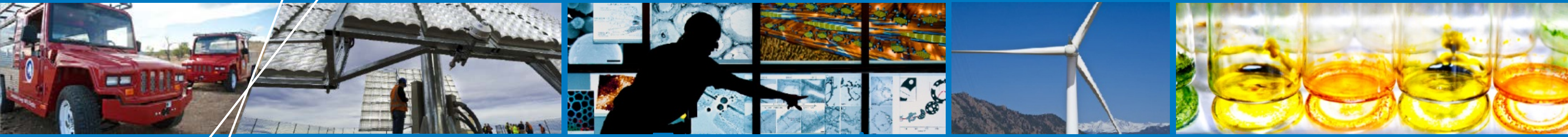
Life-Time Prediction of PEM Water Electrolysis Stacks Coupled With RES



2nd International Workshop

Durability and Degradation Issues in PEM Electrolysis Cells and its Components

Kevin Harrison

National Renewable Energy Laboratory

February 16, 2016

Outline

- **Introduction**
- **Motivation**
- **Summary of Research 2006 - 2015**
  - RES Integration
  - Electrolyzer response
  - Long-duration stack operation
- **Path Forward**
- **Conclusion**

NREL Fuel Cell & Hydrogen Technologies Program

- Hydrogen production and delivery
- Hydrogen storage
- Fuel cells
- Fuel cell manufacturing R&D
- Technology validation
- Market transformation
- Safety, codes and standards
- Systems analysis

Hydrogen Production and Delivery

Photoelectrochemical (PEC) water splitting

Photobiological water splitting

Fermentation

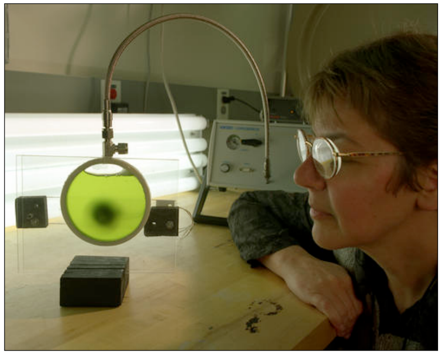
Conversion of biomass and wastes

Solar thermochemical water splitting

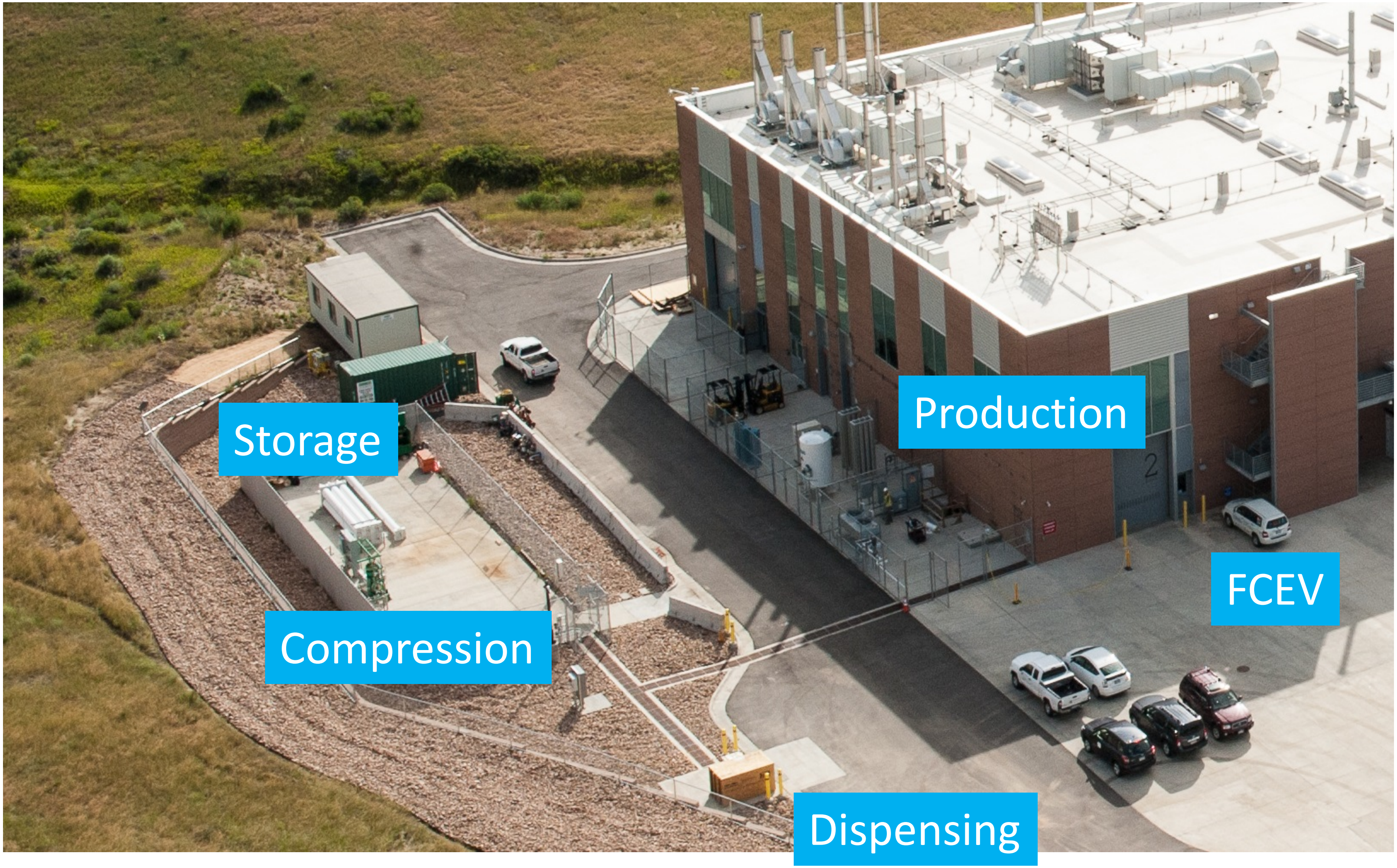
Renewable electrolysis

Dispenser hose reliability testing

Pathway analysis

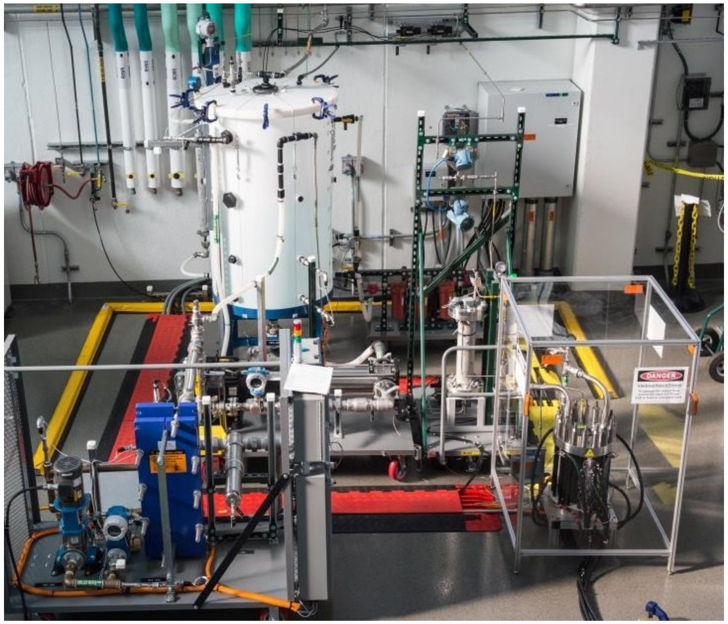


ESIF - Hydrogen Systems R&D



H_2 Generation & Dispensing Capabilities

- **Onsite H_2 production – 50 kg/day**
  - 2016 - Double production capacity
  - Adding (2) 1000A power supplies
- **Compression & Storage**
  - Three levels 200, 400 and 875 bar
  - Uses – ESIF FC labs, testing and fueling
  - Additional compression and storage
- **Dispensing**
  - Typical FCEV refueling 3 – 4 kg
  - Fueling at 350 and 700 bar
  - Fork lifts, busses and light-duty



SoCal Gas/NREL Power-to-Gas

- **~ $1M CRADA**
- **Scale-up of benchtop**
- **Solar-powered electrolysis**
- **Synthetic natural gas production**
- **Systems integration & optimization**
- **Bioreactor & Filtration**
  - Pipeline quality
  - High pressure operation
  - Push reaction limits

ENERGY SYSTEMS INTEGRATION

ESI optimizes the design and performance of electrical, thermal, fuel, and water pathways at all scales.

