FuelCell Energy

DOE Hydrogen Program

Electrochemical Hydrogen Compressor

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FuelCell Energy, Inc.

May 10, 2011

Project ID
#PD048

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_2**
- **Increases Compression Efficiency to 95% (DOE 2015 Target)**
- **Potentially reduces cost of H_2 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_2 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

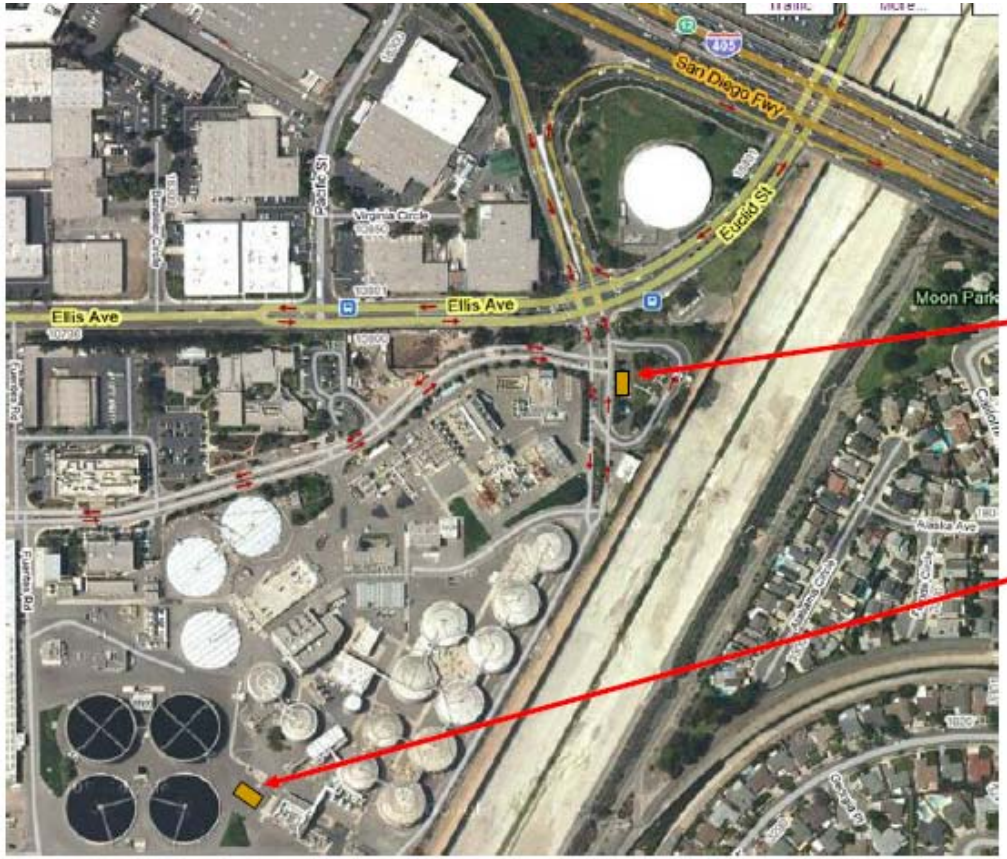
DFC Products are uniquely capable of operating on many fuels

