# 2017 DOE Hydrogen and Fuel Cells Program Review

## Renewable Electrolysis Integrated System Development & Testing


**Mike Peters*, Kevin Harrison, Huyen Dinh, Danny Terlip, Jennifer Kurtz, Josh Martin**


**June 7, 2017**

**Project ID: PD031**


***Presenter**


This presentation does not contain any proprietary, confidential, or otherwise restricted information


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**

- Start date: September, 2003
- End date: October, 2017*

* Project continuation and direction determined annually by DOE

**BARRIERS**

G. System Efficiency
I. Grid Electricity Emissions (Distributed)
J. Renewable Electricity Generation Integration (Central)
L. Operations and Maintenance

**BUDGET**

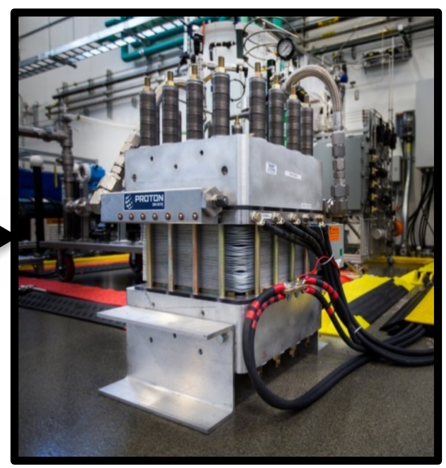
- FY16: $200K
- FY17: $200k
- Total Project Value: $6,300k

**PARTNERS**

- Xcel Energy - CRADA
- Proton OnSite - TSA
- Giner Inc. – TSA
- SoCal Gas - CRADA

# Relevance:

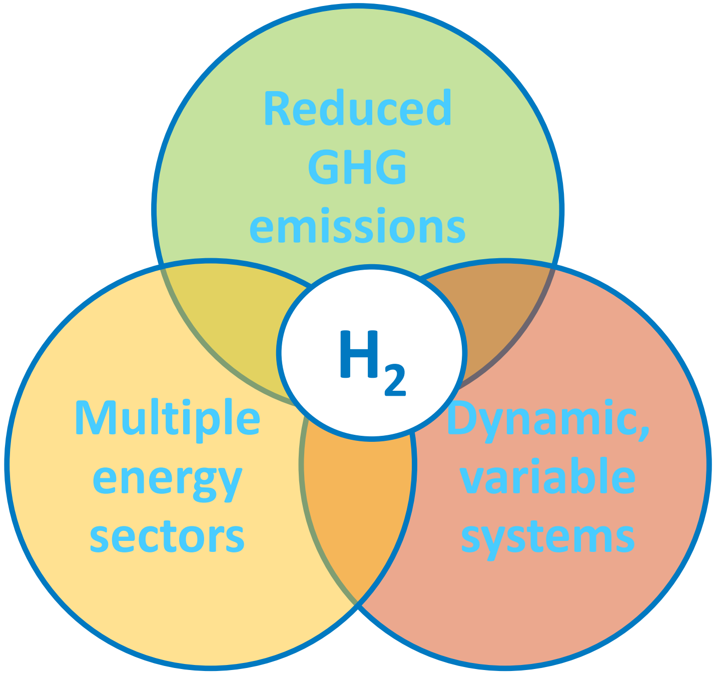
***Over the 14 year span of the Renewable Electrolysis Project, NREL has worked with electrolyzer manufactures and developers to innovate and improve upon electrolyzer size, power conversion, cost, and efficiency***



[1]http://ec.europa.eu/energy/energy2020/roadmap/doc/com_2011_8852_en.pdf

# Relevance:

- Reducing emissions across sectors
- Renewable hydrogen via LTE provides:
  - Feedstock for renewable fuels like $CH_4$ and $NH_3$
  - A near-zero carbon transportation fuel
  - Utility grid services and stabilization
  - Long-duration energy storage



# Approach:

## *Address and validate DOE goals for capital cost, efficiency, and renewable energy source integration to reduce the cost per kilogram of hydrogen produced via electrolysis*

**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 | $/kg<br>$/kW | 0.70<br>430 [e, f] | 0.50<br>300 [f] | 0.50<br>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] |

