Electrochemical Hydrogen Compressor

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Project ID #PD048

Overview

Timeline

- Project start date: 7/15/10
- Project end date: 7/14/13
- Percent complete: *92%*

Budget

- Total project funding
  - DOE share: $1993k
  - Contractor share: $629k
- Funding for FY13: $545k

Barriers

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

Partners

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

Relevance

Impact of EHC:

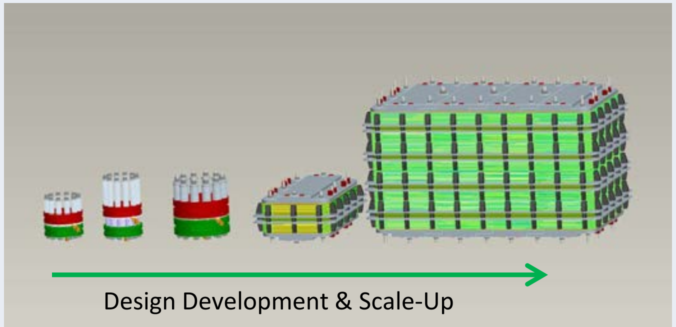
- Increases reliability/availability over current mechanical compressors
- Ensures "no possibility of lubricant contamination" (No moving parts) → Fuel Cell Quality H_2
- Increases Compression Efficiency to 95% (DOE 2015 Target)
- Potentially reduces cost of H_2 delivery to <$1/gge (DOE Long Term Target)

Approach

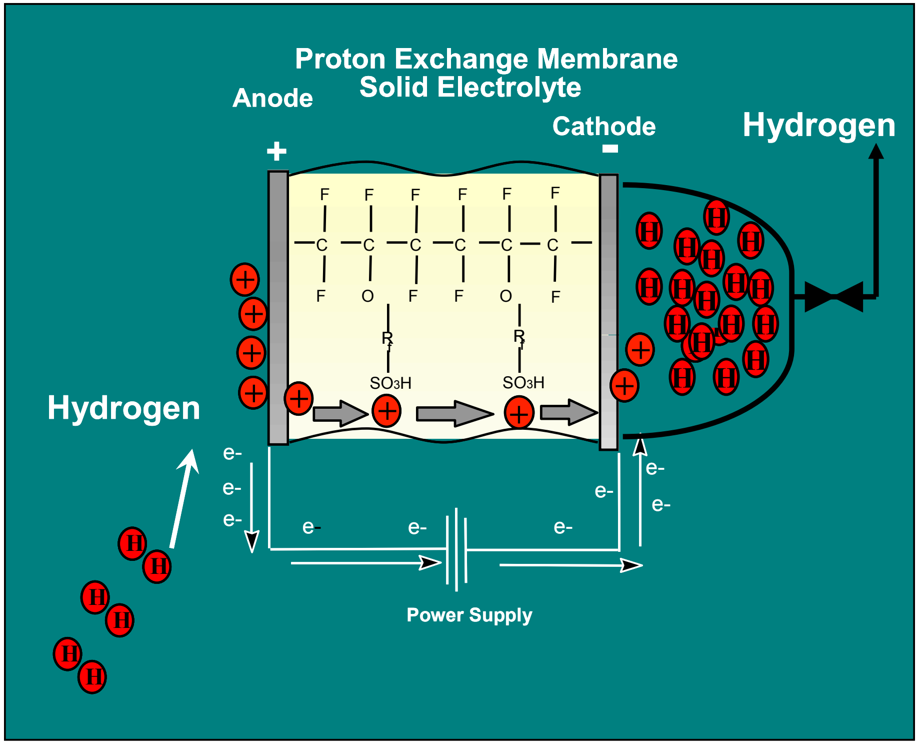
- **Use high-pressure electrolyzer experience for mechanically robust cell design**
- **Higher current density operation to minimize capital and operating costs**
- **Improved flow field design to increase H_2 recovery efficiency**
- **Simple system: Reduce capital cost by increasing cell size and reducing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

