



FuelCell Energy



DOE Hydrogen Program

# Electrochemical Hydrogen Compressor

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Project ID  
#PD048

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# Overview

## Timeline

- Project start date: 7/15/10
- Project end date: 7/14/13
- Percent complete: **27%**

## Budget

- Total project funding
  - DOE share: \$1993k
  - Contractor share: \$629k
- Funding received in FY10: \$200k
- Funding for FY11: \$500k

## Barriers

- Barriers addressed for gaseous hydrogen compression:
  - Improve reliability
  - Eliminate contamination
  - Improve energy efficiency
  - Reduce cost

## Partners

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



# Relevance

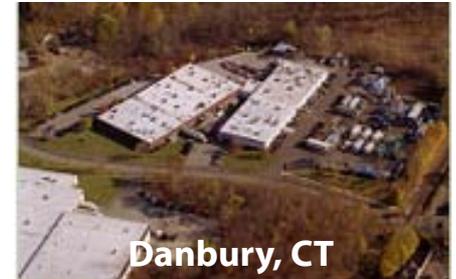
## Impact of EHC:

- **Increases reliability/availability over current mechanical compressors**
- **Ensures “no possibility of lubricant contamination” (No moving parts) → Fuel Cell Quality H<sub>2</sub>**
- **Increases Compression Efficiency to 95% (DOE 2015 Target)**
- **Potentially reduces cost of H<sub>2</sub> delivery to <\$1/gge (DOE Long Term Target)**

# Leader in Stationary Fuel Cell Power Plants

## Leading fuel cell developer for over 40 years

- MCFC, SOFC, PAFC and PEM (up to 2.8 MW size products)
- Over 700 million kWh of clean power produced world-wide (>50 installations)
- Renewable fuels: over two dozen power plants operating with ADG fuel
- Ultra-clean technology: CARB-2007 certified: Facilitates clean air permitting in California
- Internal reforming technology – enables H<sub>2</sub> co-production



# Fuel Flexibility Experience



**Westin at SFO Airport**  
*Nat Gas CHP*



**29 Palms Marine Corp Base**  
*Nat Gas Secure CHP*



**Santa Rita Jail, CA**  
*Nat Gas Fuel Cell and Solar Power*



**California WWT Plant**  
*BioGas CHP*

**DFC Products are uniquely capable  
of operating on many fuels**



**Ford Paint Shop**  
*Paint Solvent Fume Power*

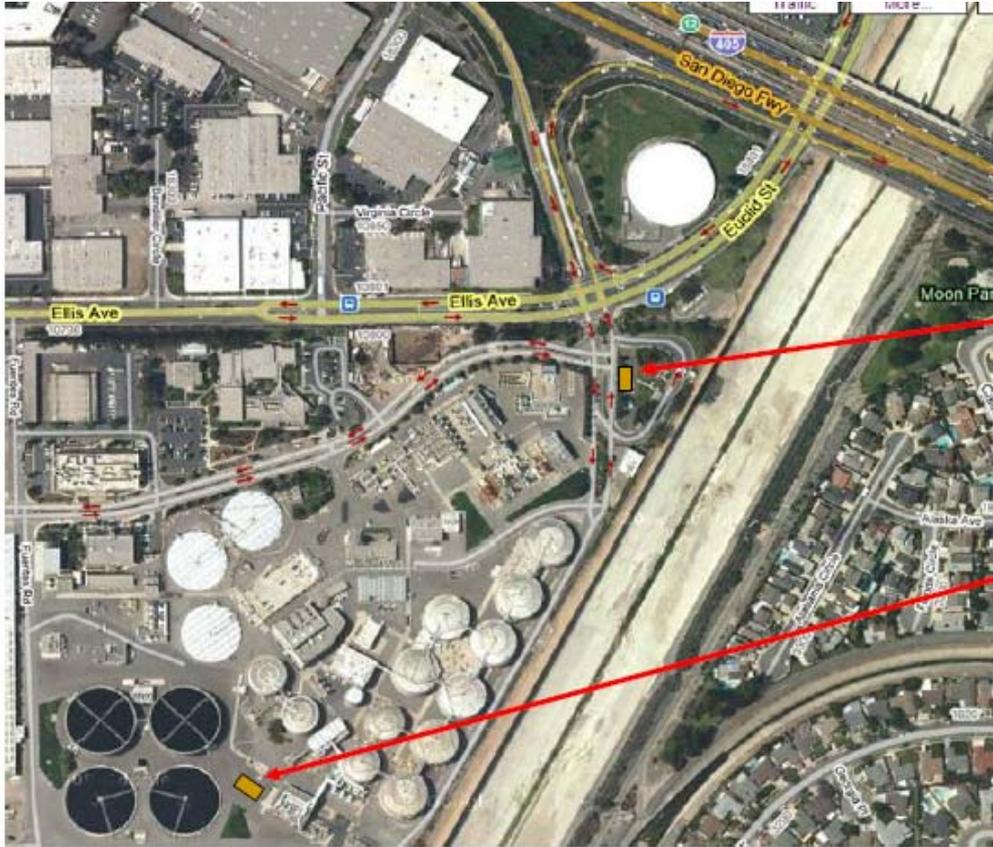


**Sierra Nevada Brewery**  
*Nat Gas and BioGas CHP*



**Pacific Missile Range**  
*Propane Secure CHP*

# Co-Production of Renewable Hydrogen at OCSD, CA



Orange County Sanitation District (OCSD)

