

Renewable Electrolysis Integrated Systems Development and Testing

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Presentation Outline

- Terms and Definitions
- Electrolyzer Characterization
- Power Electronics Design and Testing
- Xcel/NREL Wind2H2 Collaboration



Gasoline vs. Hydrogen

- Gasoline
 - 108,000 – 123,500 BTU/gal
- Hydrogen
 - 116,000 BTU/kg
- 1 kilogram of hydrogen \approx 1 gallon of gasoline
- However, if fuel cells are twice as efficient as gasoline engines, then twice the mileage with hydrogen



Hydrogen

- Hydrogen is an energy carrier, much like electricity.
- Hydrogen must be produced or extracted from hydrogen rich materials just as electricity must be produced.
- Hydrogen-based energy systems will be as safe or safer than today's gasoline.

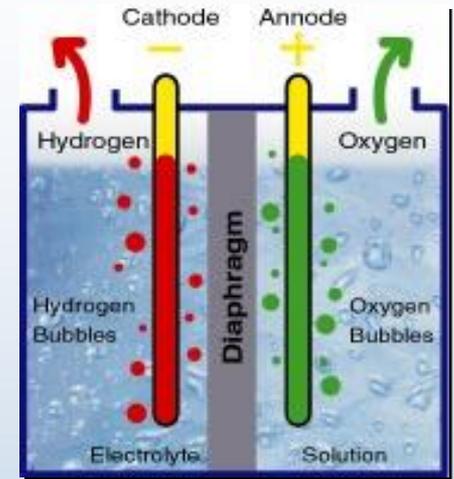
How to produce hydrogen RE? Electrolysis.



Focus of this research is on renewable H₂ production because it is the only way (today) to produce the gas without emissions.

Technology Characteristics

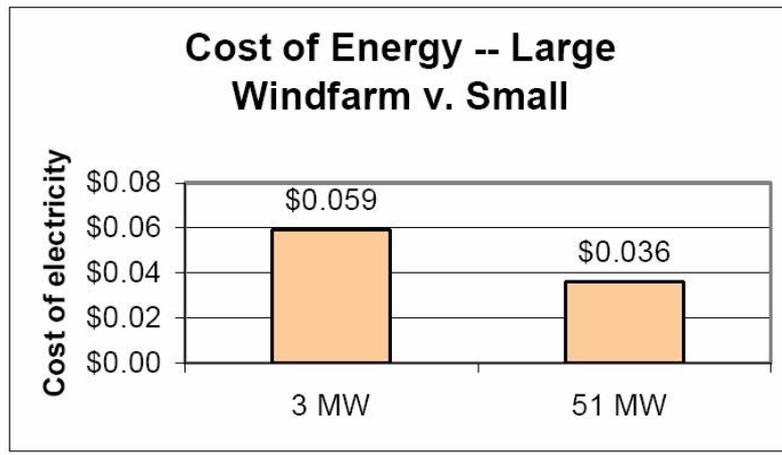
- Alkaline
 - Cheaper catalyst (Ni v. Pt)
 - Low current density (\uparrow efficiency)
 - Largest system $< 10^3$ \$ kW⁻¹
- Proton Exchange Membrane (PEM)
 - Pure water input requires H₂O vapor removal
 - Higher differential output pressure
 - Solid (not corrosive) electrolyte
 - $10^3 - 10^4$ \$ kW⁻¹
- Solid Oxide
 - R&D



Wind Energy Overview

- Fastest Growing Renewable Energy Source
- 2,500 MW installed in 2005 in US
- Cost Effective Renewable Energy Source (\$0.03-\$0.06/kWh)

Cost figures include the current wind production tax credit.