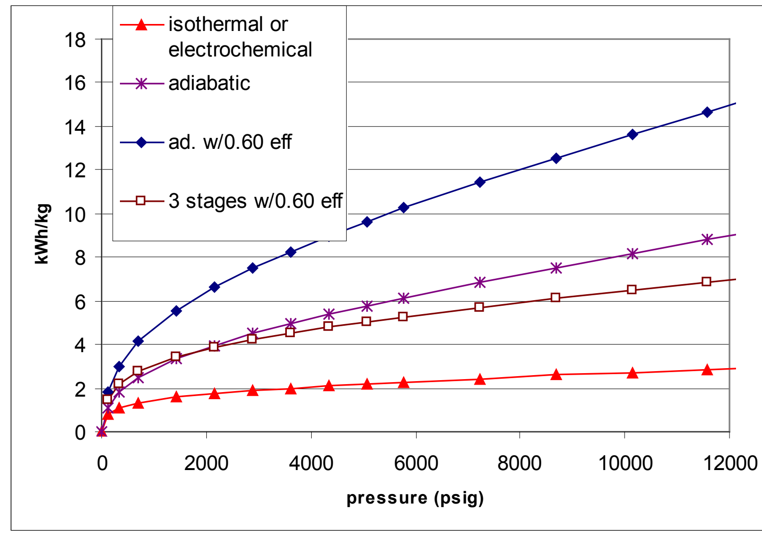
Approach

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





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

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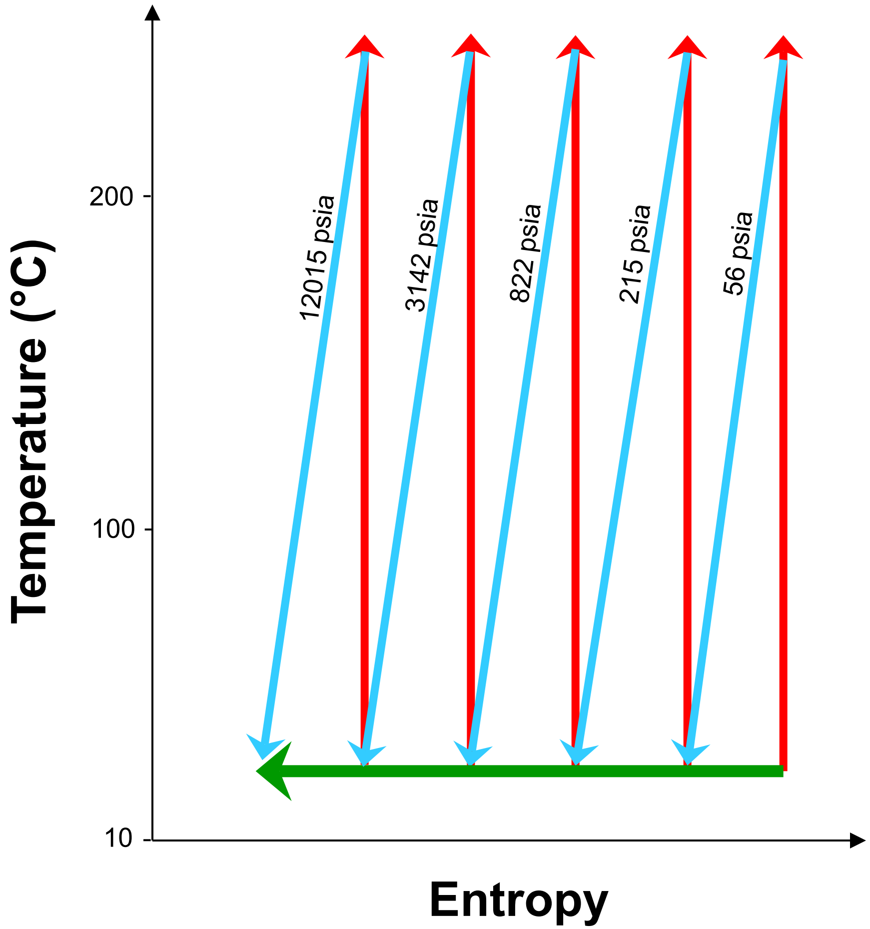
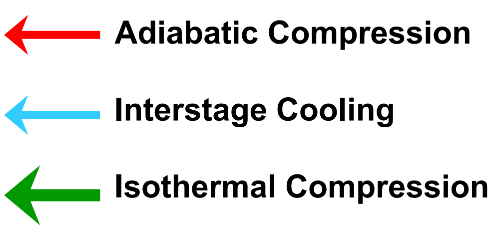
Compression Heat



