FuelCell Energy

Electrochemical Hydrogen Compressor

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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:

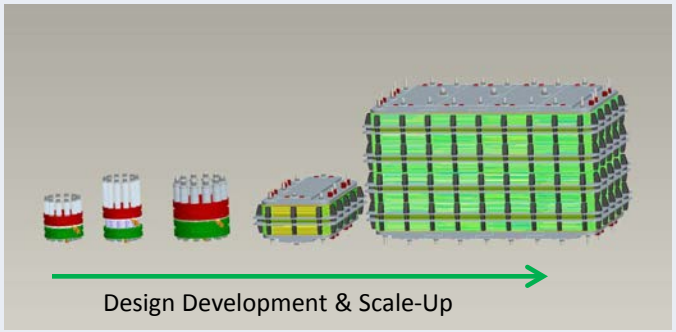
- **Increases reliability/availability over current mechanical compressors**
- **Ensures "no possibility of lubricant contamination" (No moving parts) → Fuel Cell Quality H_2**
- **Increases Compression Efficiency to 95% (DOE 2015 Target)**
- **Potentially reduces cost of H_2 delivery to <$1/gge (DOE Long Term Target)**

Approach

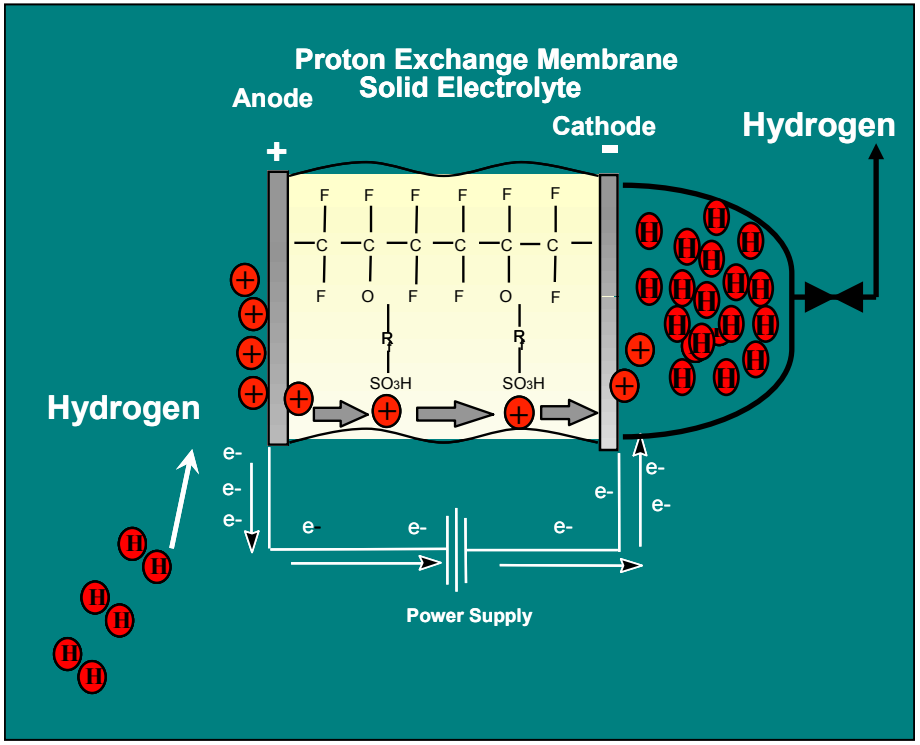
- **Use high-pressure electrolyzer experience for mechanically robust cell design**
- **Higher current density operation to minimize capital and operating costs**
- **Improved flow field design to increase H_2 recovery efficiency**
- **Simple system: Reduce capital cost by increasing cell size and reducing number of parts**

Approach

ITEM	APPROACH
Increase Pressure, Life, Efficiency	-Cell & Stack Design Enhancements -MEA Improvements -Multi-Stage Operation -Very High Single Stage Compression
Lower System Cost	-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

