



FuelCell Energy

Electrochemical Hydrogen Compressor

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FuelCell Energy, Inc.

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Project ID
#PD048

Overview

Timeline

- Project start date: 7/15/10
- Project end date: 10/14/14

Budget

- Total Funding Spent:
\$1,517,000*
- Total DOE Project Value:
\$1,993,642

Barriers

- Barriers addressed for gaseous hydrogen compression:
 - More reliable
 - Lower-cost
 - Higher efficiency

Partners

- Collaborations: Sustainable Innovations, LLC
- Project lead: FuelCell Energy

*as of 3/31/2014



Relevance

Impact of EHC:

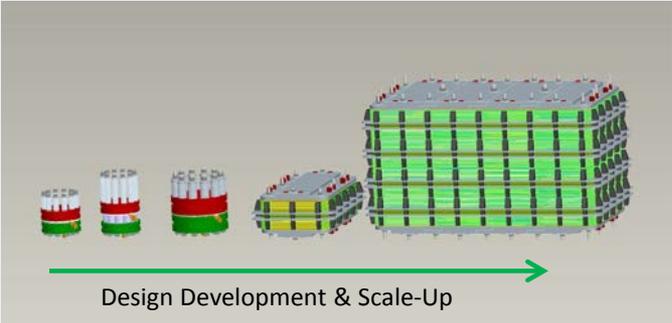
- **Increases reliability/availability over current mechanical compressors**
- **Ensures “no possibility of lubricant contamination” (No moving parts) → Fuel Cell Quality H₂**
- **Increases Compression Efficiency to 95% (DOE 2015 Target)**
- **Potentially reduces cost of H₂ delivery to <\$1/gge (DOE Long Term Target)**

Approach

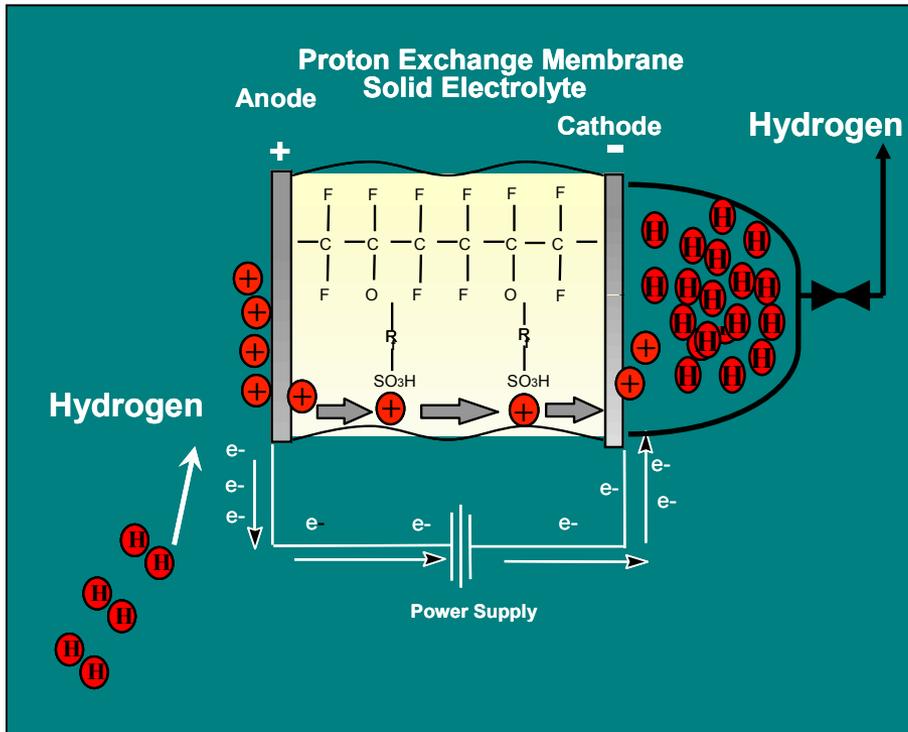
- **Use high-pressure electrolyzer experience for mechanically robust cell design**
- **Higher current density operation to minimize capital and operating costs**
- **Improved flow field design to increase H₂ recovery efficiency**
- **Simple system: Reduce capital cost by increasing cell size and reducing number of parts**