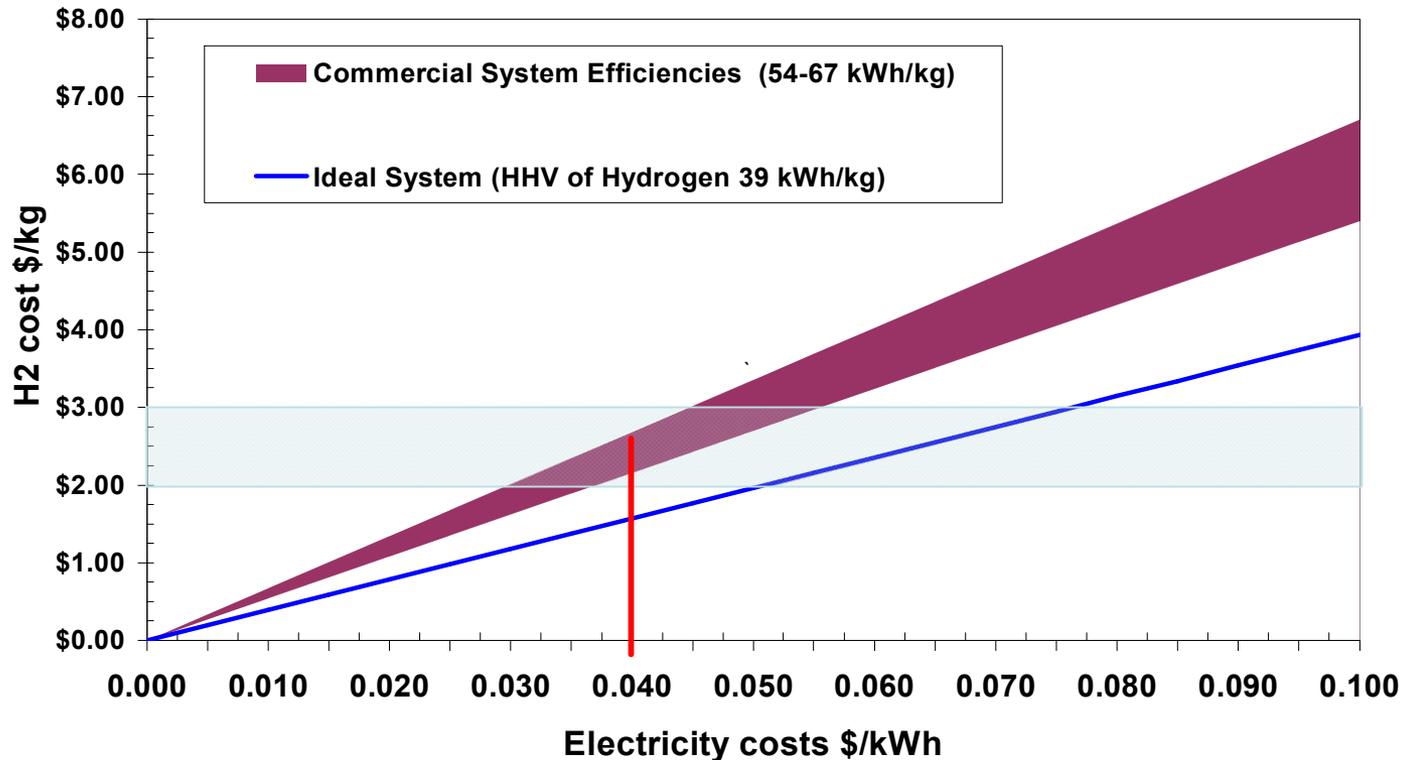


Economics of Wind – www.awea.org



Electricity Costs are Key

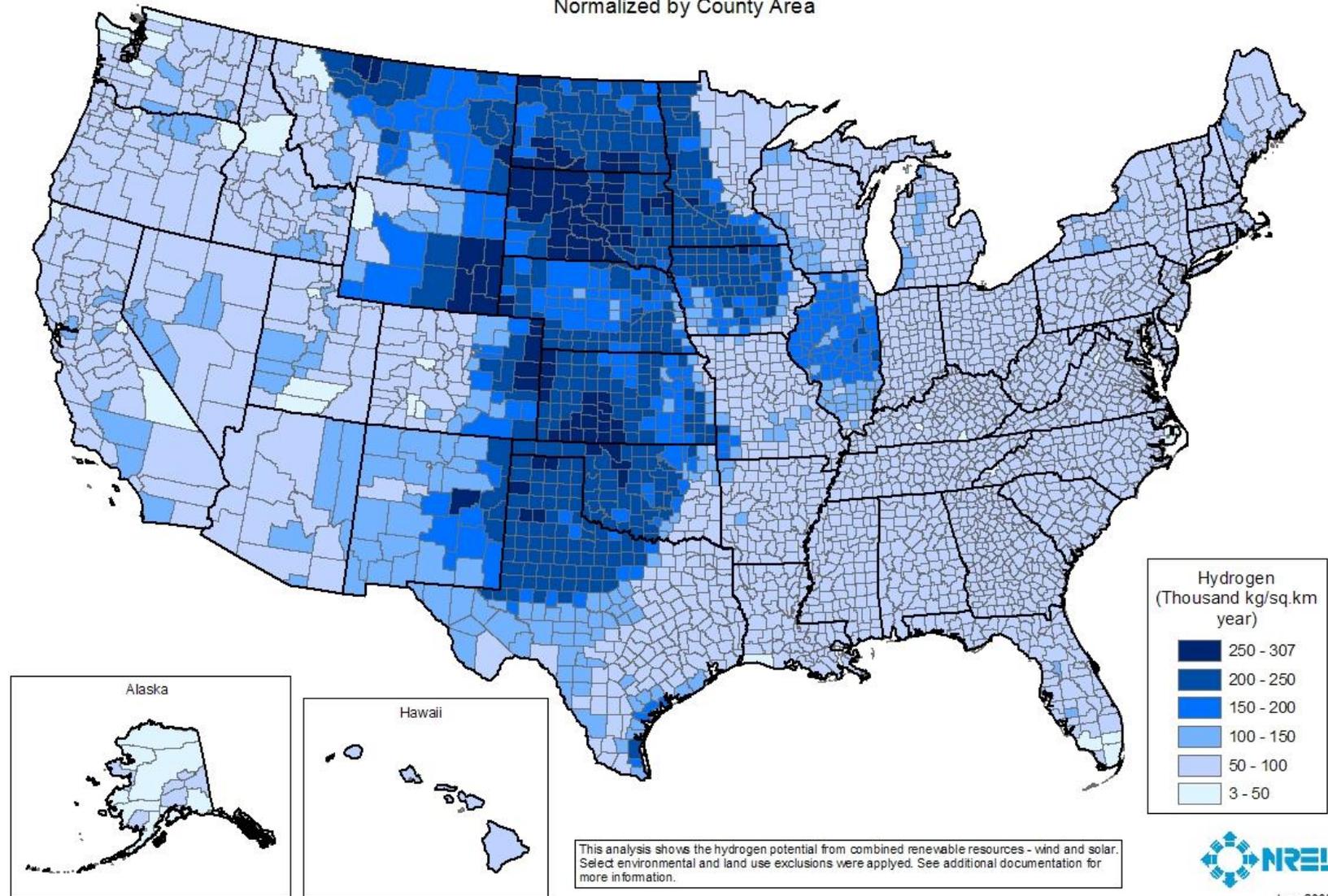
Hydrogen costs via electrolysis with electricity costs only



