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DOE Hydrogen Program

2007 DOE Hydrogen Program Review – Hydrogen Filling Station

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UNLV Center for Energy Research
May 21, 2007

Project ID
#TVP 8

OVERVIEW

TIMELINE

- Project start: 6/12/03
- Project end: 12/31/07
- 83% complete

BUDGET

- Total project funding
  - DOE $12,232,604
  - Contractor $4,131,969
- FY03 $963,372
- FY04 $2,943,232
- FY05$4,960,000
- FY06 $3,366,000

BARRIERS

- Barriers addressed (technology validation)
  - Vehicles
  - Hydrogen Refueling Infrastructure
  - Hydrogen from Renewable Resources

PARTNERS

- Project collaborations with:
  - Air Products
  - Altair Nanomaterials
  - Hydrogen Solar
  - IF LLC
  - Las Vegas Valley Water District
  - Southern Nevada Water Authority
  - Proton Energy Systems, Inc.
  - Kells Automotive
  - NREL
  - Nevada Power
  - APS

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HFS Project Partners

- UNLV Research Foundation, Project Administration and Management
- UNLV Center for Energy Research, Research & Development, Vehicle Conversions, Data Acquisition, Web Development, and Field Support
- Proton Energy & Air Products, Design of HFS, Equipment Supplier & System Installer
- Las Vegas Valley Water District, Engineering Design, Design of Electrical System for the HFS, Fleet Services, Maintenance & User of HFS and vehicles, Station Location
- Springs Preserve, Public Information, Vehicle demonstration and use
- Kell's Automotive Marine, ICE engine conversions and testing
- Altair Nanotechnology, Hydrogen Solar, Photocatalytic device development
- IF, LLC, codes and standards, roadmapping support

Partners not funded by DOE funds:

- Southern Nevada Water Authority, Energy Management, Project Management
- SNWA Engineering, project engineer for the Solar PV System
- Arizona Public Service, Design and Installer of Solar PV System
- Colorado River Commission, Maintenance of Solar PV System
- Nevada Power Company, Renewable Incentives

OBJECTIVES

OVERALL

To demonstrate current and future renewably-based hydrogen generation technology and its uses via student education and private/public partnerships.

To assist in developing a hydrogen-based business climate in the Desert Southwest

SPECIFICS

Note: Detailed listing of specifics given on next page.

- Hydrogen generation technology development
  - High pressure PEM electrolysis
  - Photo-electrochemical generation using Tandem Cells™
- Hydrogen uses:
  - Vehicle conversion technology & transfer to local businesses
- Desert Southwest hydrogen-based climate
  - Collaborate with local companies with expertise in hydrogen applications
  - Further DOE's codes & safety efforts
  - Provide a roadmap for hydrogen development in state/region

DETAILED OBJECTIVES

2003:
Design, develop, site, install and commission a hydrogen refueling station
2004:
Enhance station by improving performance for high pressure electrolysis
Design, fabricate, install and commission PV array connected to station
Convert ICE vehicle to hydrogen – design, convert, optimize, test
Convert utility vehicle to fuel cell – design, install, evaluate performance
Perform research on thin film optimization to maximize efficiency of photo-catalytic sunlight hydrogen production
2005:
Enhance station by integrating higher pressure electrolyzer with greater efficiency
Convert Ford pick-up to burn hydrogen with engine modified to use direct cylinder inject (ICE to power vehicle – fuel cell to cover electrical loads)
Develop small prototype vehicle to run as a hybrid fuel cell and an internal combustion engine
Develop and conduct hydrogen safety workshop that addresses deployment and risk management
Assess and develop a roadmap for hydrogen deployment in Nevada
Perform research in photo electric chemistry (PEC) having to do with the production of hydrogen using a Tandem Cell and nanotechnology processes
2006:
Continuing support for the refueling station including maintenance, monitoring and evaluation
Continuing support for vehicle integration with the LVVWD
Development of advanced proton exchange membranes (PEM) for electrolysis with improved ohmic resistance losses, hydrogen back-diffusion properties and performance degradation
Development of advanced PEM electrolysis Catalyst Structures
Characterization of the PEM electrolysis membrane-electrode interface
Development of advanced PEM electrolysis bipolar plates
Development of advanced high efficiency PEM electrolysis cell stack designs
Create theoretical models and numerical simulations of electronic structure and charge carrier mobility in novel PEC semiconductor and photo catalytic materials and alloysResearch new PEC semiconductor materials with appropriate bandgap and charge carrier mobility
Ensure that new PEC catalytic thin film materials maintain their activity in low temperature processing

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APPROACH

- Build a facility where generation and utilization technology can be developed, demonstrated and refined.
- Partner with LVVWD, a major potential customer for hydrogen technology applications, to install this technology in the field, applying current codes and standards.
- Identify and work with local companies interested in hydrogen technology development.
- Sponsor workshops with stakeholders and experienced personnel to collaborate on a roadmap of a hydrogen-development scenario for local area.
- Educate students extensively in the project.

TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

- Phase 1
  - Installation of Low Pressure PEM Electrolyzer Fueling Station
  - Status - **COMPLETE**
- Phase 2
  - Upgrade of Station to include High Pressure Electrolyzer
  - Status - **COMPLETE**
- Phase 3
  - Upgrade of Station to include 400 psig Large Electrolyzer
  - Status – Design Complete; System under Fabrication
- Phase 4
  - Research & Development on Higher Efficiency Electrolysis
  - Status – R&D initiated on component research & modeling

TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

Completion of Hydrogen Filling Station Installation

- Low (200 psig) Renewable-PEM Electrolyzer – 2.0 kg/day
- High (1100 psig) PEM Electrolyzer – 0.25 kg/day
- Air Products Compression/Dispensing
- PV Arrays Co-Located on Site

TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

Upgrade of Hydrogen Filling Station to 400 psig

- Design of 400 psig PEM Electrolyzer w/12 kg/day Production Capacity Completed
- Fabrication of Electrolyzer In Progress

Station's Photovoltaic System

- 4 Single-axis Tilted Trackers at 4.2 kWe each,
- Plant Output: 16.8 kW_e DC; 14 kW_e AC,
- Net metering agreement with power utility,
- Annual Expected Generation: 37,000 kWh approx.
- Not funded by DOE, but by project partners.

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Data Acquisition System

Monitored Parameters:

- Ambient temperature, relative humidity, wind speed and direction,
- Incident solar radiation on PV trackers, PV cell temperatures,
- Power usage by electrolyzers, compressors, dispenser, and chiller,
- PV system power generation,
- Hydrogen mass flow rates measurement investigated and proposed.

Electrolyzers' operation monitored remotely by Proton Energy Systems, dispenser and compressors' monitored remotely by Air Products

Data downloaded to UNLV, archived, software used to generate web site plots and do calculations.

Operator and First Responder Training, Station Formal Opening

- Safety and Training Seminars held for First Responders, LVVWD and UNLV students and staff by manufacturers,
- Conducted DOE Hydrogen Safety Panel Inspection, suggestions incorporated into systems and awaiting written recommendations.
- Station opening ceremony and media demonstration, April 12, with 95 in attendance, including Congressional delegation representatives and members of the Clean Cities Coalition.