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_2 Filling Station

ADG fueled DFC-H2® Production Unit

Energy Efficiency & Renewable Energy

Southern California Gas Company

California Environmental Protection Agency AIR RESOURCES BOARD

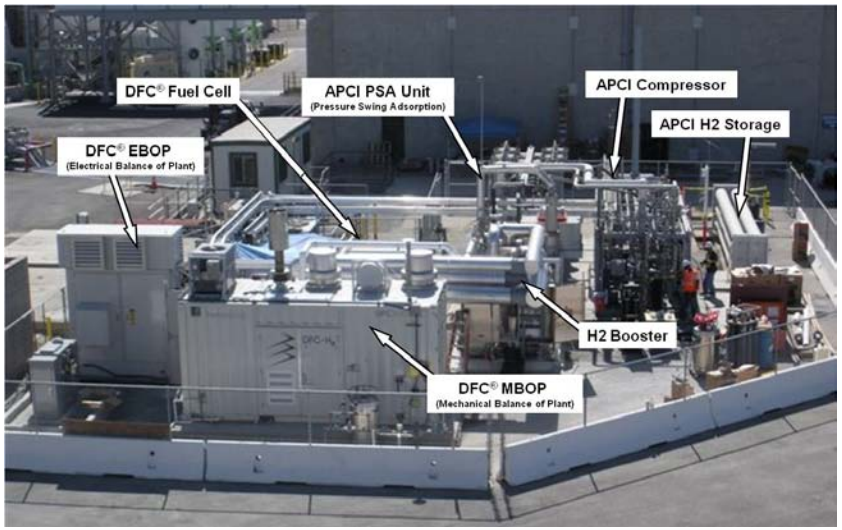
University of California - Irvine

AQMD

AIR PRODUCTS

OCSD Site Demonstration

- October 2010 – DFC-H_2 Start-up on Natural Gas
  - Co-production Efficiency (H_2 + Power) 54.2%
- November 2010 – Mechanical Completion of Hydrogen Fueling Station
- February 2011 – First Delivery of H_2 to Fueling Station
- March 2011 – Initial Test Fills of Fuel Cell Vehicles