Renewable H<sub>2</sub> Filling Station

ADG fueled DFC-H<sub>2</sub><sup>®</sup> Production Unit



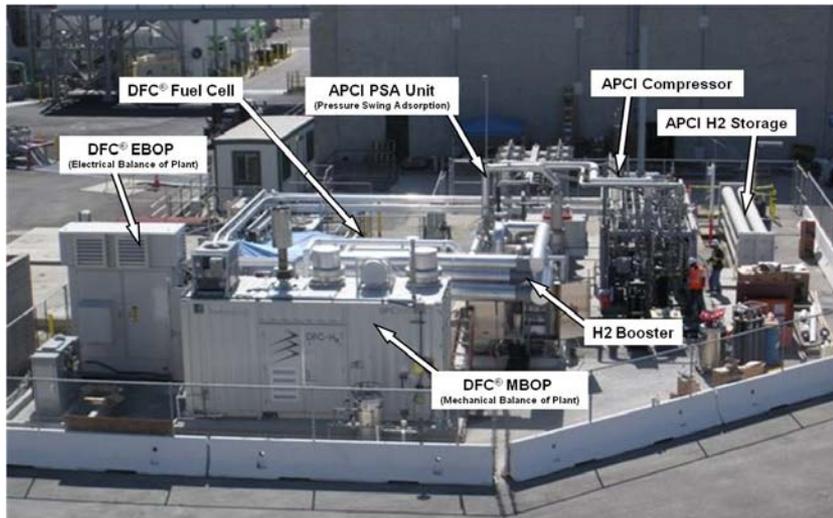
Energy Efficiency & Renewable Energy



FuelCell Energy

# OCSD Site Demonstration

- October 2010 – DFC-H<sub>2</sub> Start-up on Natural Gas
  - Co-production Efficiency (H<sub>2</sub> + Power) 54.2%
- November 2010 – Mechanical Completion of Hydrogen Fueling Station
- February 2011 – First Delivery of H<sub>2</sub> to Fueling Station
- March 2011 – Initial Test Fills of Fuel Cell Vehicles