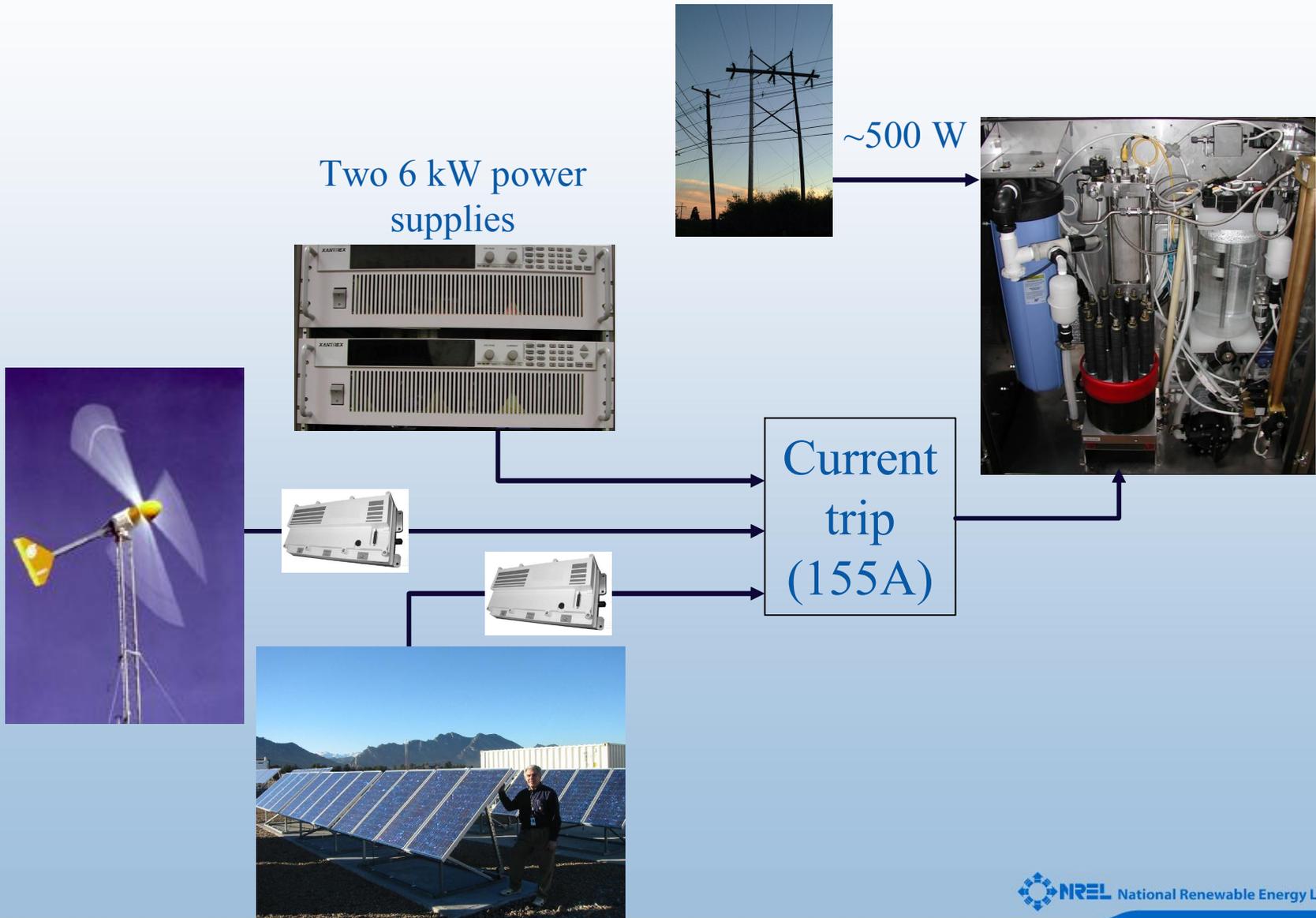
DOE: \$2.00 - 3.00 kg⁻¹ delivered, untaxed, 2005\$ by 2015