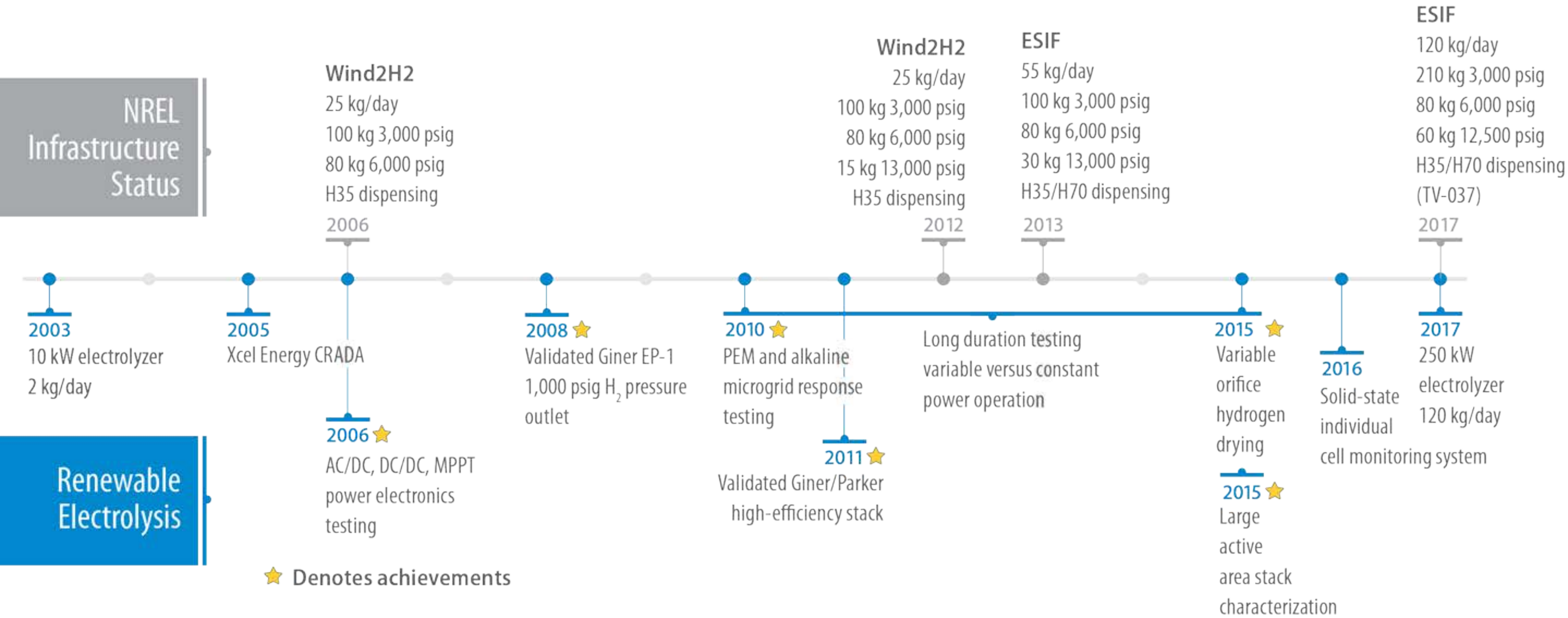
# Approach: Stack Validation

- **Validate stack performance with IV Curves**
  - Compare stack efficiency to DOE targets
  - Vary cathode pressure, temperature, current density
- **Long duration stack testing under variable power**
  - Track decay rate of PEM stacks running side-by-side
- **Individual cell voltage monitoring**
  - Monitor all cells instantaneously

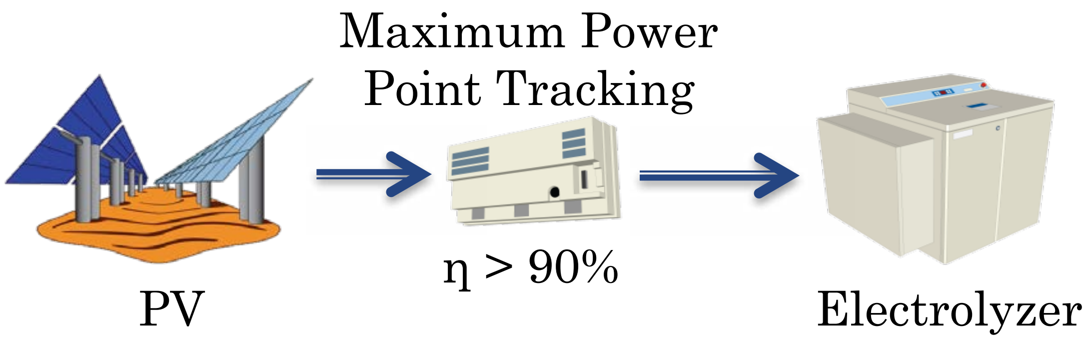
# Approach: System Innovation & Integration

- **Power Conversion**
  - Improve system efficiency through improved integration with renewable electricity sources
- **Grid Support**
  - Quantify and demonstrate electrolyzer ability to provide fast response for frequency and voltage regulation
- **Reduce Hydrogen Drying Losses**
  - NREL developed an improve drying technique to reduce losses under variable power operation

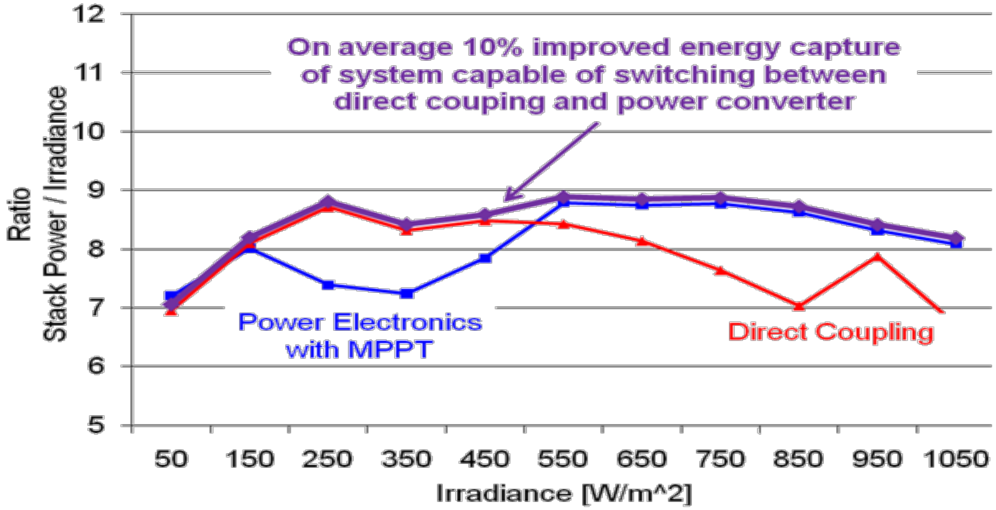
# Accomplishment: Timeline

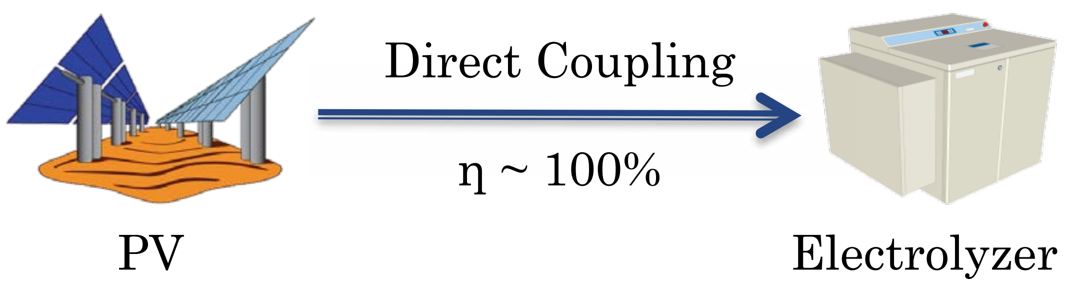


# Accomplishment: Direct Coupling vs. MPPT




***Approach would improve the efficiency of renewable H2 production by matching the polarization curves of PV & electrolyzers, enabling direct coupling.***

