

# Renewable Electrolysis Integrated System Development and Testing

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**This presentation does not contain any proprietary or confidential information.**

# Overview

## Timeline

Project Start Date: 9/2003

Project End Date: Ongoing

## Production Barriers

G. Cost

H. System efficiency

I. Grid electricity emissions

J. Renewable integration

K. Electricity cost

## Budget

Total Project Funding to date:

FY04 - \$300K

FY05 - \$400K

## Partners

Proton Energy

Northern Power Systems

Univ. of North Dakota

Xcel Energy

HNEI and HELCO

DOE Wind/Hydropower Program

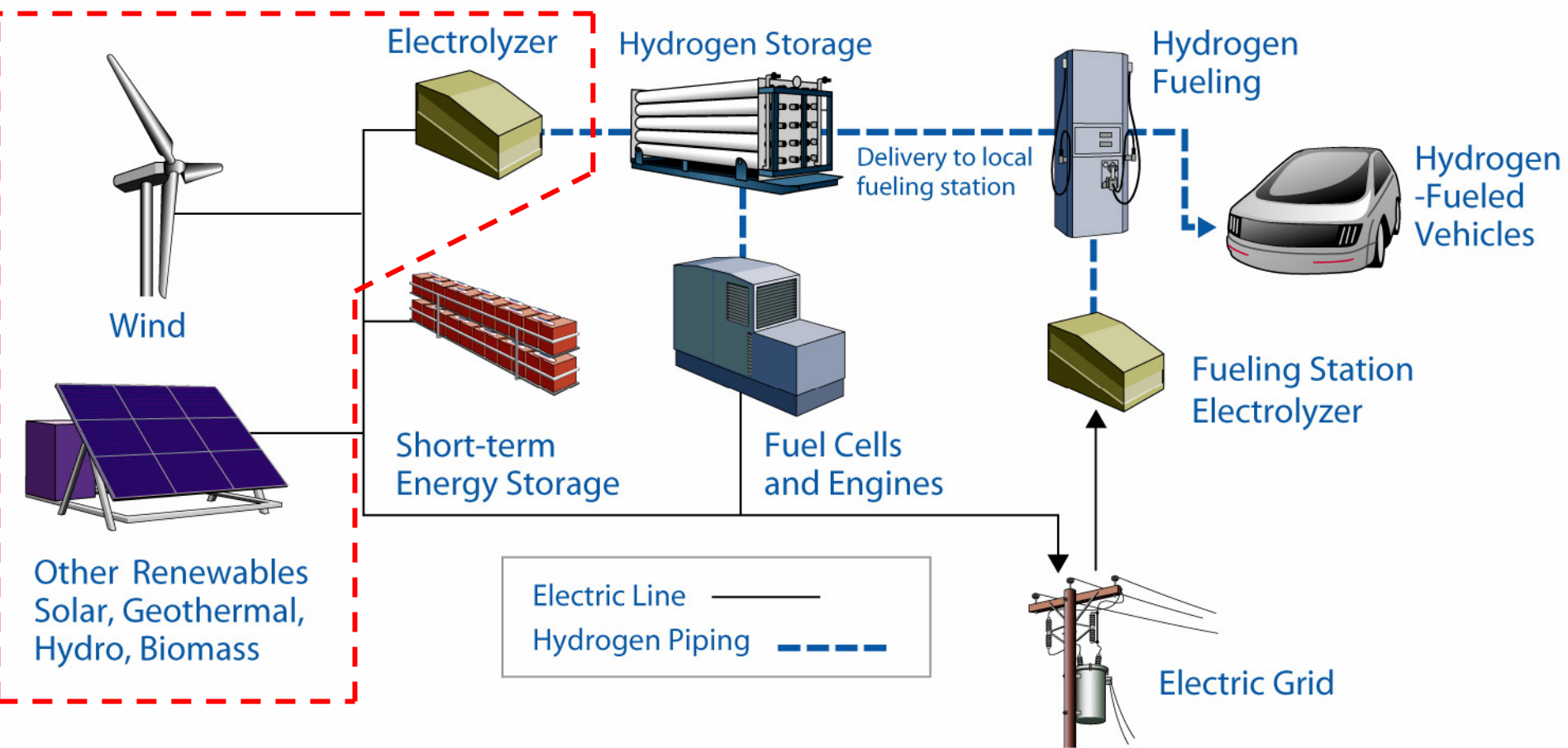
# Project Objectives

This project examines the issues with using renewable energy to produce hydrogen by electrolyzing water

- Characterize electrolyzer performance under variable input power conditions
- Design and develop shared power electronics packages and controllers to reduce cost and optimize system performance and identify opportunities for system cost reduction through breakthroughs in component integration
- Test, evaluate and optimize the renewable electrolysis system performance for both
  - Dedicated hydrogen production
  - Electricity/hydrogen cogeneration
- Verify DOE goals of:
  - grid-connected electrolysis cost of \$2.85/kg by 2010
  - renewable hydrogen production cost of \$2.75/kg by 2015.

