NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

RENEWABLE ELECTROLYSIS INTEGRATED SYSTEM DEVELOPMENT AND TESTING

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Project ID #
PD031

Overview

Timeline

Project start date: Sept 2003
Project end date: Dec 2012

Barriers

G. Cost
H. System efficiency
J. Renewable integration

Budget

$ 200k (FY09)
$ 300k (FY10)

Partners

- Xcel Energy
- Proton Energy Systems
- Univ. of North Dakota/EERC
- DOE Wind/Hydro Program

Relevance

MAIN OBJECTIVES

Demonstration

- Identify opportunities for system cost reduction and optimization as they pertain to electric utilities
- Characterize, evaluate and model the integrated renewable energy systems
- Characterize electrolyzer performance with variable input power
- Design, build and test shared power electronics

Analysis

- Develop cost models for renewable electrolysis systems
- Quantify capital cost and efficiency improvements for wind and solar based electrolysis scenarios

Testing

- Perform characterization and performance testing on electrolysis systems developed from DOE awarded projects
- Test electrolyzer stack and system response with typical renewable power profiles

Relevance

TECHNICAL TARGETS

The Wind2H2 project continues to work toward meeting technical targets of the Fuel Cell Technologies Program

Table 3.1.4. Technical Targets: Distributed Electrolysis Hydrogen Production[a, b, c]					
Characteristics	Units	2003 Status	2006[c] Status	2012 Target	2017 Target
Hydrogen Cost	\$/gge	5.15	4.80	3.70	<3.00
Electrolyzer Capital Cost[d]	\$/gge \$/kW	N/A N/A	1.20 665	0.70 400	0.30 125
Electrolyzer Energy Efficiency[f]	% (LHV)	N/A	62	69	74

Table 3.1.5. Technical Targets: Central Wind Electrolysis[a, b]				
Characteristics	Units	2006[c] Status	2012 Target	2017 Target
Hydrogen Cost (Plant Gate)	\$/gge H_2	5.90	3.10	<2.00
Electrolyzer Capital Cost[b, d]	\$/gge H_2 \$/kW	2.20 665	0.80 350	0.20 109
Electrolyzer Energy Efficiency[e]	% (LHV)	62	69	74

Relevance

BARRIERS ADDRESSED

- Capital Costs: R&D is needed to lower capital while improving the efficiency and durability of the system
- System Efficiency: In large production facilities even slight increases in efficiency enable significant reductions in hydrogen cost. Efficiency gains can be realized using compression in the cell stack
- Renewable Electricity Generation Integration: More efficient integration with renewable electricity generation is needed to reduce costs and improve performance. Development of integrated renewable electrolysis systems is needed, including optimization of power conversion and other system components from renewable electricity to provide high-efficiency, low-cost integrated renewable hydrogen production

Independent Panel Water Electrolysis Cost Estimate

- In 2009, DOE convened an independent panel to assess the cost of producing hydrogen using water electrolysis

- The Panel investigated current, state-of-the-art electrolyzer technologies including technology advances that would result in reduced capital costs or improved conversion efficiency

- The Panel estimated that, using 2009 technology, the plant-gate cost for hydrogen produced from electrolysis in a centralized facility using renewable, wind-based electricity would be $3.00/kg (expected range from $2.70/kg to $3.50/kg)

- The Panel estimated that, using 2009 technology, the cost for delivered hydrogen from electrolysis for a forecourt refueling station would be $5.20/kg (expected range from $4.90/kg to $5.70/kg)

Panel Recommendations for Cost Reductions Consistent with Goals of this Project

- Reduce the cost of balance-of-plant items, particularly for power electronics (rectifiers, transformers)

  Wind2H2 FY09 results showed that improvements in power electronics integration can reduce the total cost of wind-based electrolysis hydrogen production by 7%

- Decrease the cost of renewable power. Study the integration of electrolyzers in the development of new renewables and electricity grid plans
- Evaluate DC (direct current) and control integration of renewable power *plants (e.g., wind, electrolyzers) to reduce conversion costs*

  The Wind2H2 R&D Project investigates the areas of wind- and PV-based electrolysis integration, integration of power electronics, improvements in renewable energy conversion efficiency and energy transfer, and reduction of balance-of-plant capital costs

Approach

Test, evaluate, model and optimize the renewable electrolysis system performance for both dedicated hydrogen production and electricity/hydrogen cogeneration

Systems Engineering, Modeling, and Analysis

Develop concept platforms, develop and validate component and system models, system assessment, and optimization tools

