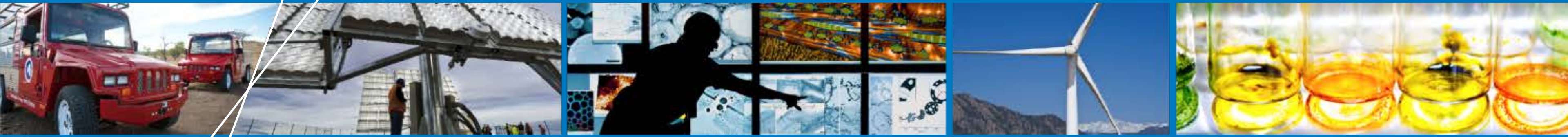
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

2015 DOE Hydrogen and Fuel Cells Program Review



Renewable Electrolysis Integrated System Development & Testing

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Project ID: PD031

***Presenter**

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Overview

Timeline

Project start date: Sep. 2003

Project end date: Oct. 2015*

Budget

FY13 DOE Funding: $460k

FY14 DOE Funding: Forward funded with FY13 funds

FY15 DOE Planned Funding: $200k

Total Project Value: $5,900k

Barriers

G. System Efficiency

I. Grid Electricity Emissions (Distributed)

J. Renewable Electricity Generation Integration (Central)

L. Operations and Maintenance

Partners

Xcel Energy (CRADA)

Proton OnSite

Giner Inc.

* Project continuation and direction determined annually by DOE

Relevance

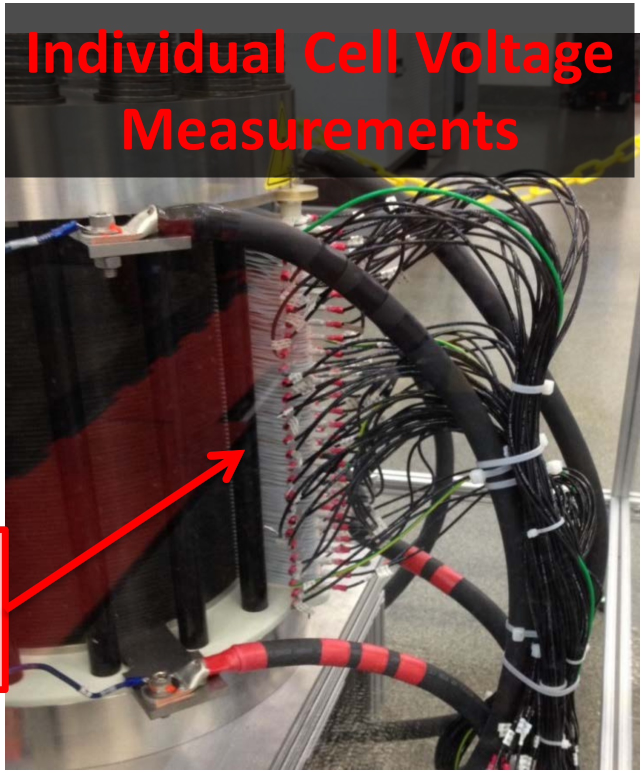
- Hydrogen is a storage fuel enabling higher penetrations of renewable electricity sources
- Electrolyzer systems are rapidly increasing in size and are able to provide:
  - Renewable hydrogen for a near-zero carbon transportation fuel
  - Utility grid services and stabilization

Impact

- As electrolyzer systems size increase there is a need to validate large active area stacks to meet DOE targets
- System efficiency under varying power operation (e.g., solar, wind) needs to be optimized to account for the intermittency of renewable energy sources

Table 3.1.4 Technical Targets: Distributed Forecourt Water Electrolysis Hydrogen Production [a, b, c]

Characteristics	Units	2011 Status	2015 Target	2020 Target
Hydrogen Levelized Cost [d] (Production Only)	$/kg	4.20 [d]	3.90 [d]	2.30 [d]
Electrolyzer System Capital Cost	$/kg $/kW	0.70 430 [e, f]	0.50 300 [f]	0.50 300 [f]
System Energy Efficiency [g]	% (LHV)	67	72	75
	kWh/kg	50	46	44
Stack Energy Efficiency [h]	% (LHV)	74	76	77
	kWh/kg	45	44	43
Electricity Price	$/kWh	From AEO 2009 [i]	From AEO 2009 [i]	0.037 [j]



Approach

- Provide independent performance testing of advanced electrolyzer stacks and systems for DOE and Industry
- Develop and optimize electrolyzer stack and sub-system performance using grid and renewable power systems
- Leverage large active area stack testing platform and balance of plant to develop system efficiency improvements

Collaborate with other NREL projects and industry

- INTEGRATE project TV030 provided electrolyzer stack test bed and hydrogen dryer
- Quality results collected as part of 700 bar station operation
- Giner Inc. provided test stack to commission stack test bed