Approach

ITEM	APPROACH
Increase Pressure, Life, Efficiency	<ul style="list-style-type: none">-Cell & Stack Design Enhancements-MEA Improvements-Multi-Stage Operation-Very High Single Stage Compression
Lower System Cost	<ul style="list-style-type: none">-Cell & Stack Design Enhancements-Increase Current Density-Increased Durability/Life-Increase Single-Stage Pressure Capability-Design for Mfg & Assembly-Lower Labor Rates-Lower Cost Materials of Construction-Lower Part Count-Leverage Economies of Scale-Increase Cell Active Area



Principle of Electrochemical Hydrogen Compressor



EHC does not follow

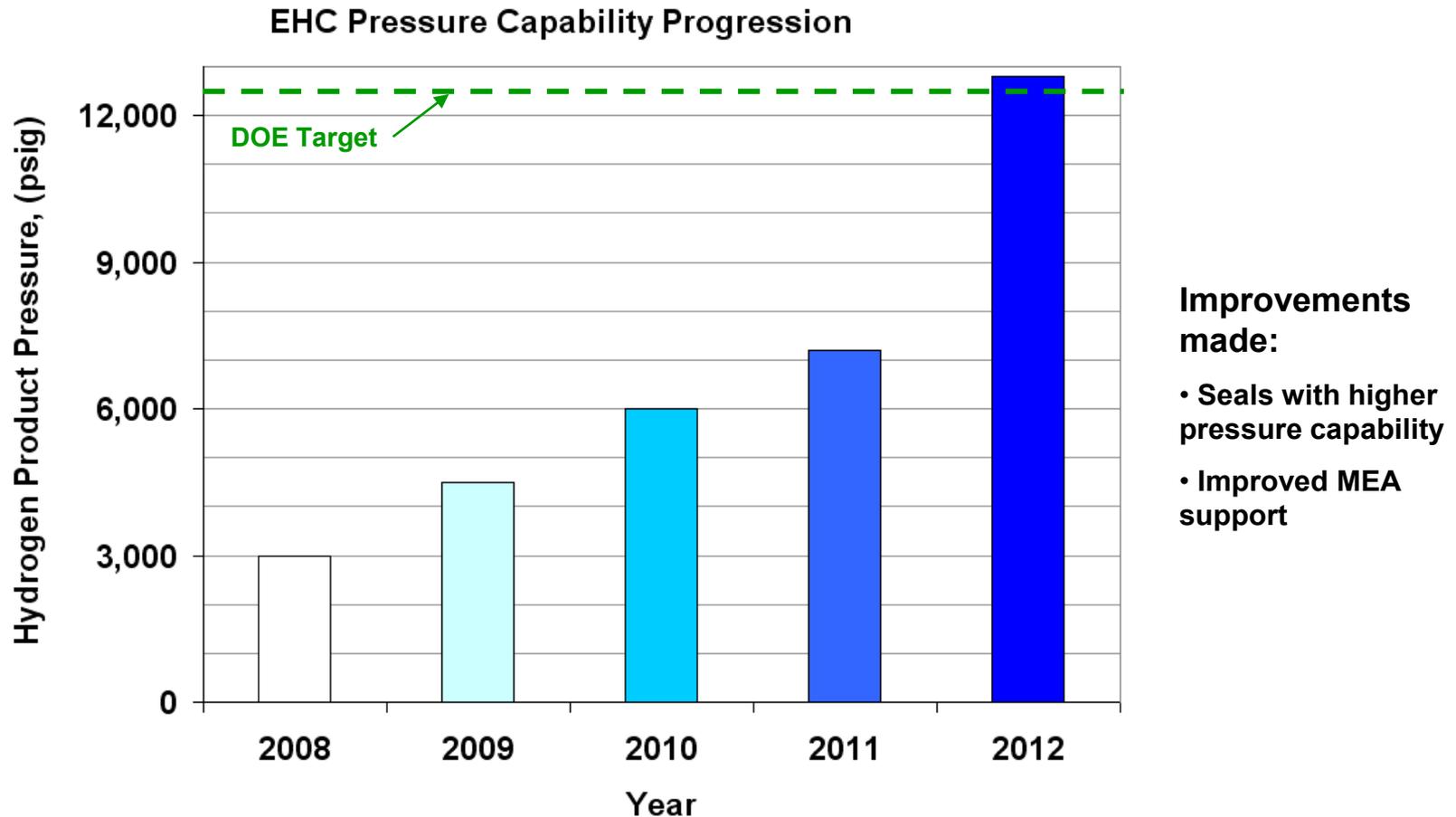
$$P V = n R T$$

Rather Nernst Eqn:

$$V_{\text{theor}} = \frac{RT}{nF} \ln \left(\frac{P_2}{P_1} \right)$$

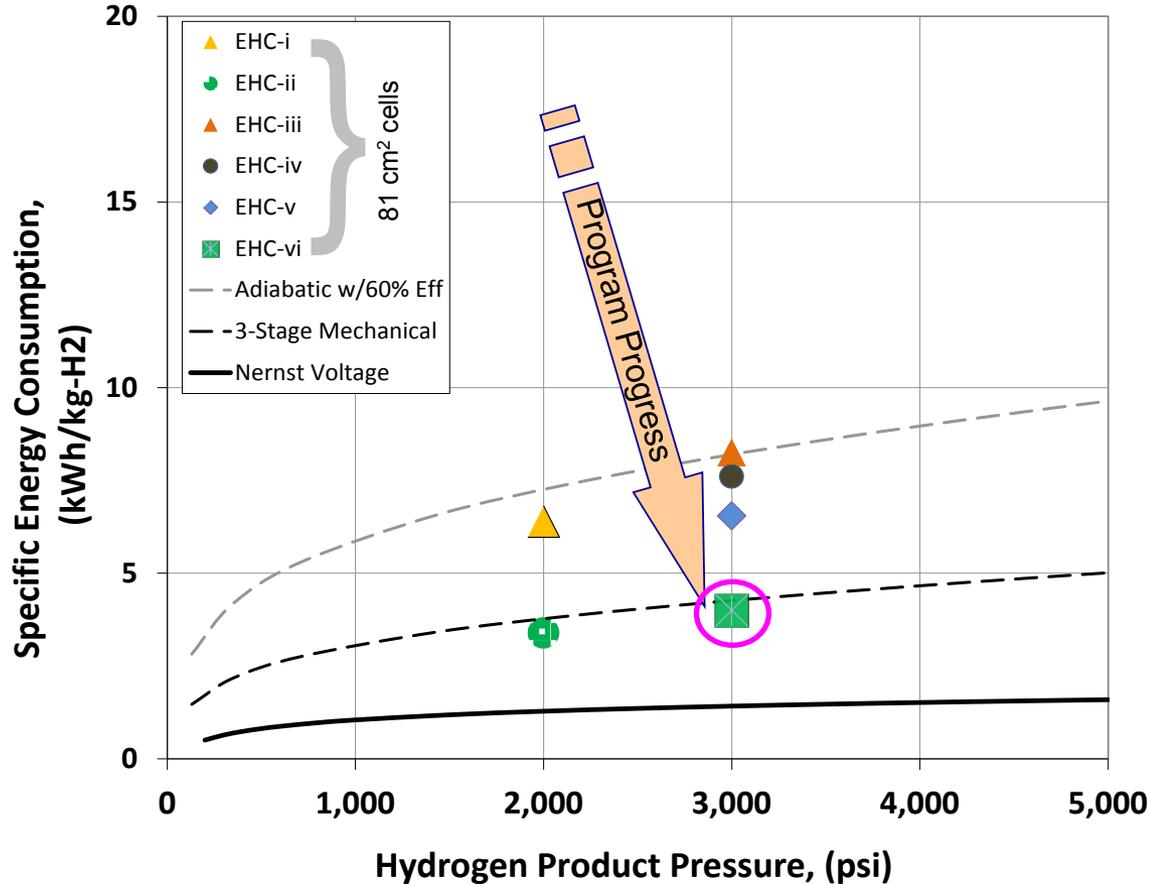
- Simple operating principle with no moving parts – **Solid State !**
- Use of hydrogen electrode for high compression efficiency