# Project Background

## *Importance and Need*



# Project Approach

## 1. Coordination, Planning and Stakeholder Development

Work with DOE and industry to develop roadmap for renewable/hydrogen production and system development.

Hold workshops on renewable/electricity/hydrogen production

## 2. Systems Engineering, Modeling, and Analysis

Development of concept platforms, development and validation of component and system models, system assessment and optimization tools

## 3. System Integration and Component Development

Work with Industry on the development of new advanced hardware and control strategies to couple renewable/electrolyzer systems

## 4. Characterization Testing and Protocol Development

Installation of equipment, performance characterization, Standard Test Procedure Development

# Project Timeline

## Renewable Electrolysis - Integrated Systems Development and Testing

Coordination, Planning and Stakeholder Development

System Integration and Component Development

System Engineering and Modeling

Characterization Testing and Protocol Development

FY 2004    FY 2005    FY 2006    FY 2007    FY 2008    FY 2009    FY 2010

Workshops

W

W

W

W

W

W

W

Electrolysis-Utility Integration Workshop  
Sept 2004

Hydrogen Utility Interest Group

\$2.85/kg

R&D Roadmap

Update Roadmap

Update Roadmap

Dev. Current Costs and Performance data

Develop Energy System Assessment Tool  
(Combine H2 and Elect. Costs)  
Develop Engineering Simulation Tool

Conduct System Optimization Studies  
Site and System Optimization with electrical system  
Optimal System components and controls

5/10kW PE Interface

50kW PE Interface

500kW PE Interface

5 kW PEM – 5kW PV & 10kW Wind

20kW Alkaline w/ PV & Wind

Design    Build    Testing

50kW PEM & 100 WT

Design    Construction    Testing

500kW Elec & 1.5MW WT

Design    Construction    Testing

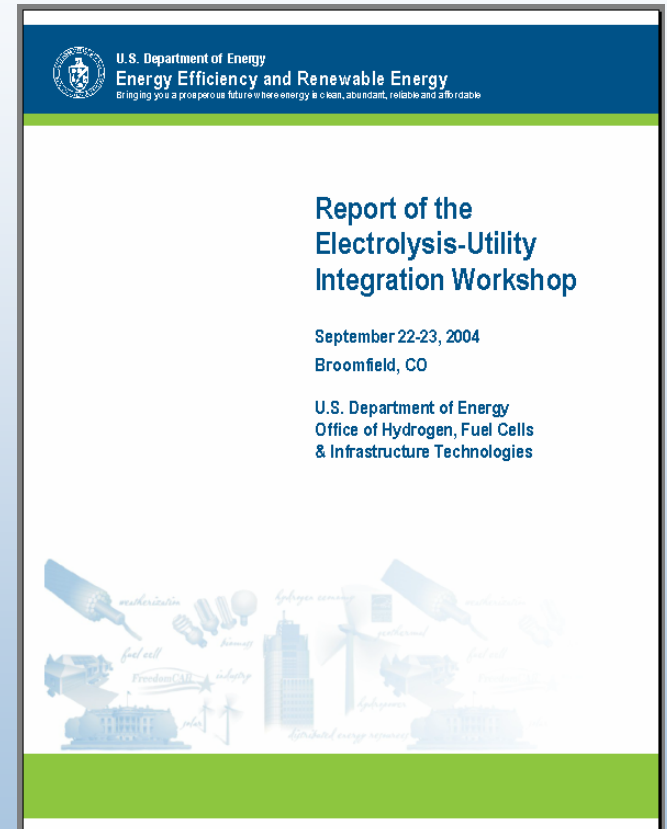
**Key:** Reduce cost by combining power electronic components, optimize system based on hydrogen and electricity production

# Technical Accomplishments

## Task 1 – Coordination, Planning and Stakeholder Development

### Utility Hydrogen Workshop – Sept. 2004

- DOE held the Electrolysis-Utility Integration Workshop to explore issues associated with providing electricity to support the wide-spread deployment of electrolysis-based hydrogen production in the U.S. to meet demand from hydrogen fuel cell vehicles in the 2020 timeframe.
- 40 People (DOE, Natl. Labs, Utilities, Industry)