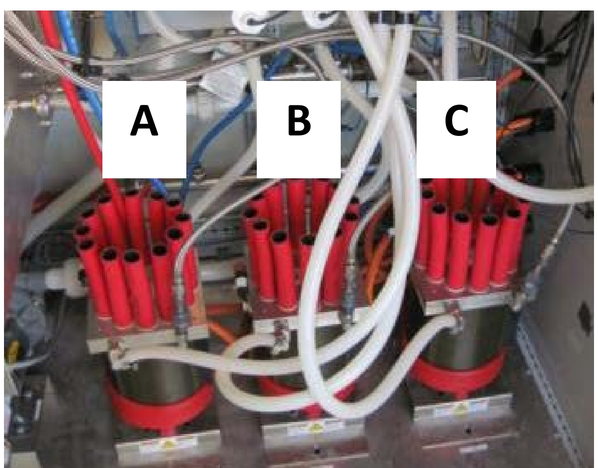
Approach

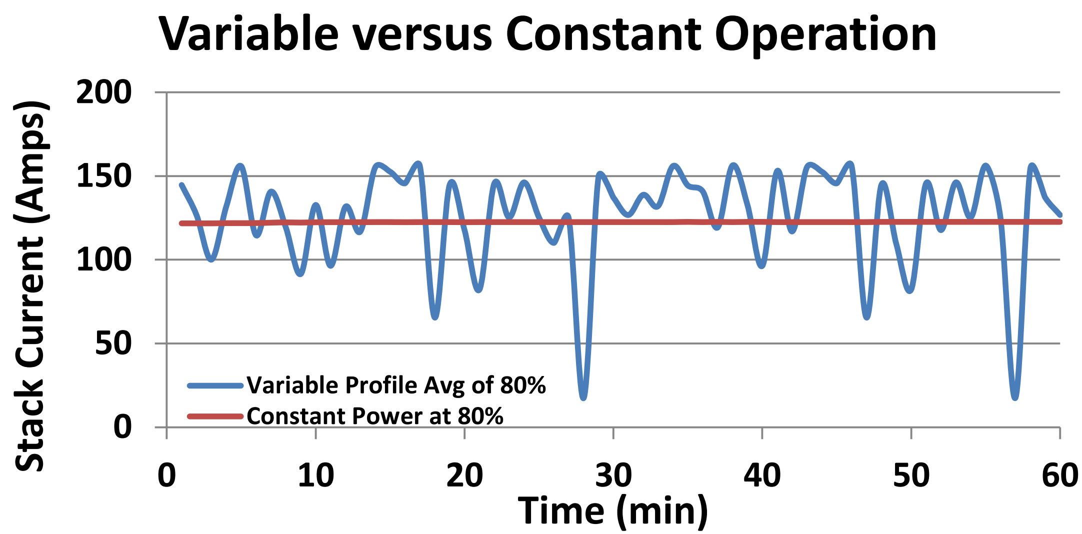
Milestone Description	Type	Due Date
Provide comparison of four different drying technologies, focusing on efficiency, capital cost and O&M cost of the different techniques. If there is a technique that has not been tested but shows promise in the Q1 detailed analyses, the technique may be designed, procured, implemented and tested.	Qtr Progress Measure (Regular)	31-Dec-14
Install and begin testing large active area stack drying system, comparing fixed flow versus variable flow desiccant drying systems. Confirm drying system removes moisture content below 5 parts per million of water in hydrogen (as per SAE J2719) for PEM stacks capable of hydrogen production in the 65+ kg/day range.	Qtr Progress Measure (Regular)	31-Mar-15
Collect 40 hours each on 3 different pressure swing adsorption drying techniques comparing the fixed flow (orifice) approach with two new linear actuated valves (variable flow) that vary in performance and price.	Annual Milestone (Regular)	30-Jun-15
Complete cumulative testing of 7500 h for two PEM electrolyzer stacks and 4500 h for a new stack under constant- and variable-powered operating conditions and compare stack decay rates of the two operational modes with results from FY14.	Qtr Progress Measure (Regular)	30-Sep-15

Technical Accomplishment

Compare Stack Lifetime: Wind vs. Constant Power Operation

- **Goal:** Analyze stack decay differences between constant- and variable-powered stack operation
  - Three 10 kW stacks under test
  - ~5,500 hour operation completed
- Proton Onsite (H-Series) – 40 kW, 13 kg/day PEM electrolyzer
- Instrumented electrolyzer and took control of AC/DC power supplies to operate stacks in variable power mode



