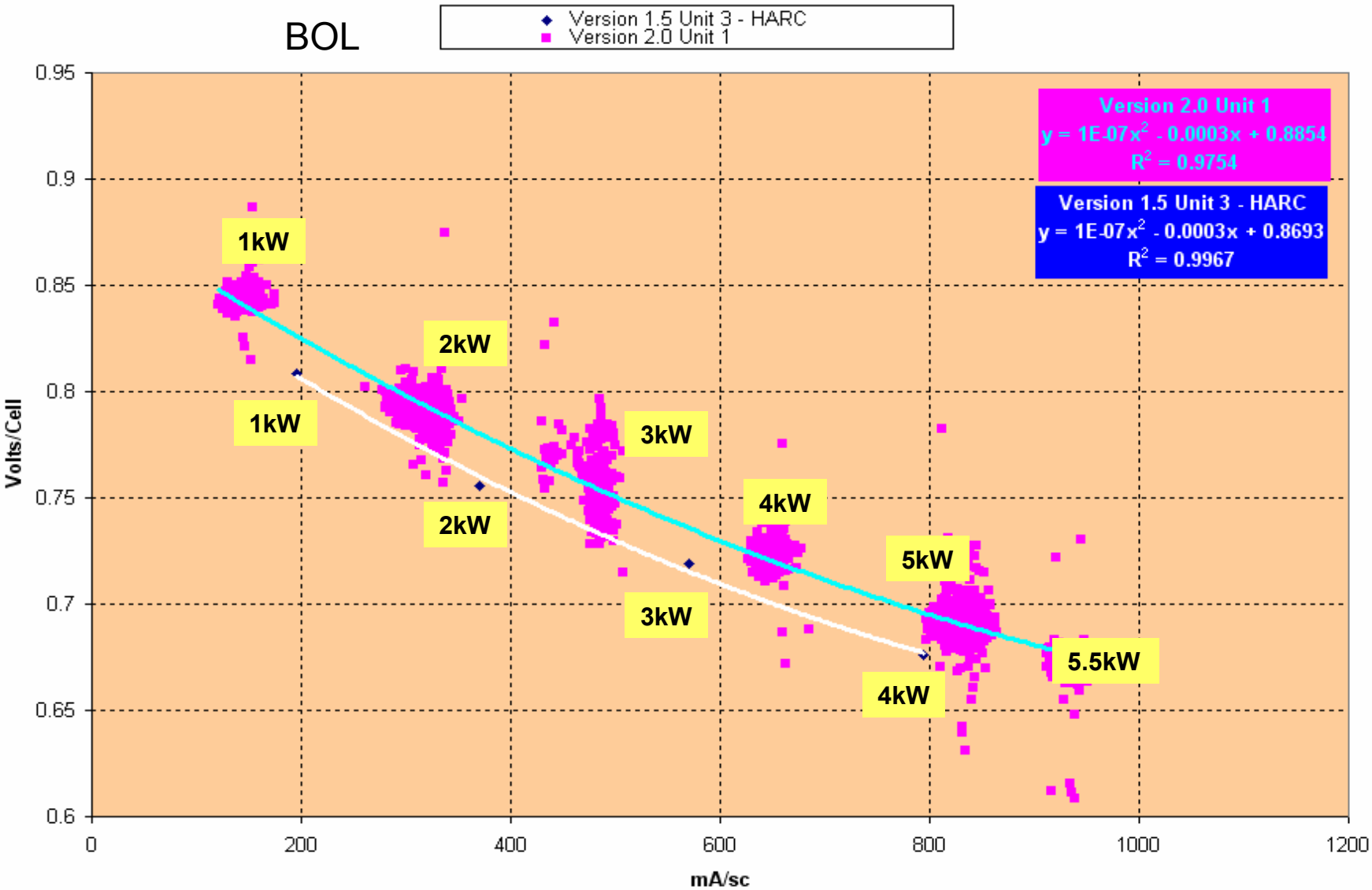




Advanced System Accomplishments

- **Rated power reached after 3 days of testing and error checking**
- **System met power output, efficiency, and initial water balance test requirements**

Advanced System – Powerplant Testing



Demonstrations

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

- Flexible output (AC Output, Grid Interconnectivity)

- Flexible fuel source (High Pressure Electrolyzer)

Demonstrations: 5kW Baseline System Endurance Testing

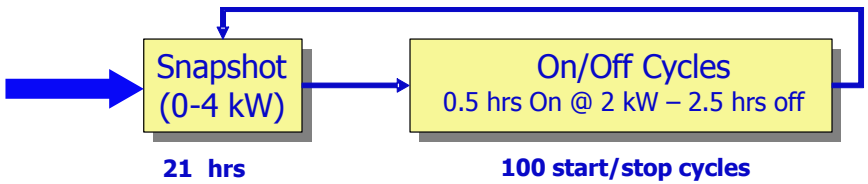
Phase I Testing Completed under non-DOE program:

- 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:

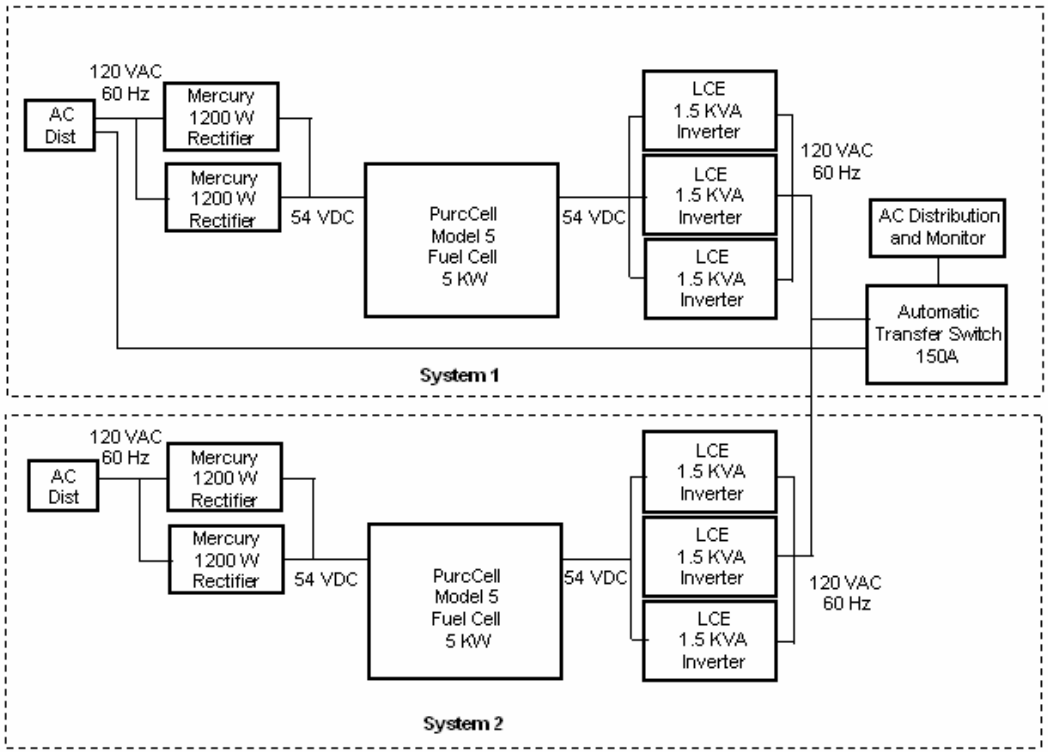
- 8158 Kilowatt hours, 2800 Load hours, and 453 Starts

Phase 2 test plan: 12 months on/off cycles

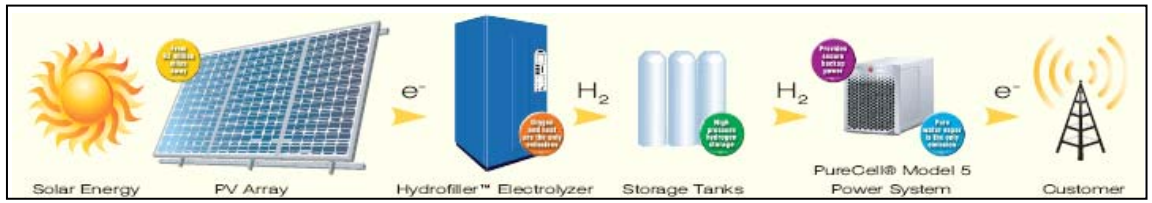


DEMONSTRATIONS: AC OUTPUT

- Parallel system assembled with Inverters, Rectifiers, Transfer Switch and AC Distribution monitor
- AC Demo testing in progress, AC output test completed.



DEMONSTRATIONS
FLEXIBLE FUEL SOURCE



- **Grid Independent Solution**
- **Initial Operation to 2300 PSI without a compressor completed.**
- **Phase III to complete 6,000 PSI Hydrogen production**