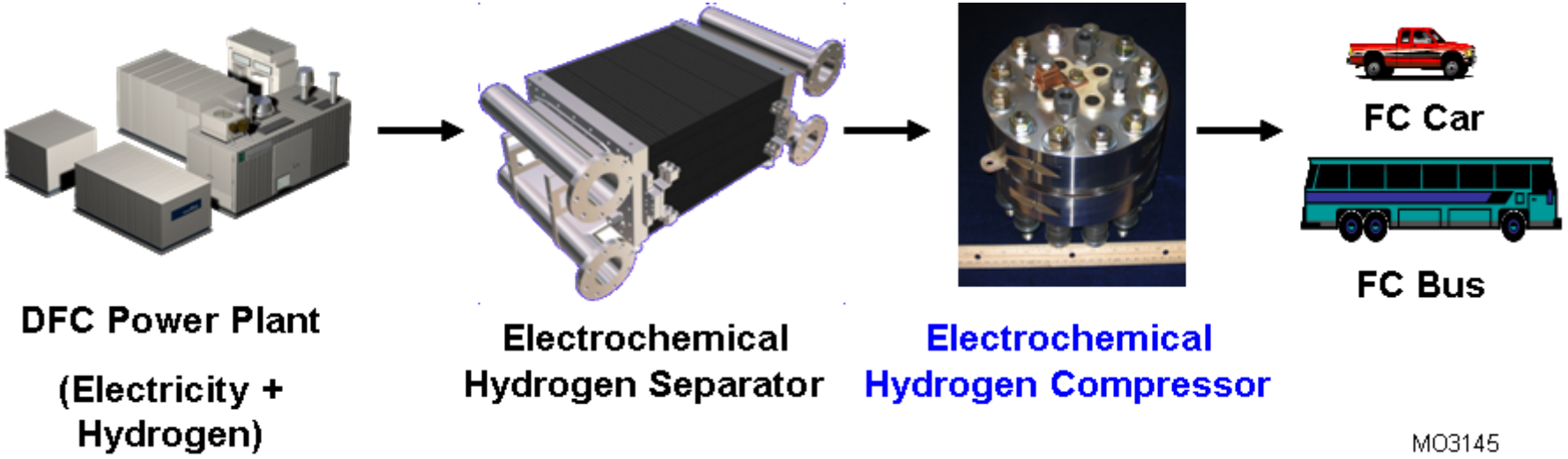
Hydrogen Energy Station

Hydrogen Fueling Station

FuelCell Energy

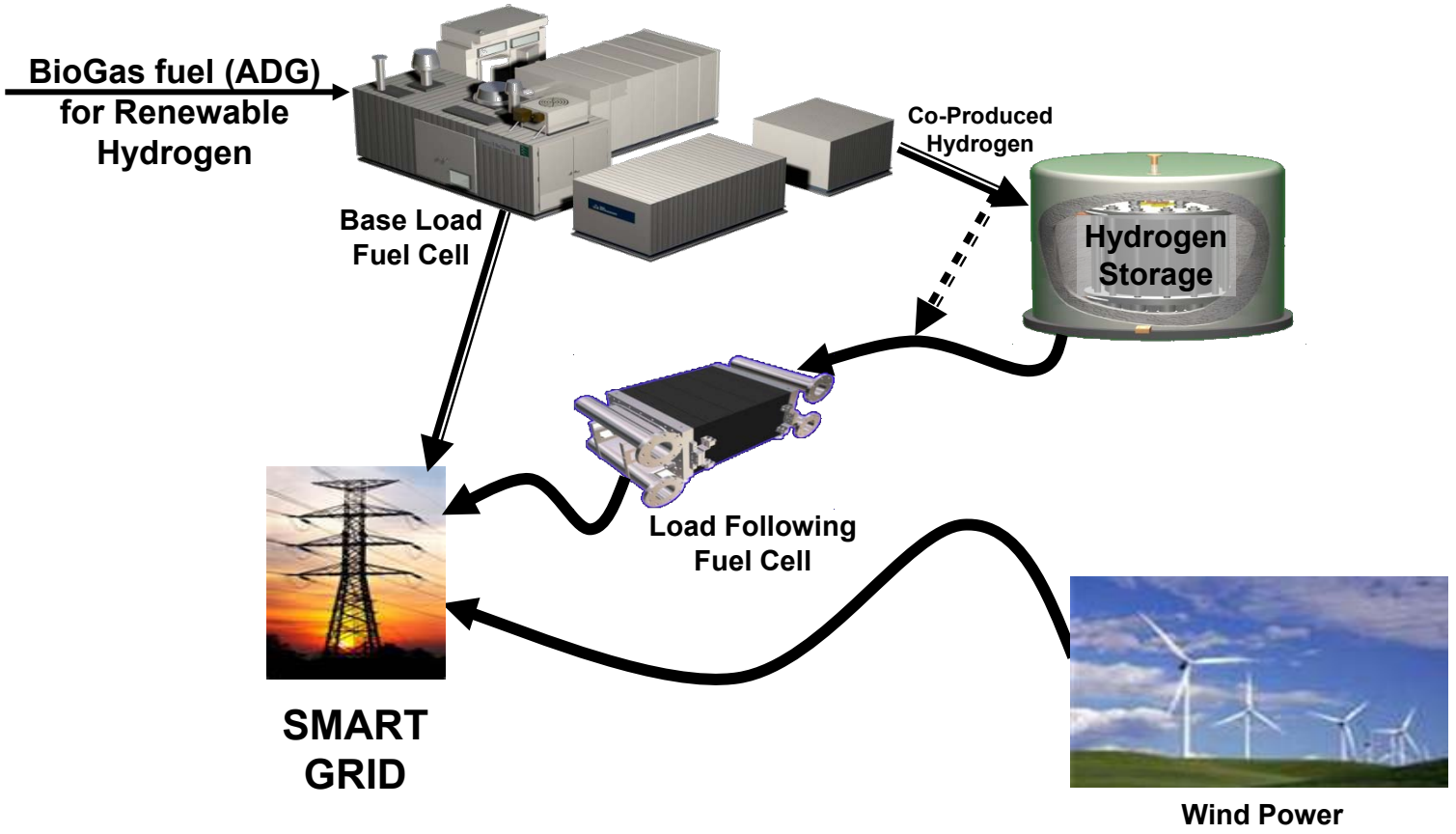
AIR PRODUCTS

Enabling Technology for Hydrogen Co-production



Technologies for Hydrogen Infrastructure and Smart Grid

DFC-H2® Applications for the Smart Grid

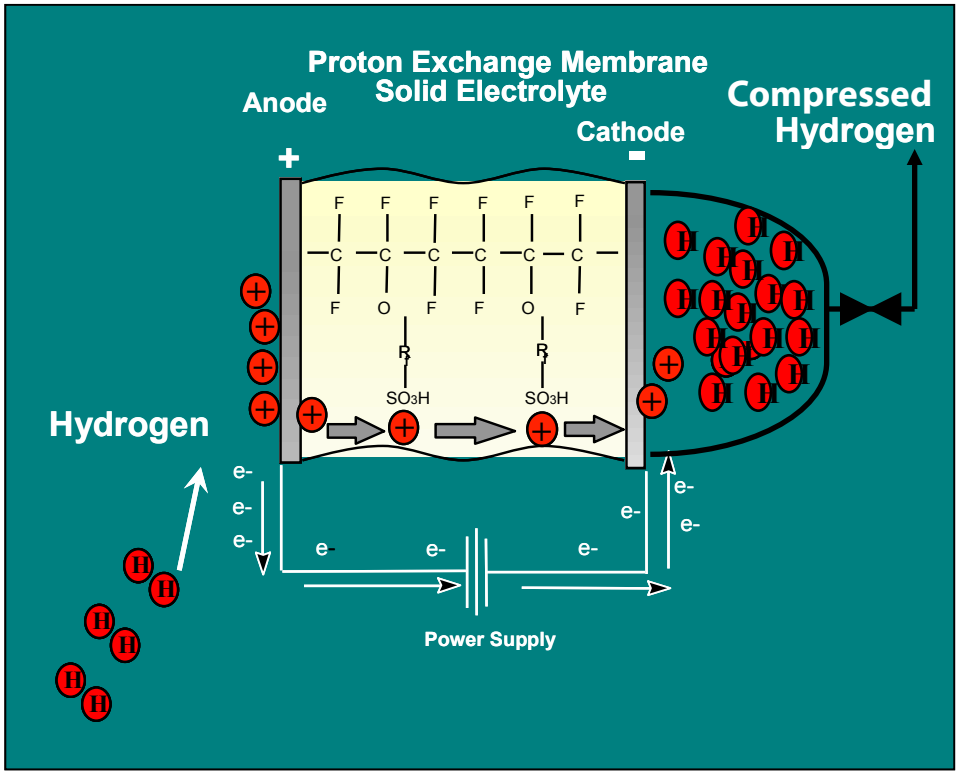


Hydrogen as Energy Storage can Support Intermittent Wind Energy