ESIF Partnerships: NREL + Southern California Gas

NREL is partnering with Southern California Gas to evaluate a new "power-to-gas" approach—one that builds on the existing natural gas infrastructure to enhance the value of solar or wind resources and has the potential to change how the power industry approaches renewable generation.

R&D Strategy

NREL and Southern California Gas are leveraging the capabilities of the ESIF to accelerate the development and testing of a fully operational, pilot-scale model of the proposed technology. The results from the experimental work will be used to develop and validate dynamic and steady-state optimization simulation models, and these models will then be used to quantify the potential impact of this power-to-gas approach to energy storage—both financially and operationally.

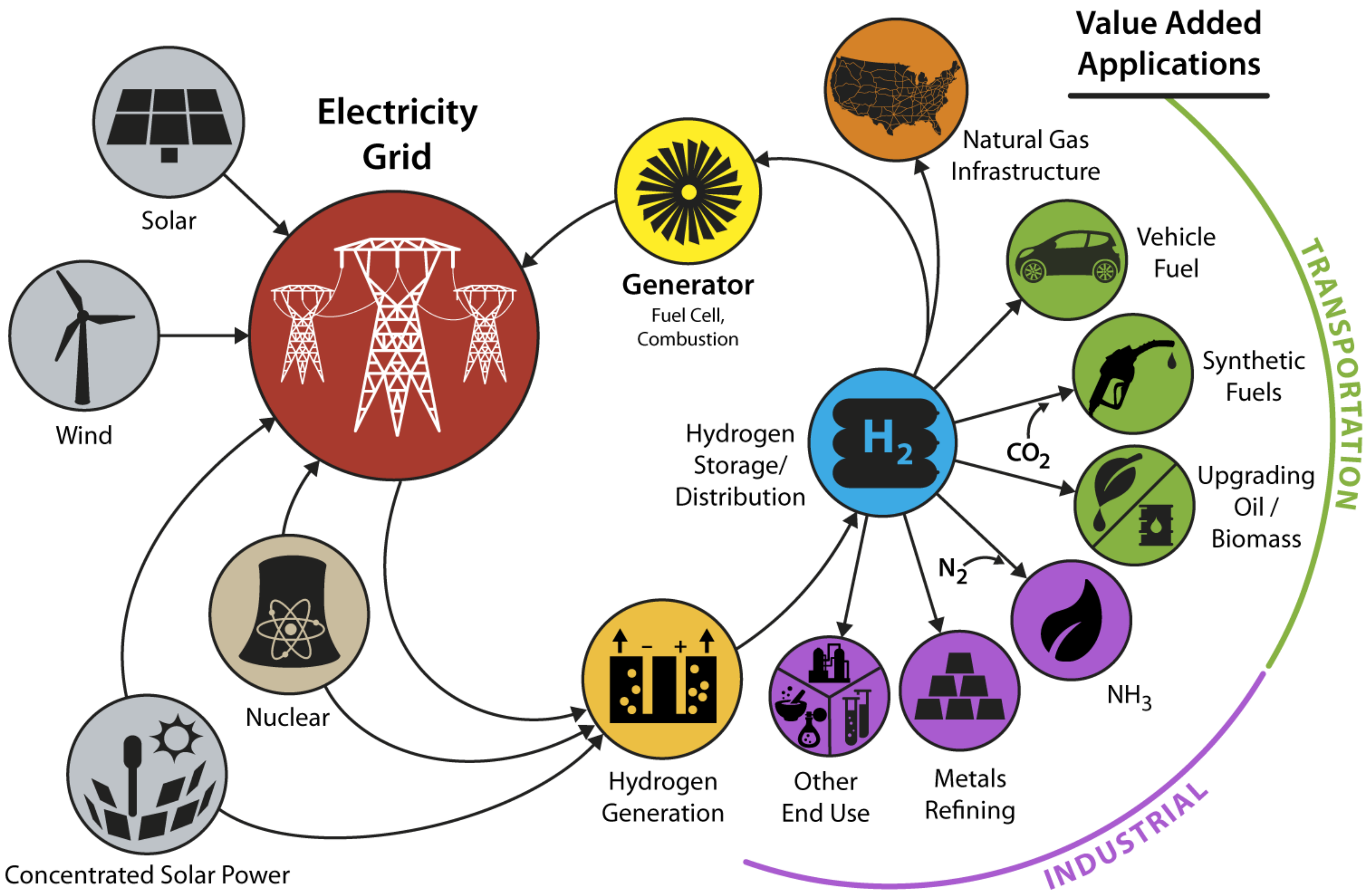
Impact

The "power-to-gas" technology has the potential to make solar and wind power a baseload asset, one that can provide reliable and dispatchable energy production. The technology differs from others in that not only does it have the potential to provide a cost-effective energy storage system, but one that can store large quantities of energy over very long time periods—enabling renewable energy that was produced during high-energy months to be used days and even months later.

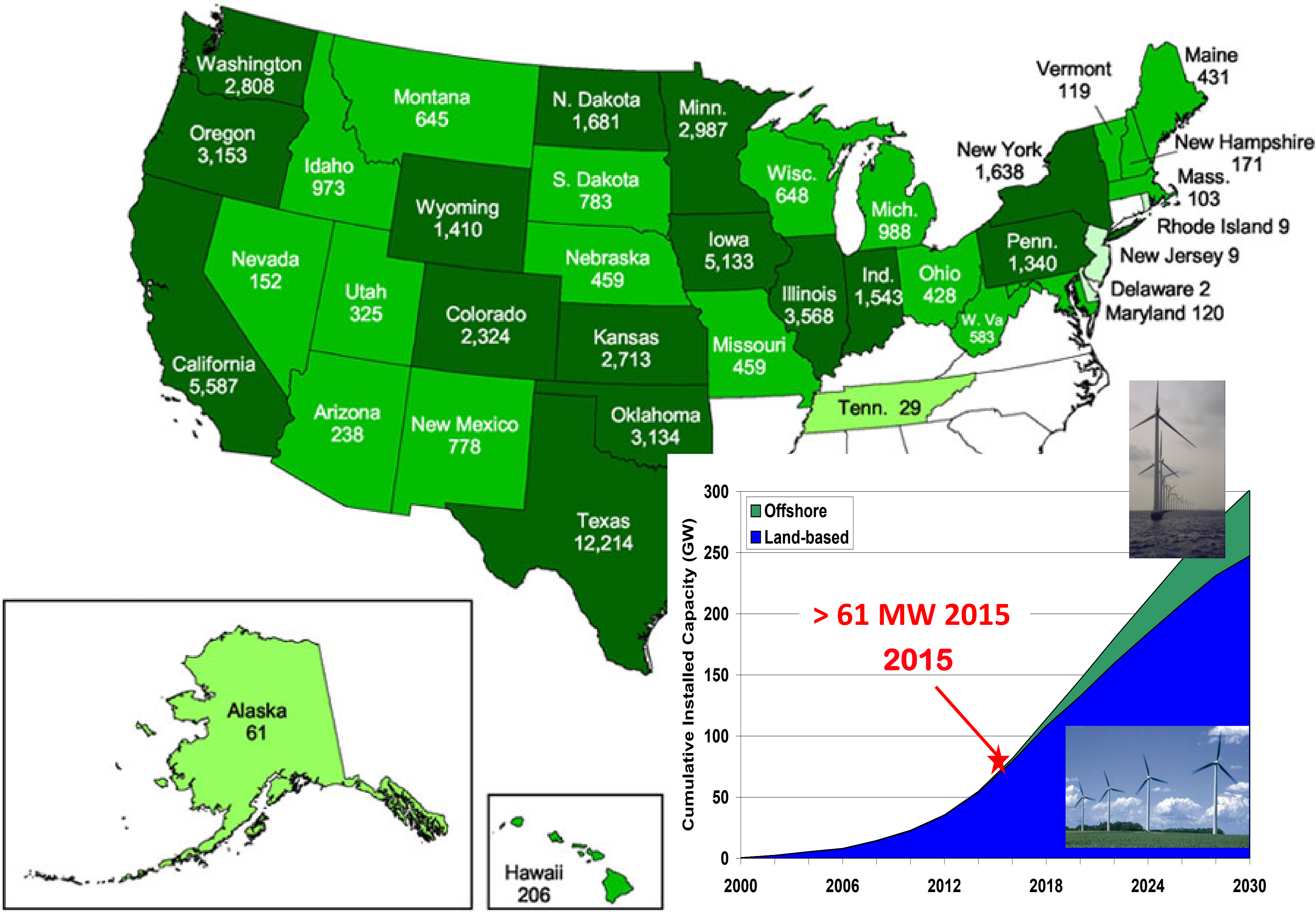
Southern California Gas is leveraging the one-of-a-kind testing environment at the ESIF to explore an innovative approach to energy storage that could enable greater deployment of wind and solar. *Photo by Dennis Schroeder, NREL 20689*