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UNLV Hydrogen Vehicle Conversions

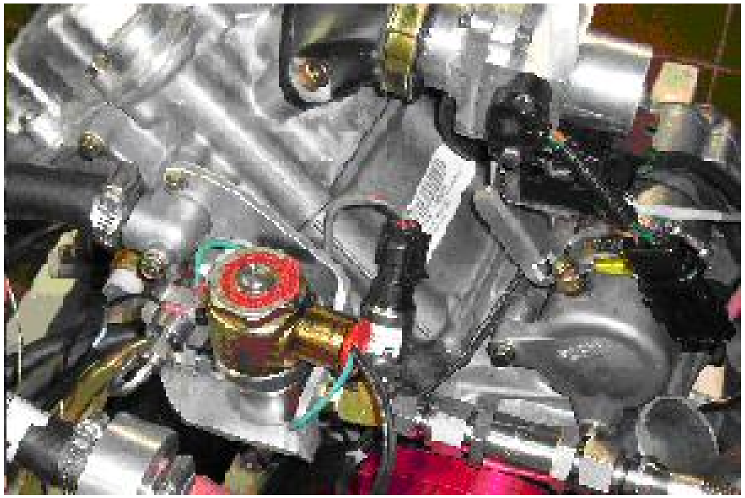
Two off road utility vehicles provided by LVVWD were converted by students:

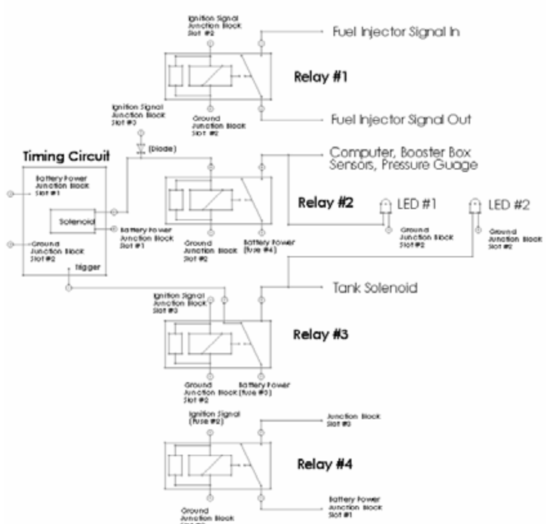
- Polaris Ranger with Internal Combustion Engine (ICE) converted to run on hydrogen. Uses locally developed, state of the art in-cylinder injection.
- Taylor-Dunn Electruck electric utility vehicle modified with the addition of a PEM fuel cell to demonstrate lower cost fuel cell vehicles.

Have garnered great interest from automotive companies since development of the vehicles and the station.

Vehicles are to be used at the LVVWD Desert Springs Preserve facilities which is the filling station location.

Polaris Ranger ICE Conversion





Modifications:

- Conventional Engine modified for direct cylinder injection of hydrogen through machined head. Crankcase venting added. Timing system modified and engine computer control added. Modifications and dynamometer testing performed at Kell's Automotive Marine. Installation and field testing performed at UNLV.
- Hydrogen fuel system added including a 0.67-kg Dynatek L026 350-bar tank with integral Teleflex TV-115 tank manifold equipped with tank solenoid/check valve and pressure relief device. Additional pressure relief device added between pressure regulator and engine components. Other components added include pressure transducer and display, fill pressure gage, filter, fill nozzle, an alternate fill connection and isolation valves. An accessible manual hydrogen isolation valve was installed to shut off hydrogen flow to the engine without using tools.
- Electrical system modifications were made with the addition of the engine control computer and control system for the engine startup and shutdown. Onboard data acquisition system to monitor parameters is in testing.

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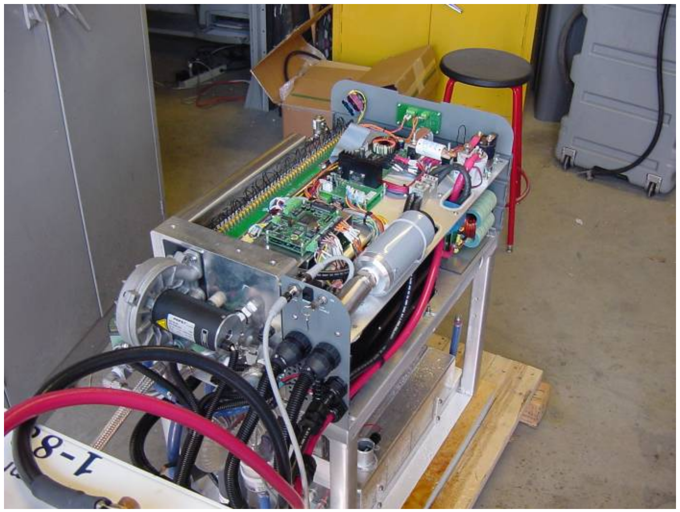
Taylor-Dunn Electruck FCV Conversion



Modifications:

- A Nuvera H2e 5.5-kW PEM fuel cell was added beneath the rear deck of the vehicle which provides power to recharge batteries and power the electric drive system, modifications were made to fuel cell cooling system for the application. Fuel cell installed at UNLV and checked by Nuvera engineers.
- 6-VDC batteries were replaced with 12-VDC batteries to allow room for the fuel cell. Power conversion unit installed to regulate voltage and regulate fuel cell load. Fuel cell sequence controls added to control fuel cell startup and shutdown. Onboard data acquisition added to monitor parameters.
- Hydrogen fuel system added including two 0.67-kg Dynatek L026 350-bar tanks with integral Teleflex TV-115 tank manifolds equipped with tank solenoids/check valves and pressure relief devices. Additional pressure relief device added between pressure regulators and fuel cell. Other components added include pressure transducer and display, filter, fill nozzle, an alternate fill connection and isolation valves. An accessible manual hydrogen isolation valve was installed to shut off hydrogen flow to the fuel cell without using tools.
- Regenerative braking to be added.

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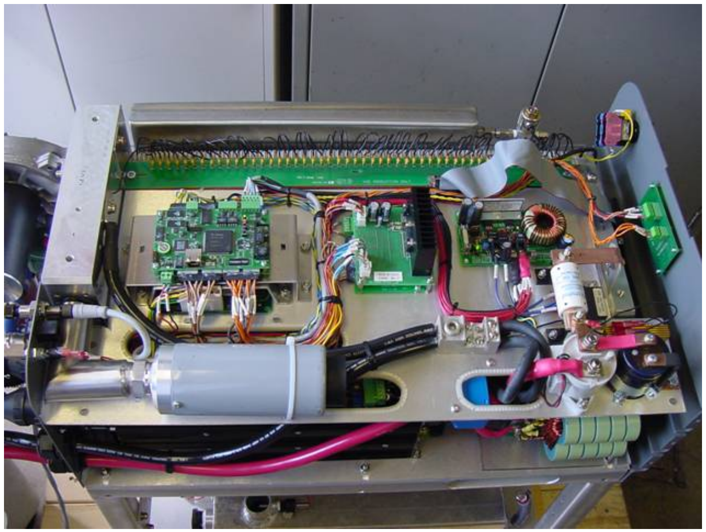
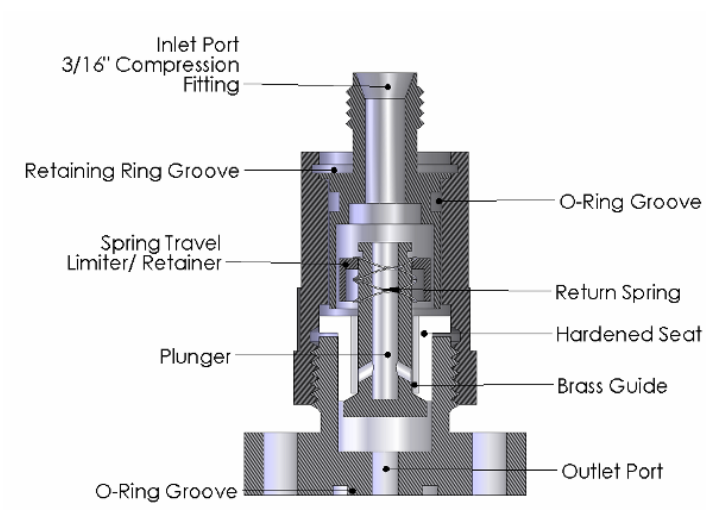
Component Specifications





- Vehicle's modifications used components specifically designed for use with hydrogen.
- Installed to the latest CNG standards, manufacturer's specifications, and hydrogen specifications when available.
- Component's manufacturer's consulted on many of the installations. Recommendations used in the systems designs.
- Fabricated components, such as the in-cylinder injection check valve, went through materials testing for suitability, bench testing, dynamometer testing, and months of vehicle road testing at the university. Components disassembled after testing and tolerances checked.
- Electrical components and assemblies, such as the FCV power conversion system and sequencing controls, bench tested through multiple cycles, load tested, and months of road testing.
- Operational Safety considered for each component used.
- Components used for high pressures and hydrogen applications checked for rating and suitability. Pressure ratings documented.