Hydrogen Potential From Solar and Wind Resources

Total kg of Hydrogen per County
Normalized by County Area



NREL's Hydrogen Test Facility



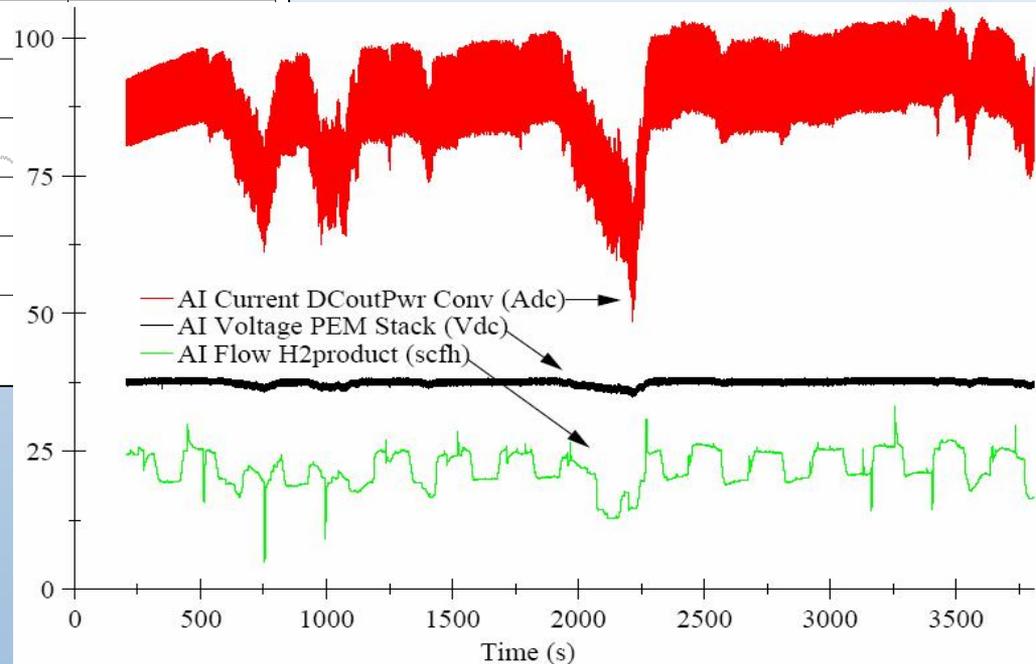
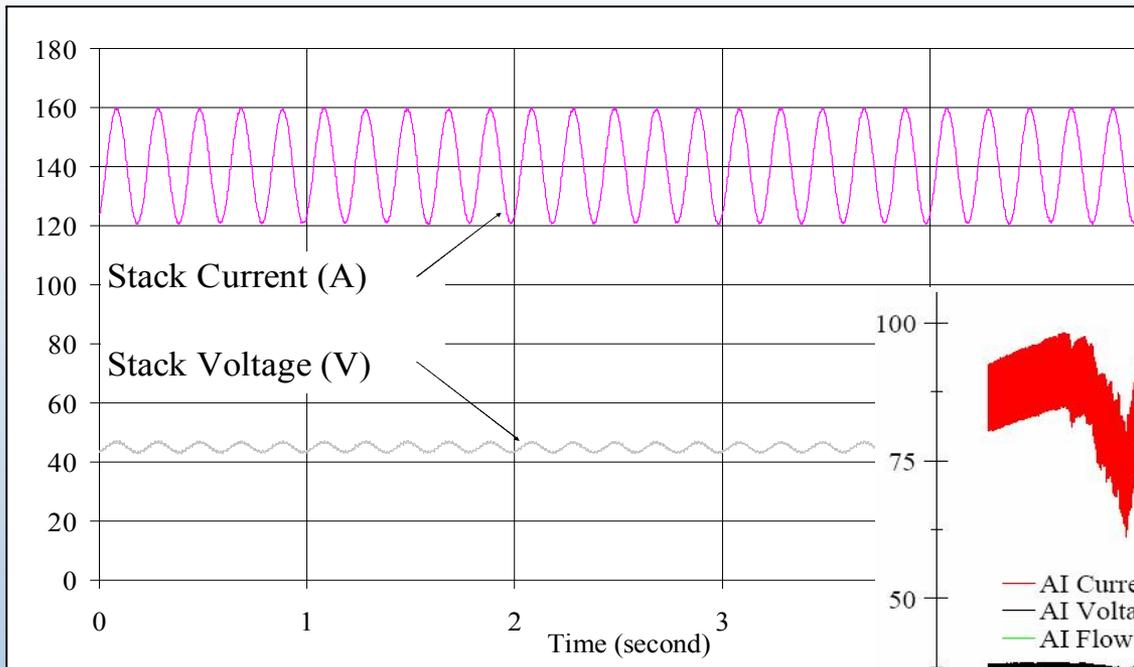
Characterization Testing and Protocol Development