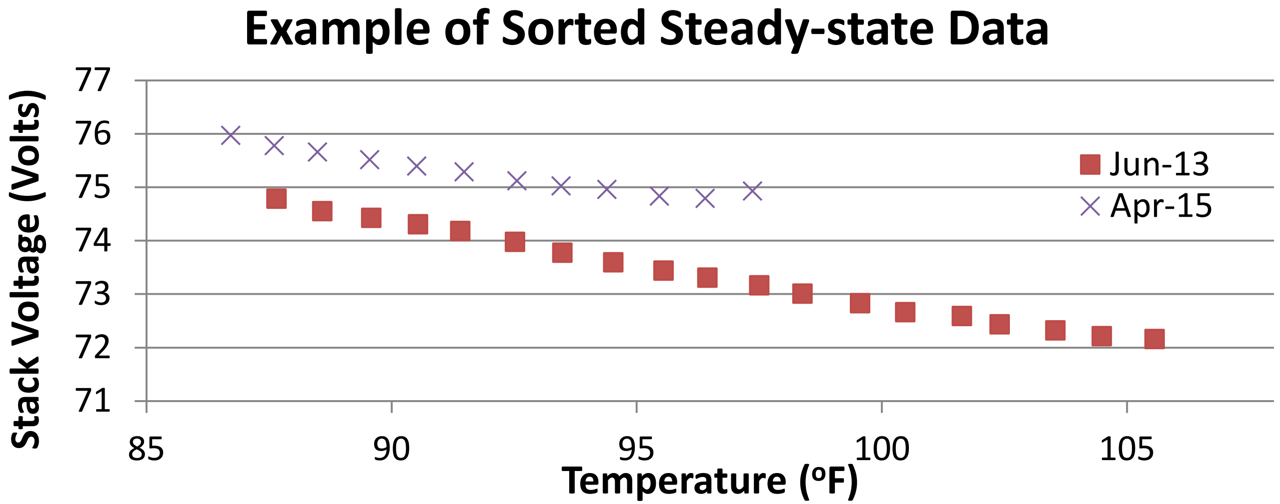


Technical Accomplishment

Long Duration Variable Stack Testing

- Stack A & B reached 5,500 hours of operation, newer stack C reached 2,500 hours of operation
- Stack decay rate calculated by running the stacks at steady-state (~155 Amps) and separating into temperature and voltage bins
- Voltage comparison of the three stacks at 104 °F is used to determine stack decay rate

Operating Mode	Stack Identifier	Decay Rate (µV/cell-h)
Variable Power	Stack A	11.5
Constant Power	Stack B	12.6
Constant Power	Stack C	21.6



NREL Electrolyzer Stack Test Bed

Located at NREL's Energy System Integration Laboratory

- AC-DC power supplies capable of 2,000 ADC and 250 VDC
- Built as a collaboration with the INTEGRATE project

System efficiency improvements in electrolyzer balance of plant

Goal is to improve system efficiency;

- Drying losses in variable operation with NREL's variable flow drying technique
    - NREL designed and Proton built research drying skid
- Optimize balance of plant based on variable stack power

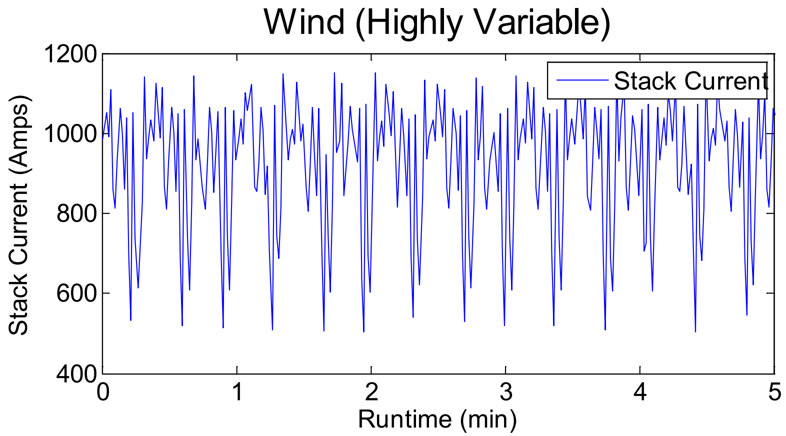
First testing completed with Giner Inc.

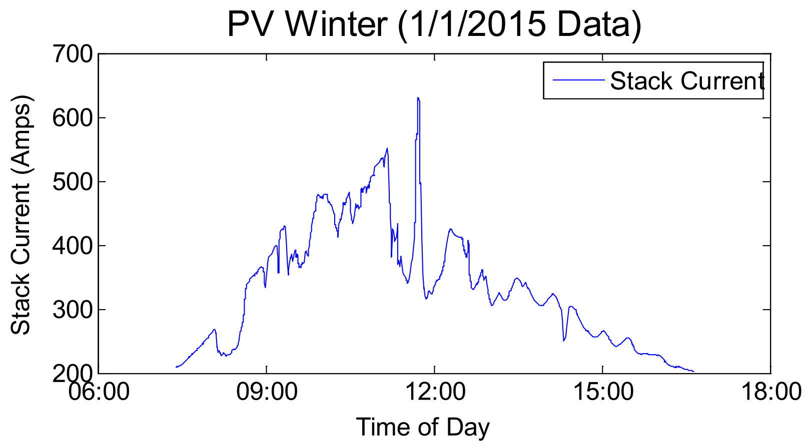
- Three 150 kW PEM stacks
- IV-Curves were collected at stack temperature of 70 °C
- Individual cell voltages were collected at different current and stack pressure levels