System Integration and Component Development

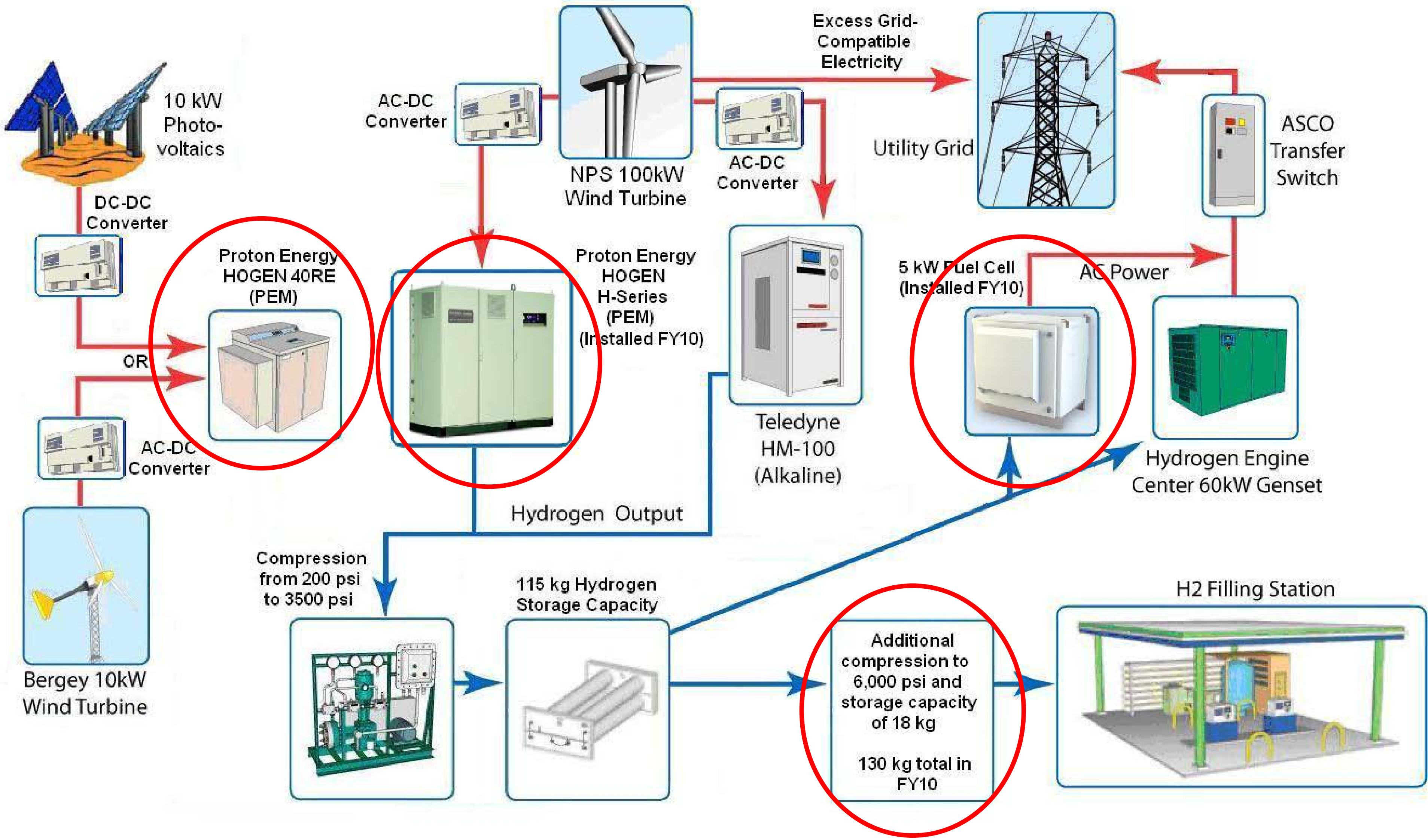
Work with industry to develop new advanced hardware and control strategies to couple renewable and electrolyzer systems

Characterization Testing and Protocol Development

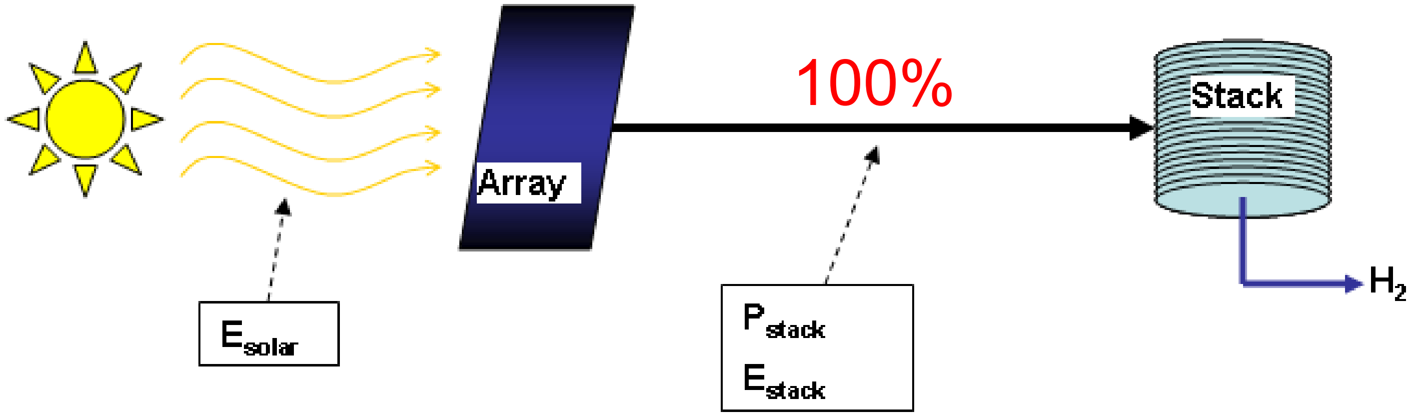
Equipment installation, performance characterization, and standard test procedure development