Current Vehicle Conversion Work

Full sized pickup truck conversion in progress:

- New, simplified, in-cylinder injectors are currently being manufactured in preparation for testing and installation,
- Vehicle computer interface research underway, components in procurement,
- Fuel system components specified and purchased,
- Auxiliary fuel cell power unit (APU) with super-capacitor storage to run vehicle electrical loads bench and load tested, safety and charging control circuits completed and ready for bench testing,
- Conversion to be completed with road testing by end of ‘07.

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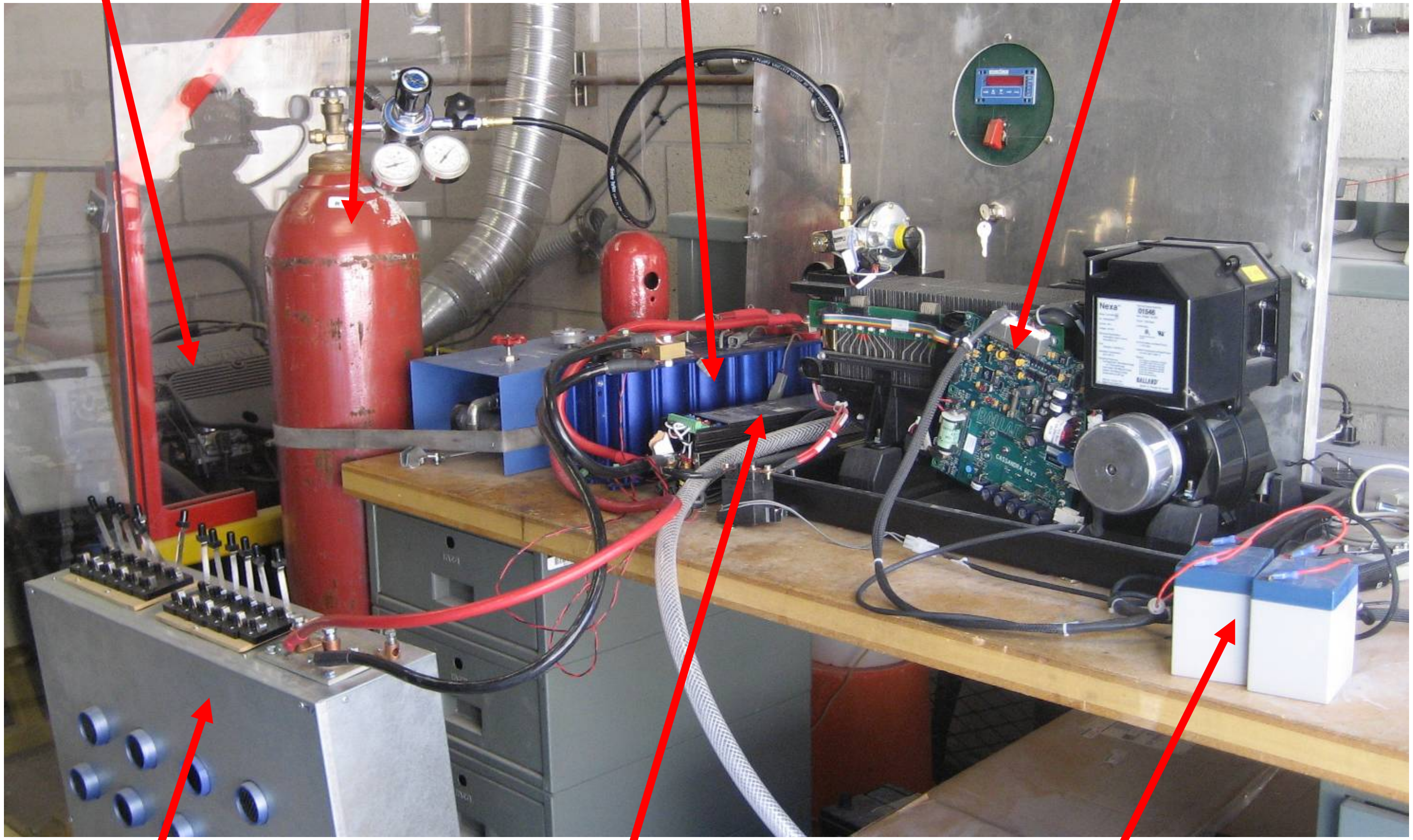
Fuel Cell APU Experimental Set-Up

V-8 Engine **Fuel Tank** **Supercapacitor** **Fuel Cell**



Load Bank **DC/DC Converter** **Battery (for start-up And shut-down)**

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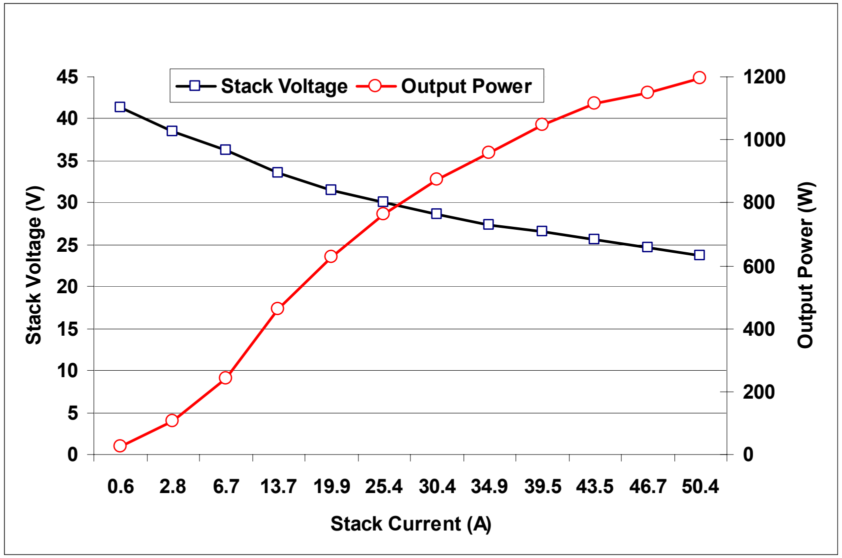
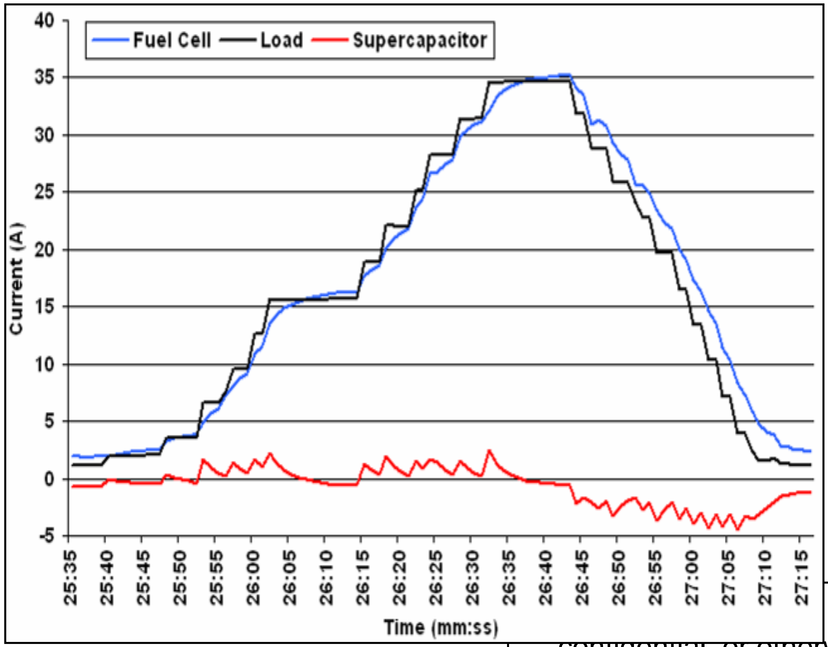
Fuel Cell APU Testing





- Actual vehicle loads measured and characterized,
- Fuel cell and super-capacitor bank sized for vehicle loads,
- Bench test conducted to test APU with vehicle loads.