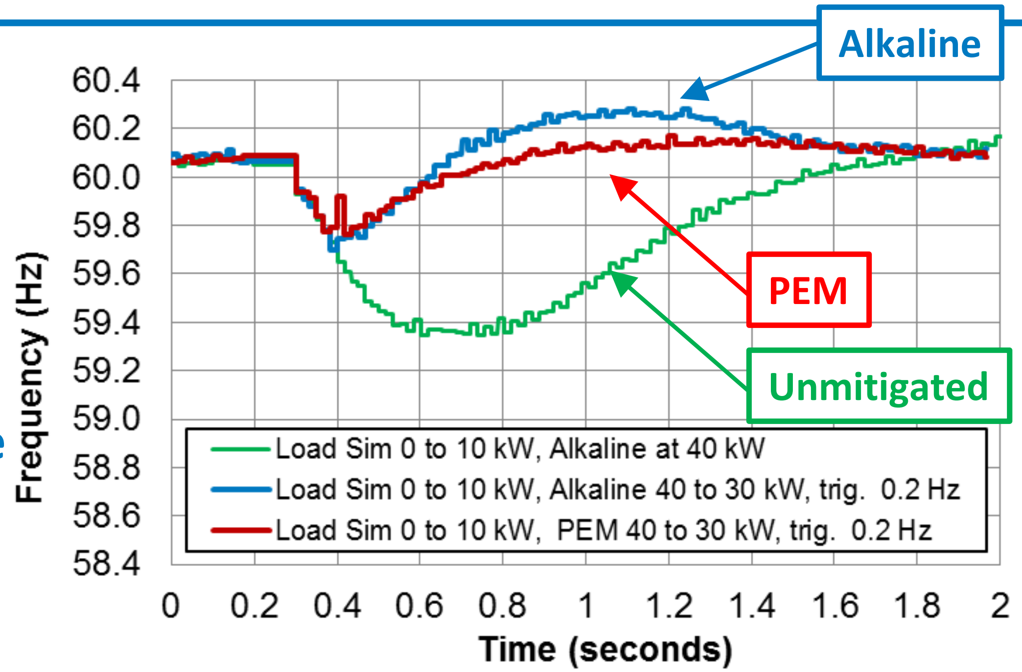


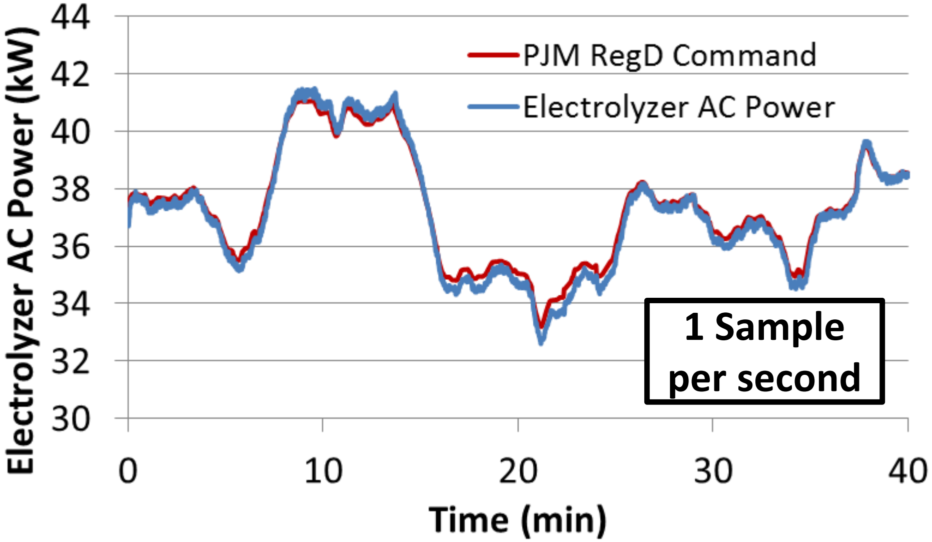



# Accomplishment: Electrolyzer Response

## Microgrid – Freq. Response

- Sensed local frequency drop
  - 10 kW resistive load
- PEM and Alkaline tests ran separately
- Both responded quickly to mitigate disturbance once freq. ≤ 59.8 Hz




## Supporting grid stability

- Typical utility profile to validate performance
- System response, not just stack
- 120 kW PEM stack operating on NREL's electrolyzer stack test bed

Source: Harrison K., Mann M., Terlip D., and Peters M., NREL/FS-5600-54658

# Accomplishment: Giner/Parker

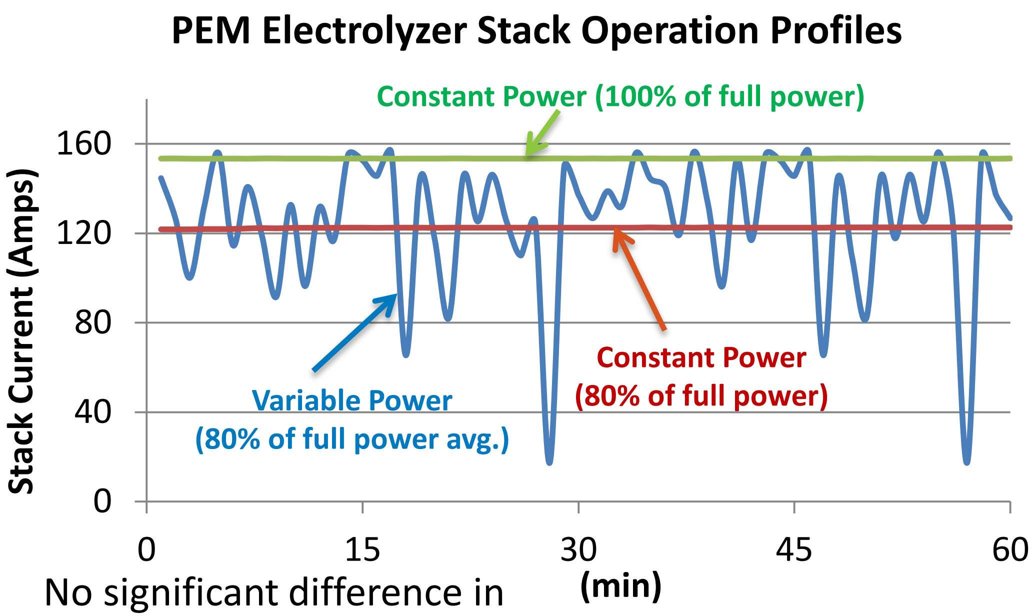
## *Gather 200 hours of data to verify against DOE stack and system efficiency*