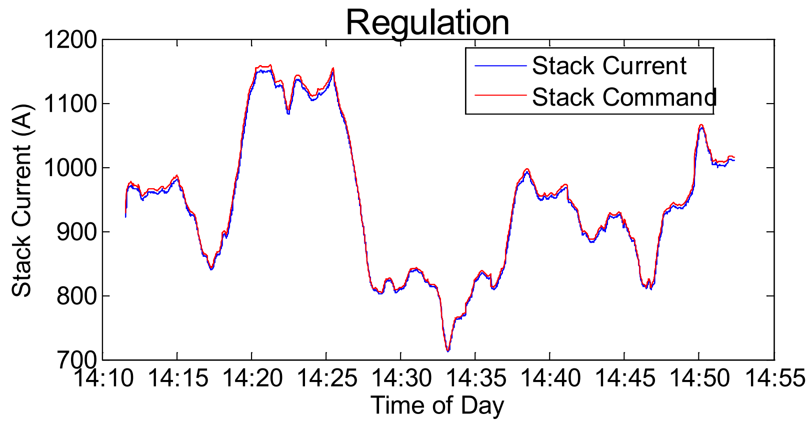
Technical Accomplishments

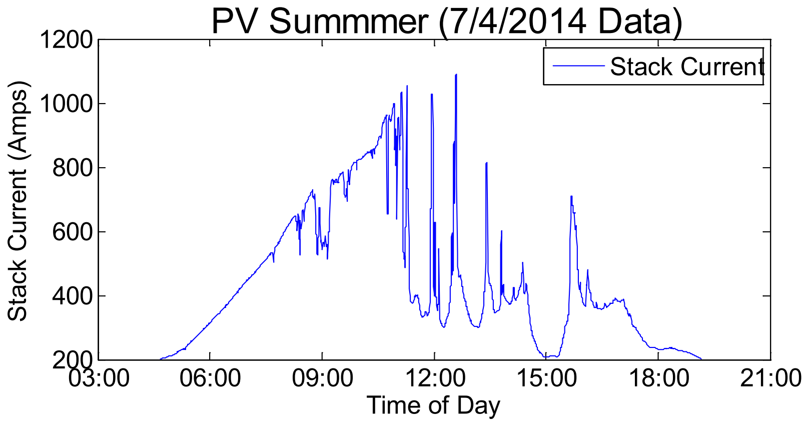
Ability to program profiles into the stack test bed

- Examples of renewable and regulation profiles
- Ran profiles with 120 kW stack from Proton









Technical Accomplishments

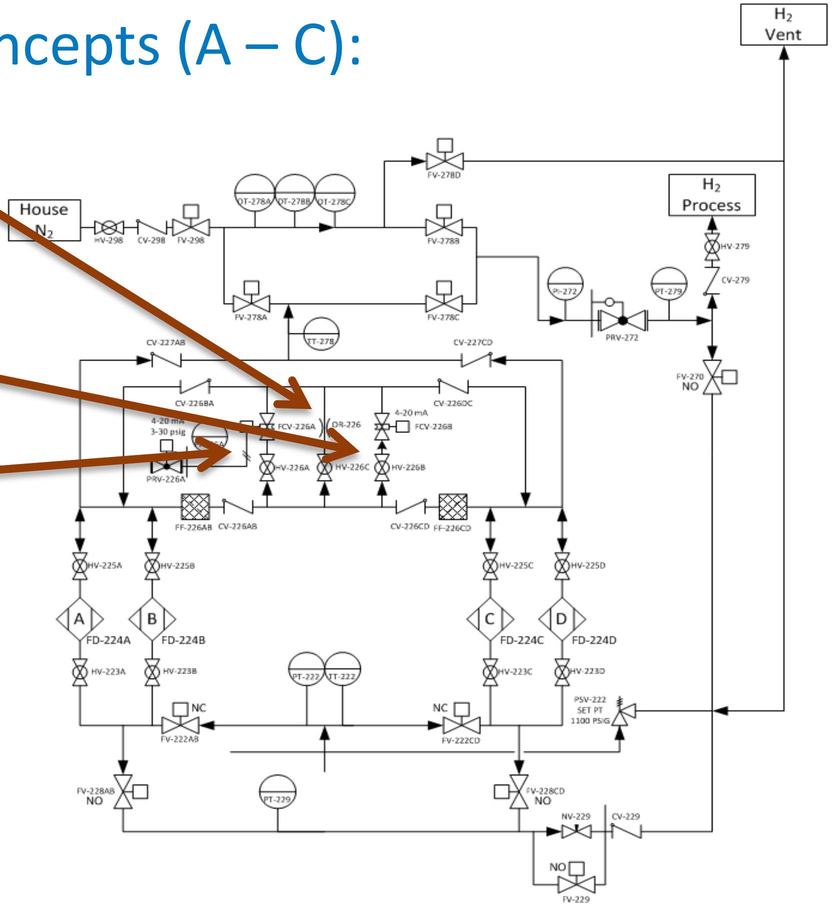
Large active area stack testing and hydrogen dryer improvements

- **Challenge:** Traditional H_2 drying systems are designed to operate at full power with a fixed amount of H_2 lost regardless of operating conditions
- **Goal:** Improve electrolyzer efficiency by optimizing electrolyzer balance of plant operation under variable conditions
- **Approach:** Reduce H_2 drying losses in pressure swing adsorption dryers to less than 3.5% of flow using variable flow approach
- Testing aims to confirm H_2 quality is not compromised with real time monitoring of water content in the H_2