- Characterization of 6 kW PEM electrolyzer to enable power electronics design
- Simulated PV and wind using power supplies
- Tested with 5 kW PV array
- Designed and tested power electronics from 10 kW wind turbine to stack

Variable Input Power

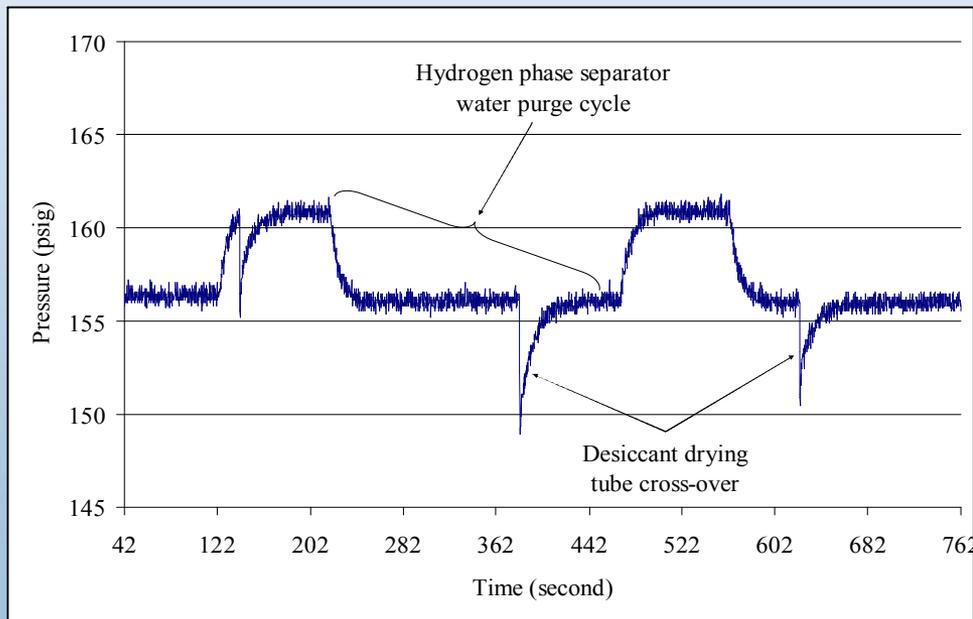
- Wind energy to stack and PV to DC/DC converter