ENERGY SYSTEMS INTEGRATION

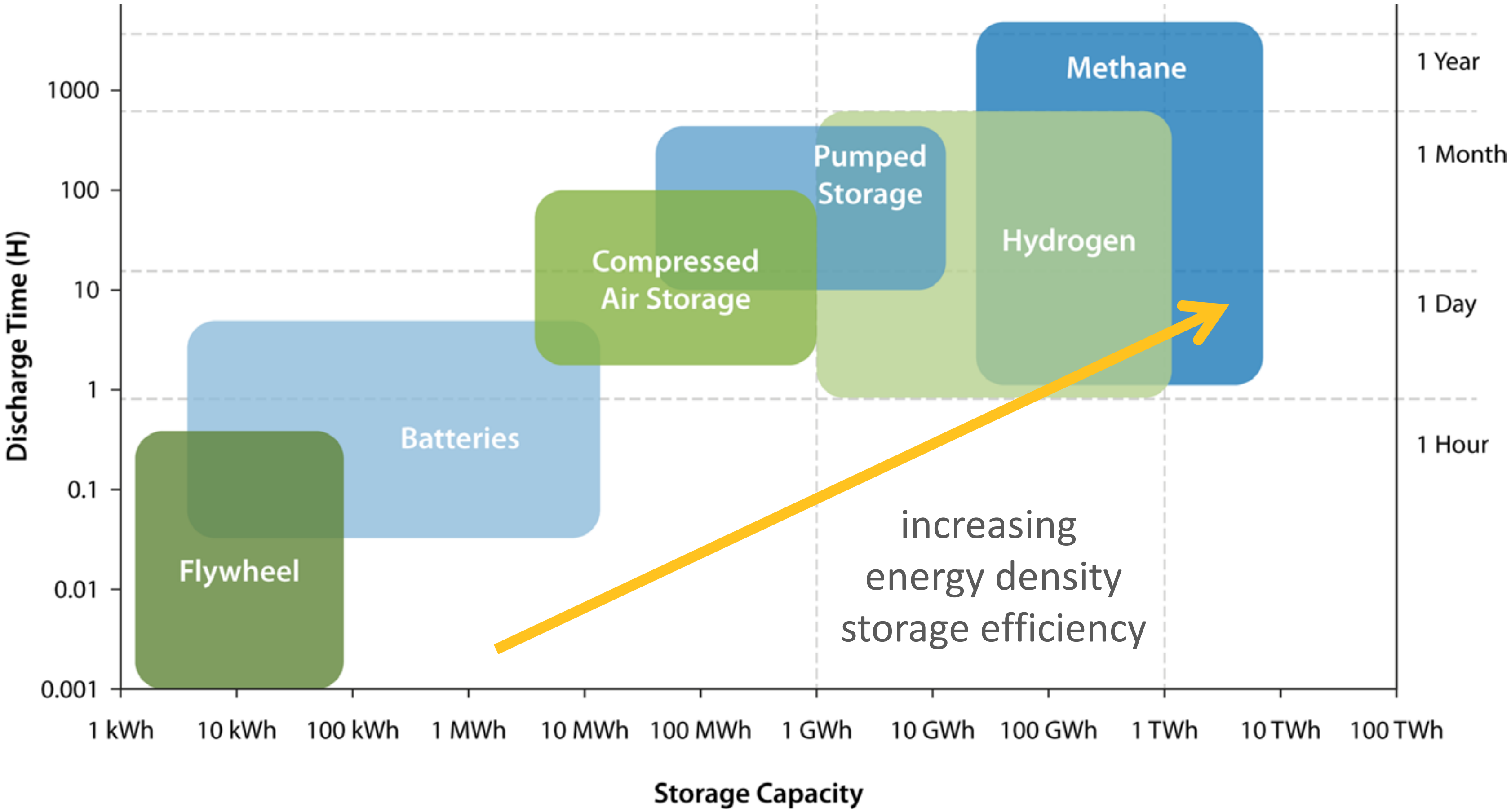
GW-Scale H_2 - Key Part of Solution



Current Installed Wind Capacity (MW)



Energy "Storage"



Hydrogen goes beyond electrons to electrons; value-added sink for electrons rather than a capacitor

Making fair comparisons is difficult, so many peripheral impacts.