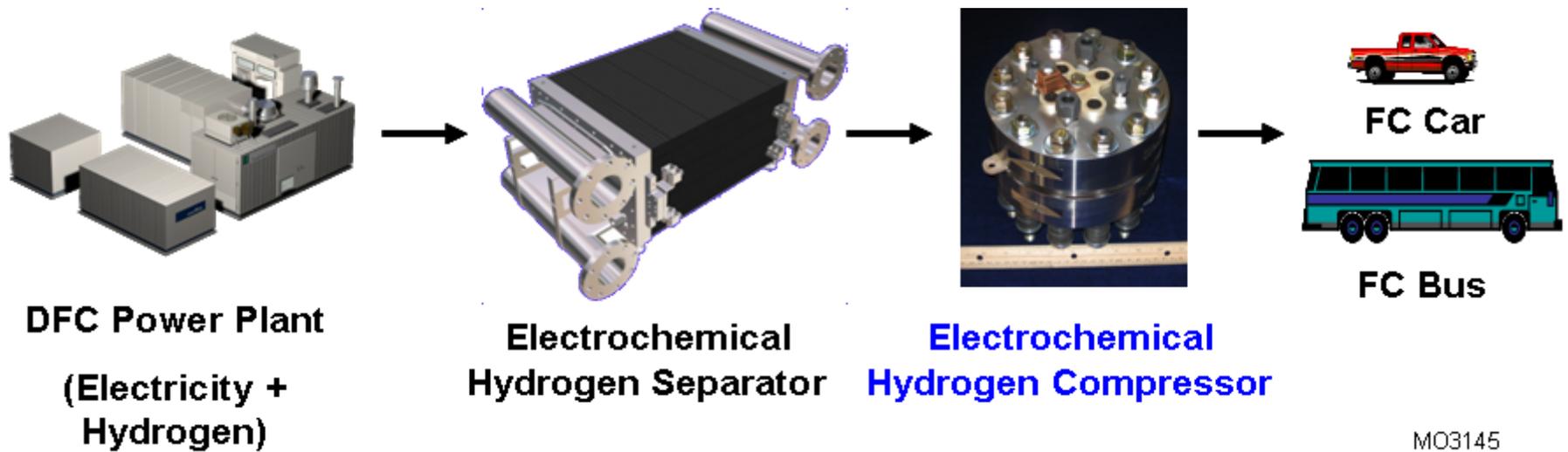


**Hydrogen Energy Station**



**Hydrogen Fueling Station**

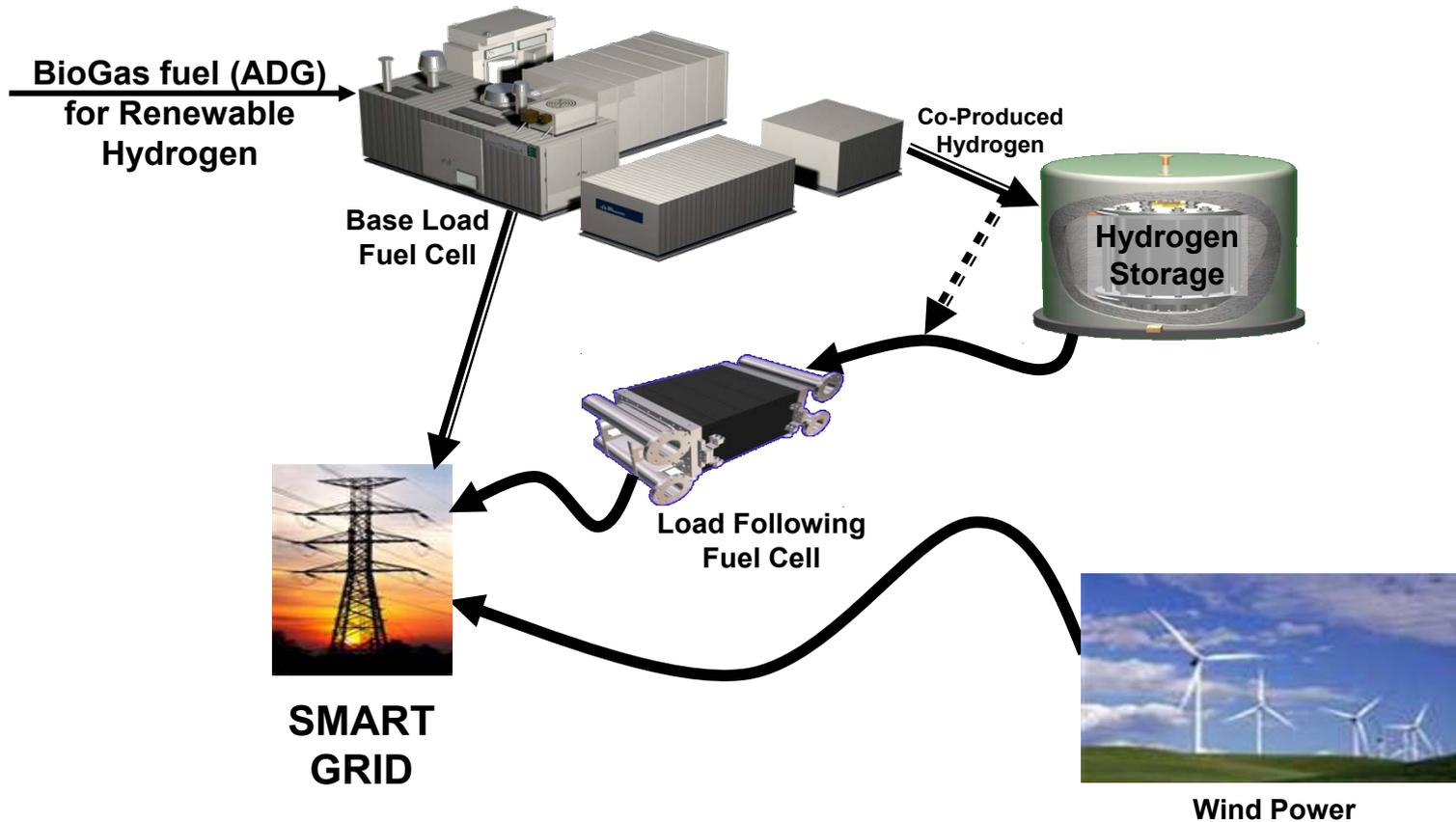
# Enabling Technology for Hydrogen Co-production