EHC Pressure Capability



Met DOE 2015 pressure target for forecourt compressors

Reduction in the Energy Consumption of EHC

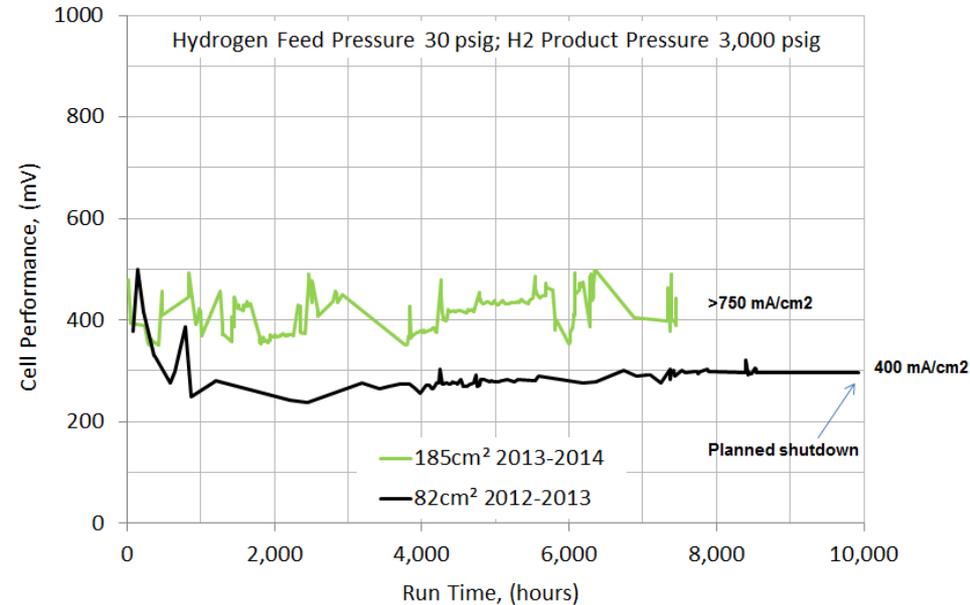
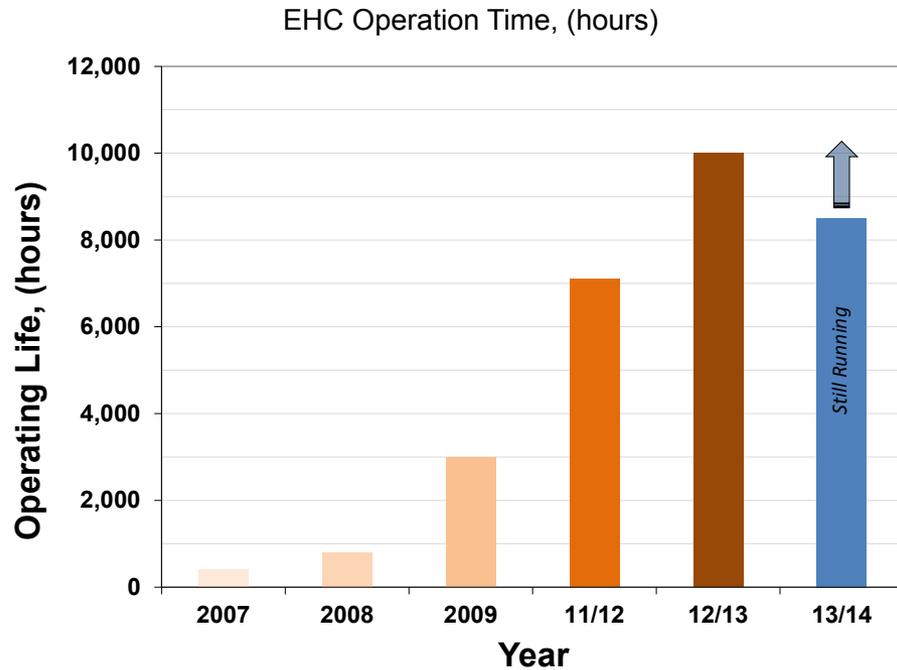


Improvements made:

- Lower cell resistance
- Lower applied voltage

Improved cell design and materials for 3,000 psi

EHC Durability



Improvements made:

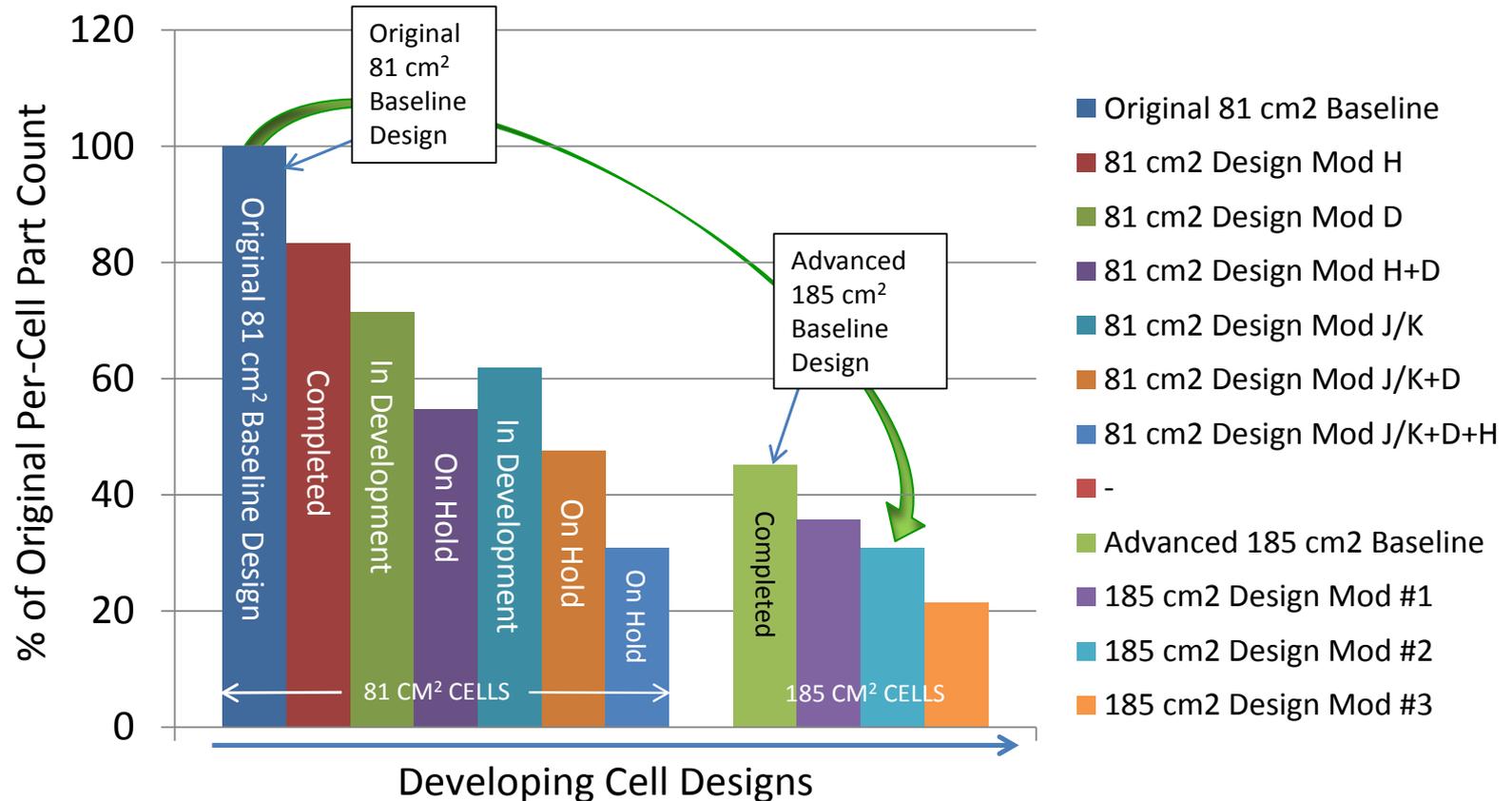
- Membrane with higher proton conductivity
- Matching electrodes
- Lower cell resistance