- Programmable power supplies to vary input power to stack

Monitor Performance

- Stack and system energy
- Hydrogen pressure, flow and quality

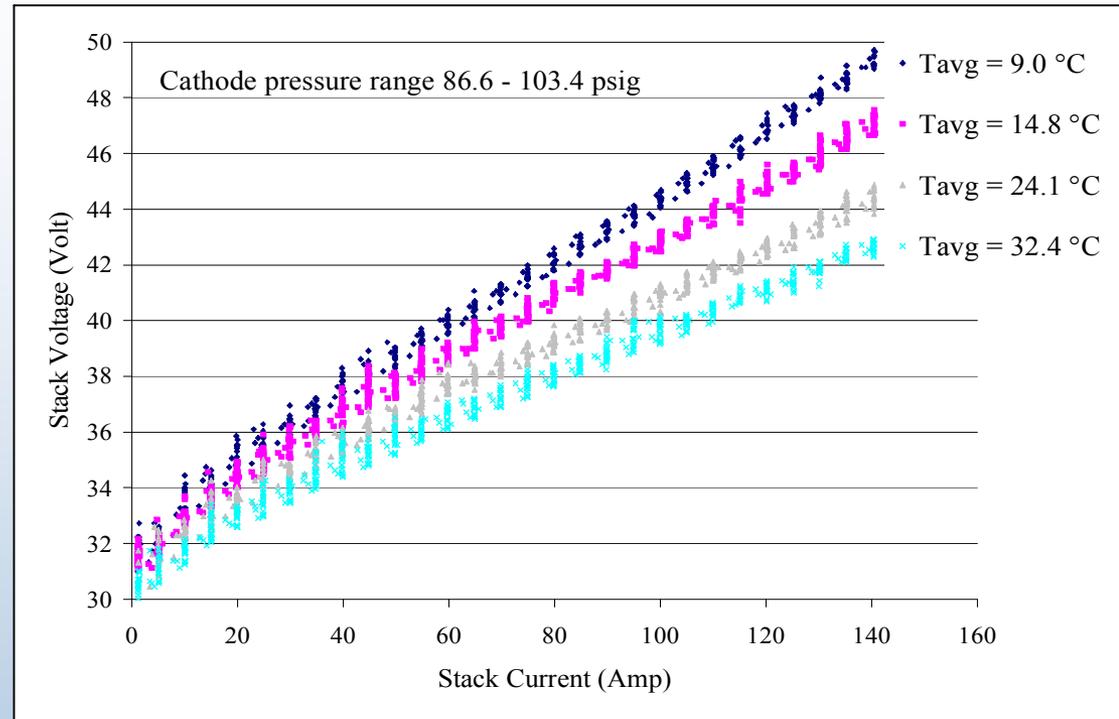
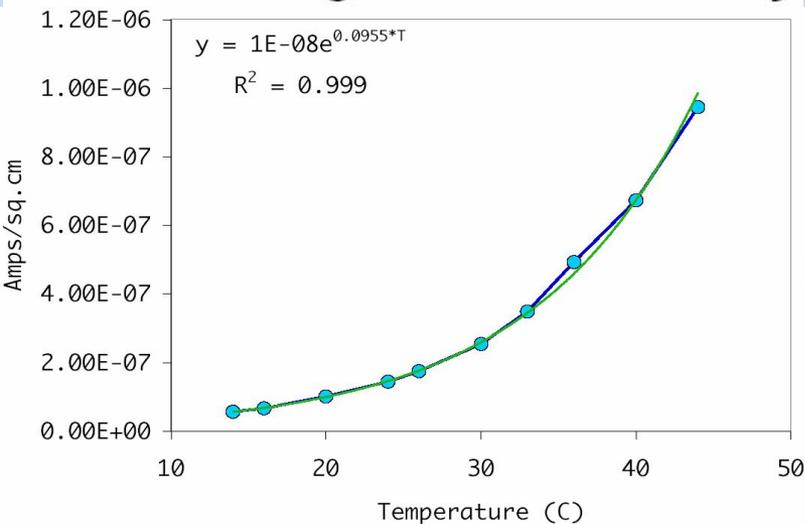


- Water temperature, flow and quality
- Impacts on grid (pf, THD)