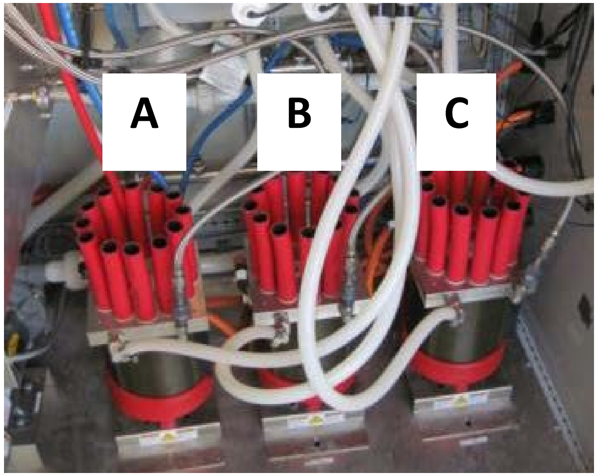
- Monitored stack dc voltage/current, water temperature, ac input voltage/current, hydrogen production (kg/hr)
- With cathode at 390 psig, 80°C, and 1300 – 1800 mA/cm$^2$
  - 73.6% stack efficiency (LHV)
- Drying losses measured at 3.5% of full stack power

# Accomplishment: Long duration

## Monitoring and Control

- Highly variable power
- Stack input and output temperature
- Stack voltage and current
- Individual control over each of 3 stacks
- Programmable wind/solar profiles



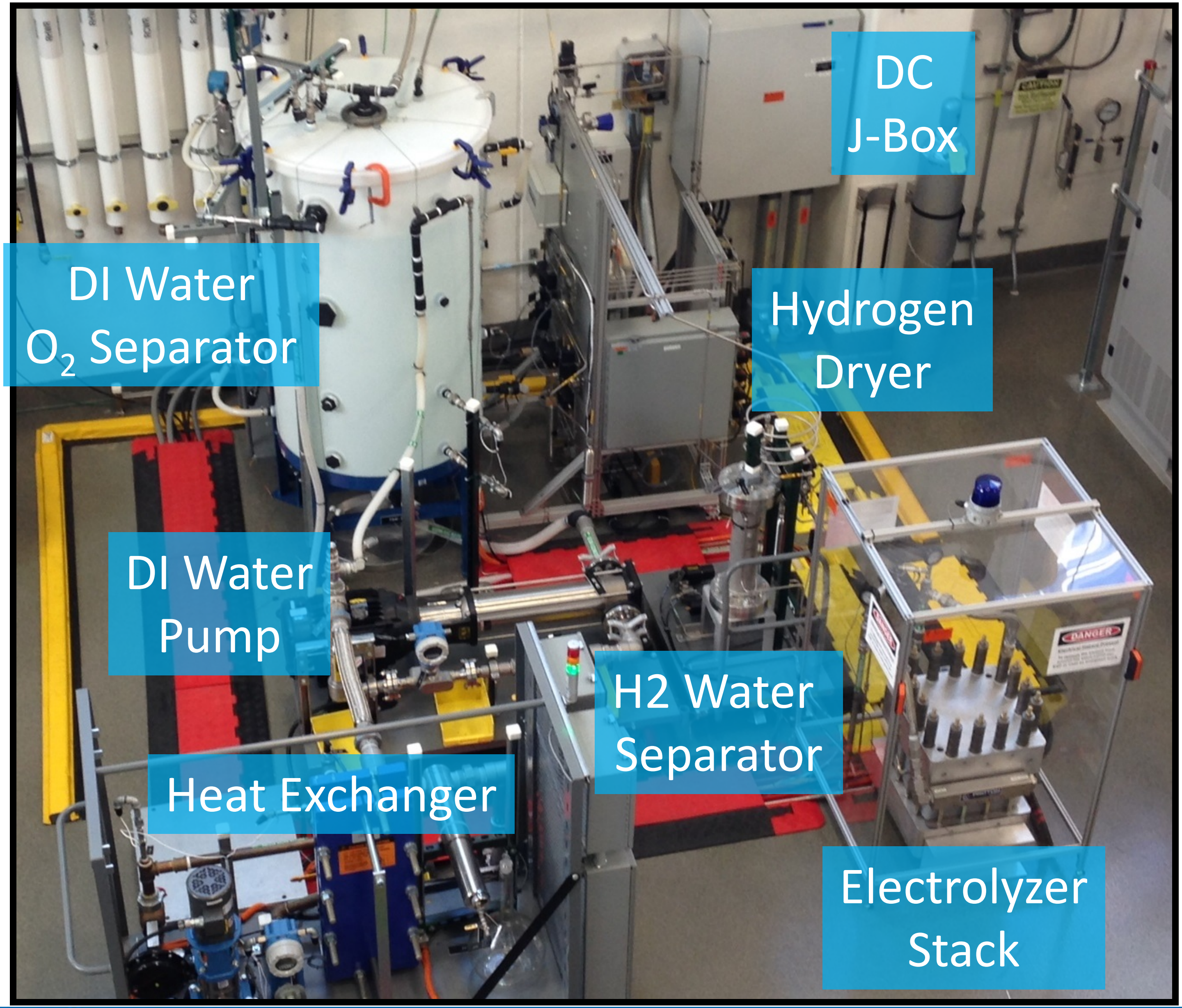




No significant difference in decay rate between the two methods

| Identifier | Type | Total Hours | Decay Rate [μV/cell-hr] |
|---|---|---|---|
| A1 | Variable | 10014 | **0.1** |
| B1 | Variable | 10112 | **1.0** |
| C1 | Constant | 12069 | **2.1** |
| A2 | Variable | 7257 | **13.3*** |
| B2 | Constant | 7257 | **30.2*** |
| C2 | Variable | 4330 | **-10.1** |