MO3145

## Technologies for Hydrogen Infrastructure and Smart Grid

# DFC-H2<sup>®</sup> Applications for the Smart Grid

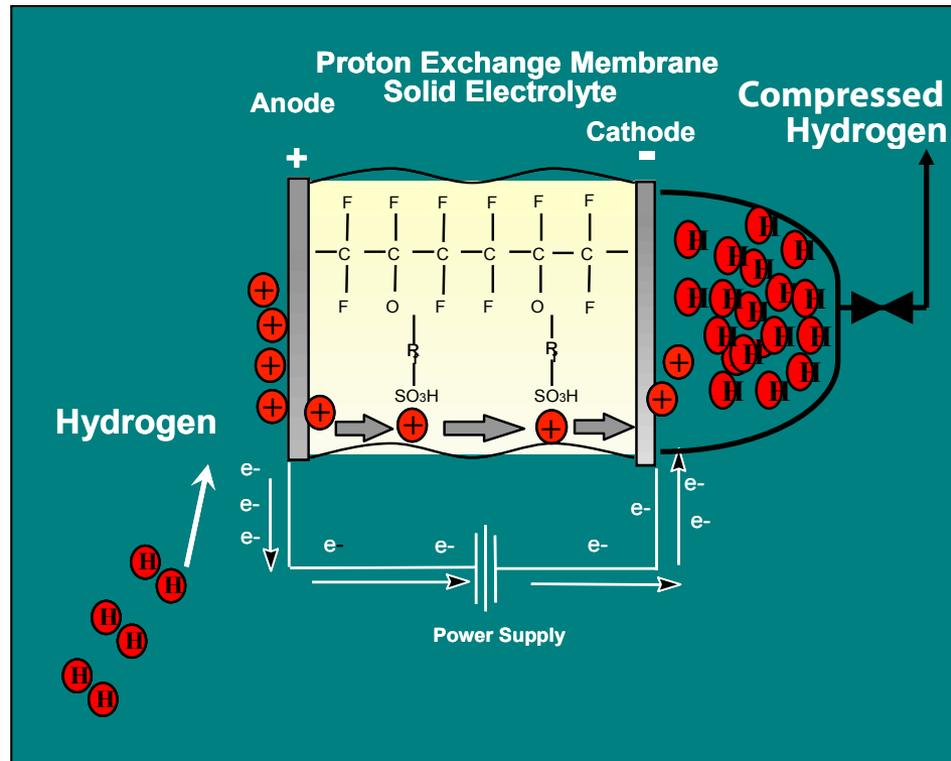


**Hydrogen as Energy Storage can Support Intermittent Wind Energy**

# Approach

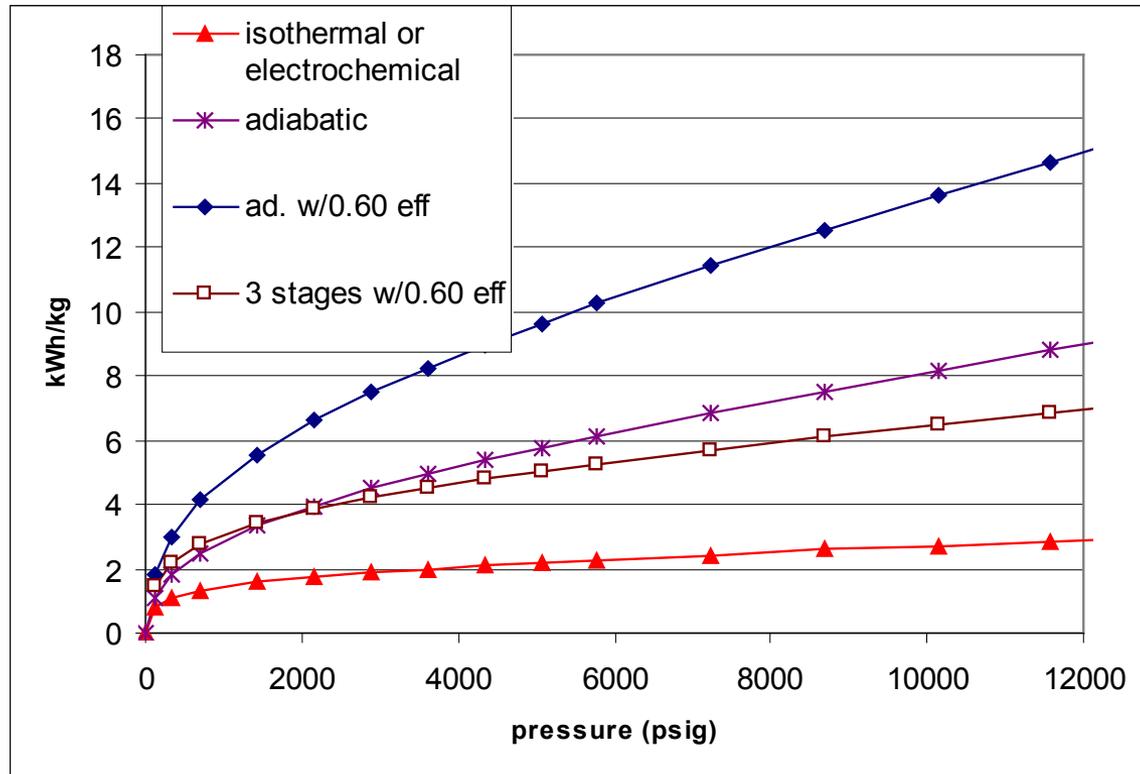
- **Use high-pressure electrolyzer experience for mechanically robust cell design**
- **Higher current density operation to minimize capital and operating costs**
- **Improved flow field design to increase H<sub>2</sub> recovery efficiency**
- **Simple system: Reduce capital cost by reducing catalyst loading and humidification requirements**

# Principle of Electrochemical Hydrogen Compressor



- Simple Operating Principle with No Moving Parts – **Solid State !**
- Use of Hydrogen Electrode for High Compression Efficiency