Wind2H2 Demonstration Project

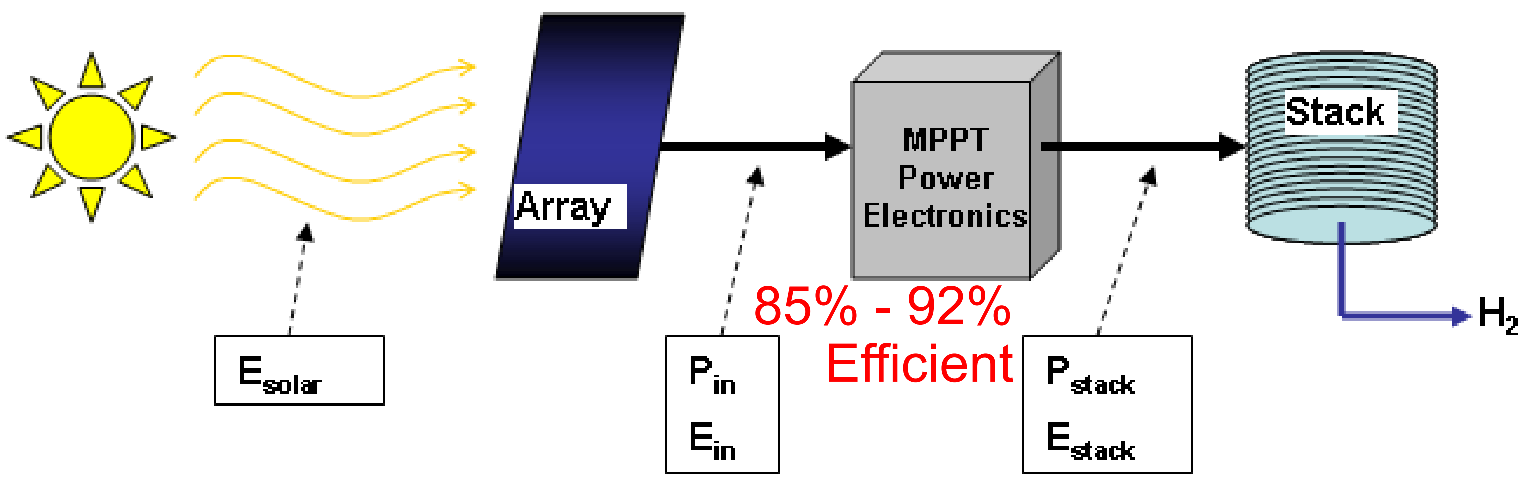
System Modifications



PV Testing Overview



Direct connect (top, no power conversion losses) versus power converter (bottom, with losses based on input PV array voltage)