Approach

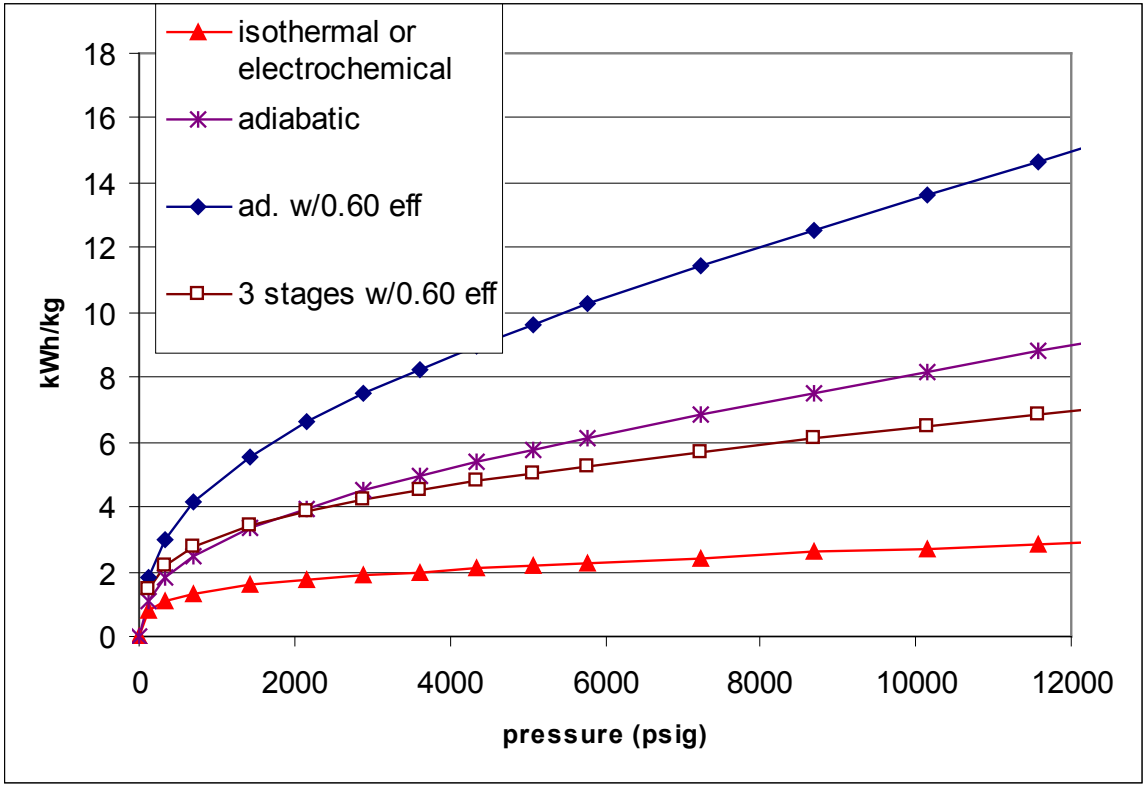
- **Use high-pressure electrolyzer experience for mechanically robust cell design**
- **Higher current density operation to minimize capital and operating costs**
- **Improved flow field design to increase H_2 recovery efficiency**
- **Simple system: Reduce capital cost by reducing catalyst loading and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