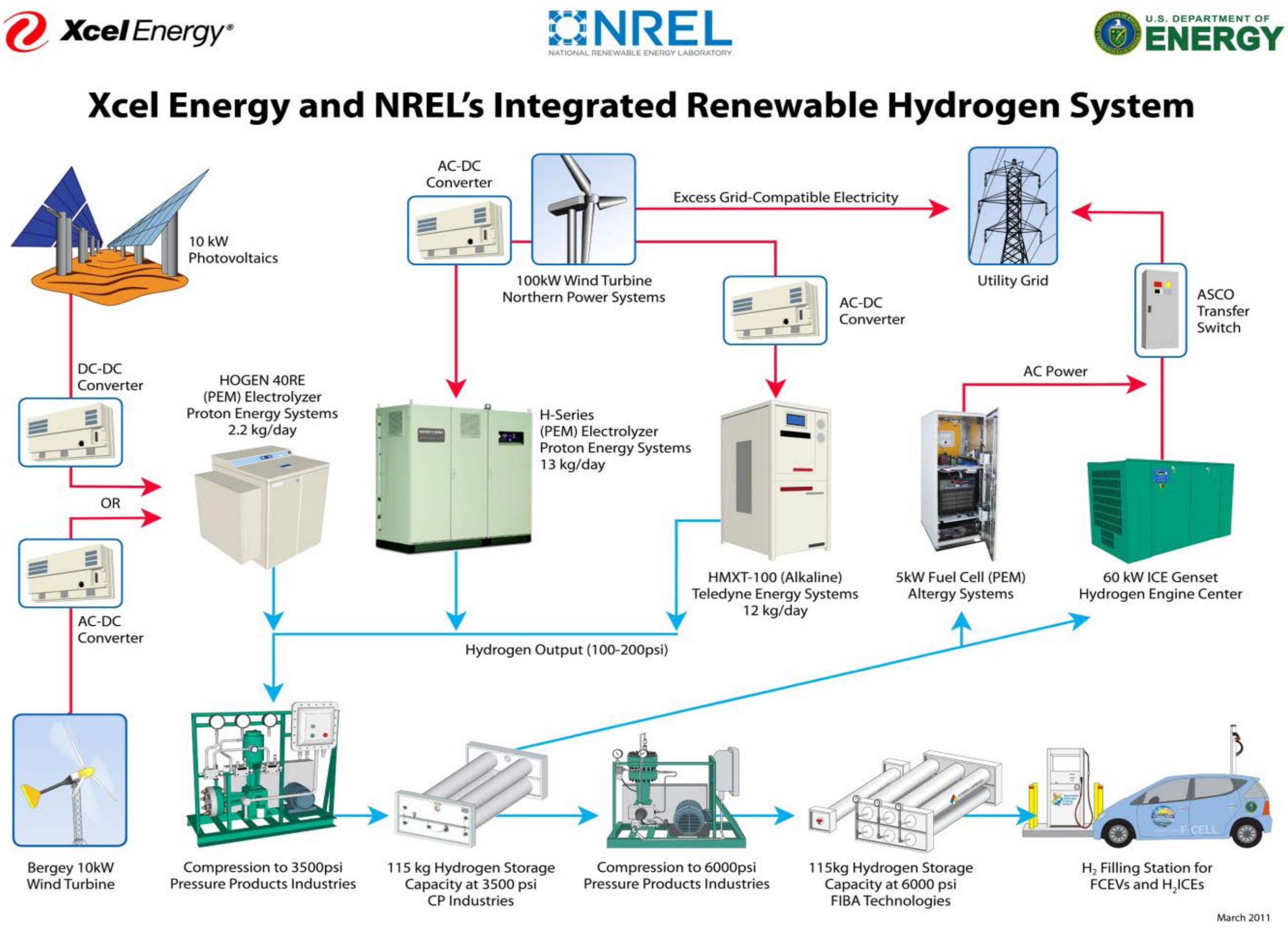
Renewable Electrolysis – Systems Integration

Primary Goals

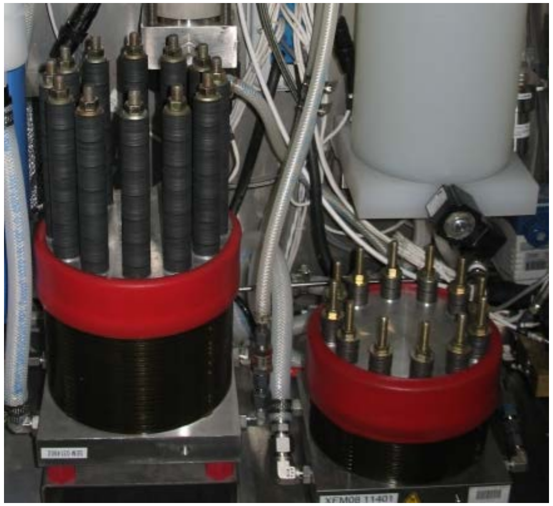
- RES Integration
- Electrolyzer Efficiency
- Power Conversion
- Grid Support
- Energy Storage

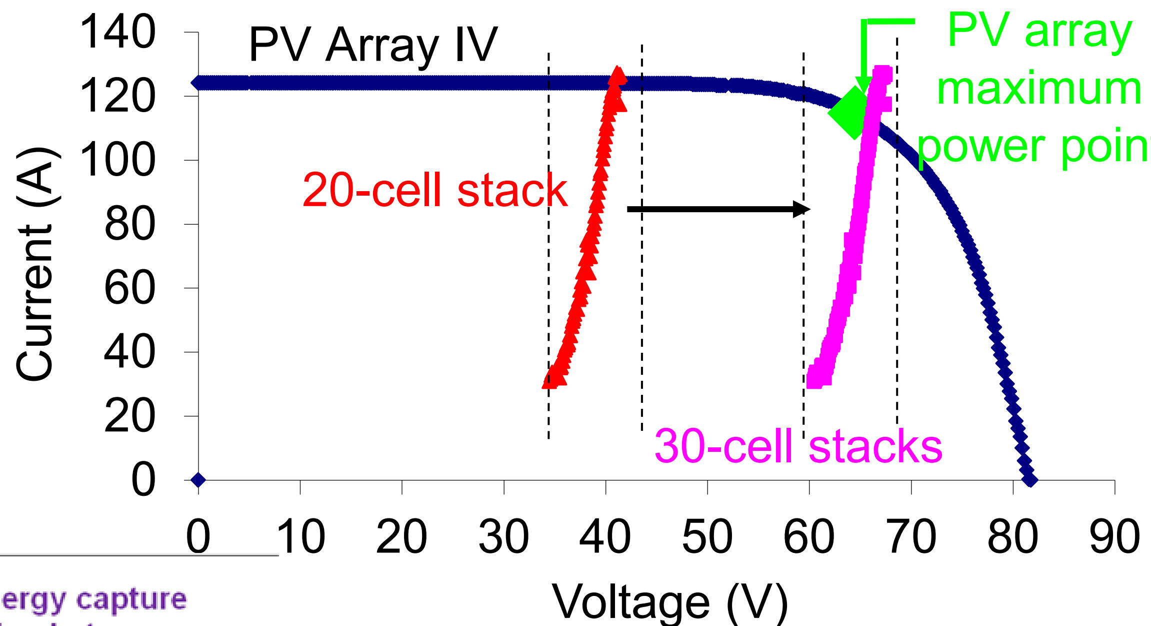
Other R&D Areas

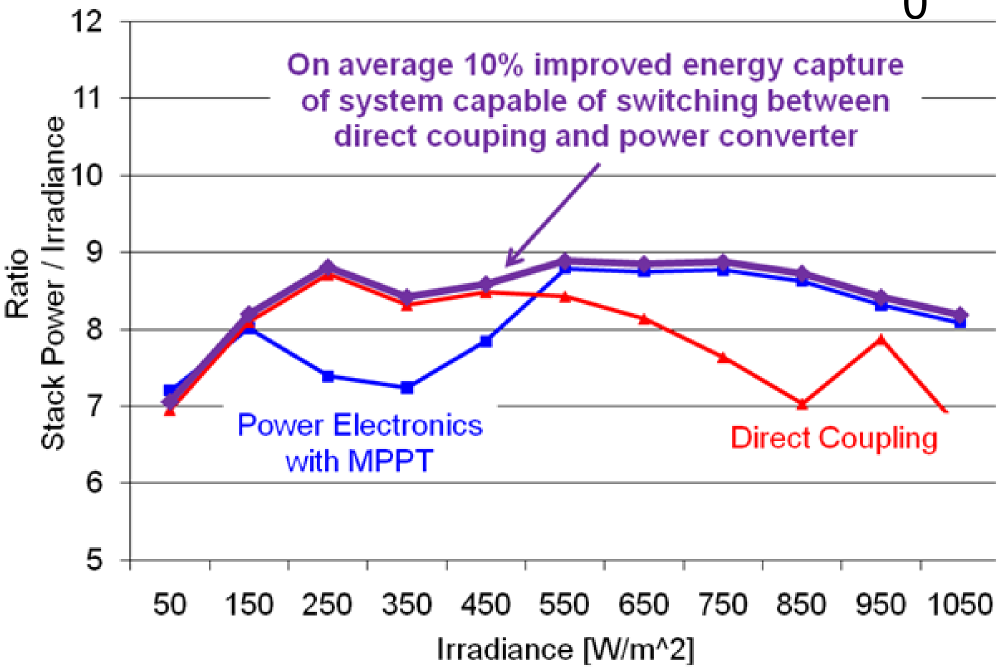
- Compressors
- Infrastructure
- Mobility