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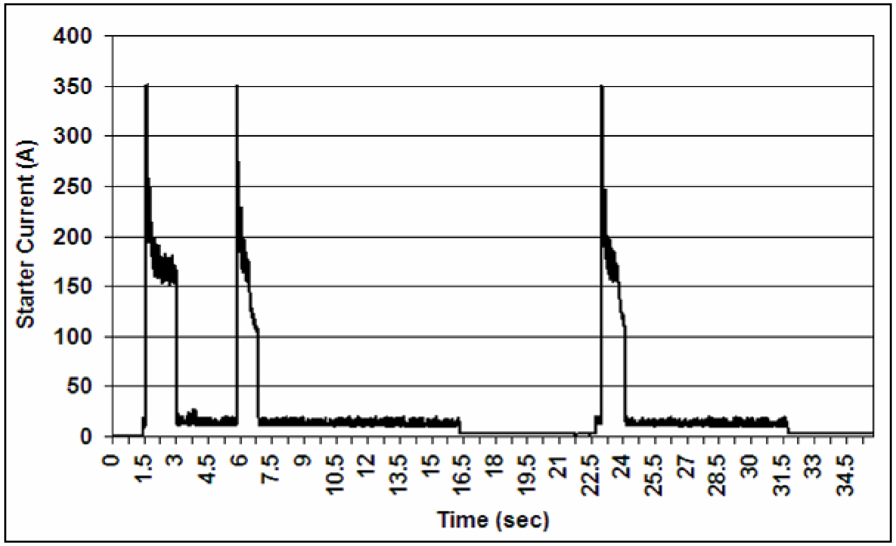
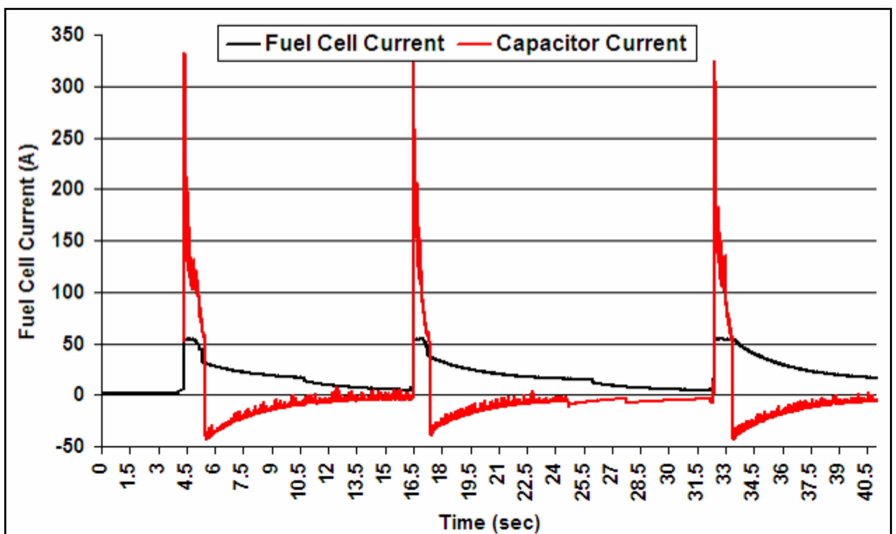
Fuel Cell APU Testing



Engine starting and operational currents from battery.



APU starting and operational currents.

TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

Higher Efficiency PEM Electrolysis

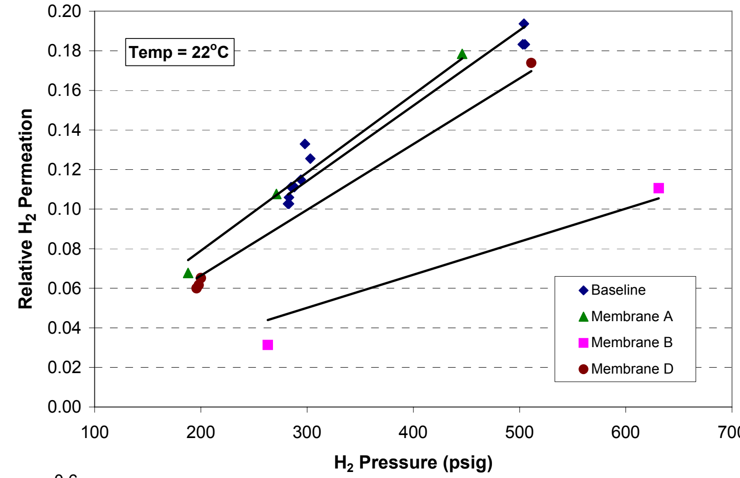
- Catalyst, Membrane, MEA Development/Testing
- Low Cost Bipolar Plate Development
- Scale-up / Manufacturing Assessment
- Renewable Interface Development
- Stack / System Modeling

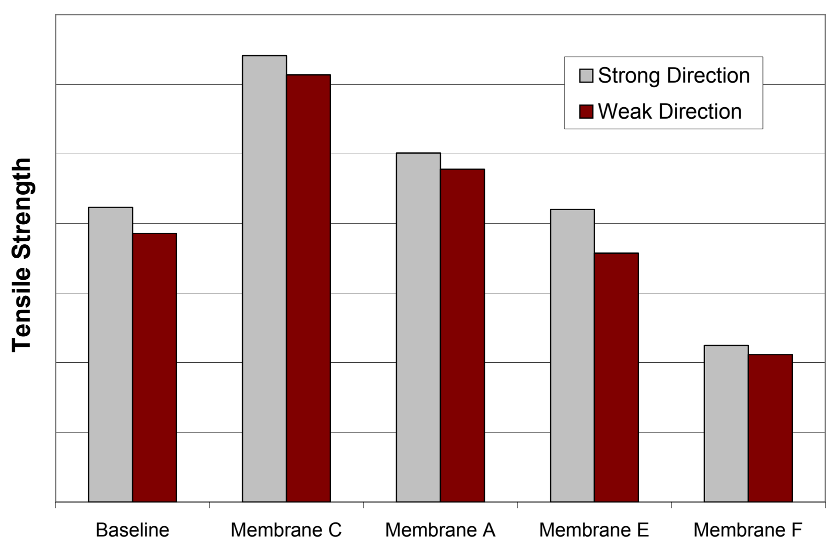
TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

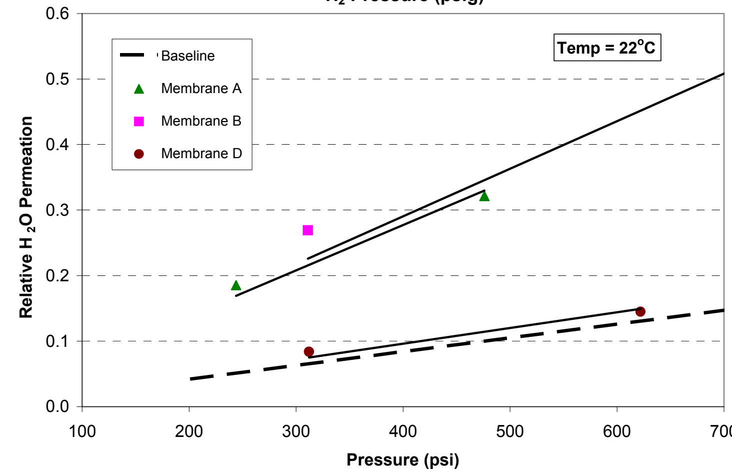
Membrane Development

Optimize:
- Cost
- Conductivity
- Permeation
- Durability

Testing:
- Identified 9 Candidates
- Mechanical, Chemical, Permeation Screenings
- MEA testing underway