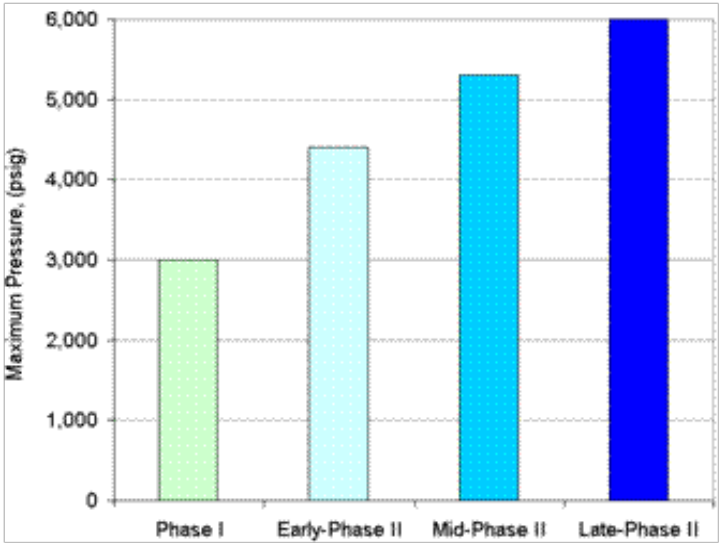
Electrochemical compression is by far the most efficient way to compress hydrogen

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_2 Compression Capability of EHC