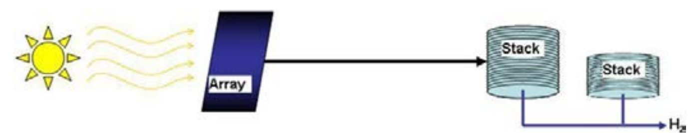
PV to H_2 – Direct and Close Coupling



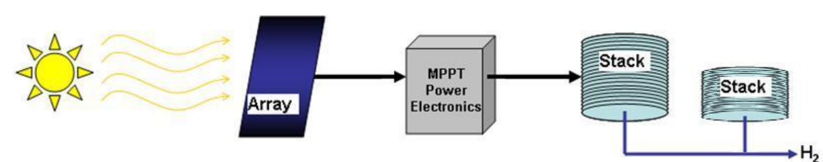




Direct Coupling



Close Coupling



Electrolyzer System Response

- **PEM & Alkaline electrolyzer systems**
  - Startup and Shutdown
  - Minimum Turndown
  - Response Time
  - Ramp Rate
  - Frequency Response

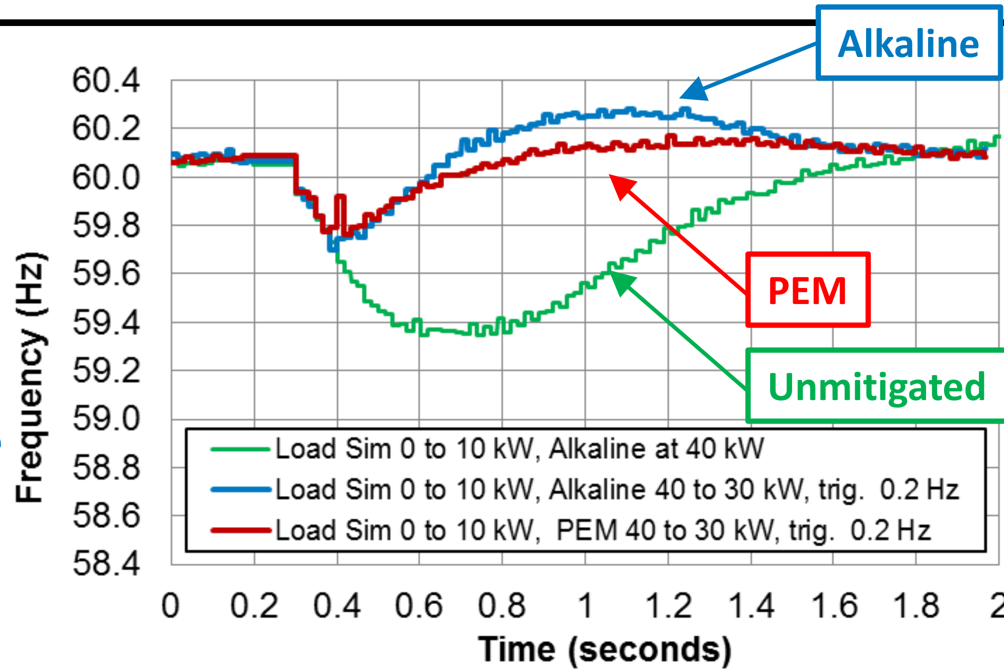
Diesel Powered Microgrid

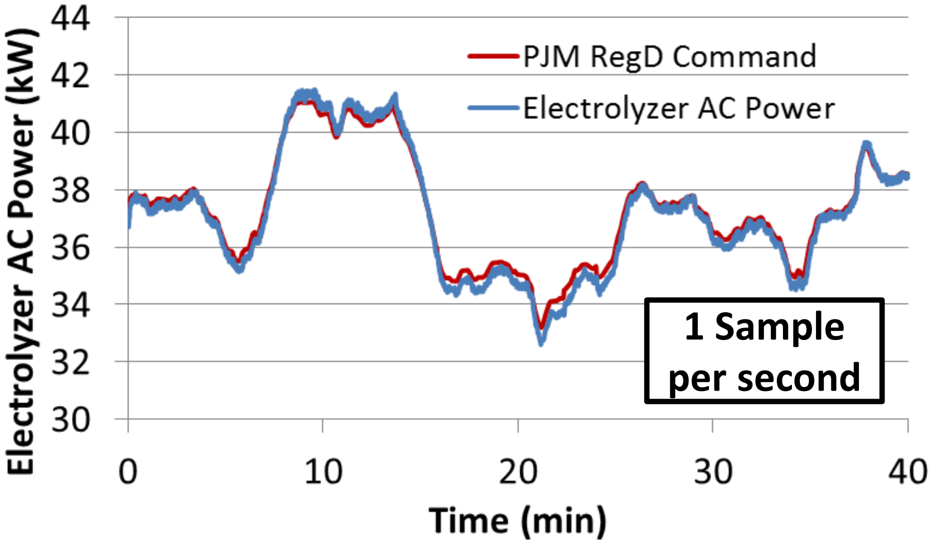
	PEM	Alkaline
Manufacturer	Proton OnSite H-6M	Teledyne Energy HMXT-100
Electrical Power	40kW 480VAC, 3p	40kW 480VAC, 3p
Rated Current	155 A per stack 3 stacks, 43 cells	220 A 75-cell stack
Hydrogen Production	13 kg/day	12 kg/day

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

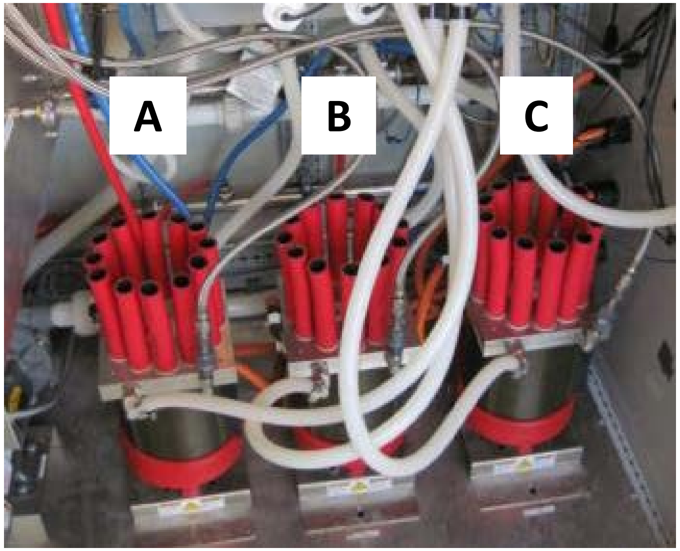
- Typical utility profile to validate performance
- System response, not just stack
- 120 kW PEM stack operating on NREL's electrolyzer stack test bed

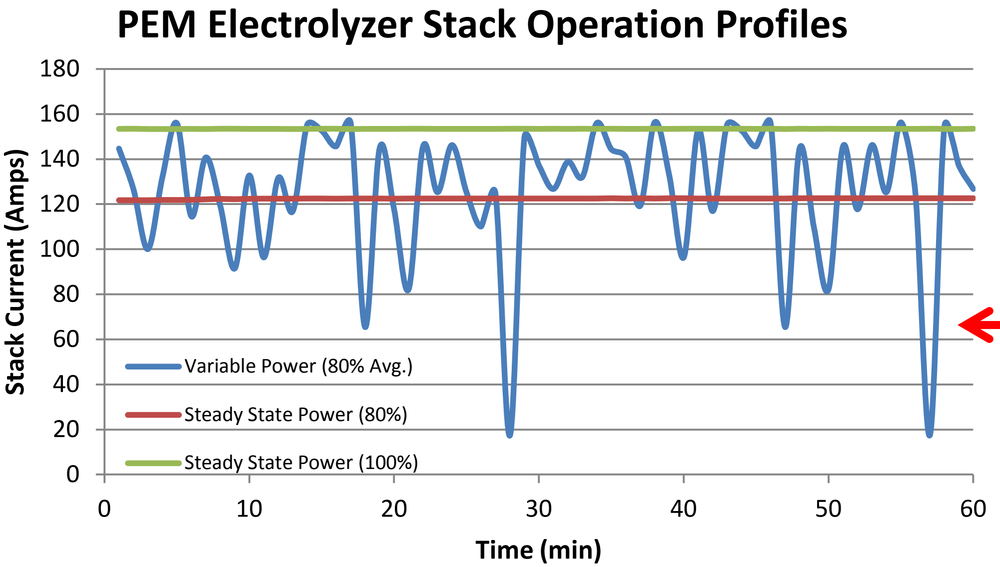
Source: Harrison K., Mann M., Terlip D., and Peters M., NREL/FS-5600-54658