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TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

Catalyst Development

Optimize:
- Cost
- Performance
- Durability

Approach:
- Survey / Procure from Industrial Suppliers
- Identify Candidates for In-House Synthesis

Progress to Date:
- Industry Surveyed; Limited Opportunities
- Initiated Synthesis of 6 Candidates
  - Single Element, Binary, & Ternary Systems Being Considered
- Focus currently on Pt-group Metals

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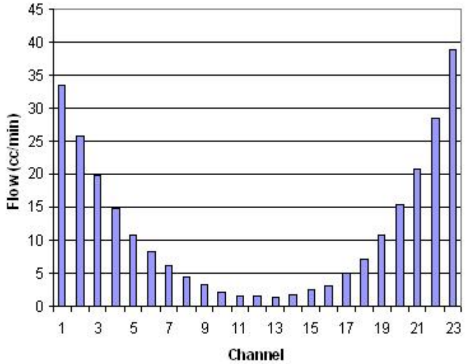
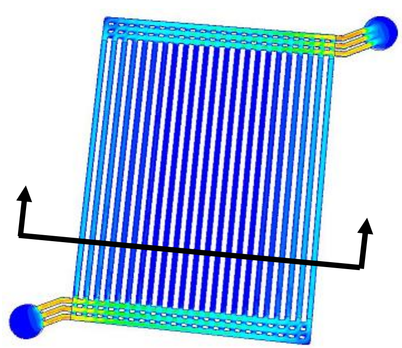
TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

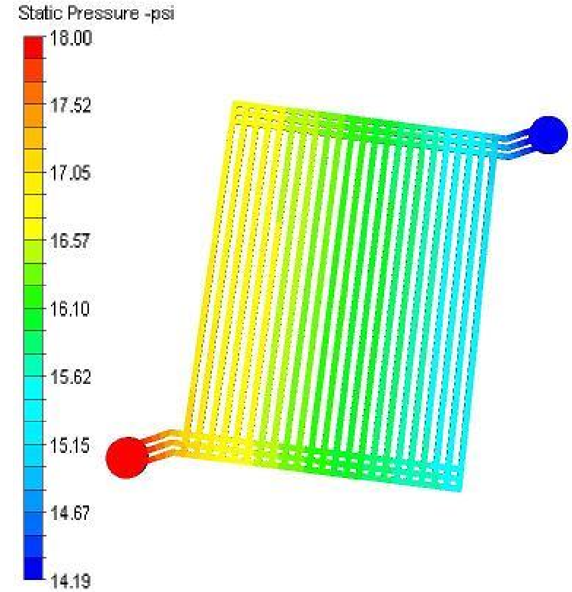
Bipolar Plate Development

Approach:
- CFD Modeling Verification
- Design Concepts Brainstorming
- CFD Optimization of Concepts
- Prototype Testing





Flow & Velocity Analysis



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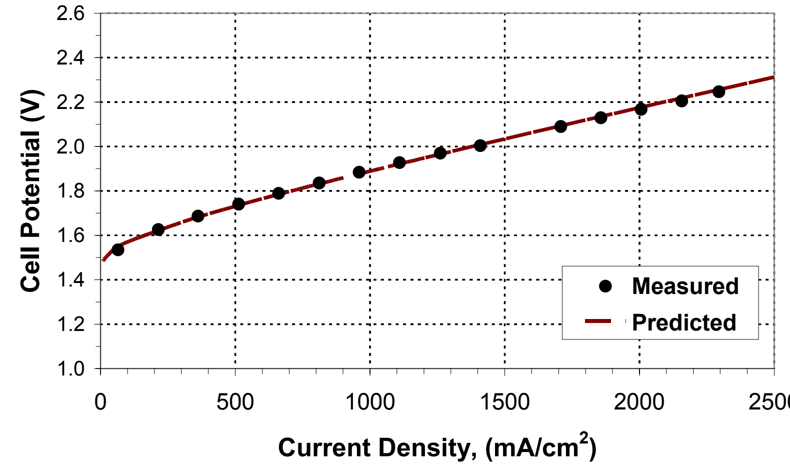
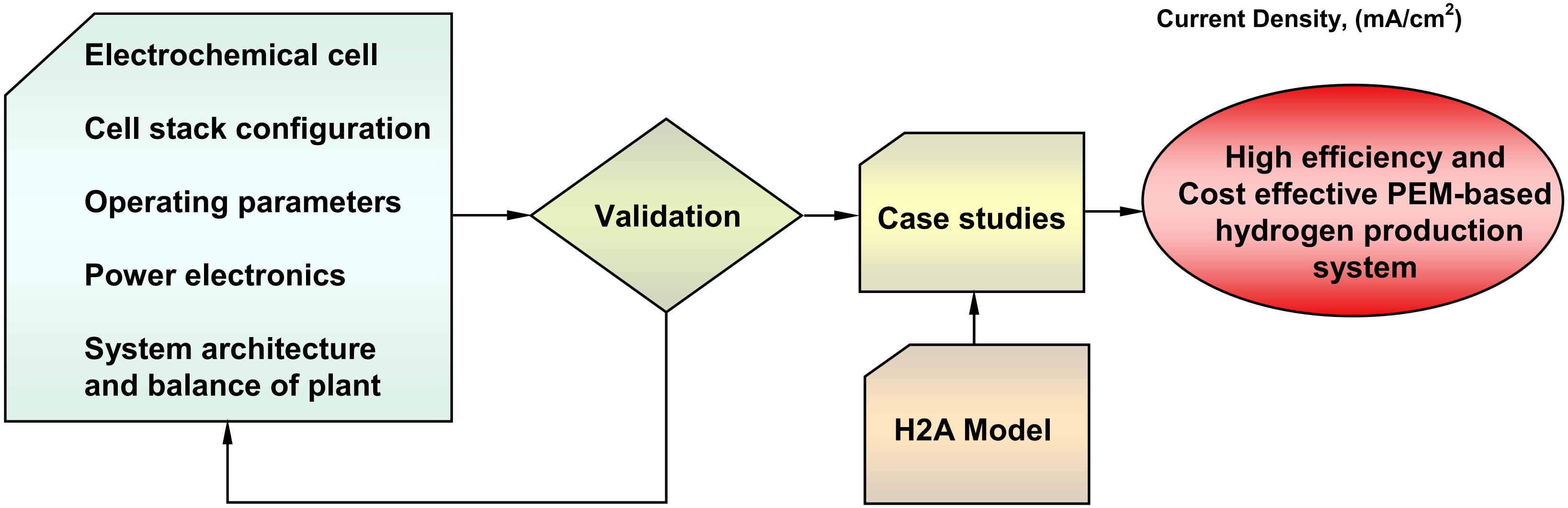
TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

Electrochemical Modeling



Approach:



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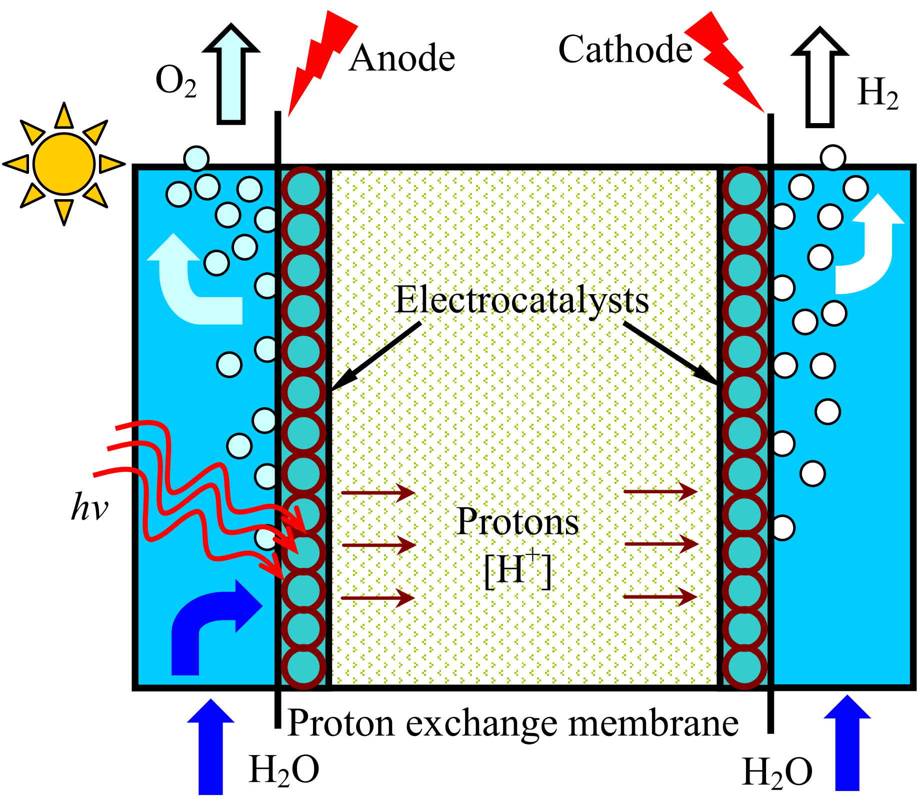
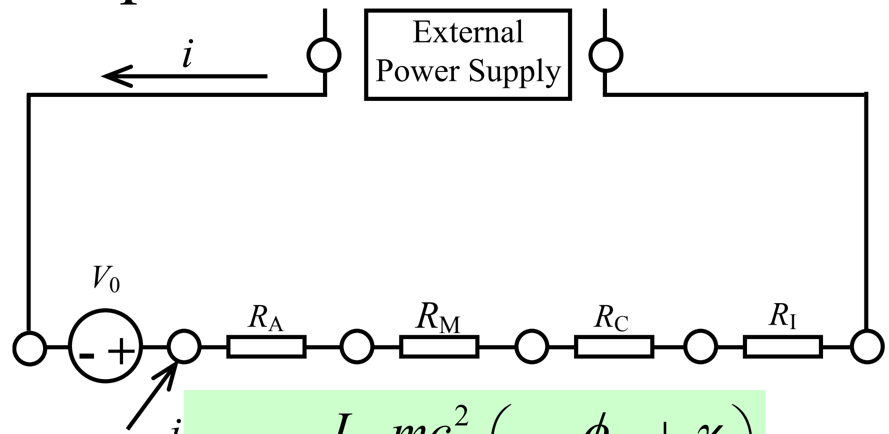
TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS



PEM Electrolysis Cell

Proposed Simplified Model - Equivalent electrical circuit

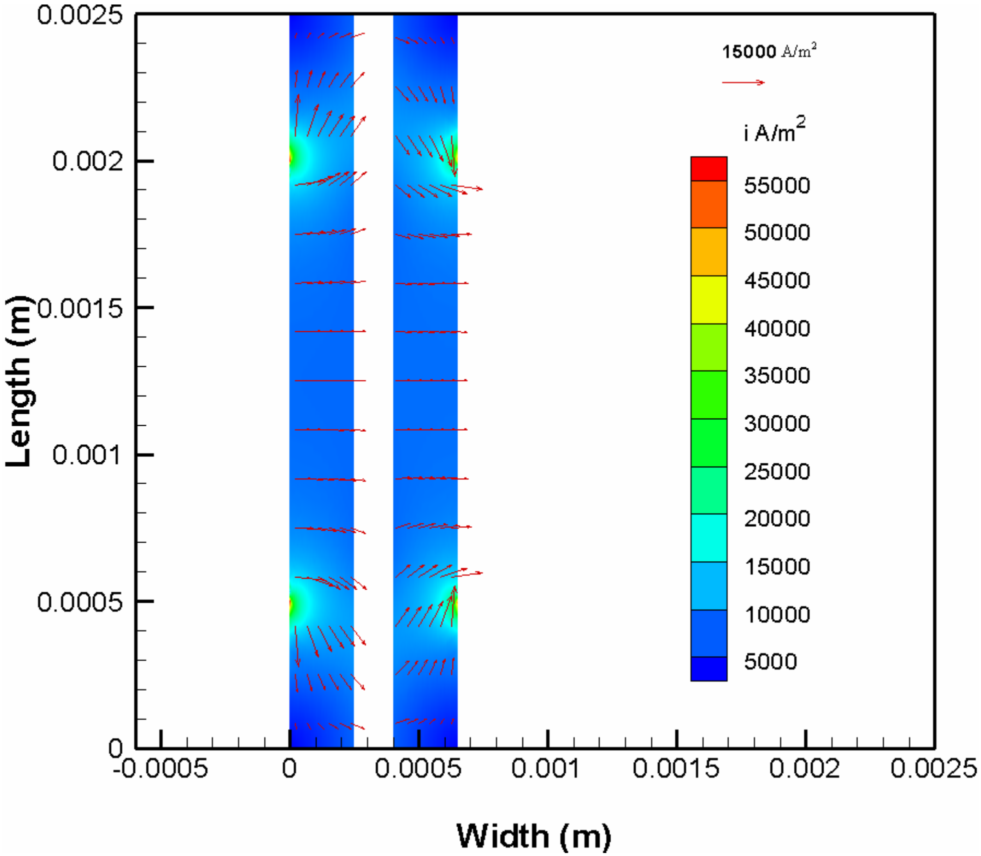


$$i_v = F\frac{I_v}{I_0}\frac{mc^2}{h^2 v^2}\left(1-\frac{\phi_M+\chi}{hv}\right)$$

$$V = V_0 + \frac{RT}{F}\sinh^{-1}\left[\frac{1}{2}\left(\frac{i-i_v}{i_{A0}}\right)\right] + \frac{RT}{F}\sinh^{-1}\left[\frac{1}{2}\left(\frac{i_C}{i_{C0}}\right)\right] + \left(\frac{L_M}{\sigma_M}\right)i + R_I i$$ *

- Nie, Chen, Boehm, and Katukota, ASME J. Heat Transfer, 2007 (In press)

TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS



Example of Numerical Results
—Current Density Distributions

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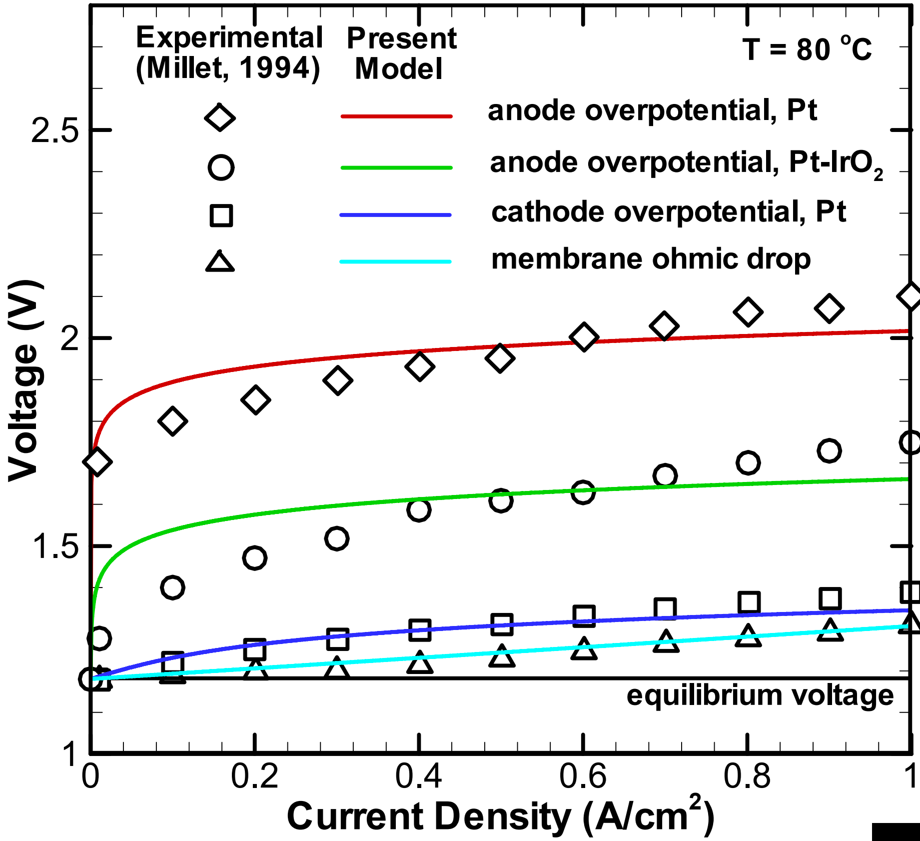
TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