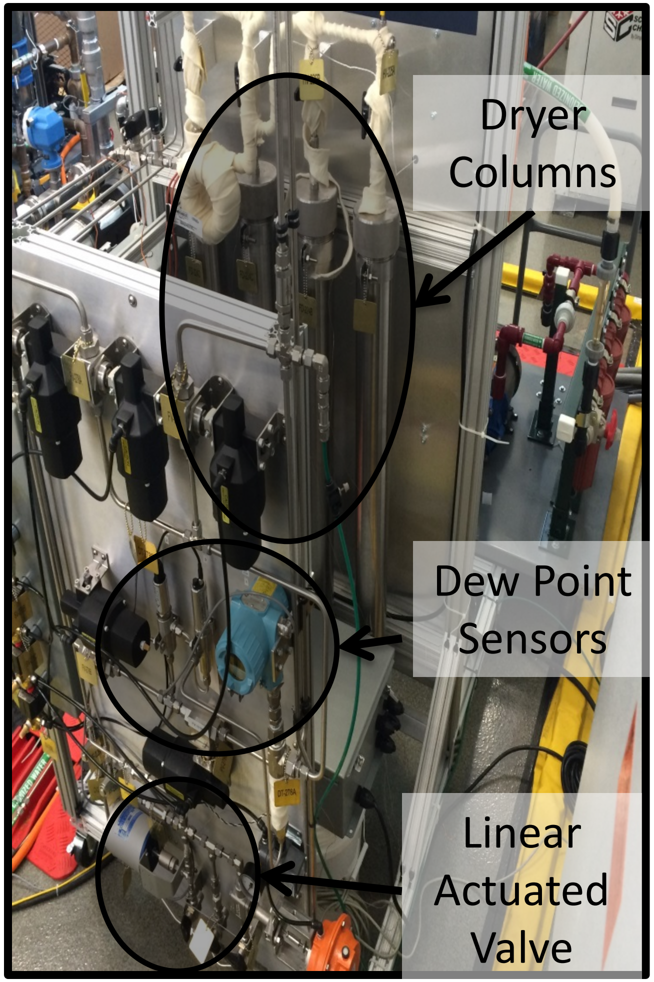
*BoP issues caused high decay rate

# Accomplishment: ESIF – Stack Test Bed

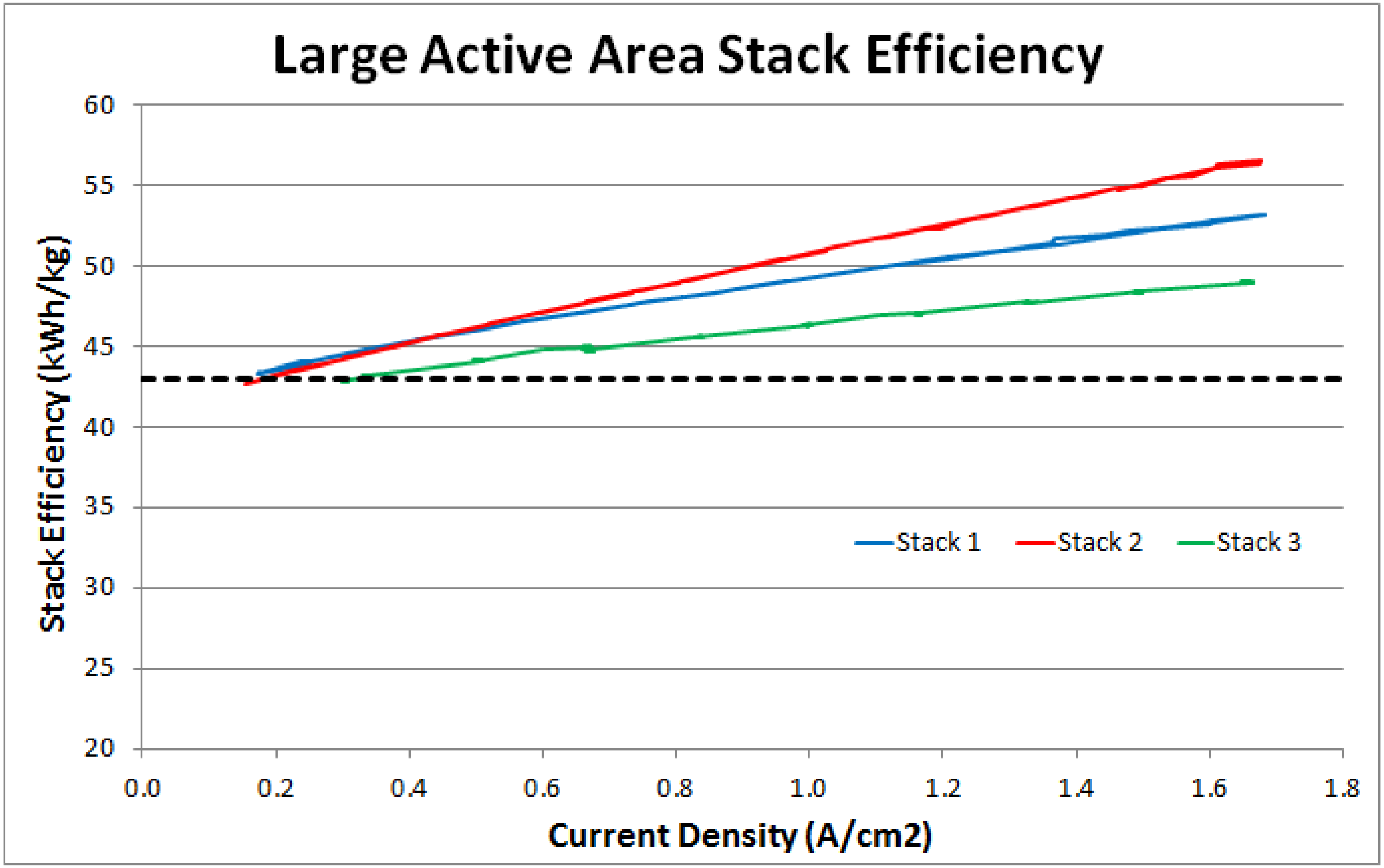


# Accomplishment: Variable Drying

- Operated a 120 kW PEM electrolyzer with variable profiles comparing two drying techniques (fixed versus variable)
- 3.5% fixed approach: Drying losses fixed at 76 g/h regardless of hydrogen flow
- 3.5% variable approach: Drying losses set to 3.5% of hydrogen flow (based on stack current)