Future Work: Phase III Overview

Fundamentals

CSA Durability, Cost & Operability, field robustness

Advanced System Refinement

Cost Reduction

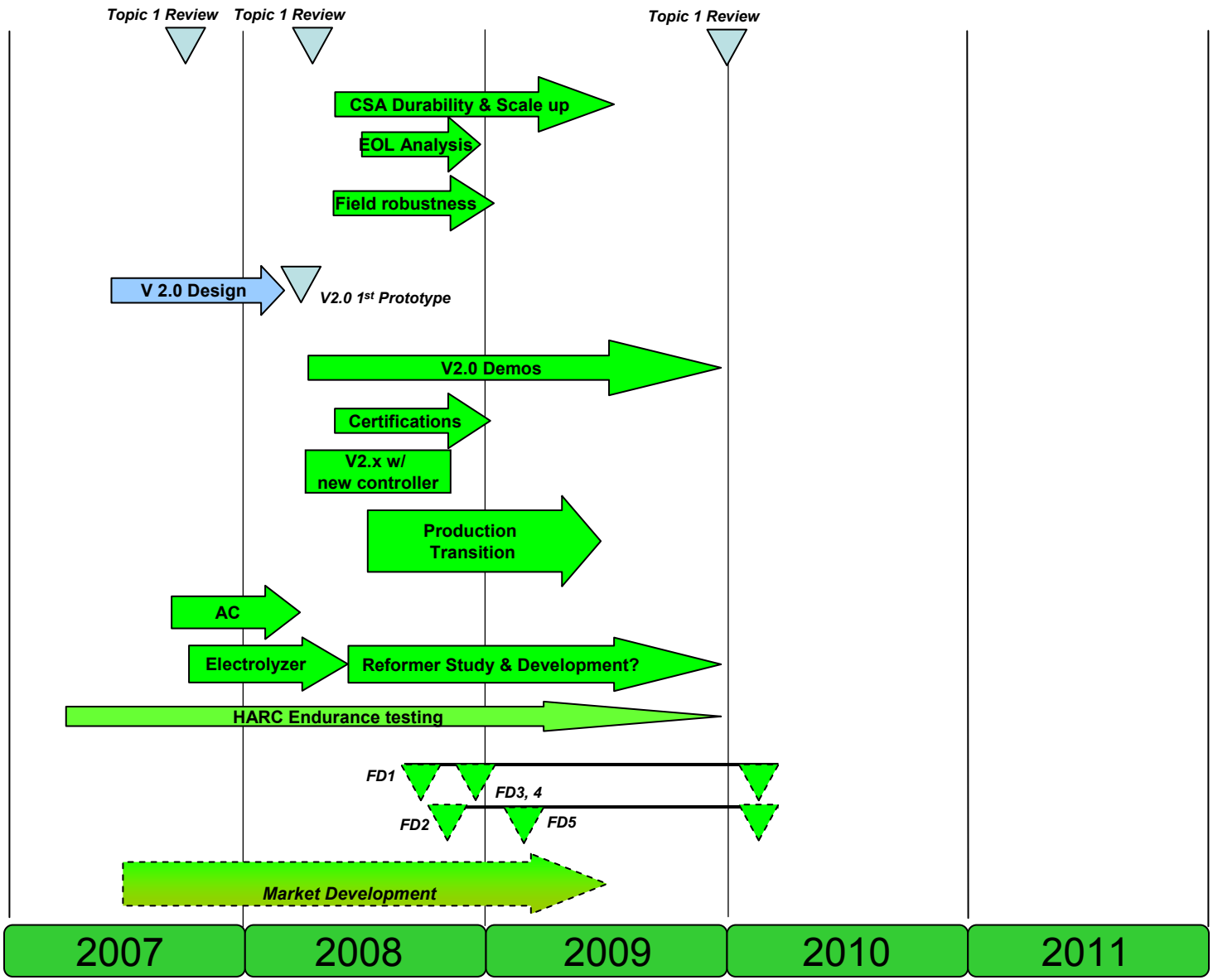
Certification

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. Accomplishing these technological achievements will enable commercialization of fuel cells for stationary power applications.**

Summary Overview: Go/No Go Metrics

Parameter	Metric	Demonstration	Result	GO/NO GO
Rating	5kW, applicability up to 200 kW range power plants	Test (5kW)	Models suggest that water balance will be maintained for rated power at 40C @ 1000meter	GO
Efficiency	>35 %	Test	@5kW net on Pure Hydrogen: Fuel Cell System without power conditioning: 51% (CSA), 42% (SYSTEM) With power conditioning: 38% Advanced system projection: 42%	GO
Primary Fuel	Hydrogen from various sources including feasibility for hydrocarbon reformate	Test	2008 Phase III work	GO
Emissions	As good as or better than U.S. requirements	Test		GO
Operation	Start time < 30 minutes, All U. S. weather conditions	Test	Demonstrated start time is 15 seconds. Cabinet heater required for sub 0 temperatures	GO
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	In non-program demonstrations, 5kW baseline powerplant unit has accumulated 2600hrs with no performance decay.	GO
Mean Time Between Forced Outages (MTBFO)	≥2,000 hours with long term goal of 5,000 hours	Test, statistical analysis	Data to be collected in 2008 endurance testing	GO
Maintainability	Web based remote control, diagnostics	Test	Demonstrated remote monitoring, control with both modem or ethernet capability.	GO
Use of thermal energy	Integration with liquid desiccant	Study	Completed	GO
Grid Interconnectivity	Any US grid with minimal equipment	Demonstration Test, UL 1741 assessment	Phase III AC 120VAC single phase demonstrated Site demonstration partners being sought	GO
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	GO