# Technical Accomplishments

## Utility Hydrogen Workshop – Sept. 2004

- **Identification of Key Opportunities**

- Grid Efficiency/Functionality/Reliability/Emissions
- Capacity and Demand
- Utility Products
- Systems Integration/Renewable Energy Utilization

- **Identification of Key Barriers**

- Market Issues
- Electricity Pricing Issues
- Electrolysis System Costs & Operation

- **Key Activities Needed**

- Technology Improvements
- Case Studies/Analysis
- Market Incentives or Conditioning
- Collaborations



# Technical Accomplishments

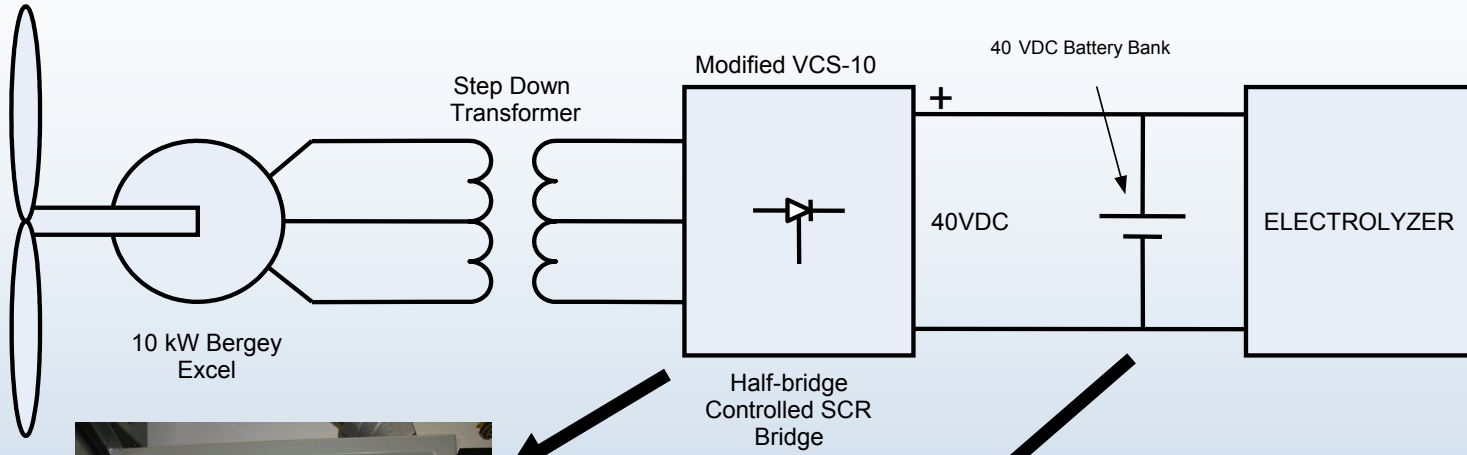
## Task 2 – Systems Engineering, Modeling, and Analysis

- Small effort in FY05
- Working with University of North Dakota on development of engineering models for system components in renewable electrolysis systems. Identifying component and system engineering models.
- Working with Xcel Energy on renewable electrolysis system assessment and optimization tools.



# Technical Accomplishments

## Task 3 – System Integration and Component Development



Completed Power Electronic Interface Modifications

# Technical Accomplishments

## Task 4 – Characterization Testing and Protocol Development



- Completed initial characterization of 5kW prototype PEM electrolyzer for power electronics design
- Completed testing with simulated PV and wind using power supplies
- Completed testing with 5kW PV array
- Started testing with 10kW Wind turbine  
(planned to complete to September)