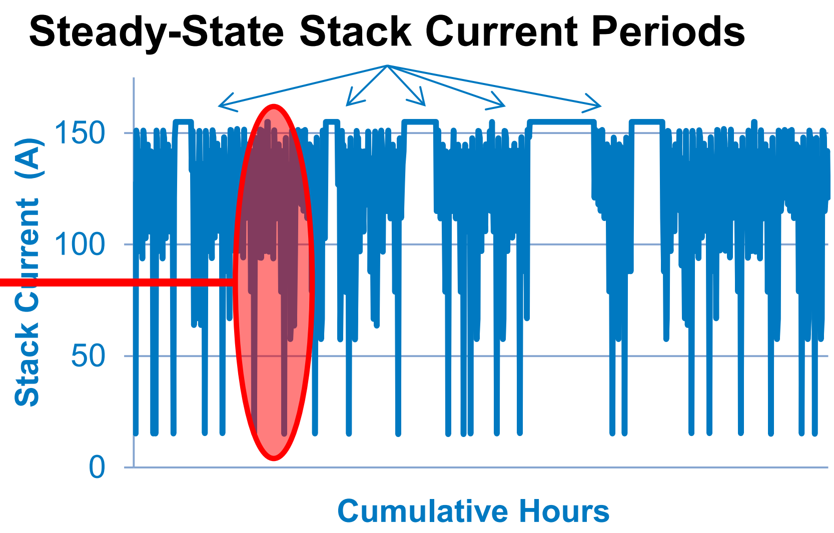
Stack Degradation Testing

Monitoring and Control

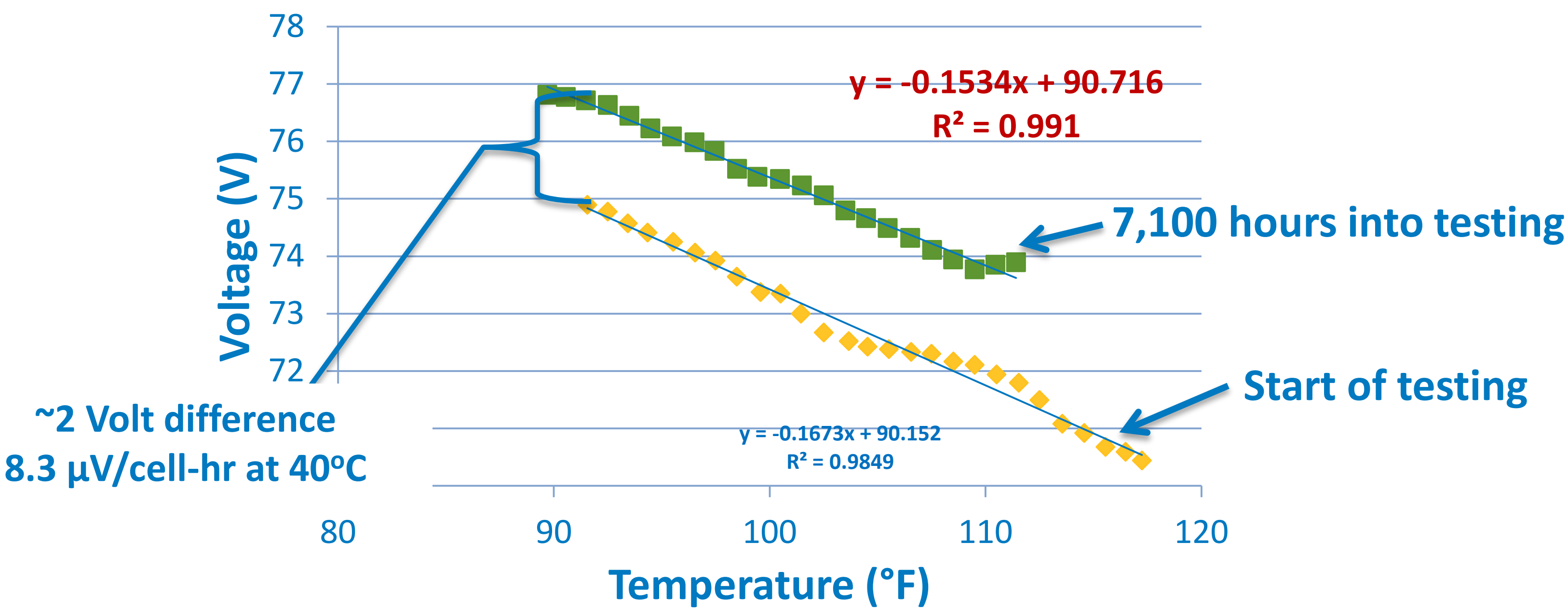
- Highly variable power
- Stack input and output temperature
- Stack voltage and current
- Individual control over each of 3 stacks
- Programmable wind/solar profiles