Technical Accomplishments

Variable flow drying concept developed and installed

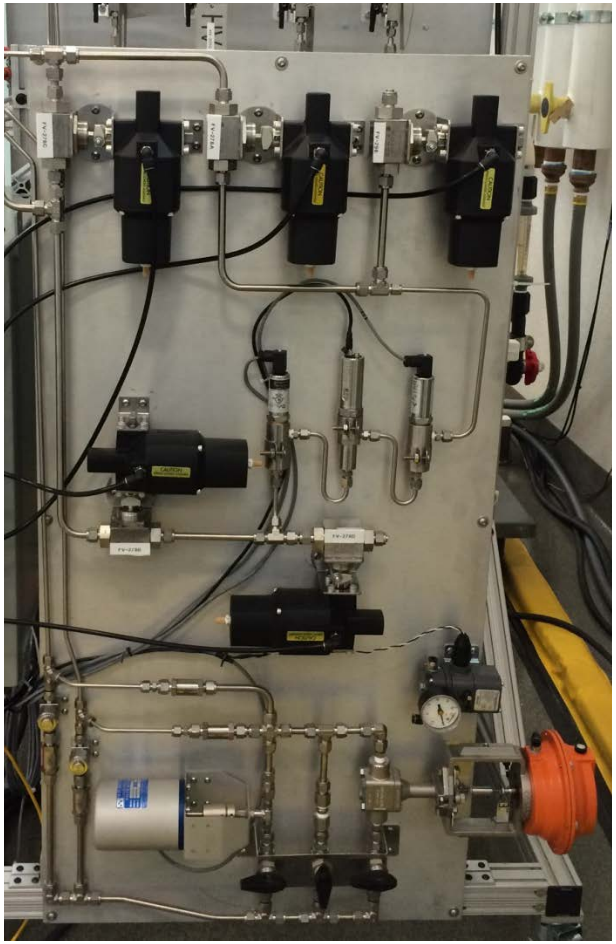
- Replace fixed orifice used in pressure swing adsorption (PSA) dryers with a linear actuated valve to accommodate varying hydrogen flow
- Currently testing 3 different PSA concepts (A – C):
  - A – (Control) fixed orifice, typically seen in electrolyzers
  - B – Variable flow valve, electrically actuated
  - C – Variable flow valve, pneumatically actuated



Technical Accomplishments

Measuring Dryer Performance

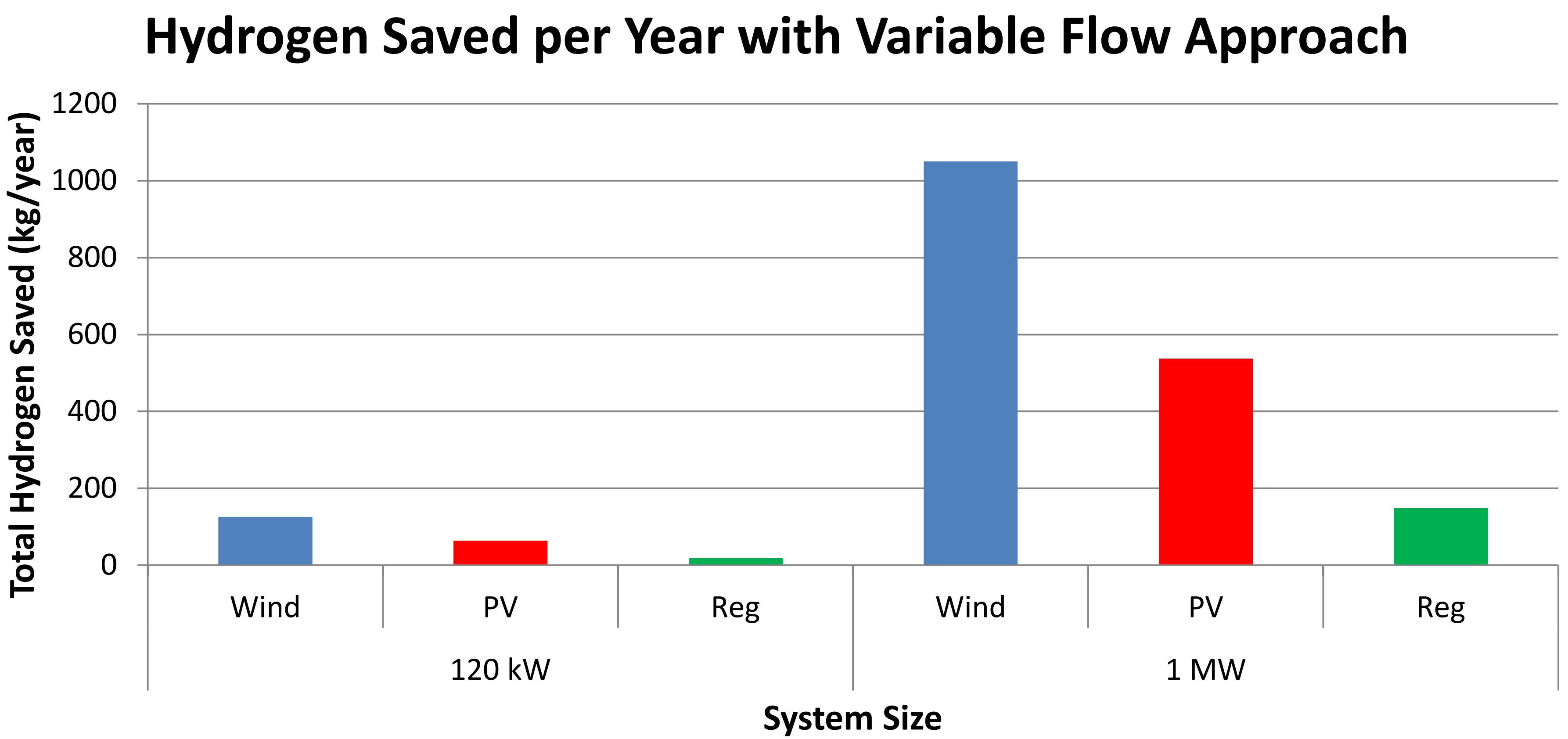
- Dew point sensors on outlet of dryer are used to track parts per million by volume (ppmv) of H_2O in the H_2
- SAE J2719 fuel quality standard is mandatory target, < 5 ppmv
- Dew point sensors are known to have issues during operation. Solutions to overcome dew point sensor challenges:
  - **Challenges:** Dew point sensors having erratic behavior, Dew point sensors drift over time
  - **Solutions:** Install multiple dew point sensors, filter data when needed, N_2 purge system to sweep any contaminants off of the sensors when needed