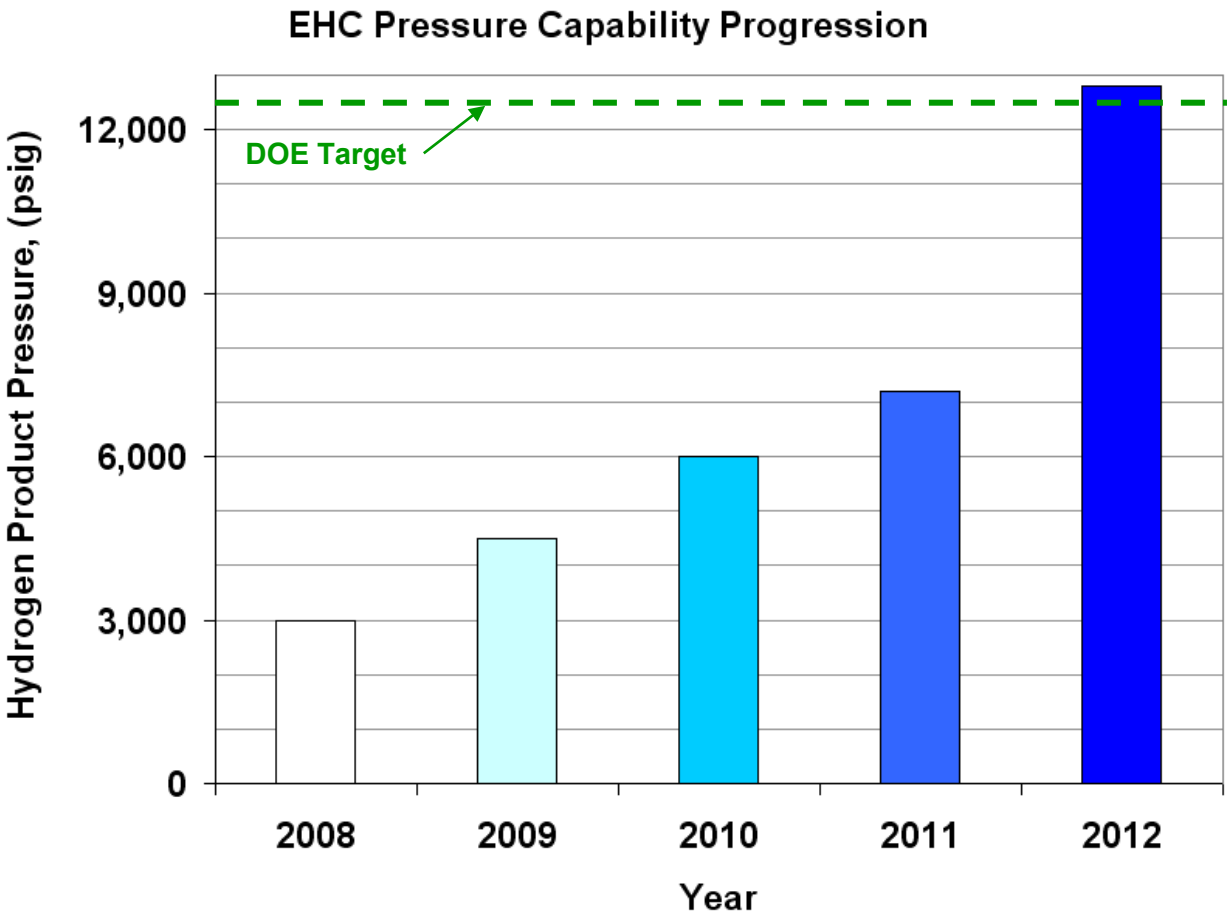
P V = n R T

Rather Nernst Eqn:

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

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

EHC Pressure Capability

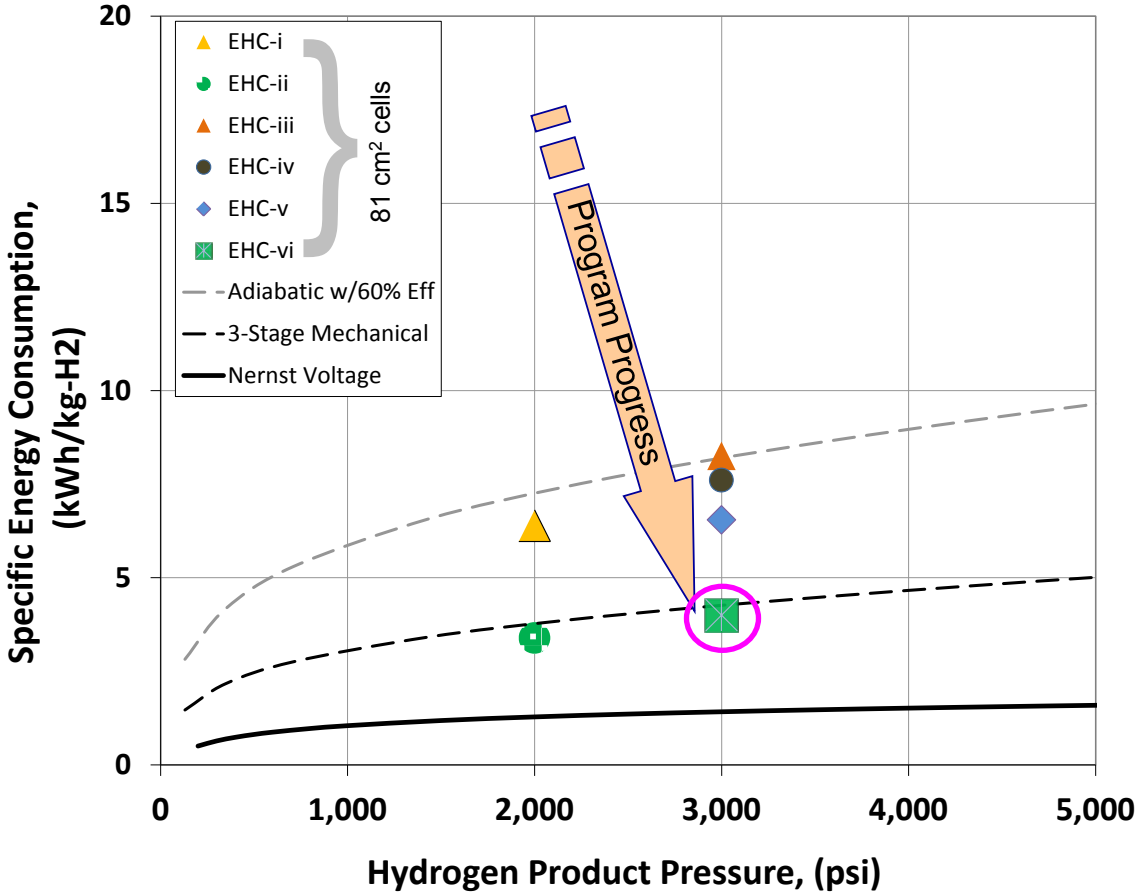


Improvements made:

- **Seals with higher pressure capability**
- **Improved MEA support**

Met DOE 2015 pressure target for forecourt compressors

Reduction in the Energy Consumption of EHC



Improvements made:

- **Lower cell resistance**
- **Lower applied voltage**

185 cm² cell

Improved cell design and materials for 3,000 psi

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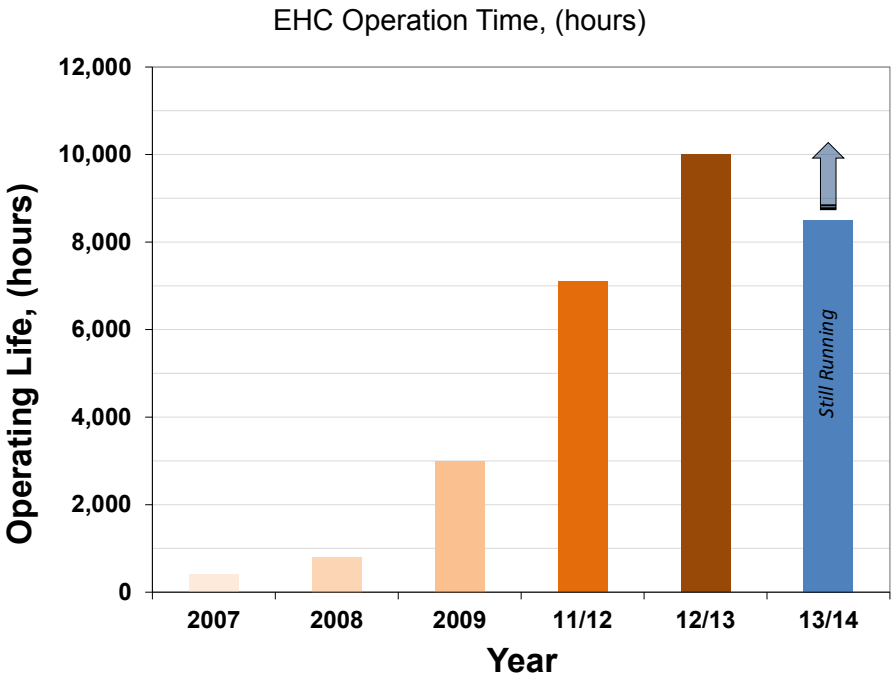
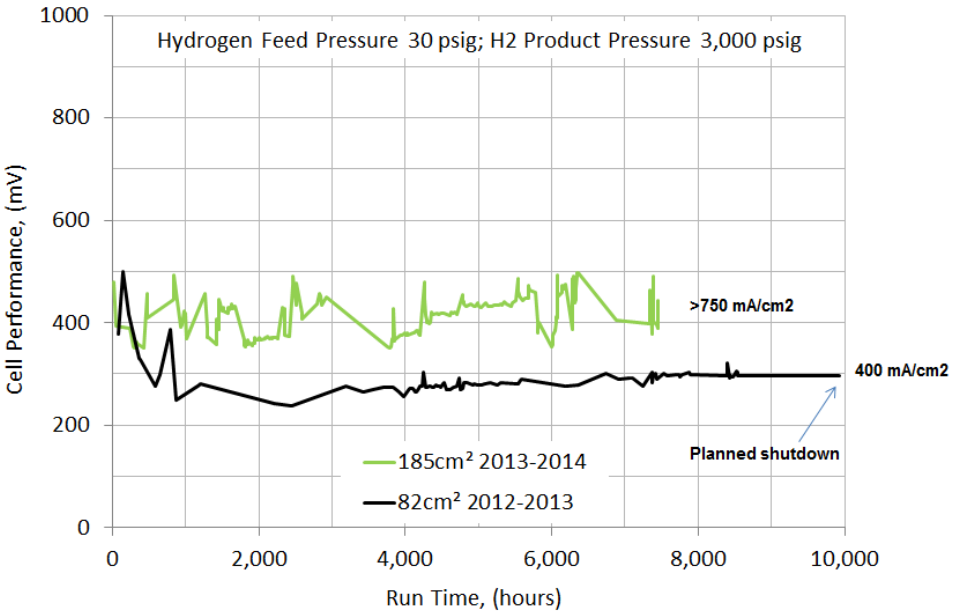
EHC Durability