10,000 hr operation at ~95% H₂ recovery

>8,500 hrs at elevated current density (≥ 750 mA/cm²) in 185 cm² cell

EHC Cost Reduction

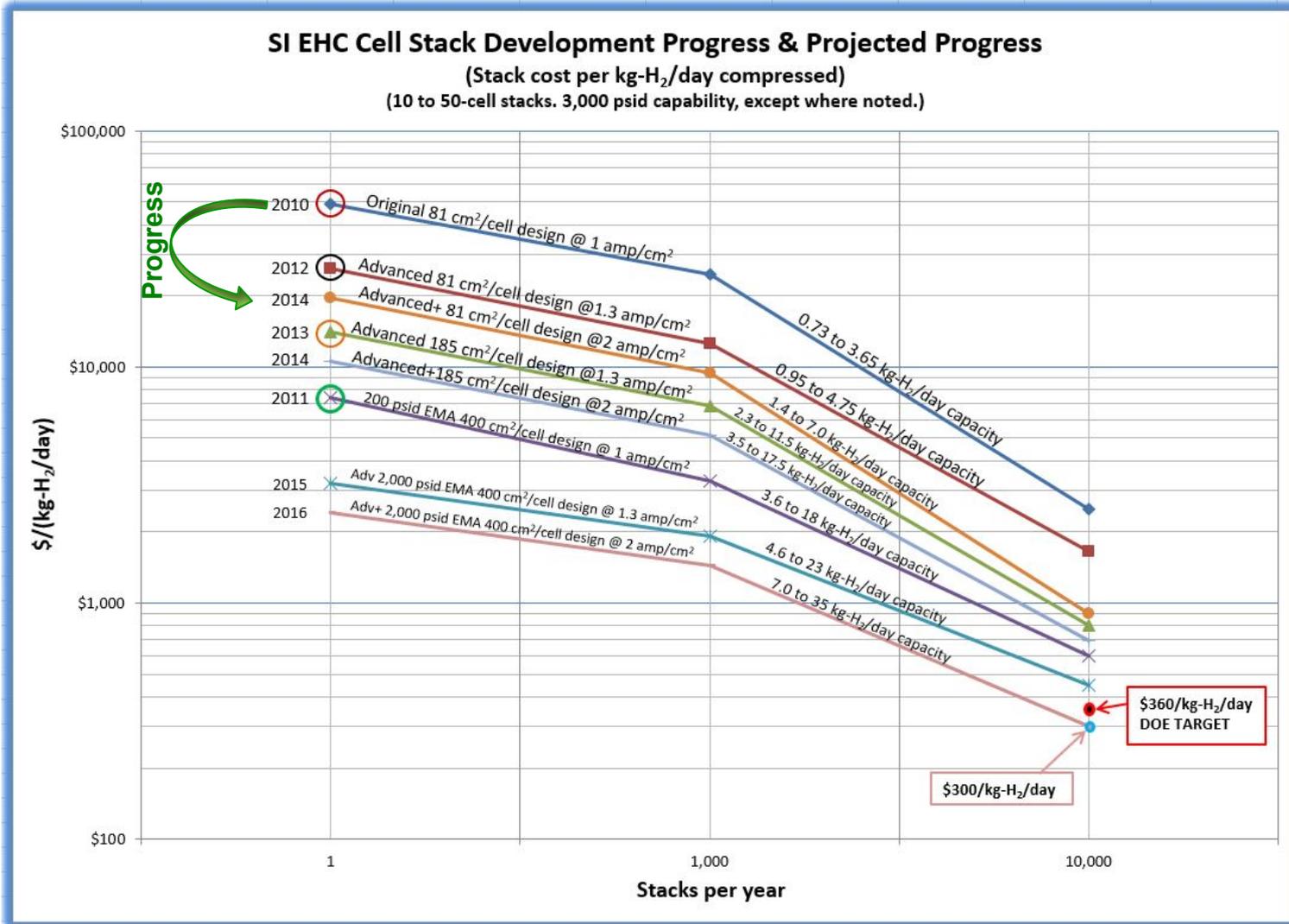
Reduction in Parts per EHC Cell



Reduced part count by 75% of original design

Opportunities for Cost Reduction

Stack Cost/H₂ Compression Capacity - \$/kg-H₂/day



Improvements :

- Higher current density operation
- Cell area scale-up
- Stack scale-up
- Reduction in # of cell parts
- Lower cost cell and stack materials
- Lower cost fabrication

Cost reduced by 60% in current program

EHC Stack Development

	3-Cell Stack #1	3-Cell Stack #2	3-Cell Stack #3	5-Cell Stack	10-Cell Stack	8-Cell Stack 185 cm ²
Pressure, (psig)	4,550	Up to 1,000	2-3,000	Up to 3,000	Up to 3,050	3,000
Current Density, (mA/cm ²)	≤500	Up to 2,200	≤500	≤450	≤500	≤720
Capacity, (lbs/day)	0.2	Up to 0.8	0.2	0.3	0.6	2.0
Operation, (hours)	150	~100	>2,000 [†]	1,800	~400	>3,800