Multistage Adiabatic Compression with Interstage Cooling

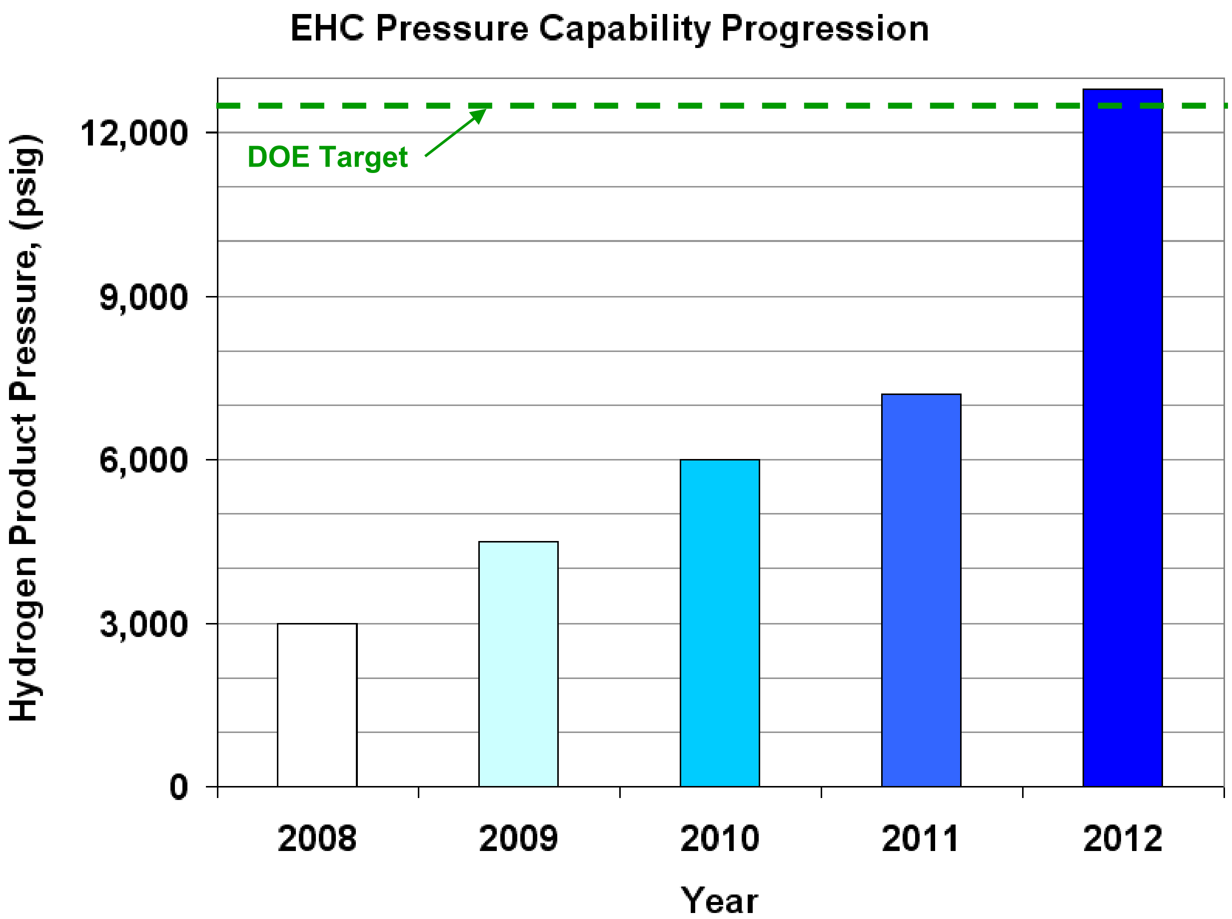
vs.

Isothermal Compression of EHC



Hydrogen does not significantly heat up during compression in EHC

EHC Pressure Capability



Improvements made:

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

Met DOE 2015 pressure target for forecourt compressors

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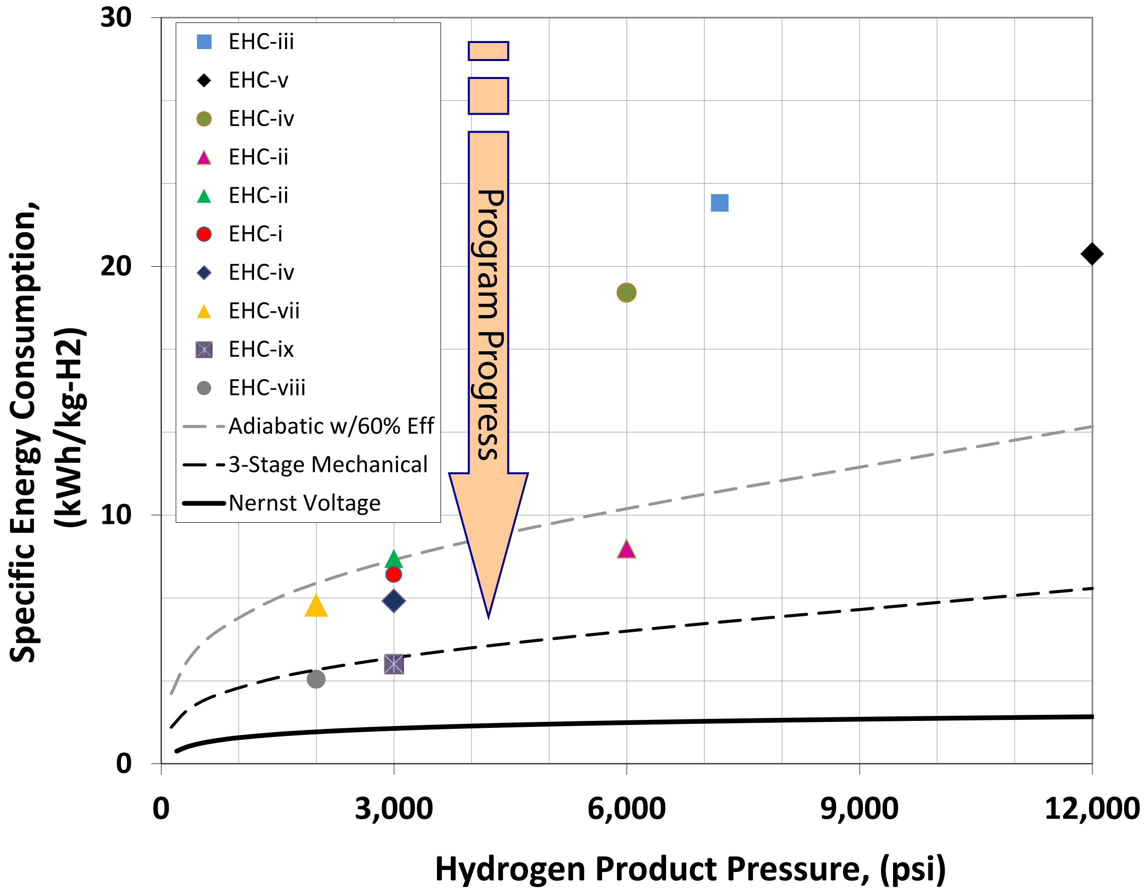
Reduction in the Energy Consumption of EHC