2009 Hydrogen Program Annual Merit Review Award

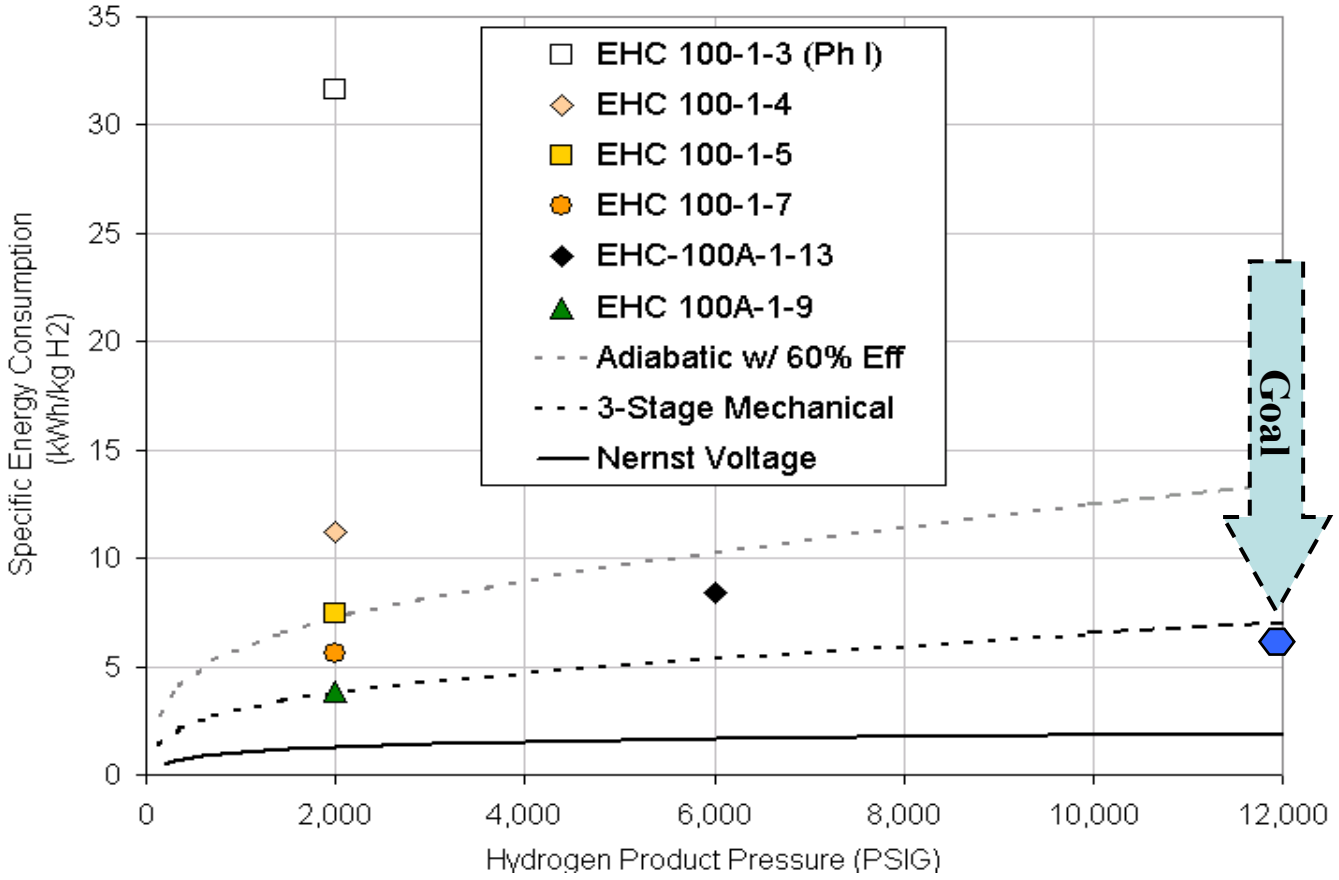
MO3292

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

Achievements in EHC Technology Development

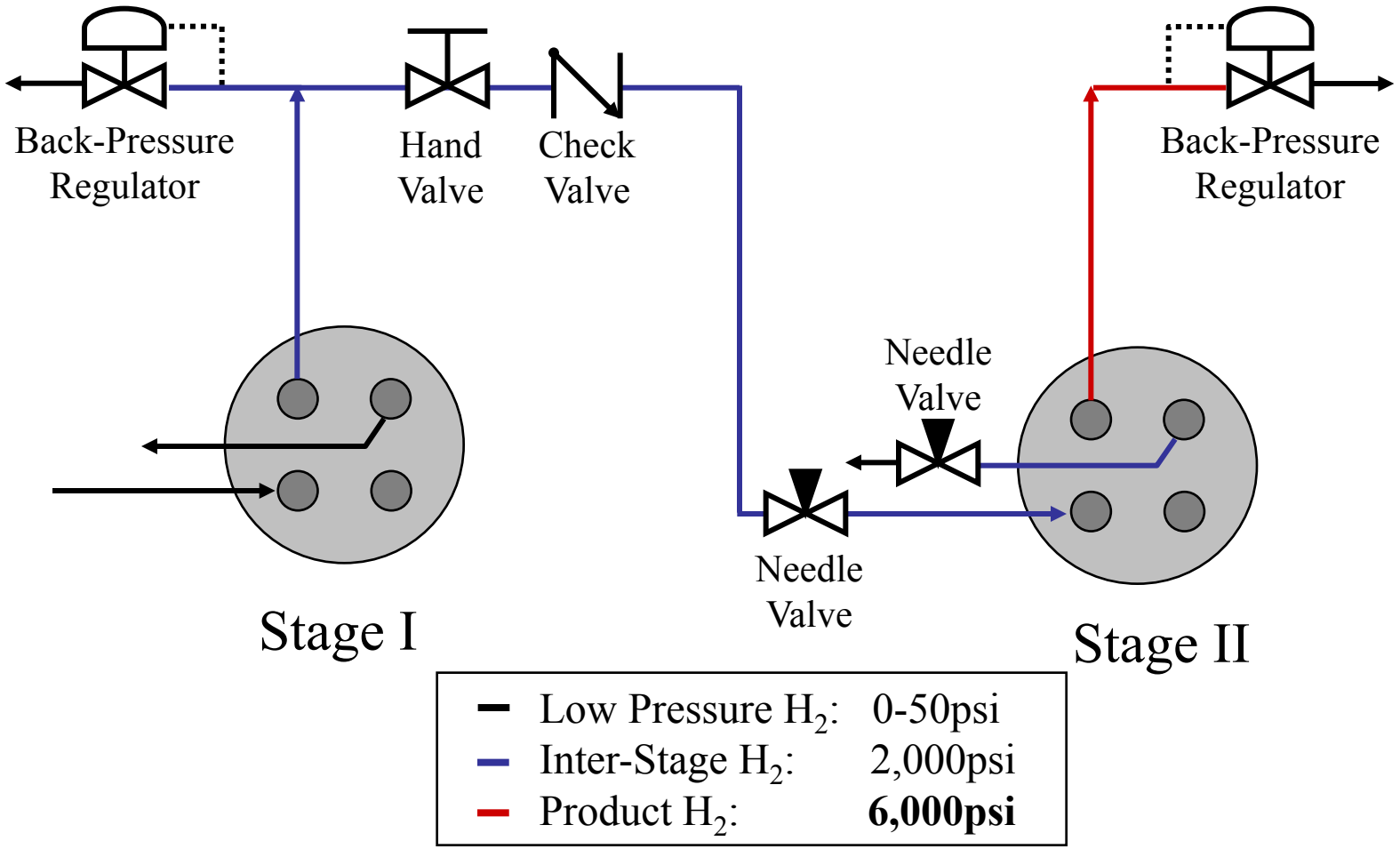
Parameter	Phase II Goals	Current Status
No. of Cells in Stack	10	**10** ✓
Durability (single cell)	2,000 hrs	**3,000 hrs** ✓
Hydrogen Recovery Efficiency	95%	**>95%** ✓
Hydrogen Product Pressure	6,000 psi	**6,000 psi** ✓ single stage **6,000 psi** ✓ 2-stage
Compression Ratio	300:1	**300:1** ✓
Minimize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