Stack Performance

IV data and electrochemistry to extract stack characteristics

Anode Exchange Current Density



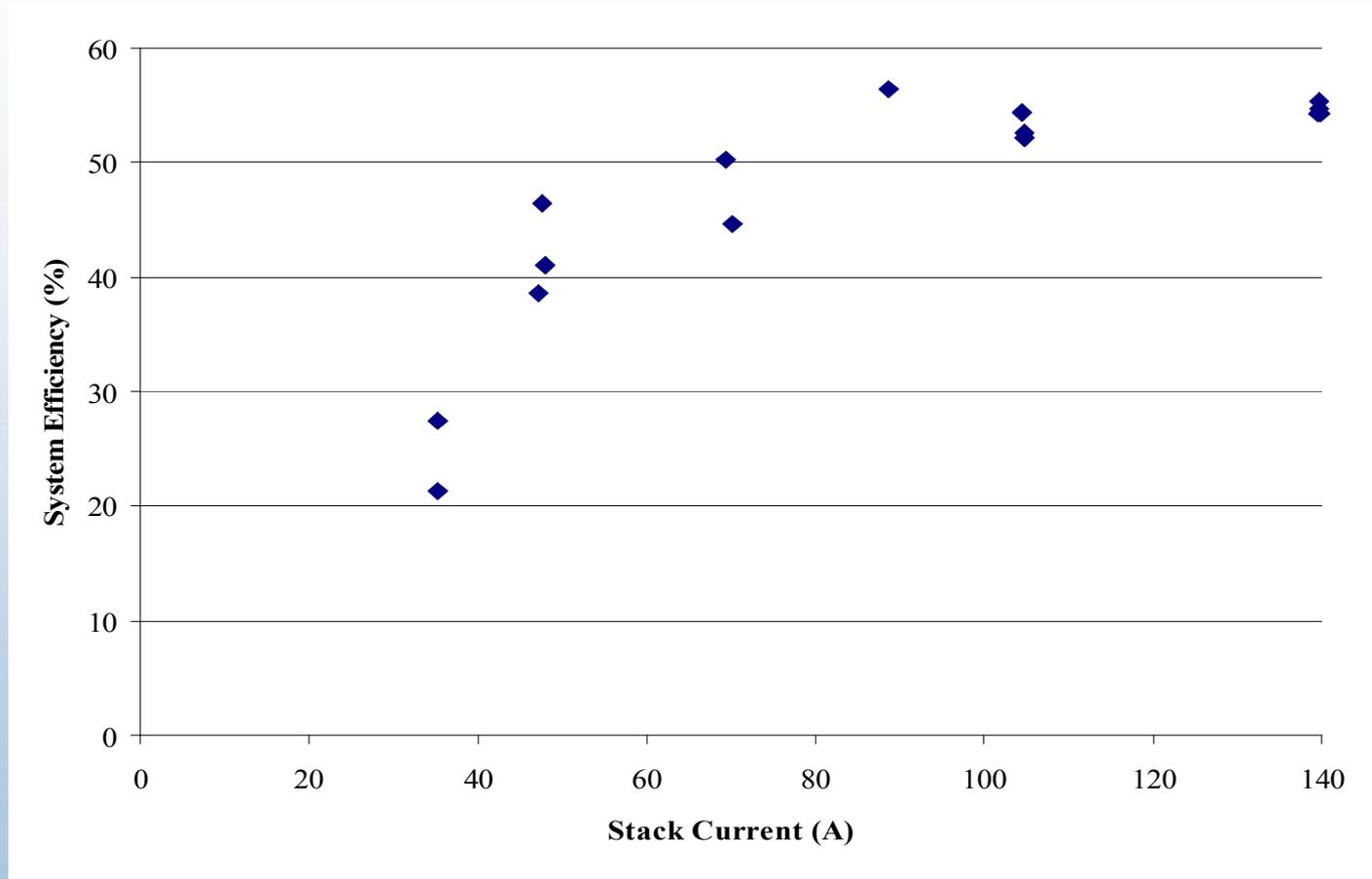
$$E = 1.20 + \frac{RT(I)}{f} \left\{ \text{Sinh}^{-1} \left(\frac{j}{2c_1} \right) + \text{Sinh}^{-1} \left(\frac{j}{2c_2} \right) \right\} + \frac{\phi}{c_3} j \quad (12)$$