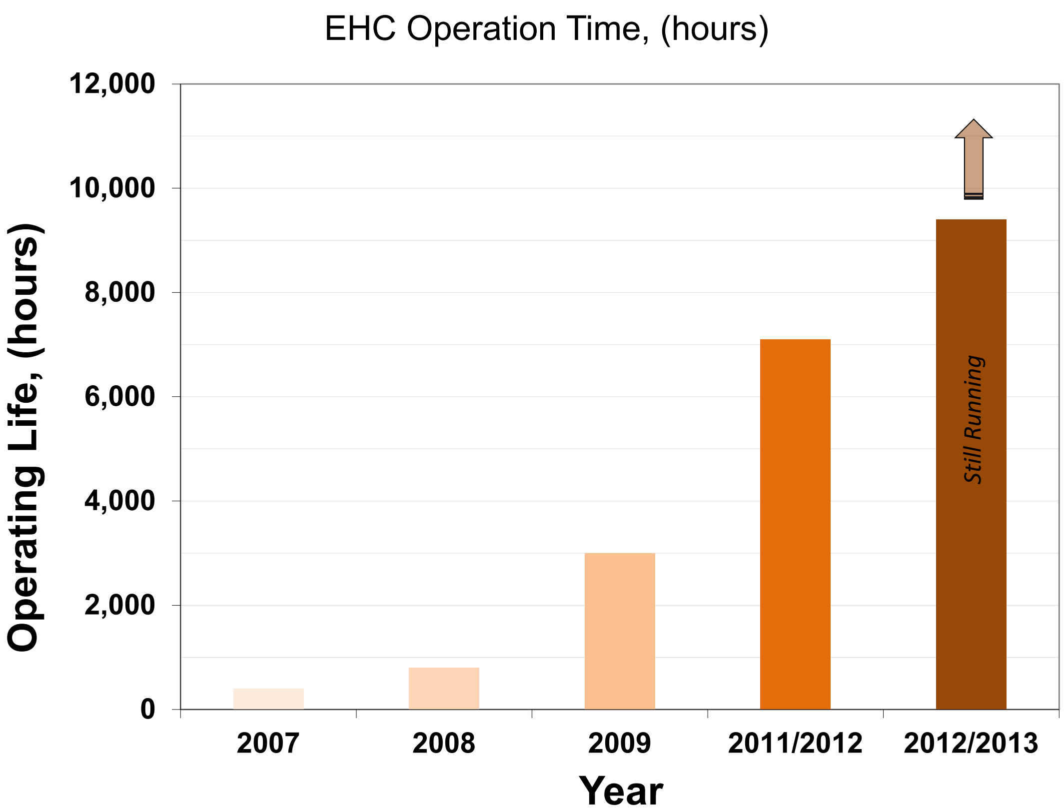
Improvements made:

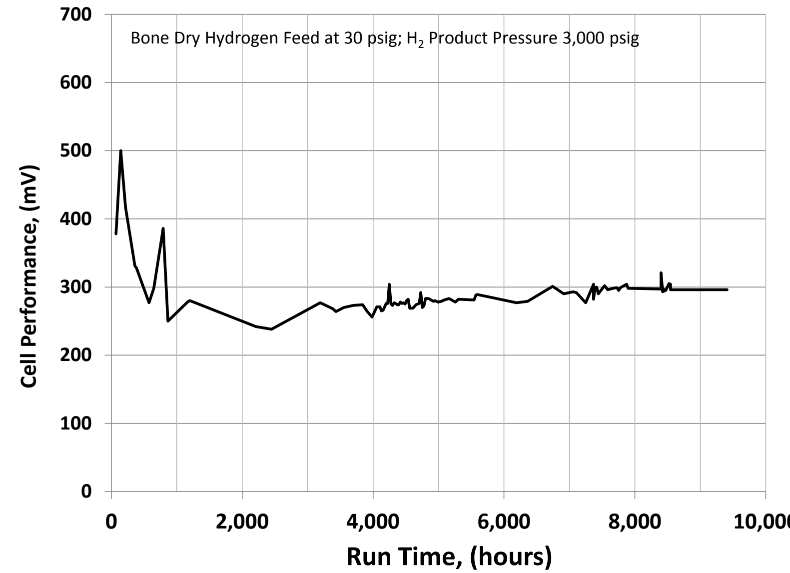
- **Lower cell resistance**
- **Lower applied voltage**

Improved cell design for 3000 psi

More effort needed for 6,000 - 12,000 psi range

EHC Durability





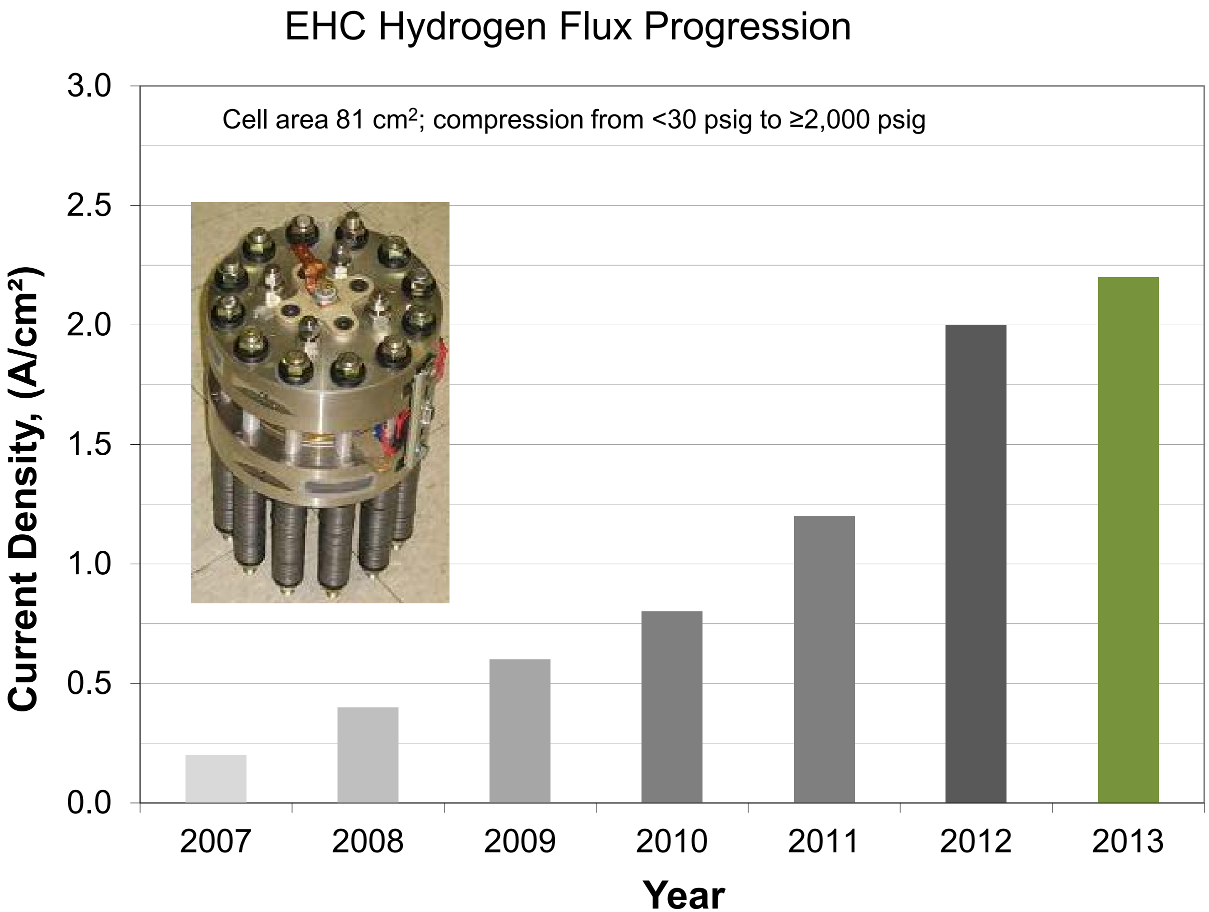
Improvements made:

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

7,000 hr operation at elevated current density (750 mA/cm^2)

Almost 10,000 hr operation at ≥ 95% hydrogen recovery

EHC Cost Reduction



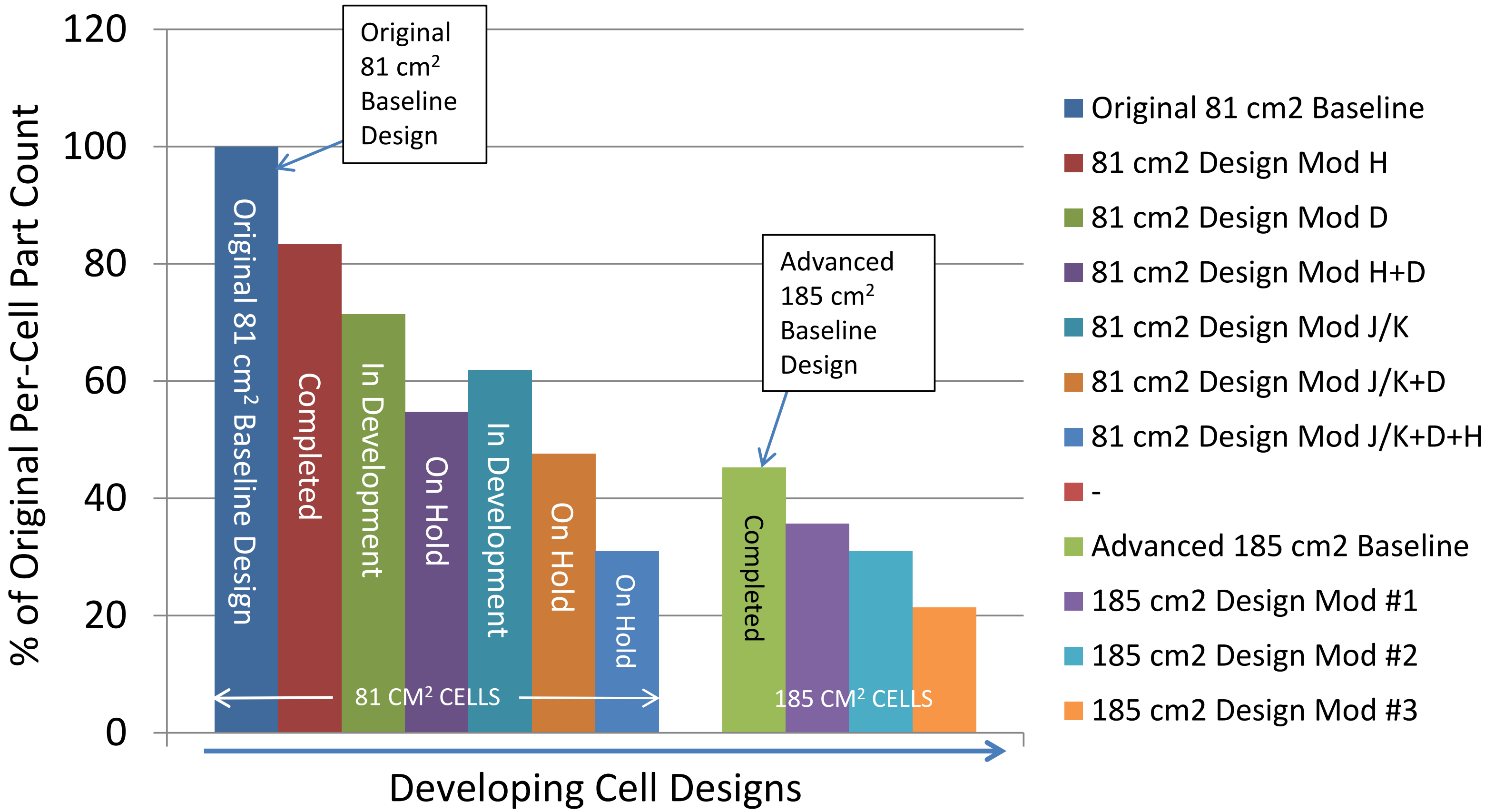
Improvements made:

- **Higher performance MEA**
- **Lower cell resistance at higher pressure**
- **Improved manufacturing tolerances**
- **Increased output**
- **Reduced part count**

Ten-fold increase in current density

Reducing Cell Part Count

(Reduction in Parts per EHC Cell)