- A hydrogen savings of 1 kg per 40 kg produced was demonstrated (2.5%)
  - Savings dependent on type of variable profile



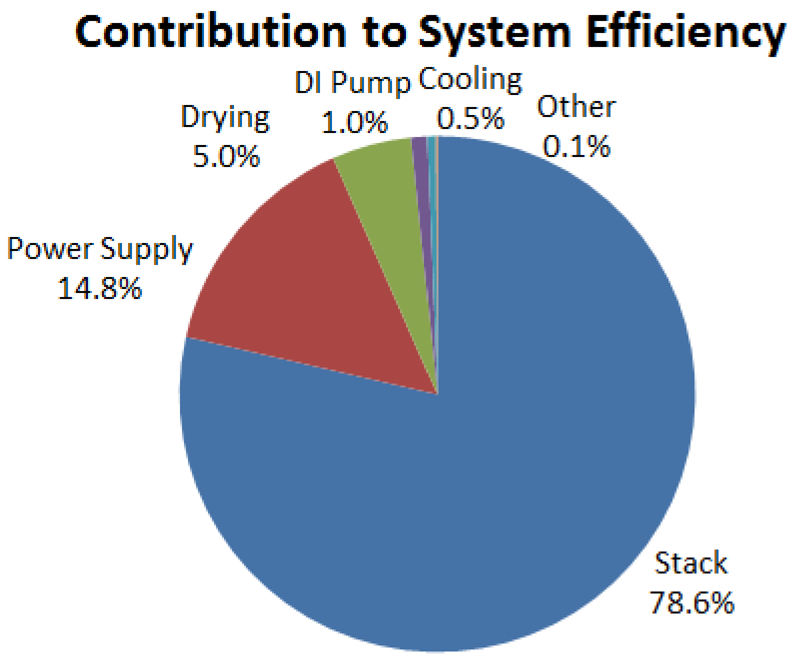
# Accomplishment: Current State of PEM Stacks



# Accomplishment: Electrolyzer Model

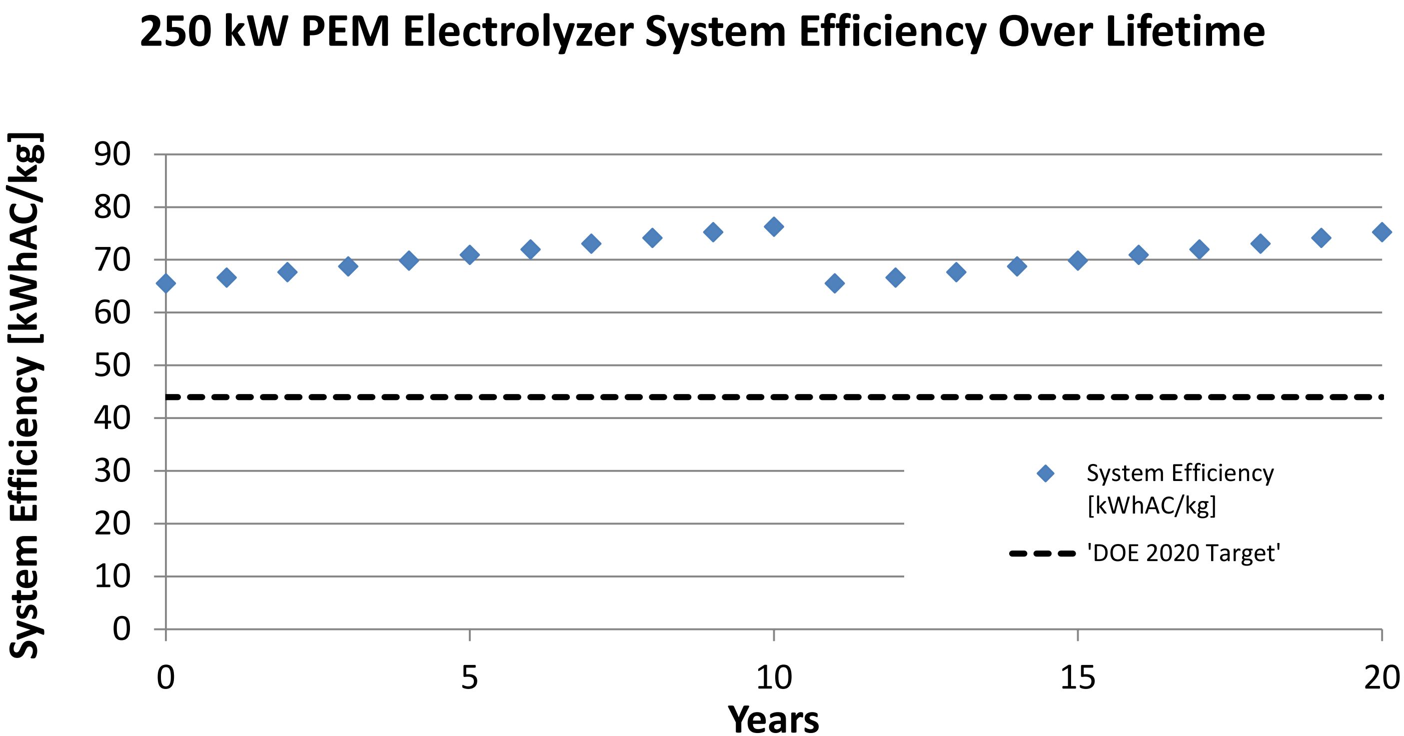
- Created a balance of plant and stack model
- Data from multiple large active area stacks were combined to obtain a generic stack performance metric
- Uses power data from ESIF stack test bed, measured the following:

  Power supply
  DI Pump
  Cooling system
  Multiple stacks

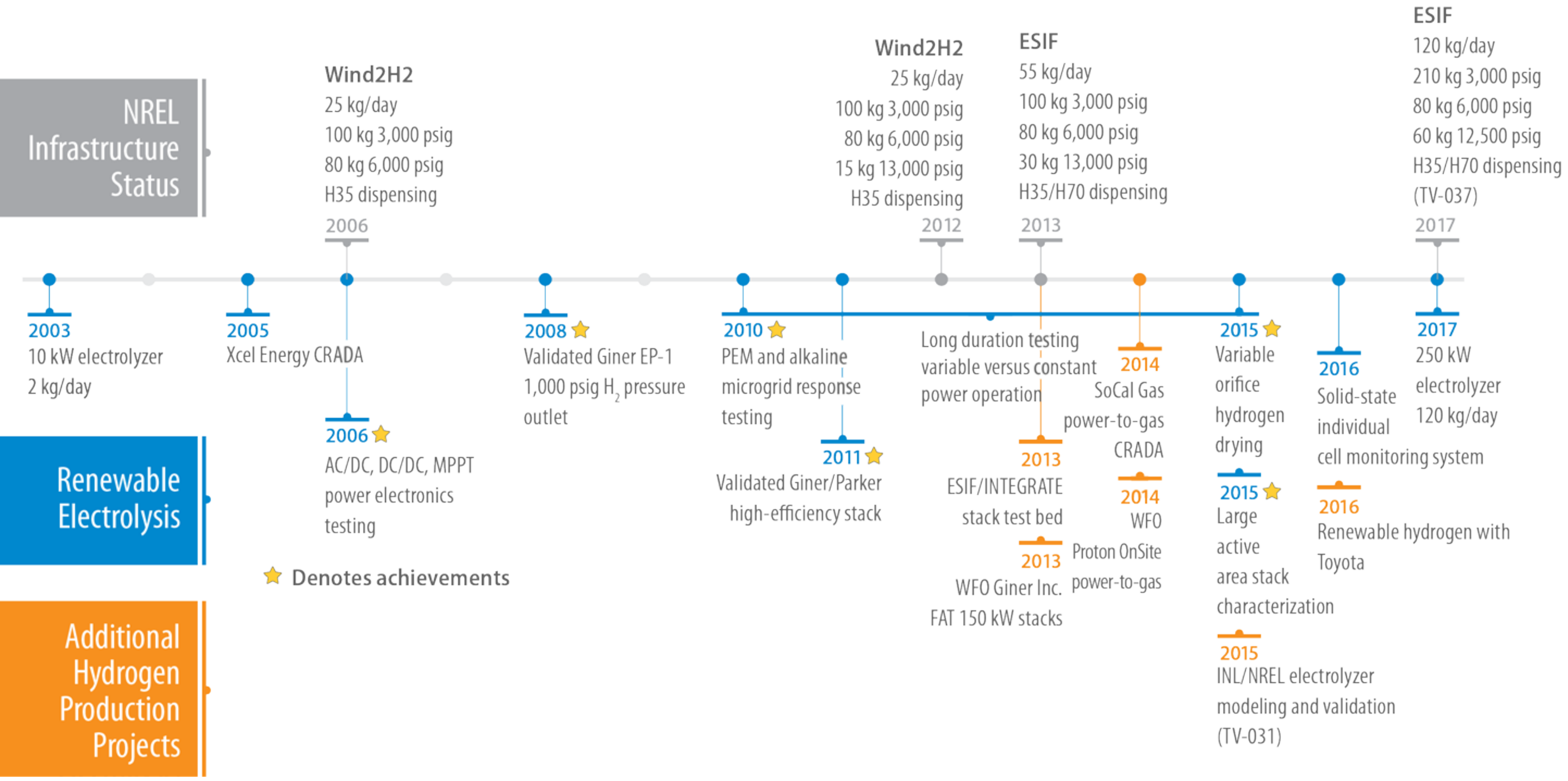


# Accomplishment: Electrolyzer Model

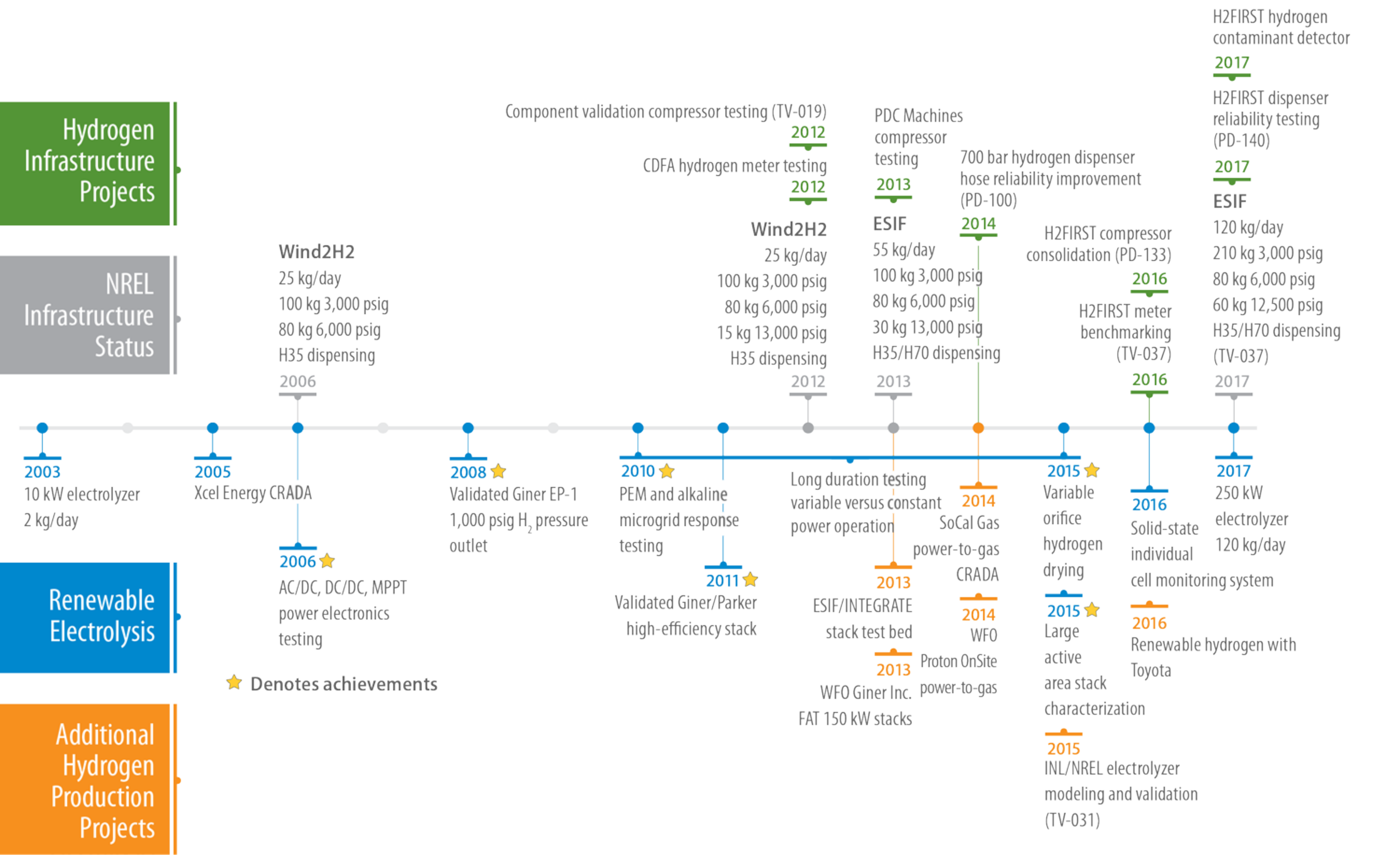
- Examines system efficiency over the lifetime of an electrolyzer
- Leverages concepts explored through the 14 year project: e.g., variable drying, stack degradation, power conversion



# Impact: Production Projects



# Impact: Infrastructure Projects



# Collaboration:

- Xcel Energy – Wind-to-Hydrogen CRADA
- Proton OnSite – Power-to-Gas TSA
- Giner Inc. – Stack validation TSA
- SoCal Gas – Power-to-Gas-to-Methane - CRADA

# Responses to Previous Year Reviewer Comments

*The issues with the dew-point sensors seemed to resonant with the members of the audience. I question, though, the lack of collaborations and coordination with experts in this field. Clearly, the data collected from these critical instruments affects resultant conclusions, etc. I recommend that subject matter experts be brought in to address this, apparently, long-term problem.*

**NREL added redundant dew point sensors and a PM schedule to ensure accuracy of the dew point sensors. The stack test bed constantly monitors moisture content and does not allow hydrogen about the 5 ppmv of $H_2O$ in the $H_2$ to go to the attached hydrogen station.**

*It is important to find other opportunities to use the electrolyzer balance of plant to improve system efficiency. A clearer message here with respect to potential avenues would have been helpful. It seems that using cooling system and H2O drop outs to improve dryer efficiency should have been an initial focus; it's nice to see it called out here though for future work. Capturing heat to warm up H2 sweeping gas to lose less H2 in drying also seems logical. Finally, the effort to continue long-duration testing, comparing stack decay rates for variable power operation and constant power operation needs better fidelity with respect to expected outcomes.*