[†] At Sustainable Innovations

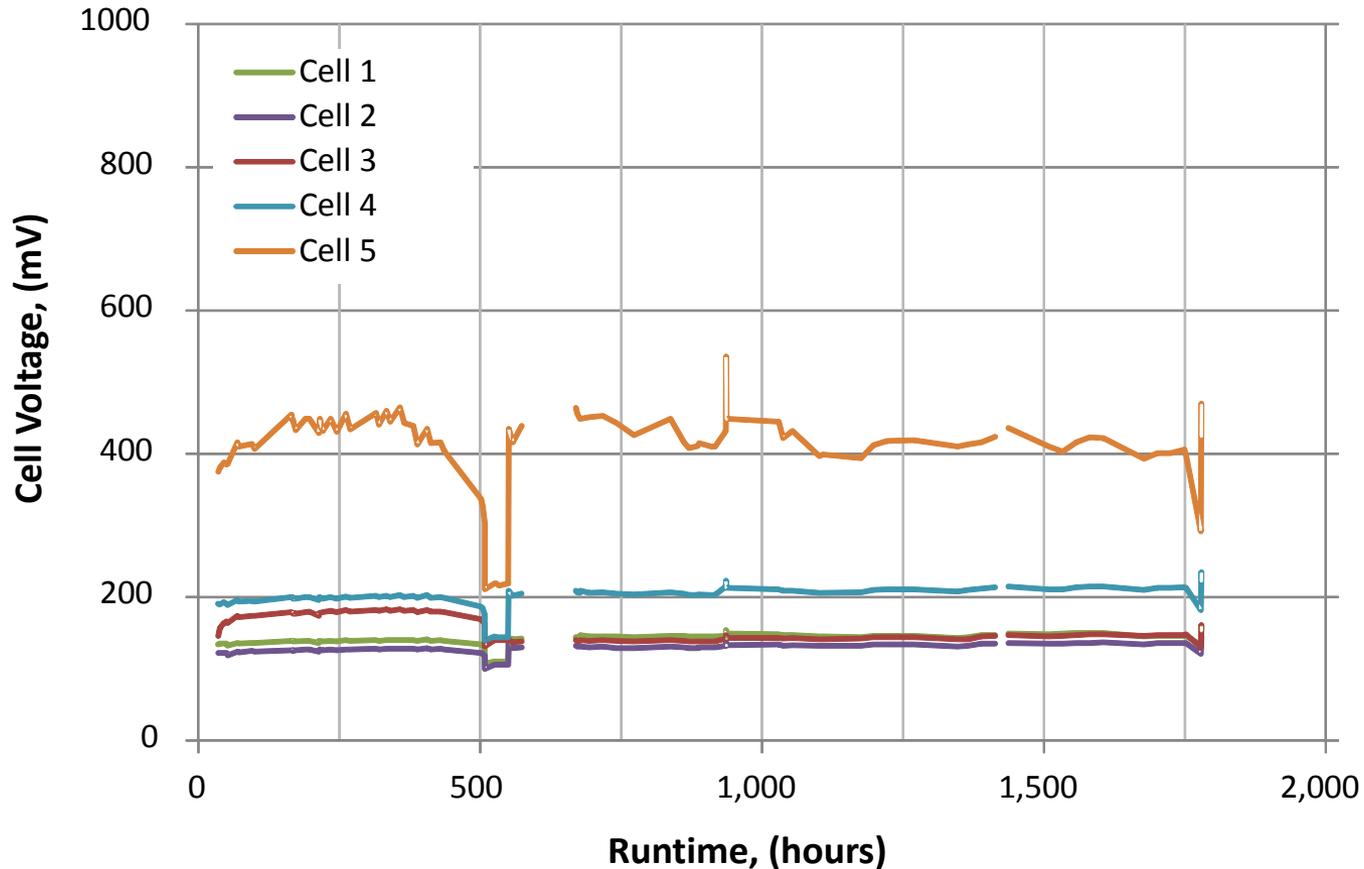
Cumulatively >8,000 hr operating experience