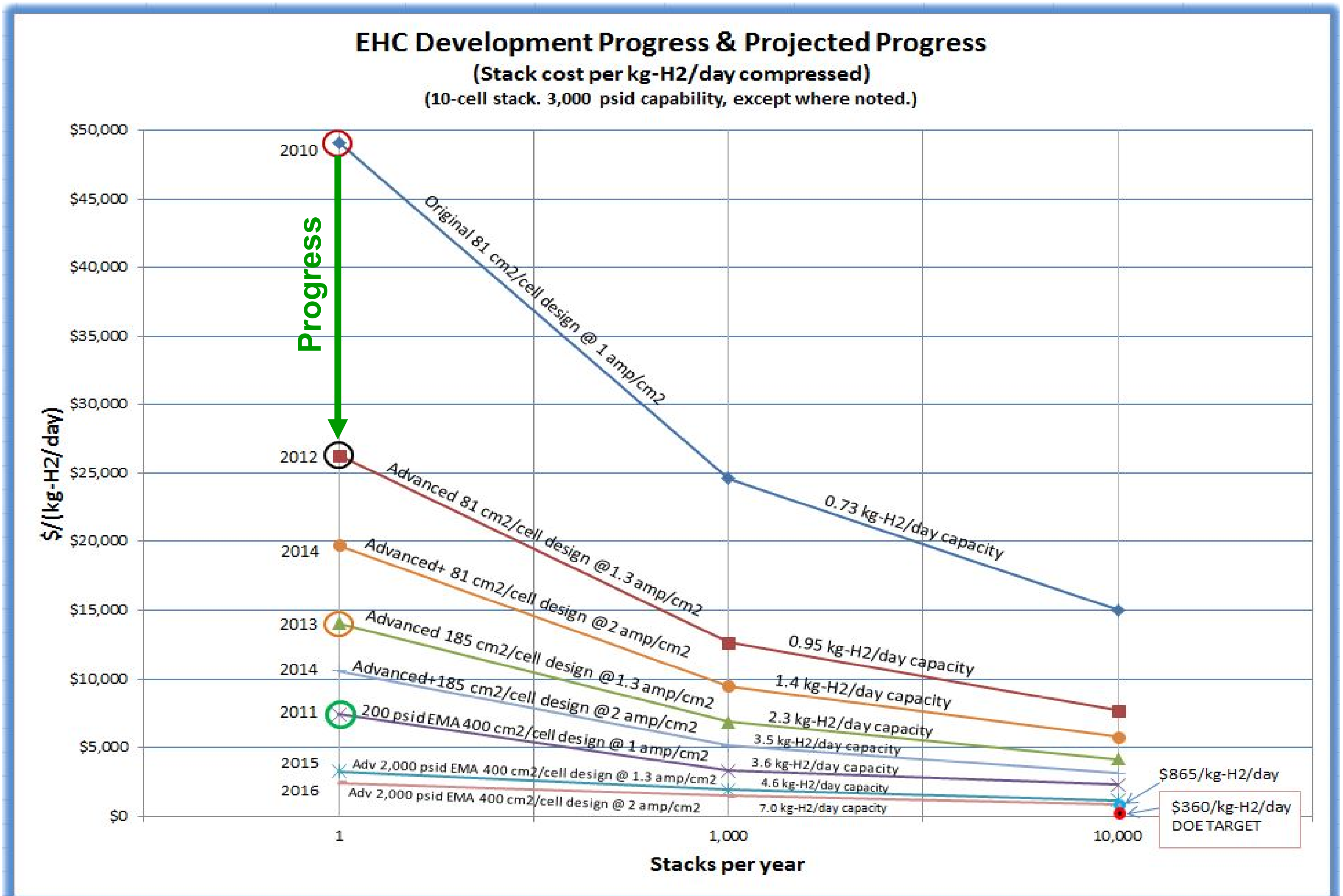


Advanced design has <50% part count of original design

Decrease in part count is opportunity for further cost reduction

Opportunities for Cost Reduction

(Stack Cost/H_2 Compression Capacity - $/kg-$H_2$/day)



Improvements planned:

- **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 50% 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
Pressure, (psig)	4,550	Up to 1,000	2-3,000	3,000	Up to 3,050
Current Density, (mA/cm^2)	≤500	Up to 2,200	≤500	≤450	≤500
Capacity, (lbs/day)	0.2	Up to 0.8	0.2	0.3	0.6
Operation, (hours)	150	~100	>2,000†	>200*	~400