# Technical Accomplishments

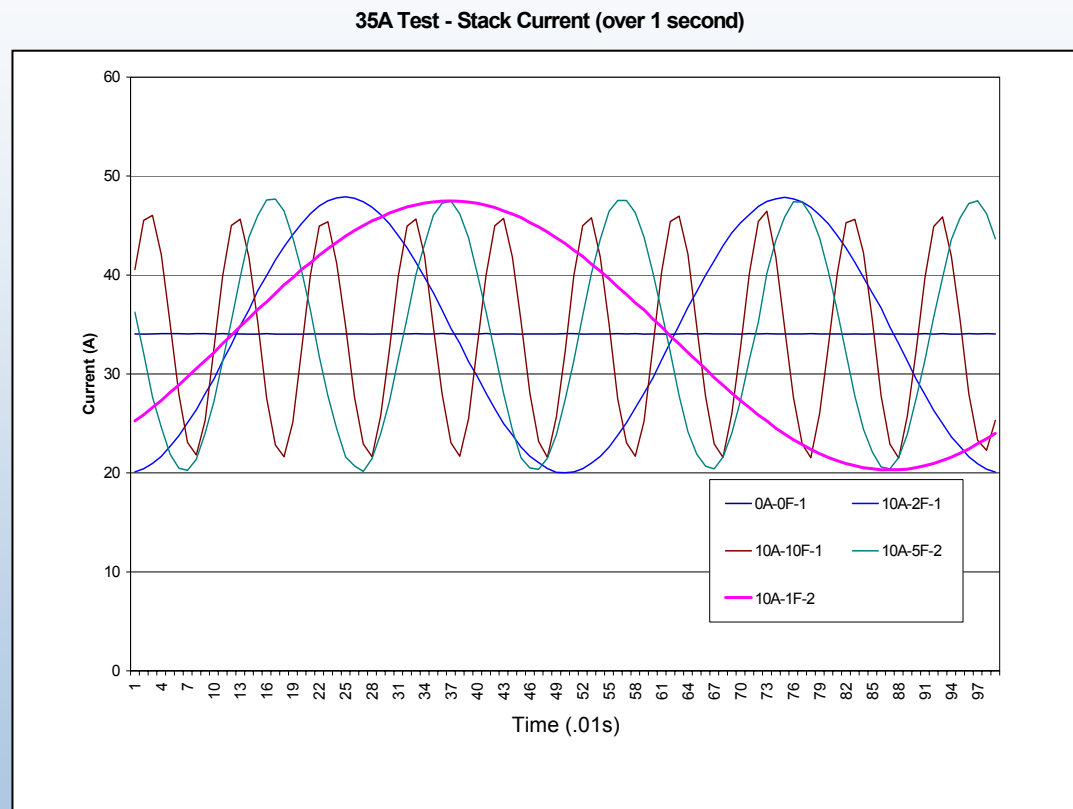
## Prototype Electrolyzer Performance Testing