Reduction in the Energy Consumption of EHC



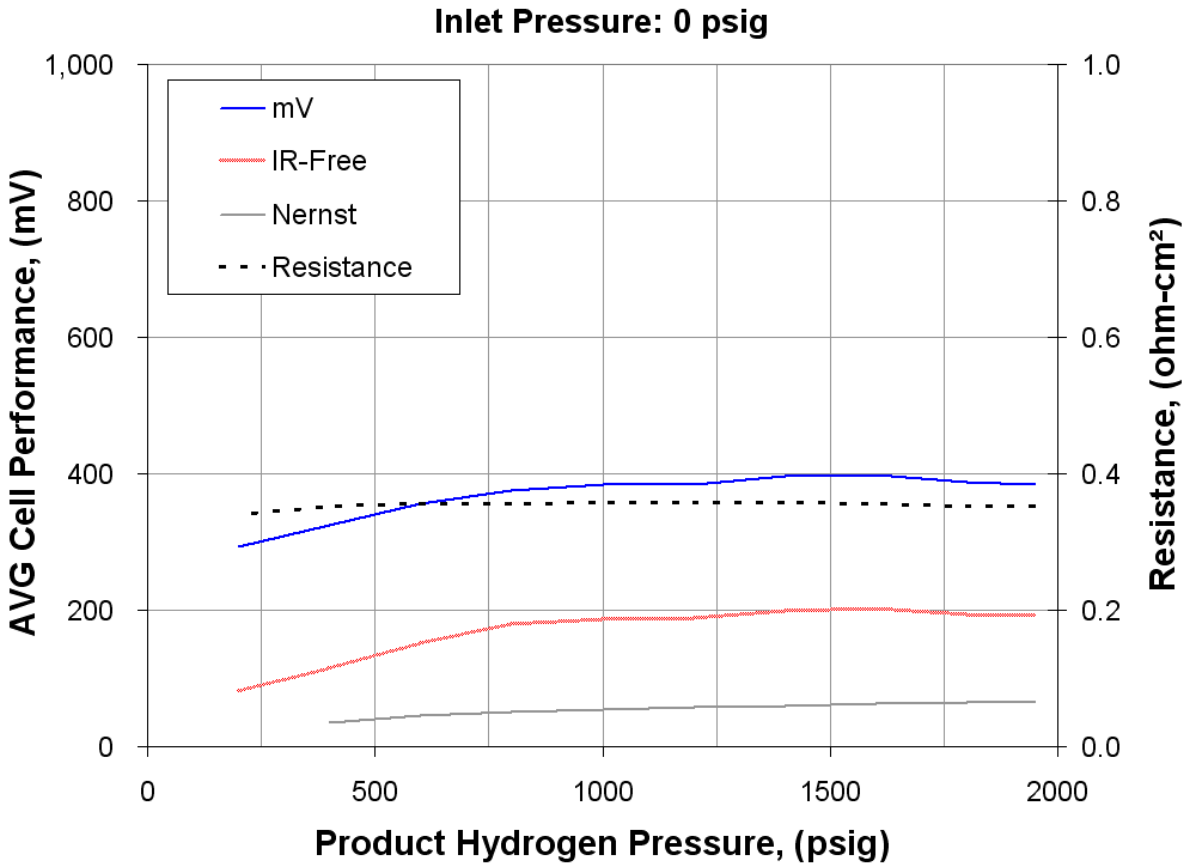
Over 80% reduction in energy consumption