* Currently In Operation at FCE
† At Sustainable Innovations

Cumulatively ~3,000 hr operating experience

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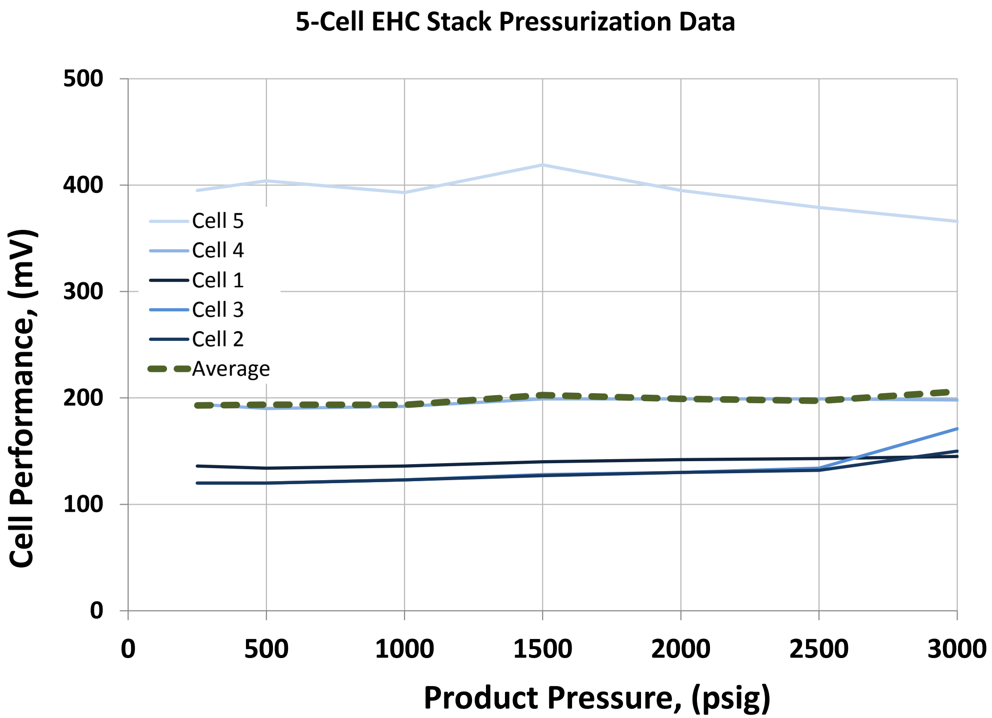
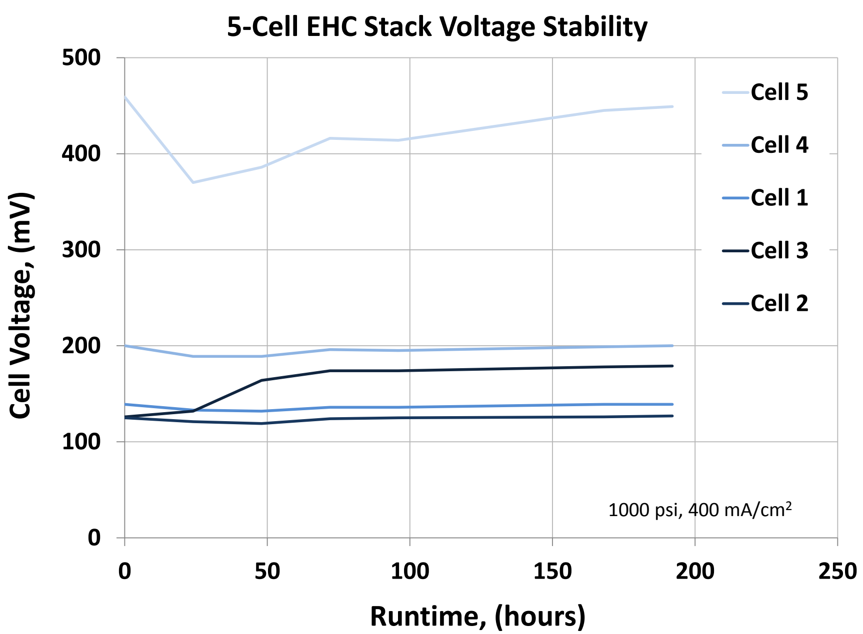
EHC 5-Cell Stack





Up to 3,000 psi capability

Achieved stable operation

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 test of 10,000 hr cell
- Continue testing of 5-cell 81 cm^2 stack
- Begin testing 185 cm^2 single cell to verify successful area scale-up
- Complete fabrication of 185 cm^2 8-cell stack
- Prepare test facility for larger capacity EHC
- Demonstrate $\geq$ 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 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**	12,500 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%	**>95%**	99.5%
Hydrogen Flux	500 -1,000 mA/cm^2	**750 mA/cm^2 for 7,000 hr**	-
Hydrogen Capacity	2-4 lb/day at 3,000 psi	**~0.6 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	**4-12 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 > 50% by increasing current density from 400 to 750 mA/cm^2 and by design improvements (reduced cell part count)**
- **Operated almost 10,000 hrs at high H_2 recovery (≥ 95%)**
- **Demonstrated single stage pressure capability to >12,000 psi**

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

Proposed Future Work: **Scale-up 185 cm^2 cell design to short stack to 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, Scott Weil, Monterey Gardiner, Paul Bakke