Improvements made:

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

10,000 hr operation at ~95% H_2 recovery

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

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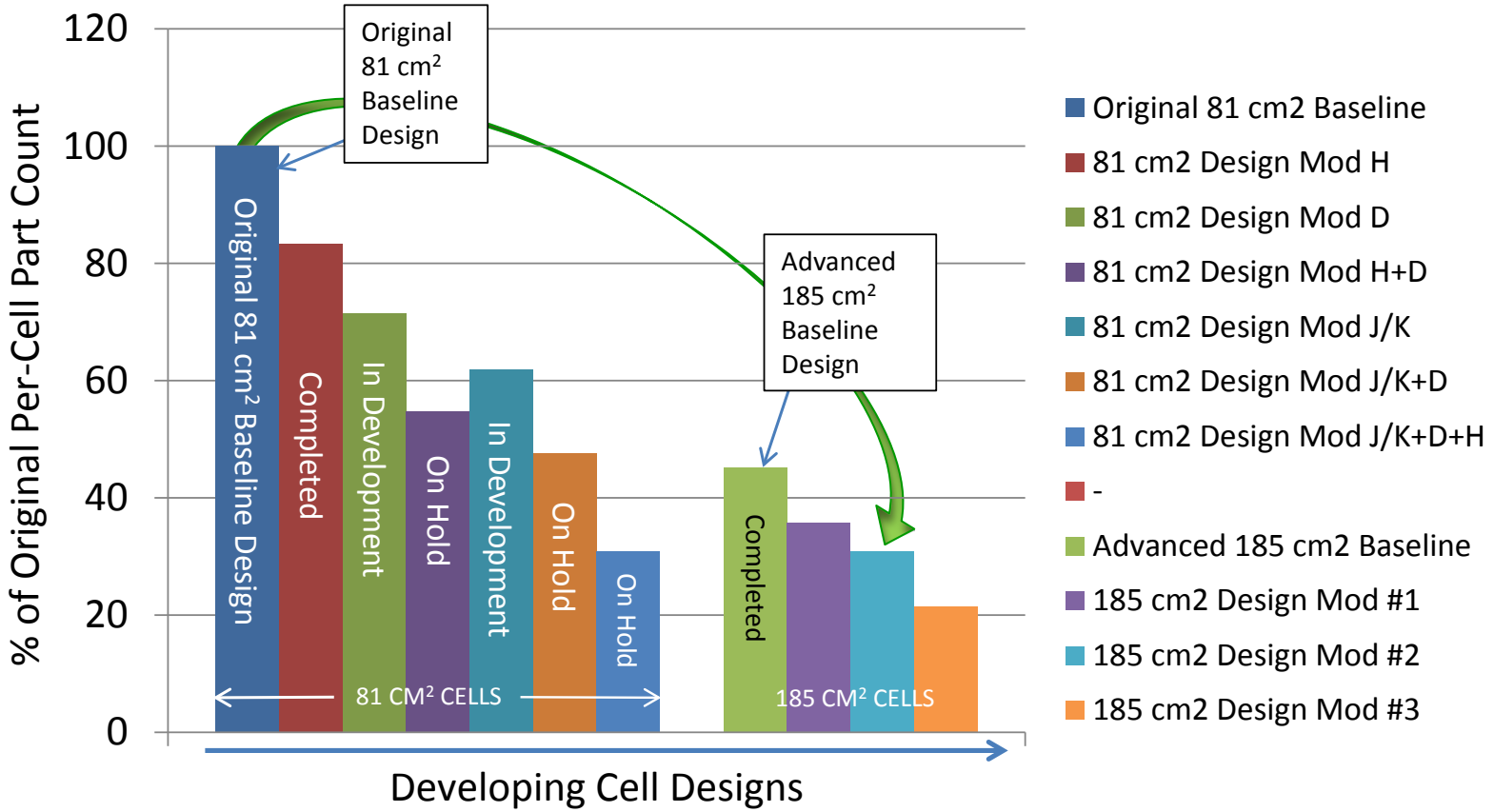
EHC Cost Reduction