Subscale Stack Durability

5-Cell EHC Stack Life Chart

Current Density 400mA/cm²; Feed Pressure 30psig; Product Pressure 1000psig

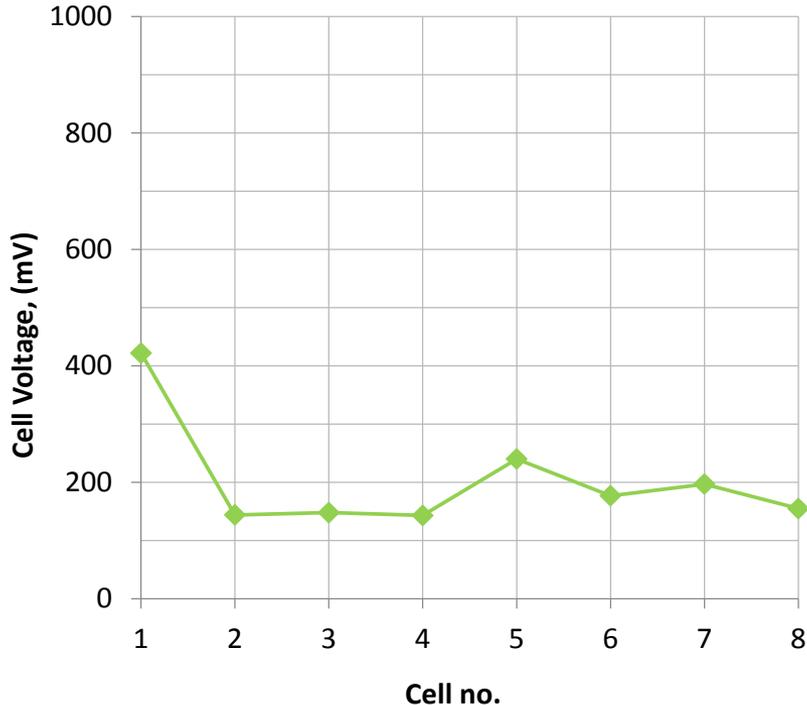


Met program target of 1,000 hr stable operation in EHC stack

Larger Area EHC Stack

EHC 8-Cell Stack: Cell Voltages

Feed pressure 30psig; Product pressure 3,000psig; 300mA/cm²



Improved cell to cell performance variation by ~50%

Increasing Hydrogen Capacity by 7x

DC Load, (Amps)	133
Average Cell Voltage, (Volts)	0.373
Flux Rate, (SLPM H ₂)	7.6
Power, (Watts)	397
Production Rate, (lb H ₂ /day)	2

Met program target of 2 lb/day hydrogen at 3,000 psi

Collaborations

Prime

- **FuelCell Energy, Inc. (Industry):**
 - System development and application engineering
 - Membrane and electrode design and fabrication

Subcontractor

- **Sustainable Innovations, LLC (Small Business):**
 - Cell and stack design and fabrication
 - Scale-up design and fabrication
 - EHC stack cost reduction and estimates



Proposed Future Work

- **Continue endurance tests of 10,000 hr and 8,500 hr cells**
- **Continue testing short stack**
- **Build and test taller EHC stack**
- **Complete test facility for larger capacity EHC stacks**
- **Demonstrate 1,000 hr operation at 2 lb/day H₂ capacity**

compressing to 3,000 psi

Scale-Up Plan to Reach 8 lb/day

Activity Covered
Under Current Funding

Activity Not Covered
Under Current Funding



5 - Cell
81 cm² Active Area
400 mA/cm²
0.3 lb/day

Single Cell
185 cm² Active Area
500 - 1500 mA/cm²
Up to 0.5 lb/day

8 - Cell
185 cm² Active Area
500 - 1000 mA/cm²
2 - 3 lb/day

25 - Cell
185 cm² Active Area
500 - 1000 mA/cm²
Up to 8 lb/day

Achievements in EHC Technology Development

Parameter	Program Goals	Current Status	DOE Goals
Hydrogen Product Pressure	Up to 3,000 psi building block, 6-12 kpsi	12,800 psi single stage 6,000 psi 2-stage	12,700 psi
Hydrogen Inlet Press.	5 - 300 psi	0 – 2,000 psi	300 psi
Compression Ratio	Up to 300:1	300:1	43:1
Hydrogen Recovery Efficiency	90 - 95%	>98%	99.5%
Hydrogen Flux	500 -1,000 mA/cm ²	≥750 mA/cm² for >8,500 hrs (185 cm² cell)	-
Hydrogen Capacity	2-4 lb/day at 3,000 psi	2 lb/day	Up to 1000 kg/day
Endurance Capability	1,000 hrs at 3,000 psi	>10,000 hrs at 3,000 psi	>5 years
Compression Efficiency	<10 kWh/kg at 3,000 psi	3-12 kWh/kg from <30 to 3,000 psi	6.2 kWh/kg from 300 to 12,500 psi

Project Summary

Relevance: Provide highly efficient, reliable and cost-effective hydrogen compression (up to 6,000/12,000 psi)

Approach: Develop electrochemical compressor – solid state device

Technical Accomplishments:

- Reduced capital cost by >60% by increasing current density, increasing cell active area and by design improvements (reduced cell part count)
- Operated >8,500 hrs in 185 cm² cell at ≥ 750 mA/cm² at high H₂ recovery ($\geq 95\%$)
- Demonstrated 2 lb/day capacity at 3,000 psi in 185 cm² stack

Collaborations: Active partnership with industry (Sustainable Innovations) on materials, design and fabrication

Proposed Future Work: Scale-up to taller stack to further increase throughput and lower the cost

Acknowledgement

- FCE: Pinakin Patel, Ray Kopp, Jonathan Malwitz,
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- Sustainable Innovations, LLC: Trent Molter and team
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