Technical Accomplishments

Hydrogen savings with variable flow

- Preliminary analysis of why these savings are important
- Systems are growing in size, real savings happen as larger systems come online



Collaborations

Formal

Giner Inc.

- Work for Others
- Tested (3) 150 kW stacks

Xcel Energy (CRADA)

- Wind-to-Hydrogen demonstration project since 2005

Internal to NREL

700 bar hydrogen station

- Quality results

INTEGRATE

- Large active area stack test bed
- H_2 drying system

Future Work

- Finalize testing and report on on-going dryer testing to optimize drying losses
- Continue long duration testing comparing stack decay rates for variable power operation and constant power operation
- Find other opportunities to use the electrolyzer balance of plant to improve system efficiency
  - Capturing heat to warm up H_2 sweeping gas to lose less H_2 in drying
  - Using cooling system and H_2O drop outs to improve dryer efficiency

Responses to Previous Year Reviewers' Comments

- This project was not reviewed last year

Summary

Relevance: Goals consistent with reducing capital cost, improving stack and system efficiency and integrating systems with renewable energy sources

Approach: Develop and demonstrate advanced controls, novel sub-systems, system-level improvements and integrate with renewable energy sources to reduce the cost of hydrogen

Technical Accomplishments:

- Reached 5,500 hours of operation on (3) 10 kW stacks to analyze stack decay differences between constant- and variable-powered stack operation
  - Stacks showed a decay rate of 11 - 22 μV/cell-h
- Collaborated with INTEGRATE to build electrolyzer stack test bed
- Purchased, installed, commissioned and began testing H_2 variable dryer concept
  - Installed linear valves and orifice in parallel paths for testing
  - Solved dew point challenges

Collaborations:

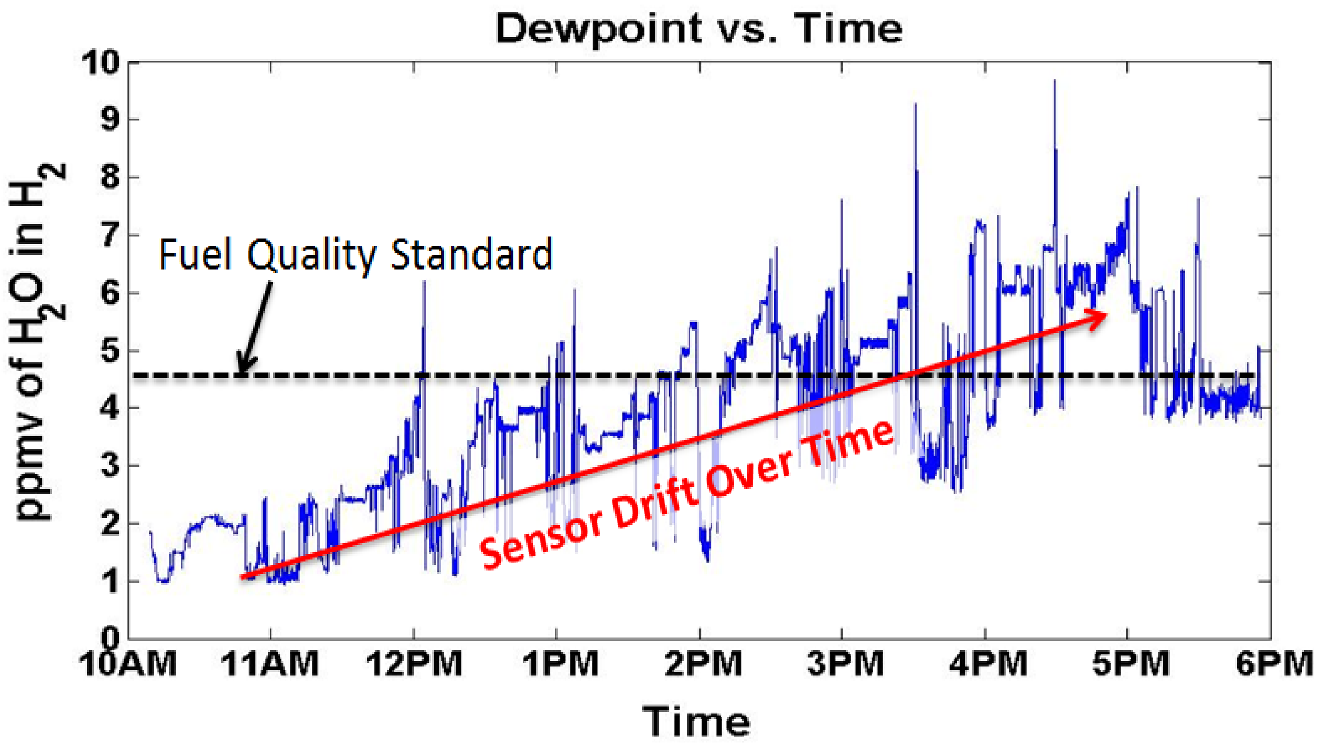
- Giner Inc. - Large active area stack testing
- Internal - 700 bar station, INTEGRATE