$$c_1 = j_{A,o} = 1.65 \times 10^{-8} \quad (13)$$

$$c_2 = j_{C,o} = 0.09 \quad (14)$$

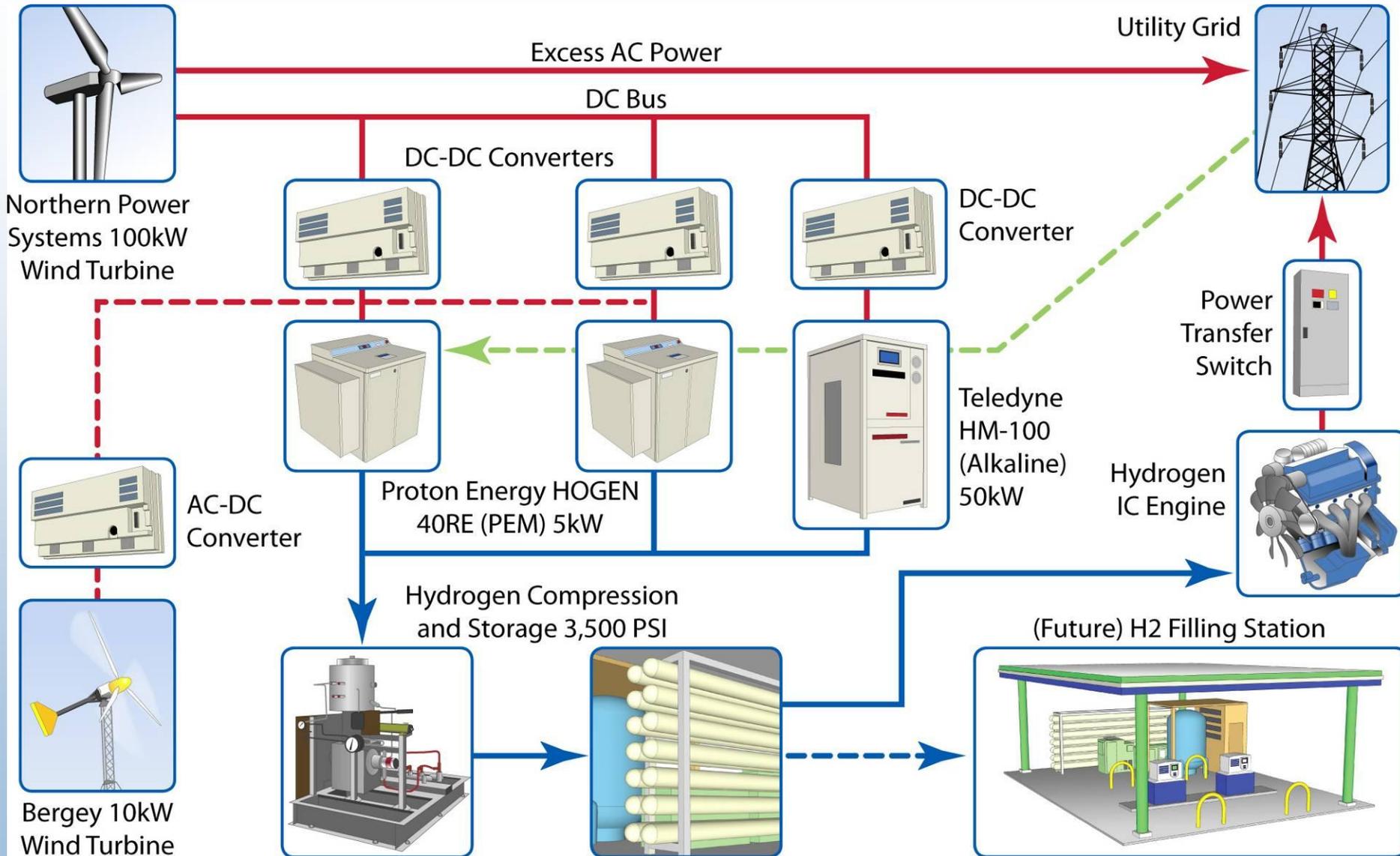
$$c_3 = \sigma = 0.075 \quad (15)$$

System Performance



System efficiency of PEM system at various levels of current

Xcel Energy/NREL Wind2H2E Project



Project Goal - Integration

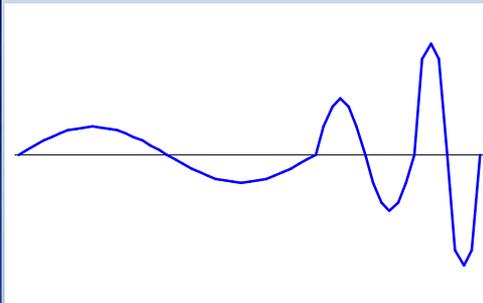
- Multiple electrolyzers of both PEM and alkaline technologies.



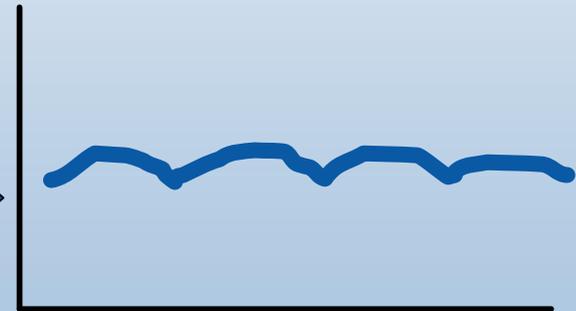
- Ability to accommodate the varying energy input from wind turbines

Project Goal – Direct Coupling

- Variable speed wind turbines ‘directly-coupled’ to the hydrogen-producing stacks of commercially available electrolyzers.



Variable
Magnitude &
Frequency AC



Project Goal - Demonstration

- Gain operational experience of a hydrogen production facility.
- Compression of product gas and the use of a hydrogen internal combustion engine.
- Develop standard test protocol.



Current Day Electrolyzer Companies



Acknowledgements

- ❖ NREL Electrical Systems Team
 - Ben Kroposki, Chris Pink, Bill Kramer, Joshua Price and Pete Gotseff
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- ❖ Xcel Team
 - Frank Novachek, Vicki McCarl, Brad Hollenbaugh and Curtis Perry
- ❖ EPC
 - John Cornish, Kevin Mastriona and site crew.

Where is NREL Electrolysis Info?

<http://www.nrel.gov/publications/>

> Search for “electrolysis” or “wind and hydrogen”

- 2006 - *Electrolysis: Information and Opportunities for Electric Power Utilities*
- 2006 - *Wind Energy and Production of Hydrogen and Electricity -- Opportunities for Renewable Hydrogen*
- 2005 - *Renewable Electrolysis Integrated System Development and Testing*
- 2005 - *Analysis of Hydrogen Production from Renewable Electricity Sources*
- 2004 - *Summary of Electrolytic Hydrogen Production: Milestone Completion Report (currently being updated. Available early 2007)*
- 2004 - *Hydrogen Storage in Wind Turbine Towers*

**Thank you for your
attention!**