# Calculated Compressor Performance Values



**Electrochemical compression is by far the most efficient way to compress hydrogen**

# Approach to Achieving 12,000 psi Pressure Capability

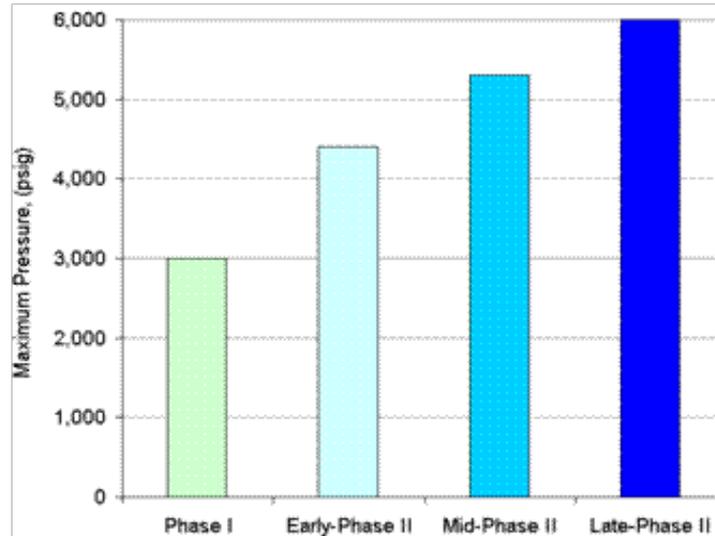
- **Design and Demonstrate Common Building Block (2,000 - 3,000 psi) for dual-use applications (industrial + fuel cell vehicles)**
- **Improve Performance of the building block (seals, creep, etc.) and implement lower cost fabrication processes**
- **Develop a Cascade System for 6,000 – 12,000 psi Capability**



# Technical Accomplishments and Progress – Previous Work



Baseline EHC Hardware Design



Progress in H<sub>2</sub> Compression Capability of EHC



2009 Hydrogen Program Annual Merit Review Award

MO3292

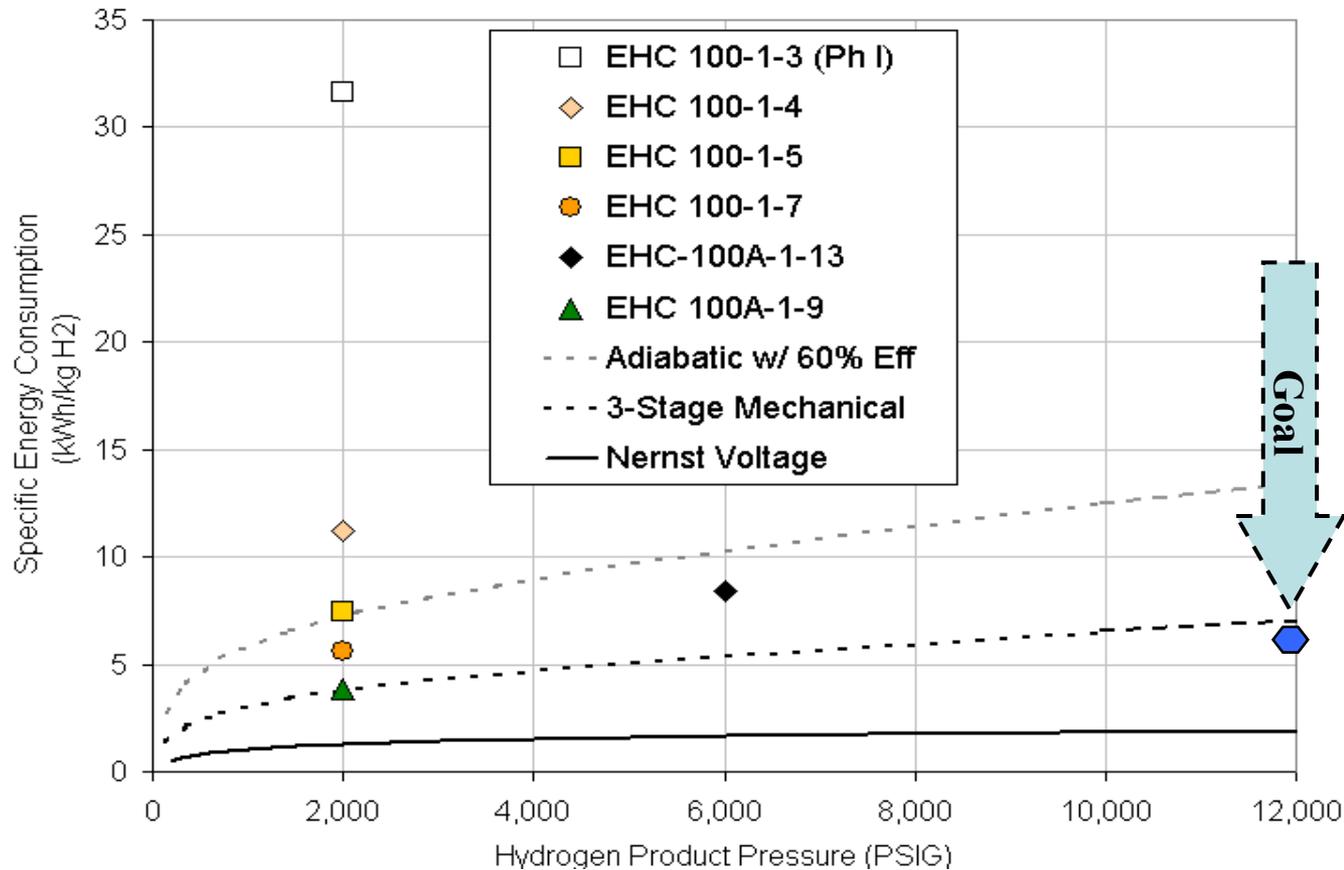
## Excellent Progress Made in EHC Cell Technology (DOE – Phase II – SBIR)