### Steady State Characterization

- Run for 1.5 Hours with Grid and PS/Grid at rated power

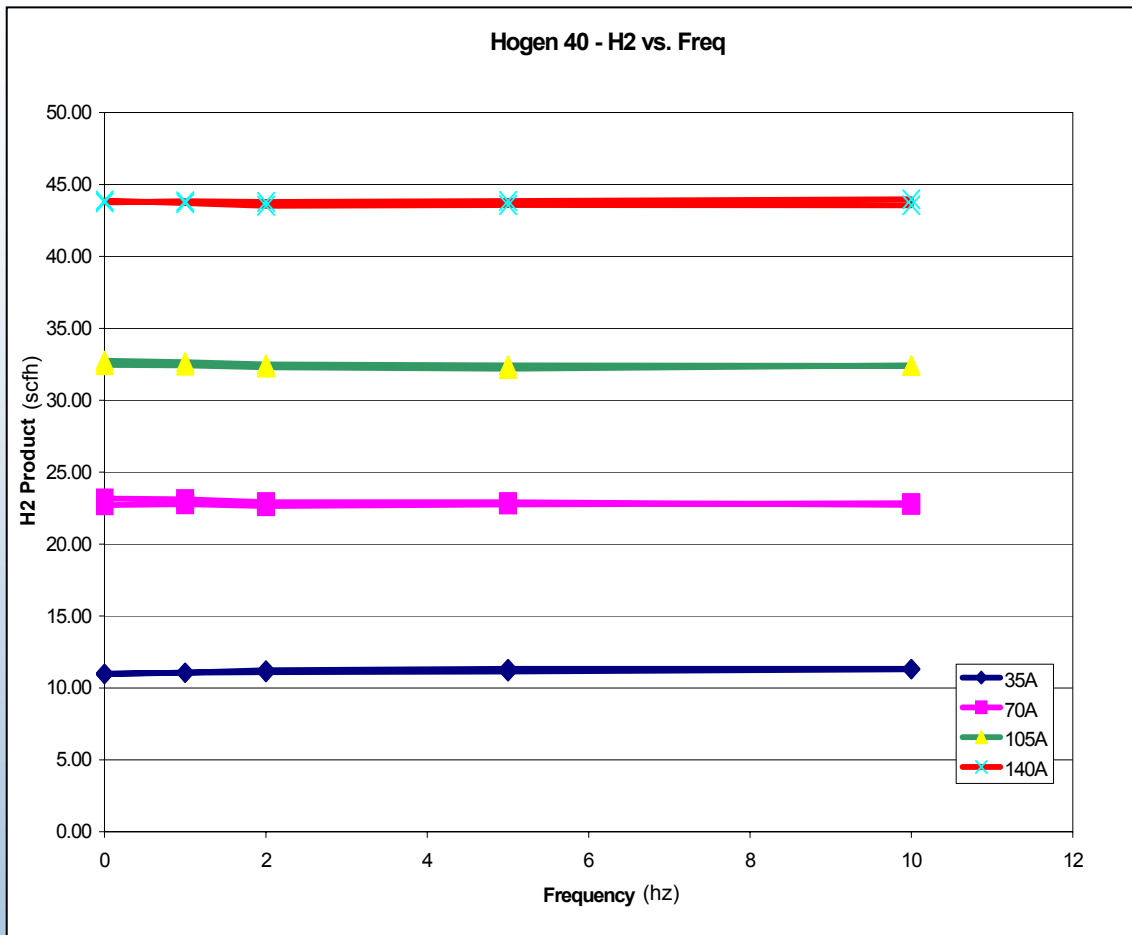
### • Variable Input w/ Power Supplies

- 25%, 50%, 75%, 100% Rated output current (15min)
- Added 10A Sine wave at 0,1,2,5,10 Hz
- This was to determine how much ripple in the DC current the electrolyzer stack could take and not effect performance



Sample current waveforms used to characterize stack frequency response

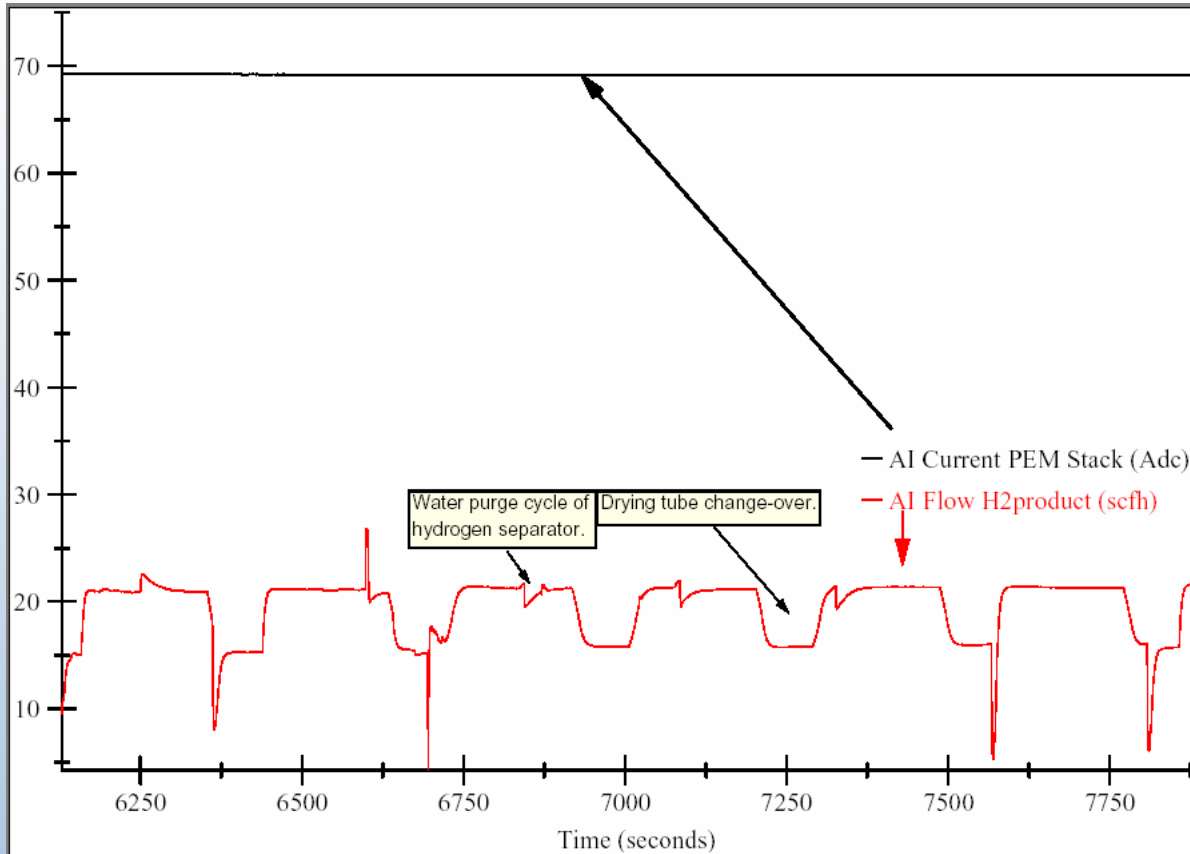
# Technical Accomplishments



These results show that there is no effect of large DC ripple on hydrogen production.