**Cooling system with dropouts and heating the H2 were potential next steps within this project. There are many ways to get incremental savings in system efficiency. Expected outcomes for continuing the long duration testing were evaluated and the team ultimately decided to discontinue that testing.**

# Future Work:

**End of FY17**

- Techno-economic analysis of CPV integrated with PEM electrolyzer
- Continue testing of individual cell voltage monitoring system
- Publish final project report

**Continuing Projects**

- Renewable Hydrogen with Toyota
- INTEGRATE
- INL/NREL Modeling
- H2@SCALE
- HydroGEN

# Summary

**Relevance:**

- Electrolyzer manufacturers have scaled systems from a few kW to hundreds of kW in the past decade

**Approach:**

- Assess capital cost, efficiency, and renewable integration solutions with electrolyzer production
- Provide third party validation of stack and system components
- Improve system efficiency through
    - Power conversion innovation
    - Reducing drying losses

**Technical Accomplishments:**

- 2003 10 kW Electrolyzer validation testing
- 2005 Xcel Energy – Wind2H2
- 2006 AC/DC, DC/DC testing
- 2008 Validated Giner EP-1, 1,000 psig H2
- 2010 Micro grid response testing
- 2010 Giner/Parker high efficiency stack
- 2011 Proton long duration testing
- 2013 Electrolyzer stack test bed at ESIF
- 2015 Variable drying approach
- 2016 Individual cell voltage monitoring

**Collaborations:**

- Xcel Energy
- Proton
- Giner

**Proposed Future Research:**

- Publish report to close out the project

# Technical Backup Slides

# Publications and Presentations

- Presentation at the ACT Expo, “Renewable Hydrogen Production for Use in Hydrogen Fuel Cell Vehicles,” Dallas, Texas, May 2015
- 228th Electrochemical Society Meeting, “Large Active Area Electrolyzer Stack Test Bed – Design, Data and Development”, Phoenix, Arizona, October 2015
- 2nd International Workshop, Durability and Degradation Issues in PEM Electrolysis Cells and its Components, “Lifetime Prediction of PEM Water Electrolysis Stacks Coupled with RES”, Freiburg, Germany, February 2016
- Solar Fuels Generation - PV and Electrolysis Workshop, “Renewable Electrolysis – Systems Integration and Optimization”, Institute of Energy Conversion, University of Delaware Energy Institute, February 2016