# Achievements in EHC Technology Development

Parameter	Phase II Goals	Current Status
No. of Cells in Stack	10	<b>10</b> ✓
Durability (single cell)	2,000 hrs	<b>3,000 hrs</b> ✓
Hydrogen Recovery Efficiency	95%	<b>&gt;95%</b> ✓
Hydrogen Product Pressure	6,000 psi	<b>6,000 psi</b> ✓ single stage <b>6,000 psi</b> ✓ 2-stage
Compression Ratio	300:1	<b>300:1</b> ✓
Minimize Hydrogen Inlet Pressure	5 psig	<b>&lt;5 psig</b> ✓
Pressure Cycling	≥20 cycles to 3,000 psi in 10-cell stack	<b>20 cycles to 3,000 psi in 10-cell stack</b> ✓
Hydrogen Flux	500 mA/cm <sup>2</sup>	<b>1,000 mA/cm<sup>2</sup></b>

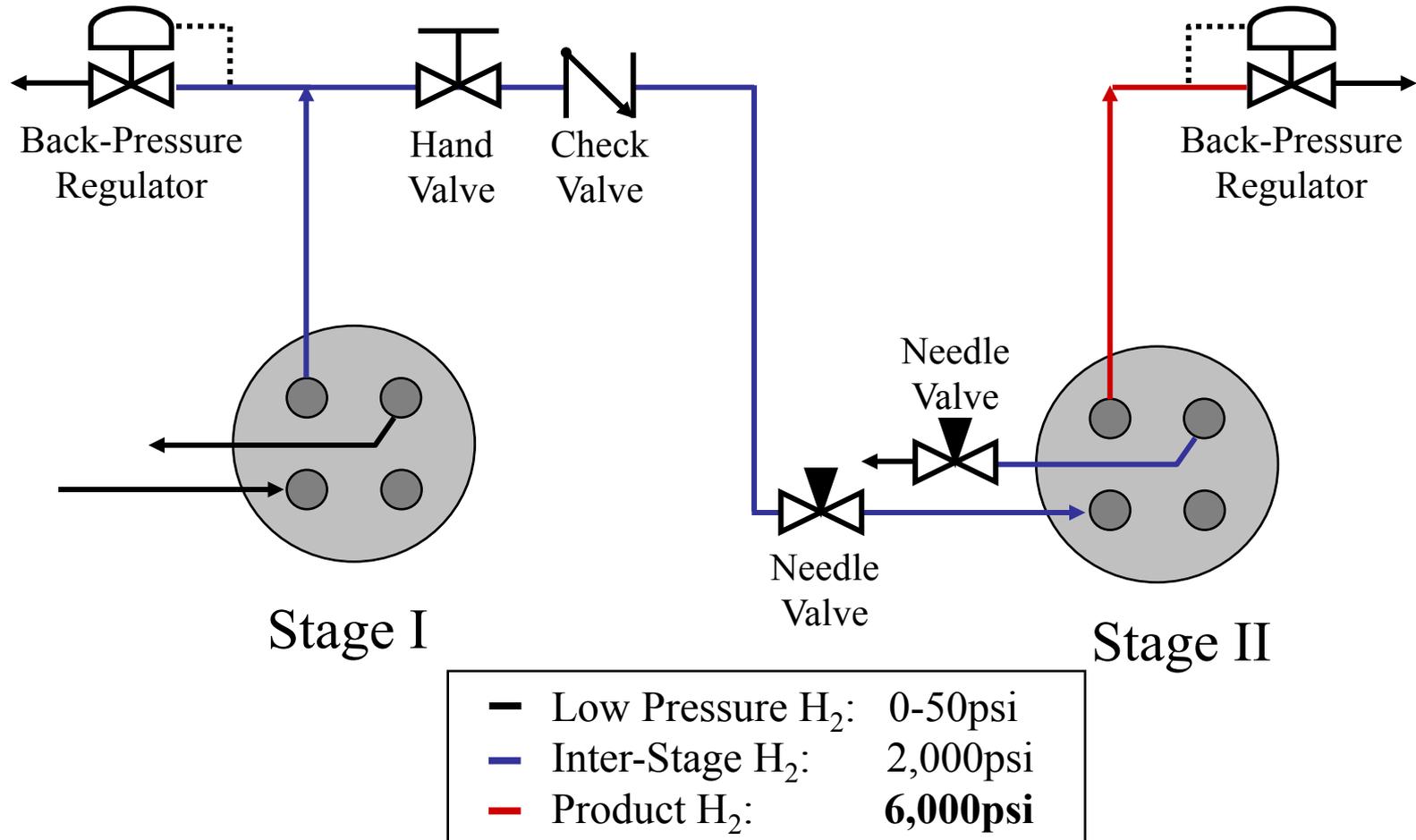


# Reduction in the Energy Consumption of EHC



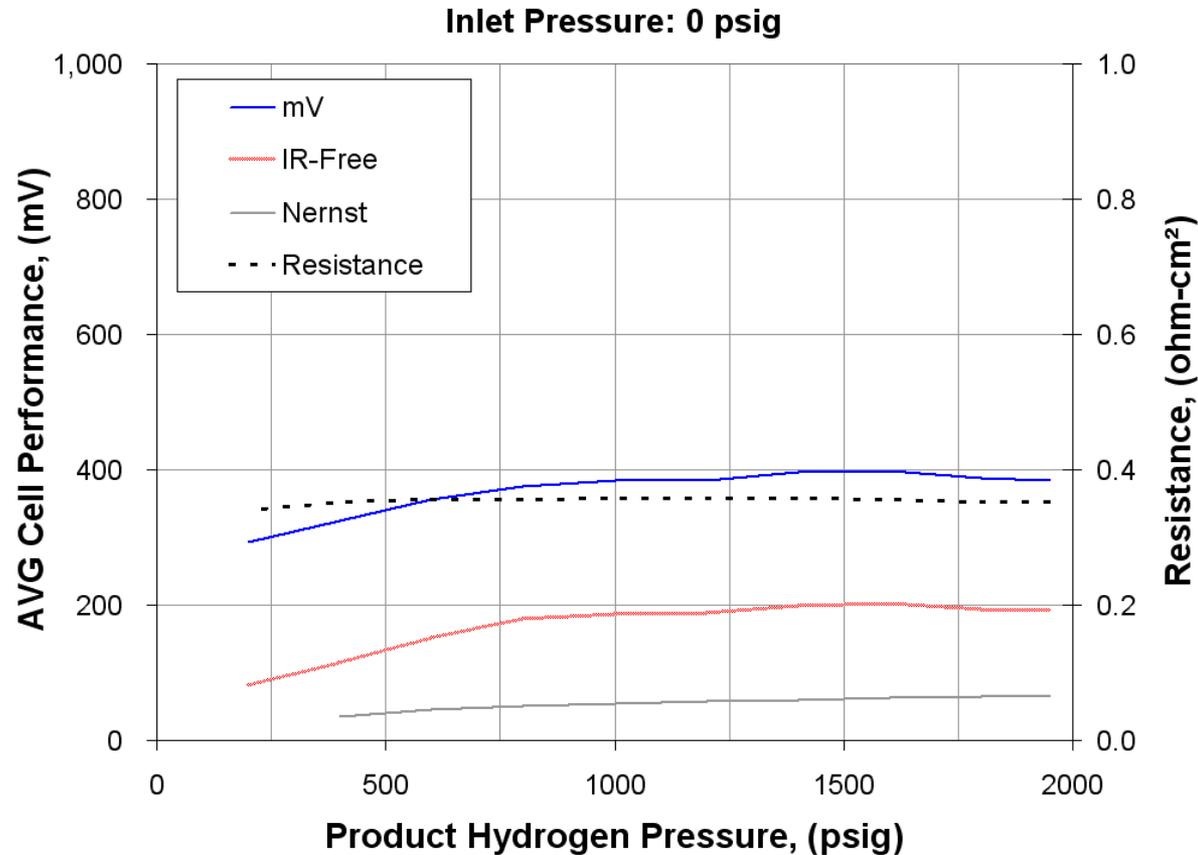
**Over 80% reduction in energy consumption**