Hydrogen production (scfh) during complex waveform (AC + DC) testing at various frequencies (hz) and input current levels (A).

# Technical Accomplishments



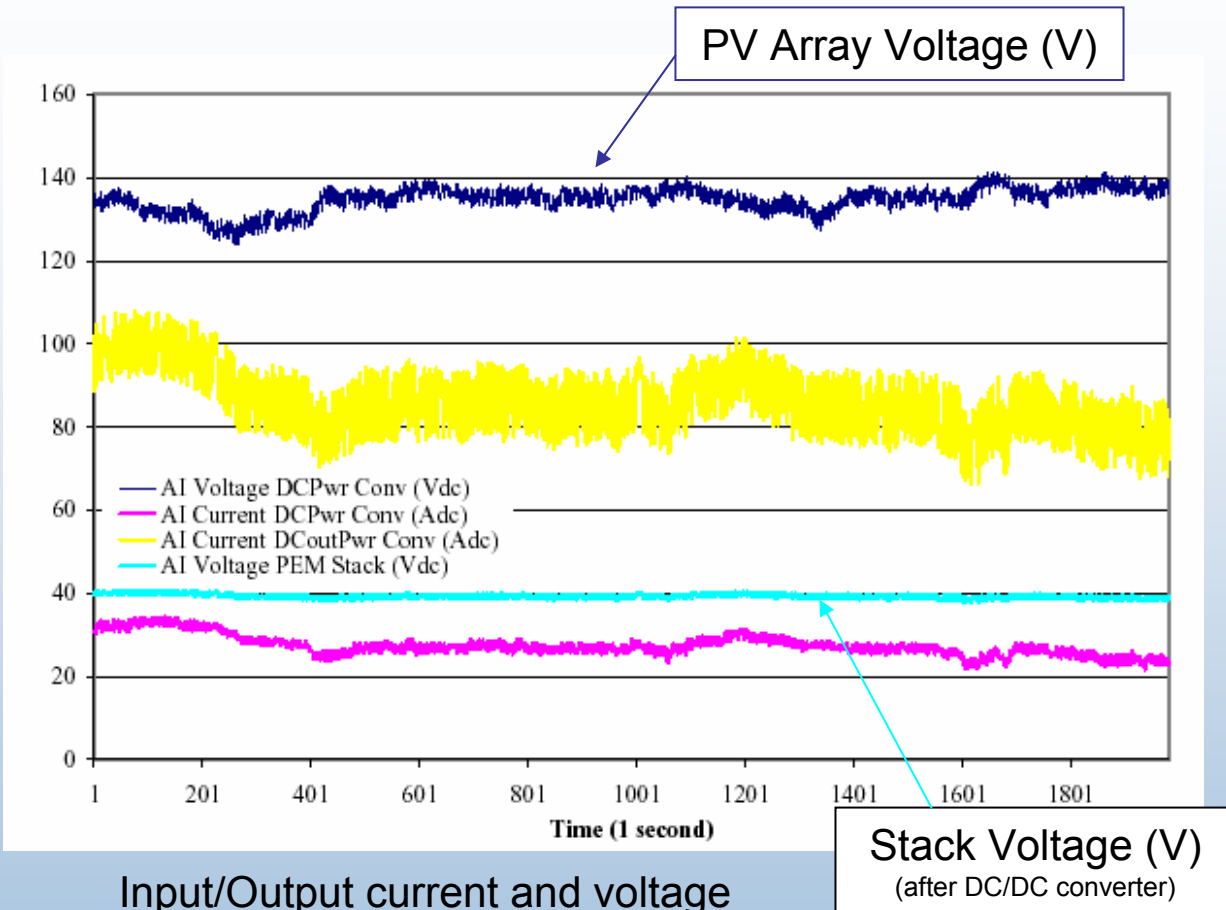
70 A stack current for 30 minutes shows hydrogen product flow rate fluctuations due to internal water and drier management.

The testing shows the variability in hydrogen production for this specific model.

This is due to the high drying requirements for the hydrogen product.

This can be modified by the manufacturer depending on hydrogen product needs.