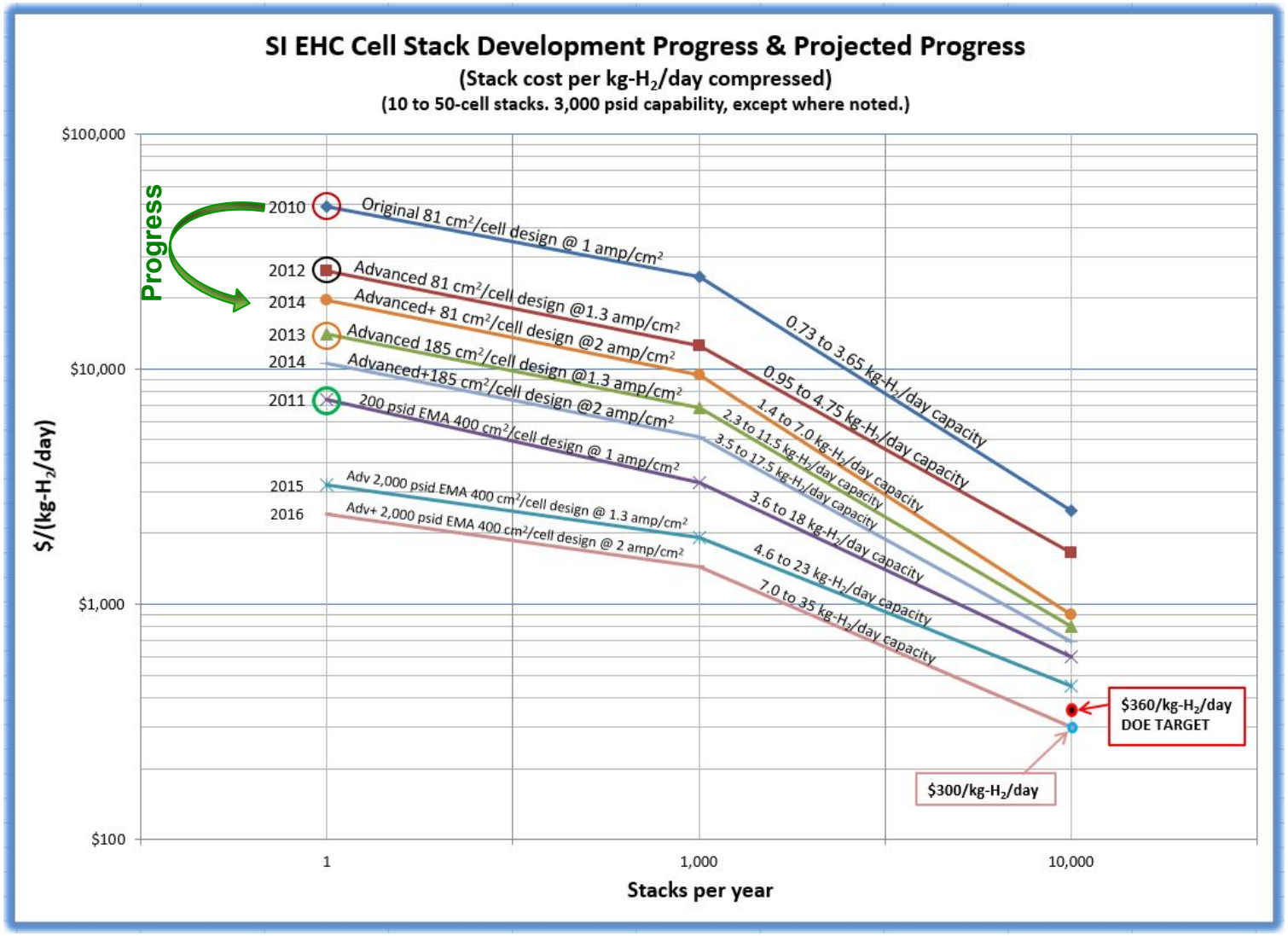
Reduction in Parts per EHC Cell



Reduced part count by 75% of original design

Opportunities for Cost Reduction

Stack Cost/H_2 Compression Capacity - \$/kg-H_2/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

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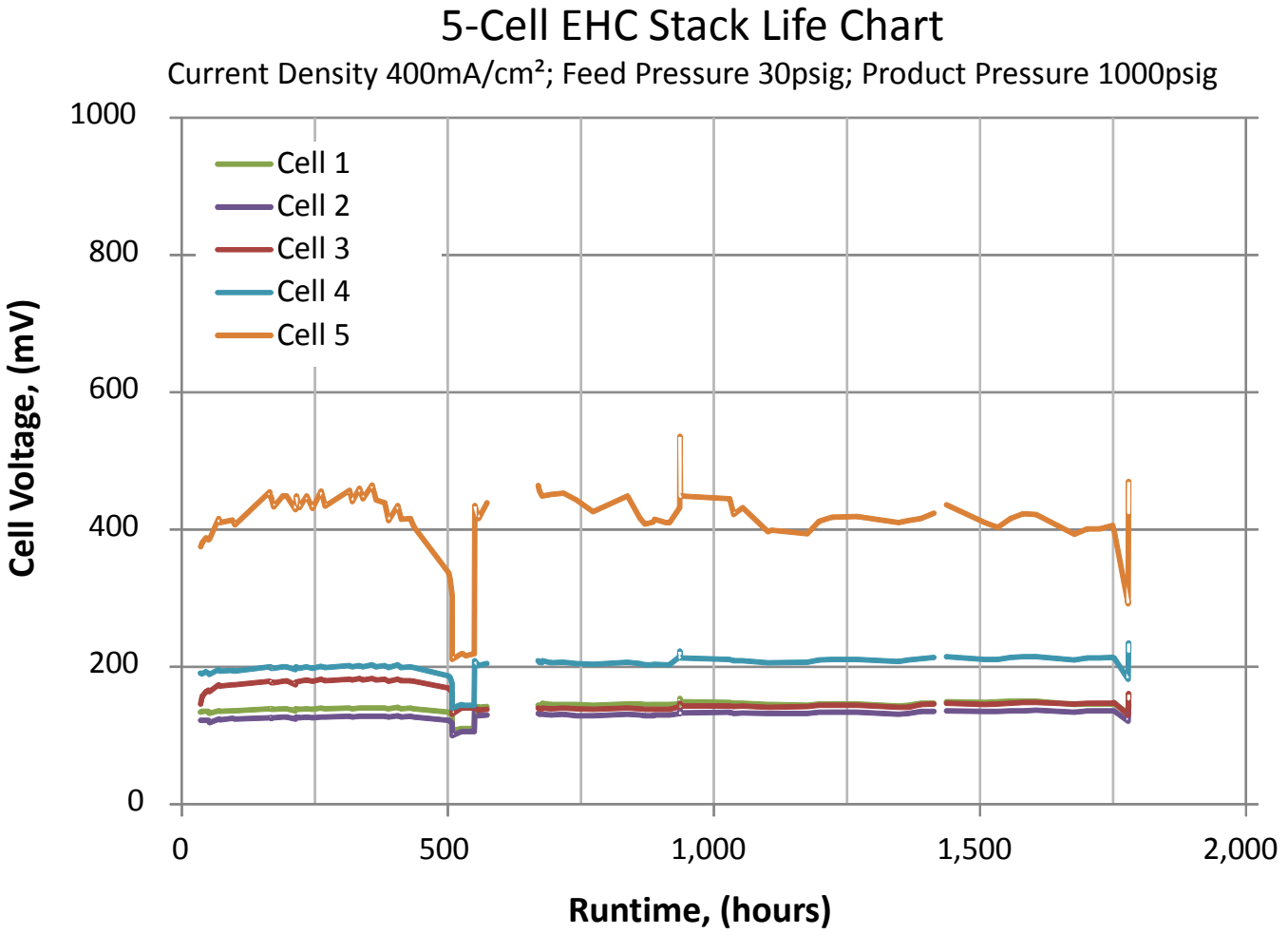
EHC Stack Development