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**

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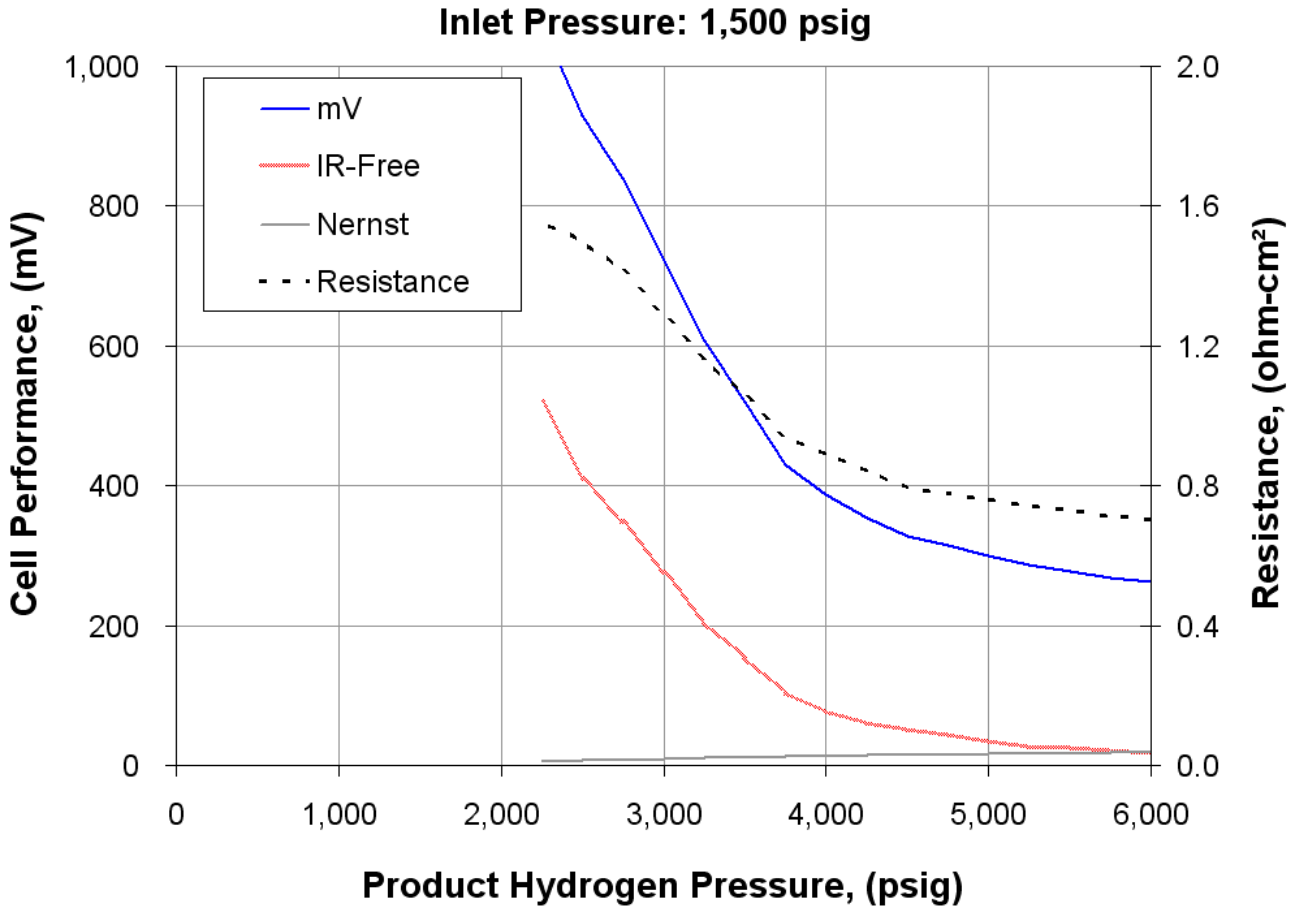
Sustainable Innovations

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_2 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^2 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

Activity Not Covered
Under Current Funding

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

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

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

20 - Cell
200 cm^2 Active Area
500 – 1000 mA/cm^2
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^2)**
- **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^2 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