# Technical Accomplishments

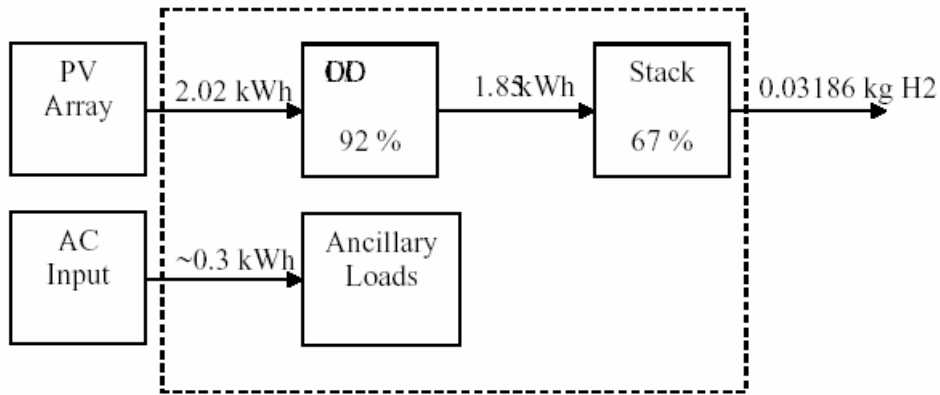


Input/Output current and voltage waveforms for DC/DC converter.

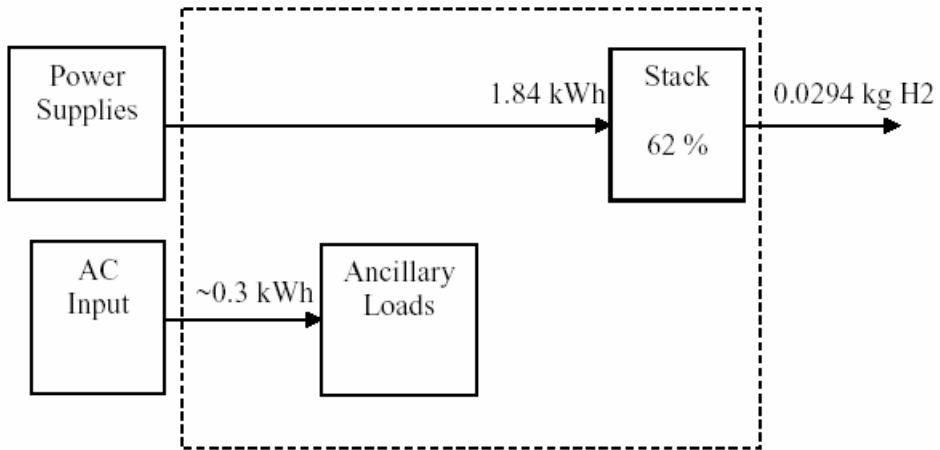
This data shows the functionality of the current DC/DC converter when testing with the PV array.

The top line (dark blue) is the PV array voltage. This must be converted to a lower voltage for the PEM stack (light blue)

# Technical Accomplishments



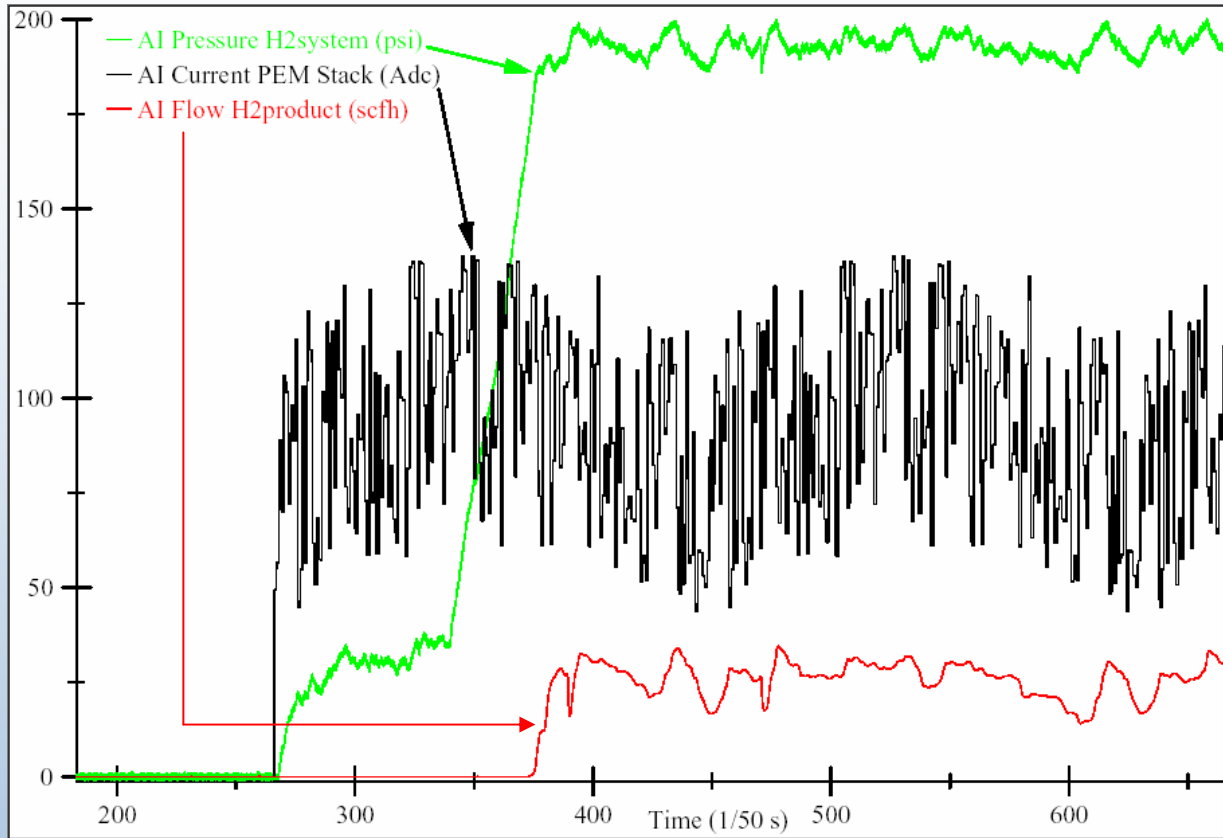
System component efficiencies during actual PV test.