Voltage – Current Density Curves



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TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

—Proposed the simple photoelectrochemical model for predicting power requirement and hydrogen production rate from solar energy for PEM electrolyzer cell

—Developed CFD model for simulating momentum and species transport and electrode kinetic reactions for water electrolyzer cell

—Performed parametric studies of the effects of temperature, external power and illumination intensity on the operation of electrolysis cell

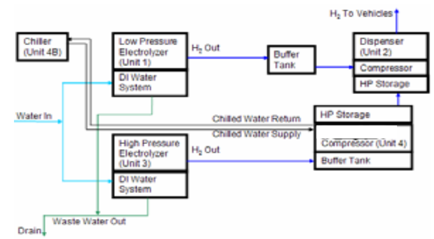
—Revealed the strong non-uniformity in the distributions of channel velocities for the bipolar plate, and investigated effects of different flowrates

TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

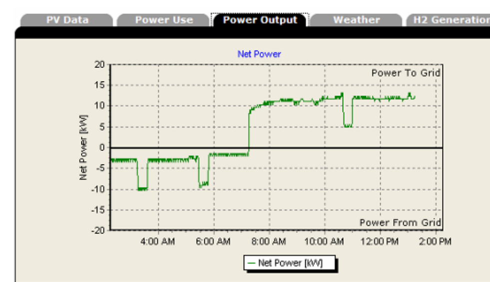
Project Web Site, www.hydrogen.unlv.edu

Hydrogen Filling Station Description

Detailed system diagrams and equipment specs



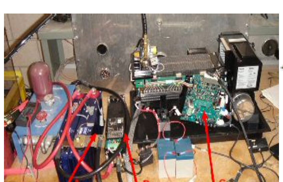
Real time data display
PV power generation
Equipment power usage
Weather conditions

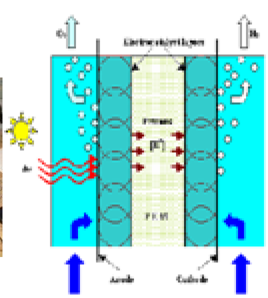


Internal Combustion Engine

Vehicle Conversion Information

Additional Hydrogen Tasks





Fuel Cell Vehicle

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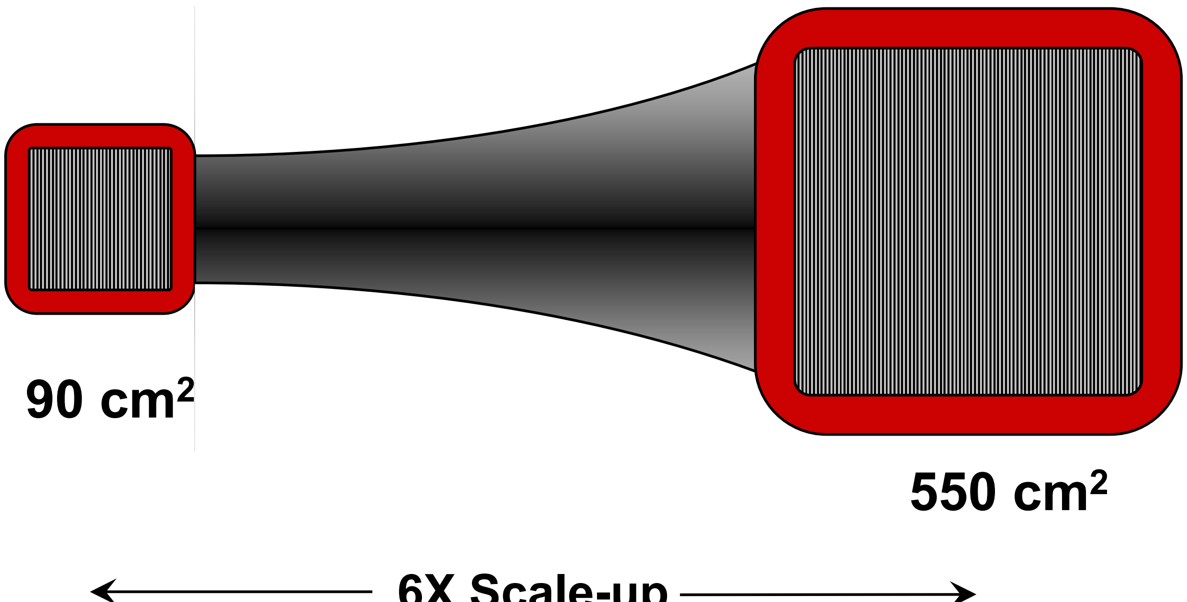
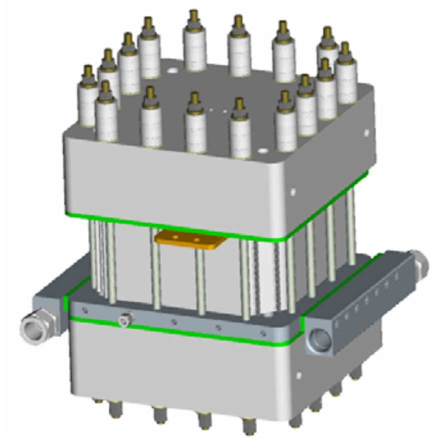
TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

Electroylzer Design Scale-up Pathway





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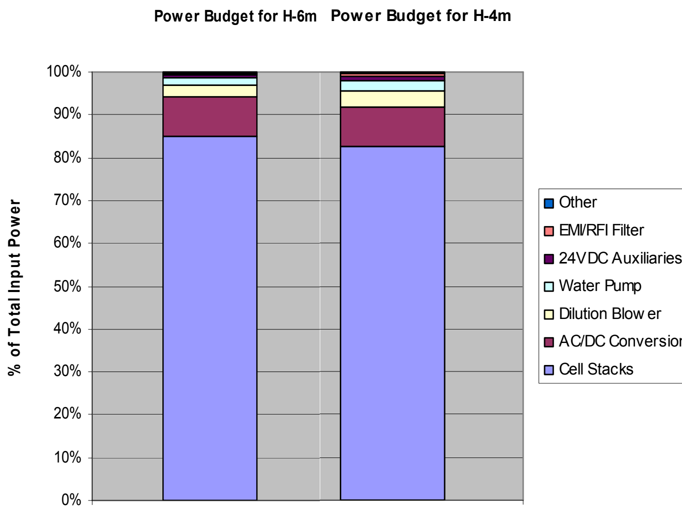
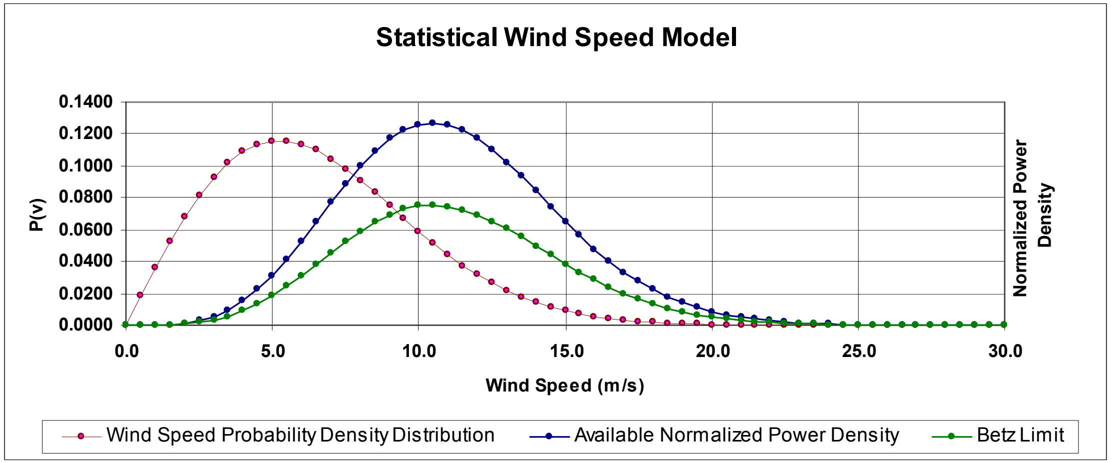
TECHNICAL ACCOMPLISHMENTS/ PROGRESS/RESULTS