Proposed Future Research:

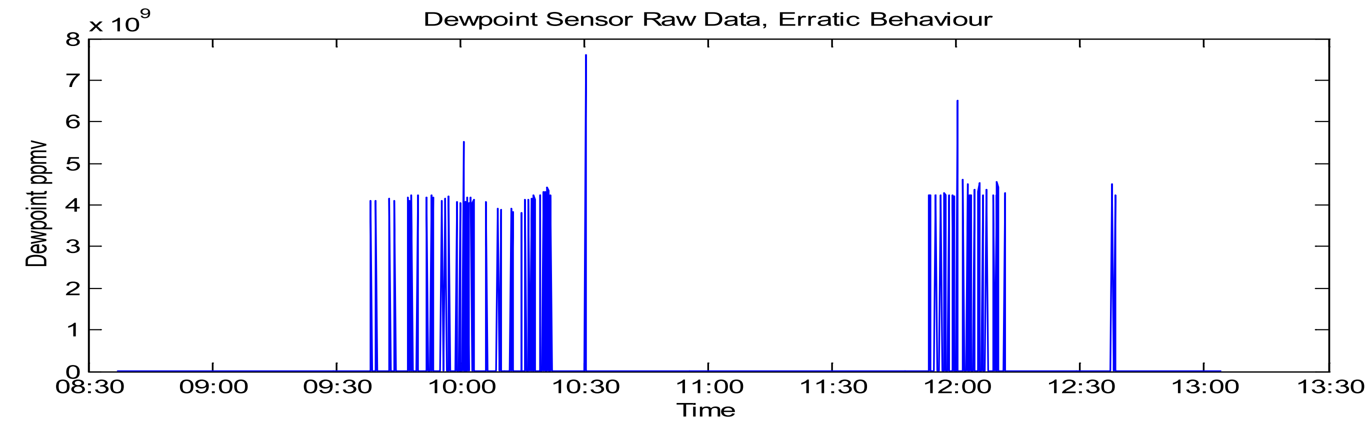
- Finalize testing and report on on-going dryer testing to optimize drying losses
- Continue long duration testing comparing stack decay rates for variable power operation and constant power operation
- Find other opportunities to use the electrolyzer balance of plant to improve system efficiency