Stack Degradation Testing

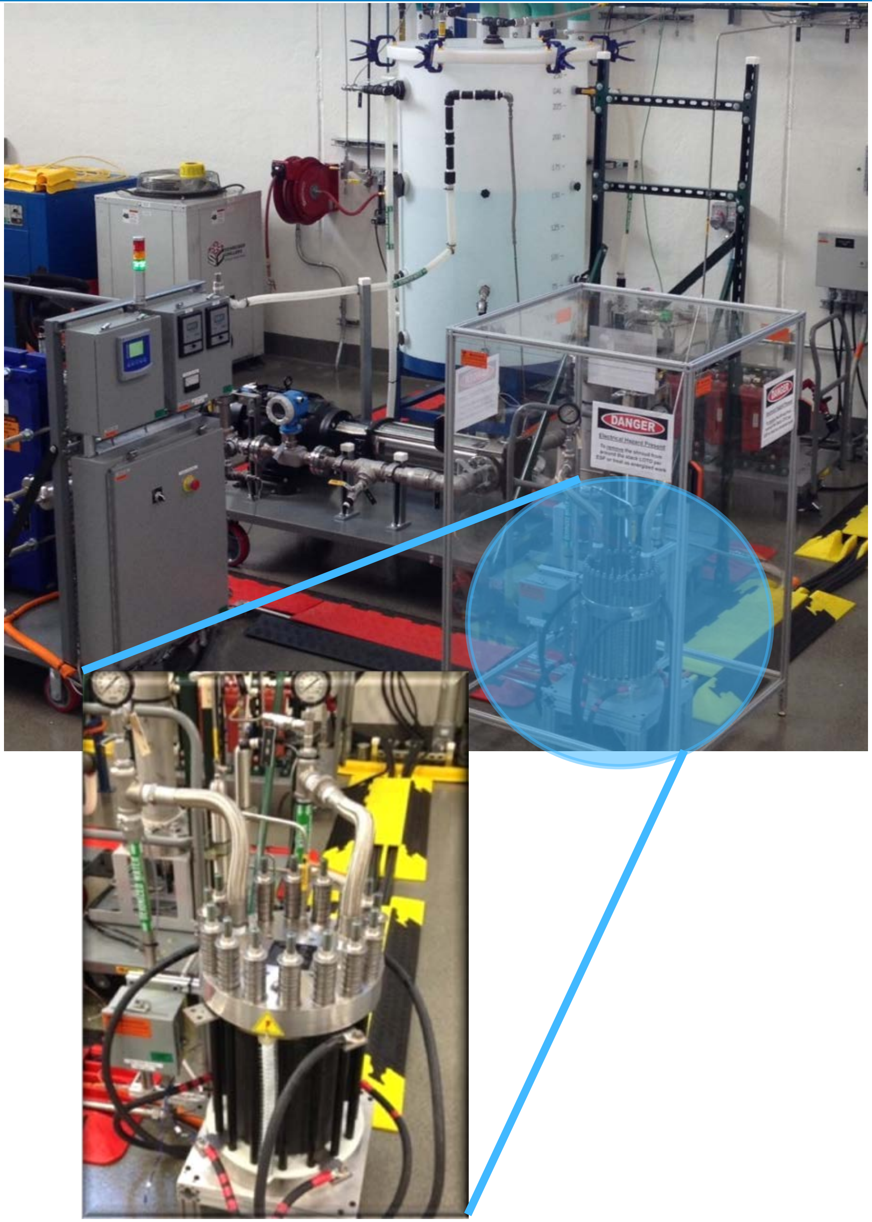


Stack-Test	Mode	Runtime [Hours]	Decay Rate [µV/cell-h]
~~A-1~~	~~Variable~~	7538	~~16.7~~
B-1	Variable		9.7
C-1	Constant		9.2
A-2	Variable	5738	4.4
~~B-2~~	~~Constant~~		~~14.3~~
~~C-2~~	~~Variable~~	~~4265~~	~~-7.2~~

NREL Electrolyzer Stack Test Bed

Goal - Reduce cost of hydrogen

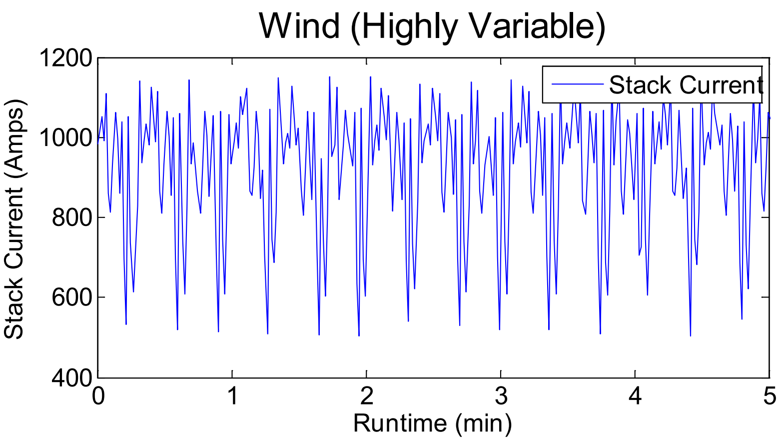
- Modular design
- Develop and demonstrate
  - Advanced power and control systems
  - Balance of plant optimizations coupled to RES
- Provide flexible validation platform
- Provide up to 4000 A, 250 V DC
- Cell-level voltage sensing
- 250 kW stack (2016)

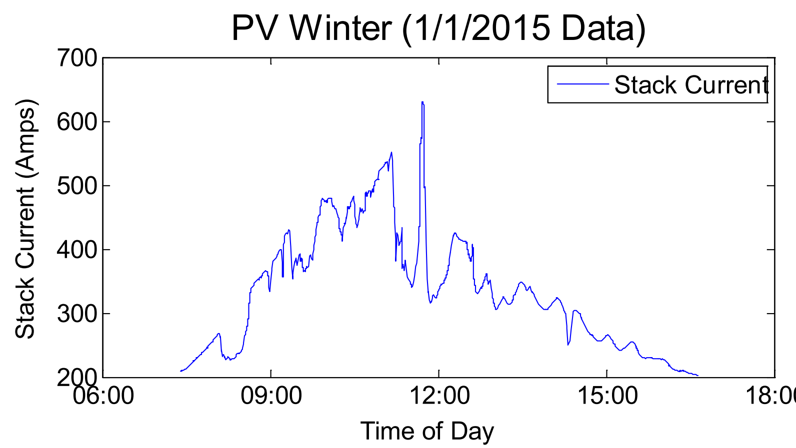


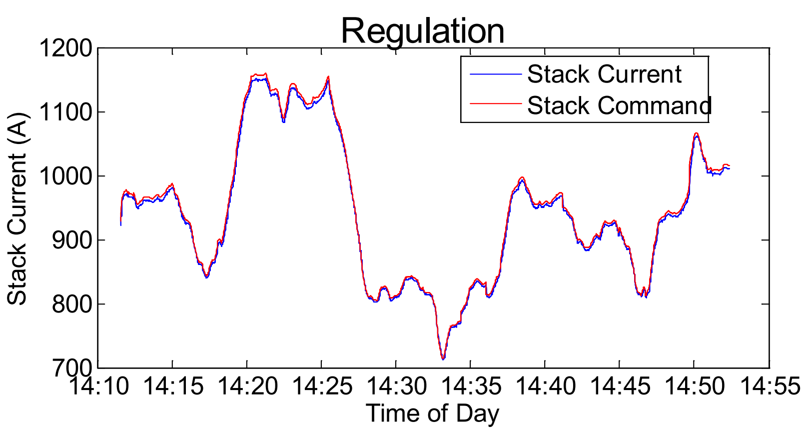
Simulating Renewable & Regulation Profiles

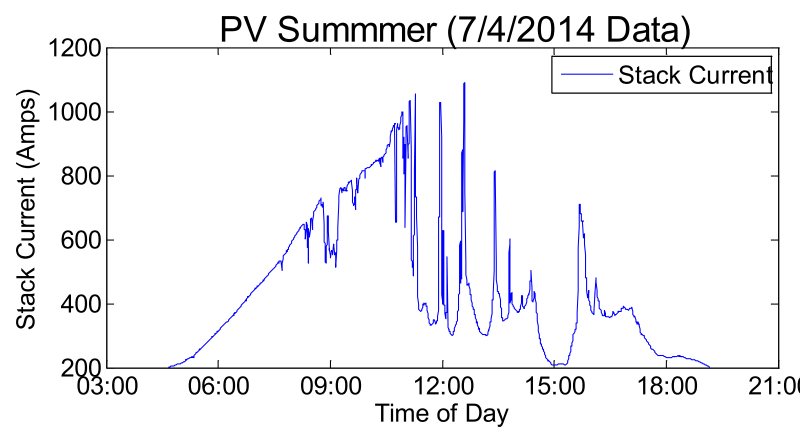
Ability to program profiles into the stack test bed

- Examples of renewable and regulation profiles
- Profiles using 120 kW stack from Proton Onsite