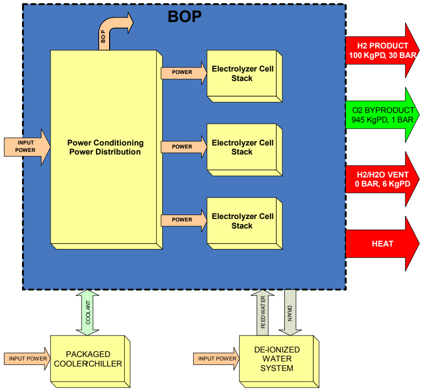
Renewable Interface Development



Approach:

- Information Gathering
  - Baselining current systems
- Variability & Intermittency
- Power & Energy





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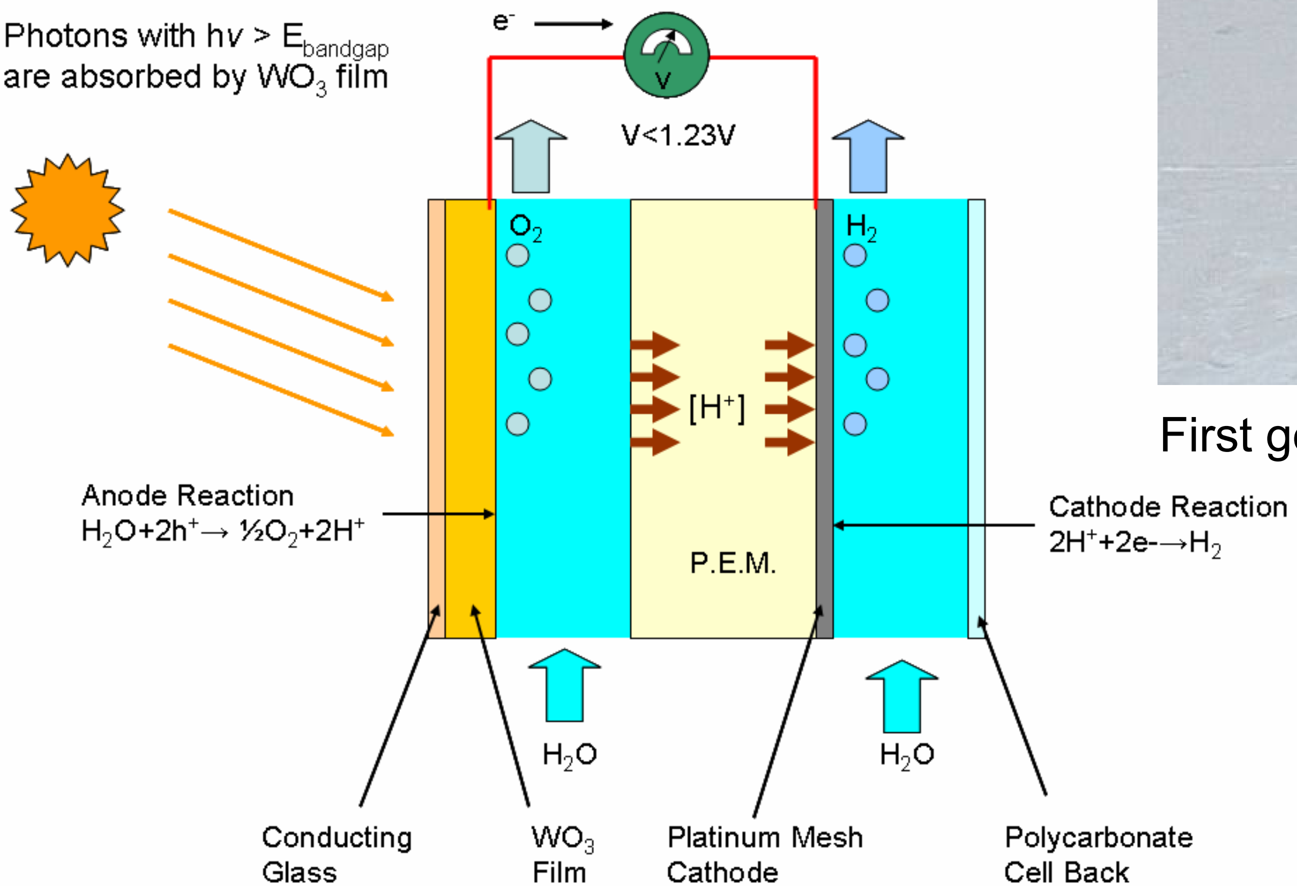
Photoelectrochemical (PEC) Hydrogen Production



First generation cells on test stand

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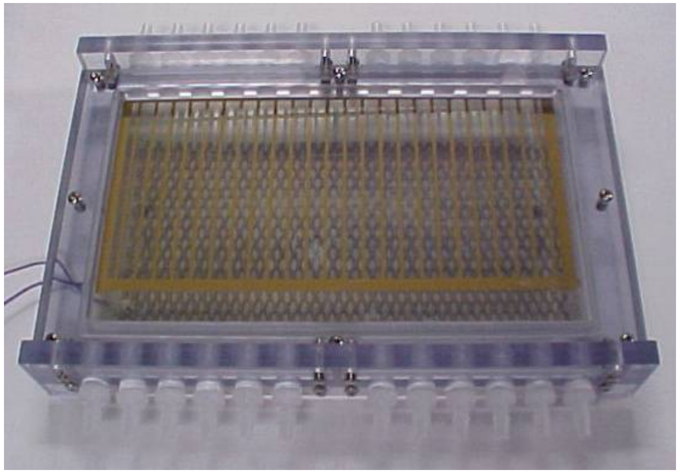
Test Cell Design and Construction

The Test Cells Are Designed to Allow for the Following:

- Variable electrolyte flow-rate over the electrodes
- Variable anode/membrane and cathode/ membrane spacing
- Variable externally applied voltage
- Dimensional stability with regard to electrode/membrane spacing
- Uniform flow over the electrodes

Machining the cell bodies



Finished test cell

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FUTURE WORK

- Complete the installation of the 400 psi electrolyzer system
- Continue to monitor station performance and vehicle characteristics
- Complete the conversion of Ford pickup with H2 ICE and FC electrical power
- Complete photoelectric cell studies for current configuration
- Complete the phase 4 work
- Tabulate cost information comparisons
- Continue to include a major component of student training in the project

SUMMARY

- The project is nearing a very successful completion.
- An excellent example of a renewable energy hydrogen filling station applicable to distributed application in the Southwest is now being demonstrated.
- Low cost vehicle conversions have been completed and are in operation.
  - Components designed here for these vehicles are being considered for use by major manufacturers.
  - Some of the components will simplify future conversions.
  - Expertise gained in the region in these technologies has been immense.
- A large number of students have been trained as a result of this project. These students have graduated at all levels from BS through PhD.
- The project has impacted a large number of fleet services throughout the Southwest, increasing awareness and interest in hydrogen technologies on a broad range of applications.
- This project has successfully brought together a significant public/private partnership, and this is one of the few projects in existence that combines a technical validation project with an active research component. This latter point was underlined to us when the DOE Safety Review Panel visited our project a few months ago.