# 2-Stage EHC System Concept



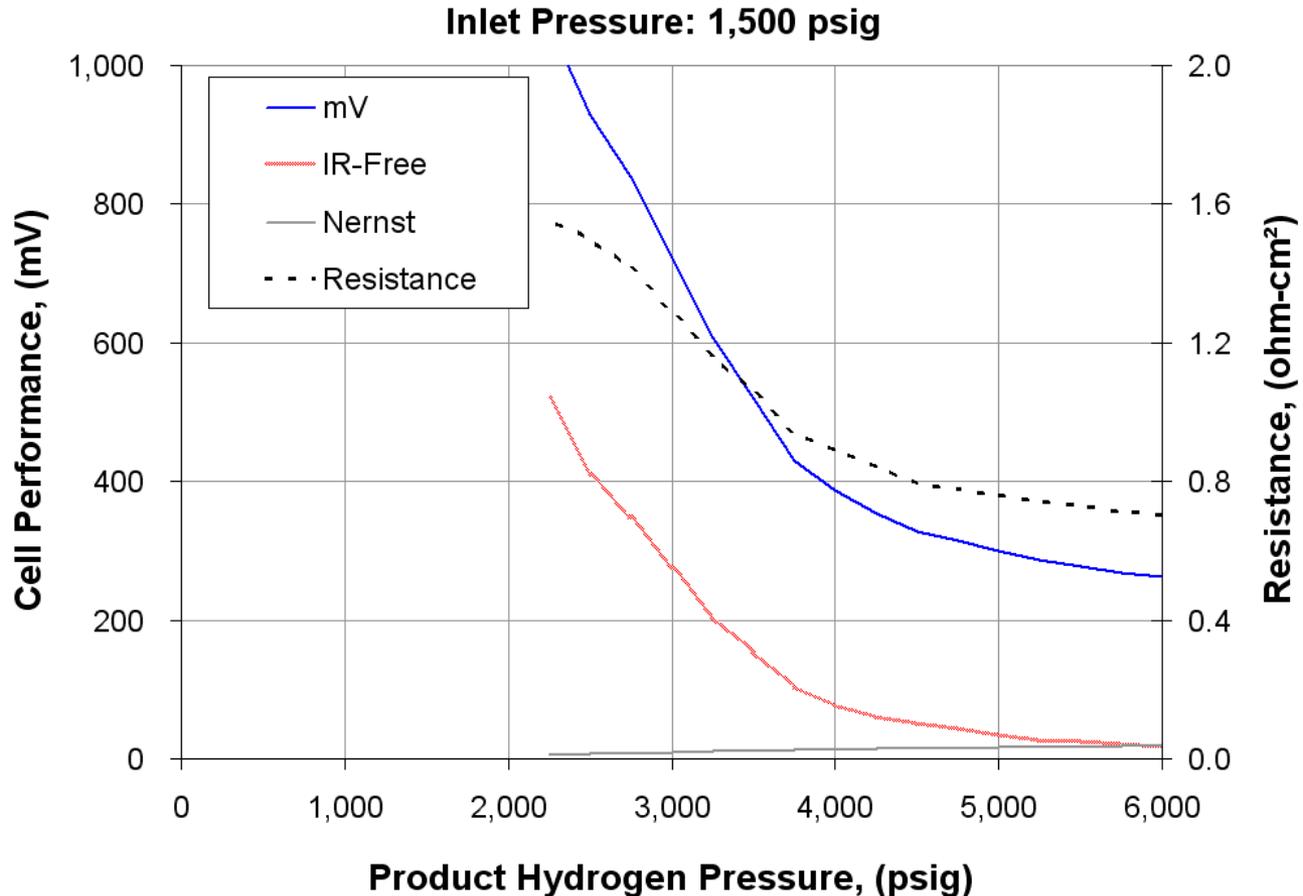
**High level control strategy developed**

# Stage I: 2-Cell EHC Stack



- Stack runs very stable at 1,500 psi
- Flat resistance curve

# Stage II: 6,000 psi EHC Cell



**Cell runs better at higher pressure**

# Collaborations

## Prime

- **FuelCell Energy, Inc.\* (Industry):**
  - **Leading fuel cell developer for over 40 years**

## Subcontractor

- **Sustainable Innovations, LLC\* (Industry):**
  - **Cell and stack design and fabrication**
  - **Scale-up design and fabrication**
  - **EHC stack cost estimates**

\* Within DOE H<sub>2</sub> Program

# Proposed Future Work

- **Fabricate and test four baseline cells – screen 17 improvement ideas**
- **Validate baseline stack design (up to 5 cells) - demonstrate 500 hr life at 2,000 - 3,000 psi**
- **Select promising advanced EHC cell design options**
- **Complete advanced EHC cell design review**
- **Fabricate cell hardware for advanced design (200 cm<sup>2</sup> active area)**
- **Design test facility for two-stage compression up to 12,000 psi**



# Scale-Up Plan to Reach 8 lb/day

Activity Covered  
Under Current Funding



Single Cell  
200 cm<sup>2</sup> Active Area  
500 – 1000 mA/cm<sup>2</sup>  
Up to 0.4 lb/dy

3 - Cell  
200 cm<sup>2</sup> Active Area  
500 – 1000 mA/cm<sup>2</sup>  
Up to 1.2 lb/dy

10 - Cell  
200 cm<sup>2</sup> Active Area  
500 – 1000 mA/cm<sup>2</sup>  
Up to 4 lb/dy

Activity Not Covered  
Under Current Funding

20 - Cell  
200 cm<sup>2</sup> Active Area  
500 – 1000 mA/cm<sup>2</sup>  
Up to 8 lb/dy

# 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% ( $H_2$  flux increased to 1,000 mA/cm<sup>2</sup>)
- Developed 2-stage EHC system concept
- Validated 2-stage EHC hardware feasibility at 2,000/6,000 psi level

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

**Proposed Future Work:** Scale-up cell design to 200 cm<sup>2</sup> active area to increase throughput and lower the cost

# Acknowledgement

- FCE: Pinakin Patel, Ray Kopp, Jonathan Malwitz
- Sustainable Innovations, LLC: Trent Molter and team
- DOE: Monterey Gardiner, Scott Weil, Paul Bakke