PV simulation system diagram and stack efficiency



# Technical Accomplishments



This graph show the hydrogen output and pressures for the simulated wind turbine inputs.

Once actual wind data is taken, it will be simulated with the power supplies.

Wind turbine simulation showing system pressure, stack current, and hydrogen flow.

# Remainder of FY05

## 1. Coordination, Planning and Stakeholder Development

Complete R&D Roadmap for renewable/hydrogen production

## 2. Systems Engineering, Modeling, and Analysis

Complete system engineering model identification with UND

Conduct system assessment and optimization and with Xcel Energy on wind-electrolysis projects

## 3. System Integration and Component Development

Start design of optimal power electronics interface with wind turbine

## 4. Characterization Testing and Protocol Development

Complete testing of 5kW PEM electrolyzer with wind turbine interface

Publish technical report on system performance

# Responses to Previous Year Reviewers' Comments

**Comment:** Need to study system optimization given intermittent operation of electrolyzer due to renewable energy duty cycle.

**Response:** This is being addressed in the current research by examining the ability to have the system produce hydrogen or electricity and possibly using grid power to assist in the hydrogen production at low wind or solar periods.

**Comment:** Consider expanding scope to look at controls required to determine where initial energy, e.g., electric from wind, could be best utilized; direct to grid on for H<sub>2</sub> production - cost vs. revenue optimization.

**Response:** Working with Xcel Energy in FY05 on system optimization and economics and adding work in FY06 to expand studies.

**Comment:** Other commercial organizations will want to use the power interface, and there should be a process to allow them to access this e.g. CRADA or others.

**Response:** Plan is to develop CRADAs with companies as this work progresses to address IP concerns with power electronics interface development.

# Future Work

## FY06 Plans

- Install and test small (20kW) alkaline electrolyzer
- Update power electronics interface to reduce components and costs
- Complete standard test protocol development for renewable-electrolyzer performance and operation
- Start Model/simulation of renewable-electrolyzer performance

## FY07-FY10 Plans

- Design and test larger wind (100kW) – electrolyzer (50kW) test, then 1.5MW wind turbine size project

# Publications and Presentations

*“Toward A Renewable Hydrogen Future: Feasibility Ahead?”* Susan Hock, Carolyn Elam, and Debra Sandor, Solar Today, May/June 2004

*“Grid-Based Renewable Electricity and Hydrogen Integration”*, Carolyn Elam and Ben Kroposki, National Renewable Energy Laboratory presented at the Electrolysis-Utility Integration Workshop, September 2004, Broomfield, CO

# Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

## Hydrogen leakage and ignition during testing with electrolyzers

- Our approach to deal with this hazard is to design the test environment for the electrolyzer in accordance with NREL's risk assessment / hazard identification and controls protocols.
- This project used a failure mode and effects analysis (FMEA) in the analysis of the design and operation of the electrolyzer and test area.
- This matrix led to the installation of redundant hydrogen sensors and a control program that will shut down the electrolyzer when 0.4% of hydrogen is detected and will activate an emergency fan at 0.8% hydrogen. (NREL uses the 0.8% hydrogen (20% LEL) as a standard level for emergency shutdown)
- This project was also visited by the DOE Hydrogen Safety Panel in June 2004. The panel's report noted that *"Safety Review Team was able to see a system that was being built with a strong sense of safety. The influence of NREL's ES&H group is seen in the detailed PHA and the adherence to their policies and procedures."*