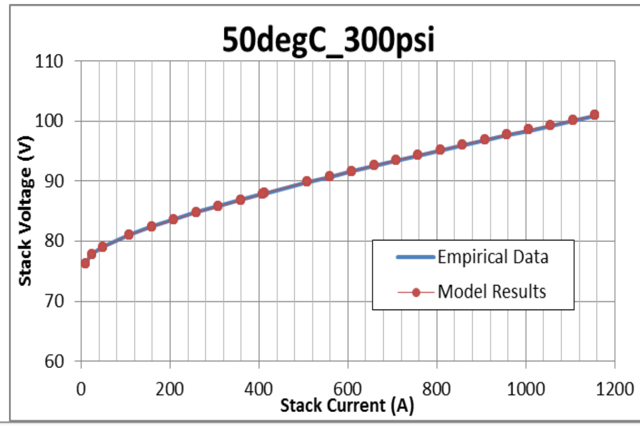


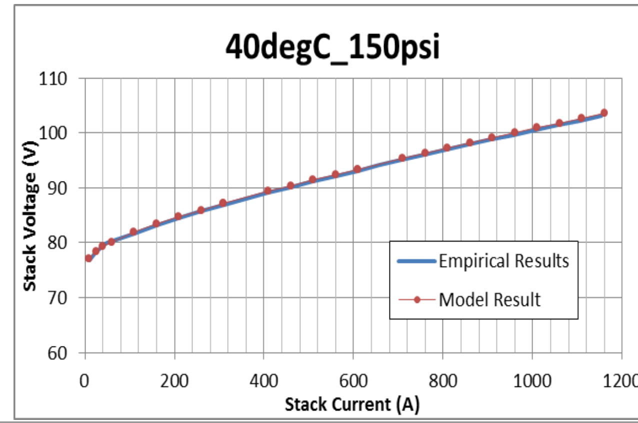


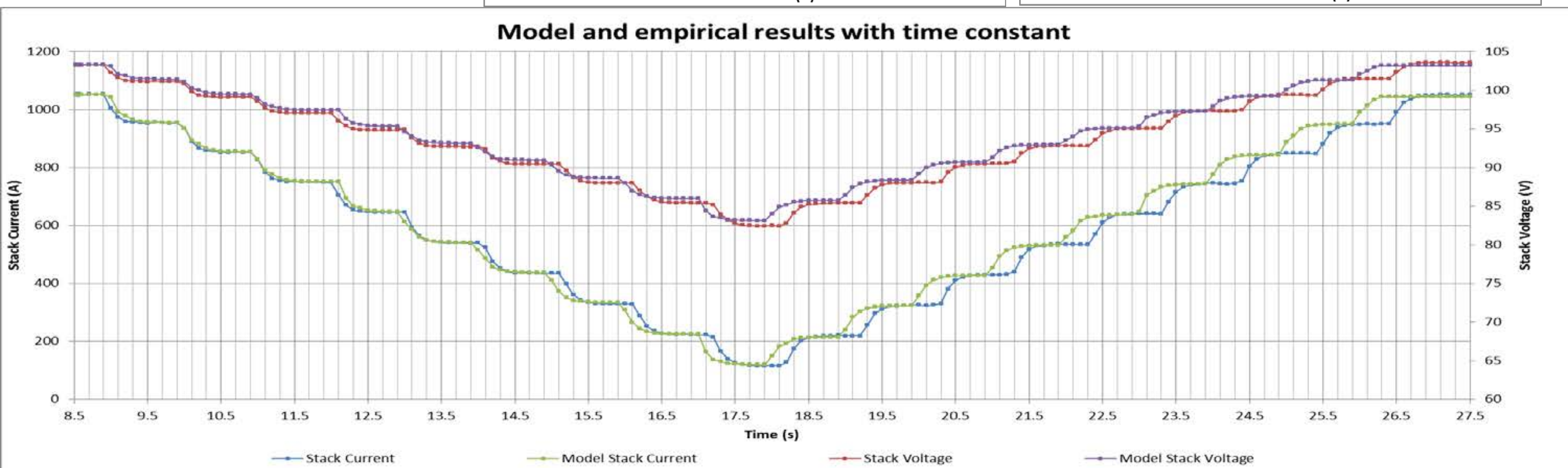


Dynamic Modeling and Validation of Electrolyzers in Real Time Grid Simulation

Curve-fitting to determine electrochemical properties and time response

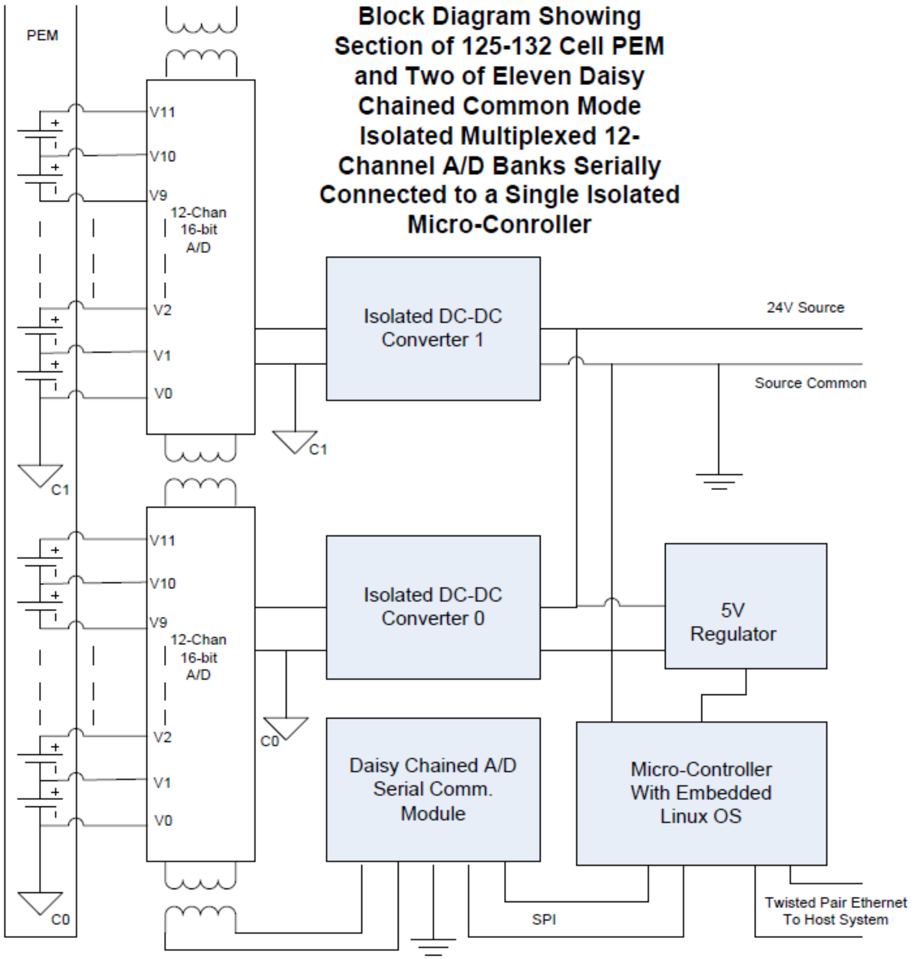






Path Forward – Stack Testing Variable Power

- **Solid State Design**
- **Cell level monitoring**
  - Isolated common mode
  - Multiple (< 5) Samples/sec
  - Up to 125 cells @ 2V/cell
- **16 bit A/D**
  - ~1mV resolution
- **µController-based data acquisition, communications and archiving alongside system data**



Summary

- **One way to store a growing amount of renewable electricity for energy storage, chemical feedstock (e.g., CH_4, NH_3) and fuel for mobility**
  - Zero-carbon fuels and chemicals
- **Low temperature electrolyzers can provide sub-second electrical response to participate in grid ancillary services**
- **There doesn't seem to be a significant difference between stacks operating with variable versus constant power**
- **Advanced power systems and BoP R&D will continue to improve efficiency**
- **Grid operational and power market rule changes will ease integration challenges for large-scale electrolyzer systems**
  - Expanding markets for flexible electrical loads

References

20% Wind Energy by 2030

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PV – Stack Coupling

http://www.hydrogen.energy.gov/pdfs/progress11/ii_e_4_harrison_2011.pdf

http://www.hydrogen.energy.gov/pdfs/review11/pd031_harrison_2011_o.pdf

PEM & Alkaline Electrolyzer Response Testing

http://www.hydrogen.energy.gov/pdfs/progress12/ii_d_3_harrison_2012.pdf

http://www.hydrogen.energy.gov/pdfs/review12/pd031_harrison_2012_o.pdf

Kevin Harrison

National Renewable Energy Laboratory

Kevin.Harrison@nrel.gov