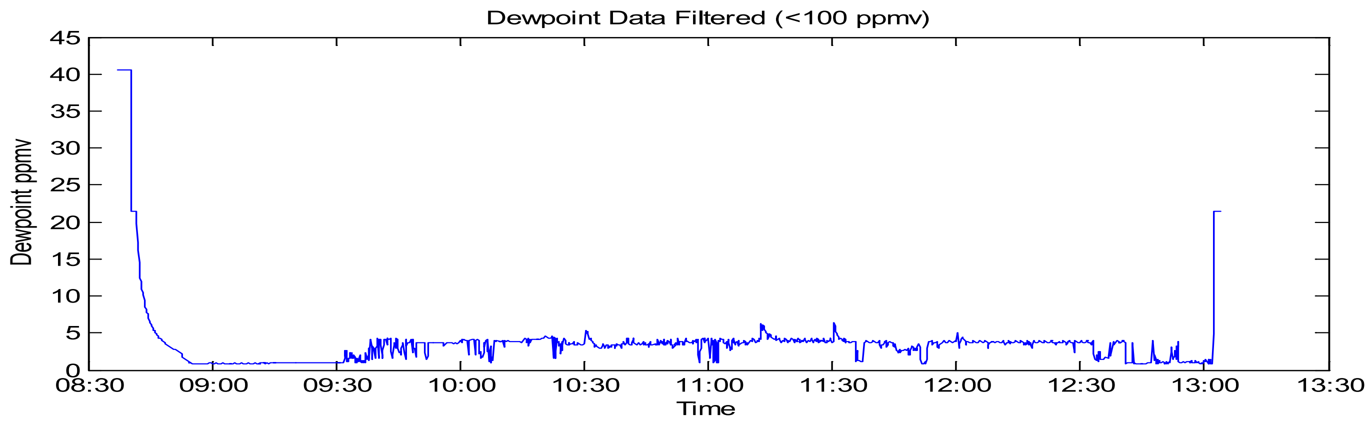
Technical Backup Slides

Dew Point Sensor Drift Over Time



Dew Point Sensor Erratic Behavior



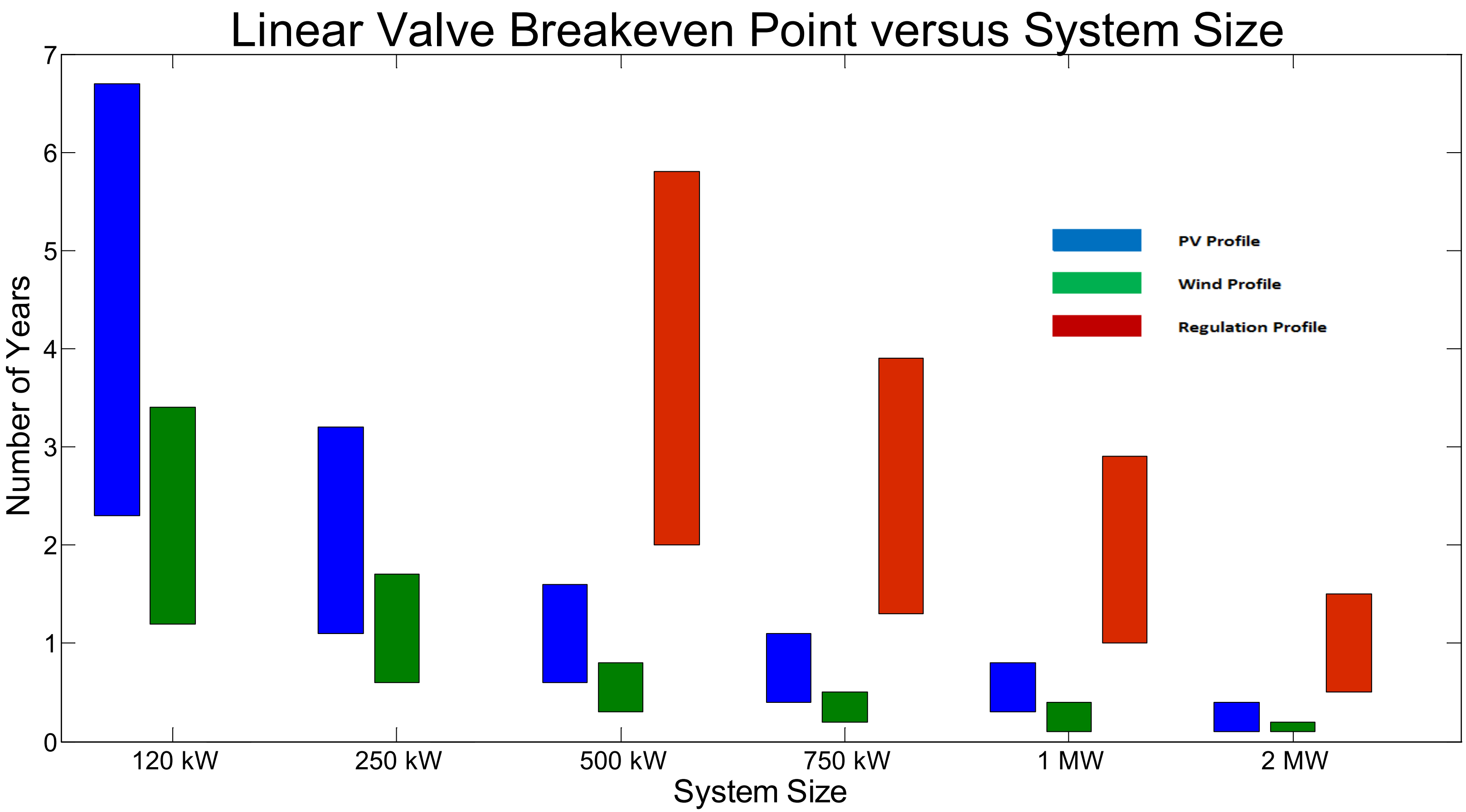


Hydrogen Savings Analysis Details

Assumptions

- Estimates on installing/implementing one linear actuated valve on one system based on experience. Cost would go down as more valves are implemented and controls are duplicated
- Price of H_2 6 – 10 $/kg
- Valve Costs Hardware:
    - Valve, Linear Actuator
- Valve Costs Labor:
    - Installation, Controls

Linear Valve Breakeven



Technical Accomplishments

Dryer Characteristics

- Calculated flow based on stack current for the 120 kW stack from Proton
  - 52 kg/day
- Initial drying losses calculated at
  - 9 – 11 kg/day
  - 17 – 21% of H_2 lost
- Drying system designed for 135 kg/day
  - 6 – 8 % of H_2 lost theoretically
- Added control valve on vent line to reduce losses to < 10% at full operation