	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



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

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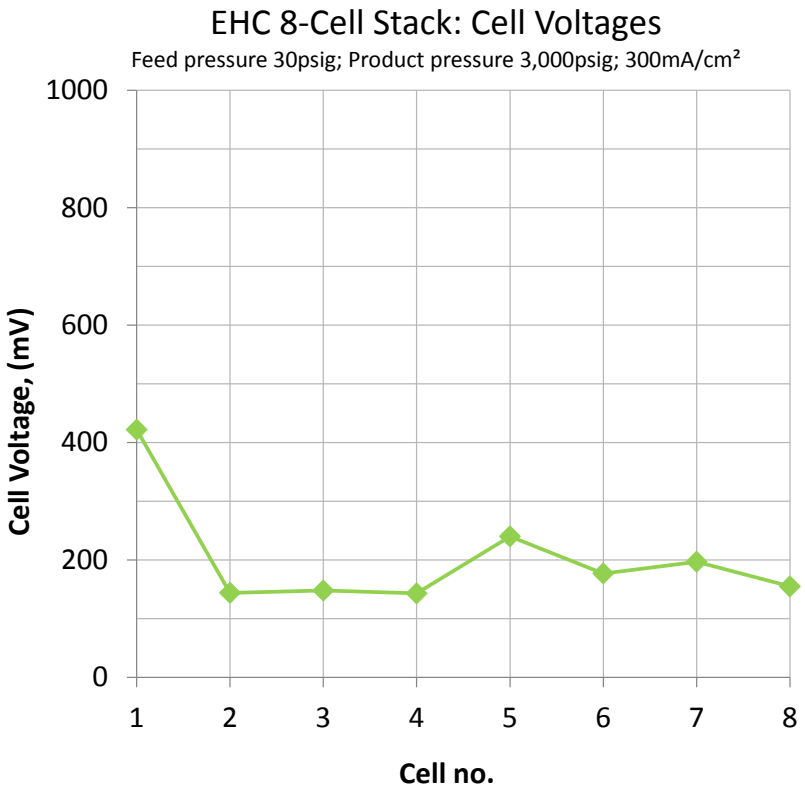
Larger Area EHC Stack



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 H_2 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 cm^2 Active Area
400 mA/cm^2
0.3 lb/day

Single Cell
185 cm^2 Active Area
500 - 1500 mA/cm^2
Up to 0.5 lb/day

8 - Cell
185 cm^2 Active Area
500 – 1000 mA/cm^2
2 - 3 lb/day

25 - Cell
185 cm^2 Active Area
500 – 1000 mA/cm^2
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/cm^2 for >8,500 hrs (185 cm^2 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 cm^2 cell at ≥750 mA/cm^2 at high H_2 recovery (≥ 95%)**
- **Demonstrated 2 lb/day capacity at 3,000 psi in 185 cm^2 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, Paul Pinard
- Sustainable Innovations, LLC: Trent Molter and team
- DOE: Erika Sutherland, Dave Peterson, Sara Dillich, Monterey Gardiner