2009 Technical Accomplishments

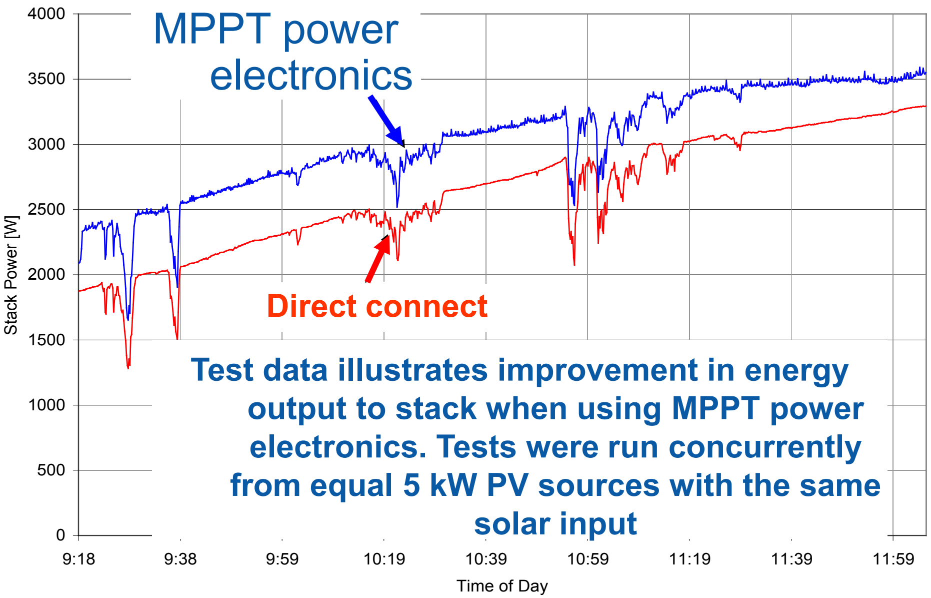
PV-Powered PEM Electrolysis

Capital Costs: Onboard power electronics (AC/DC) are relatively expensive accounting for 15 to 30% of the system cost. This problem is exacerbated when renewable power sources are used, adding a second on-board power electronics module

Accomplishment: NREL designed, built and tested a power electronics converter that captured between 10% – 20% more energy than the direct-coupled PV array.

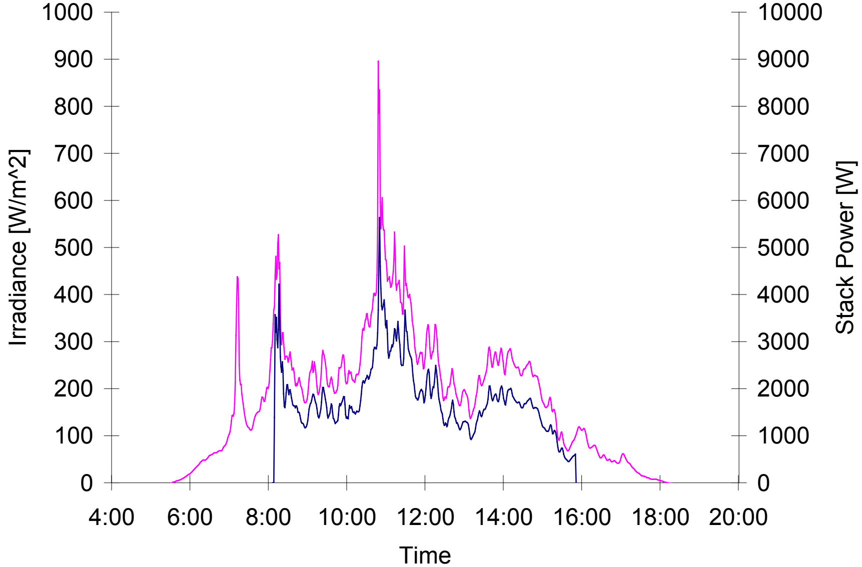
The power converter operates with an efficiency between 85% – 92%, incorporates a maximum power point tracking algorithm, utilizes off-the-shelf and low-cost components.

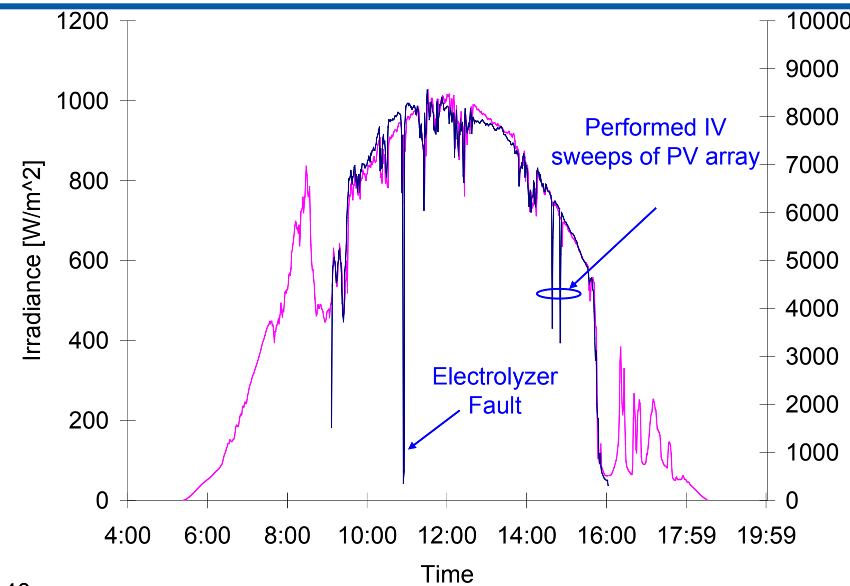
The upper graph shows the IV curve of the 20 cell stack and the more optimal operation around the MPPT with the addition of the 10 cell stack in series.

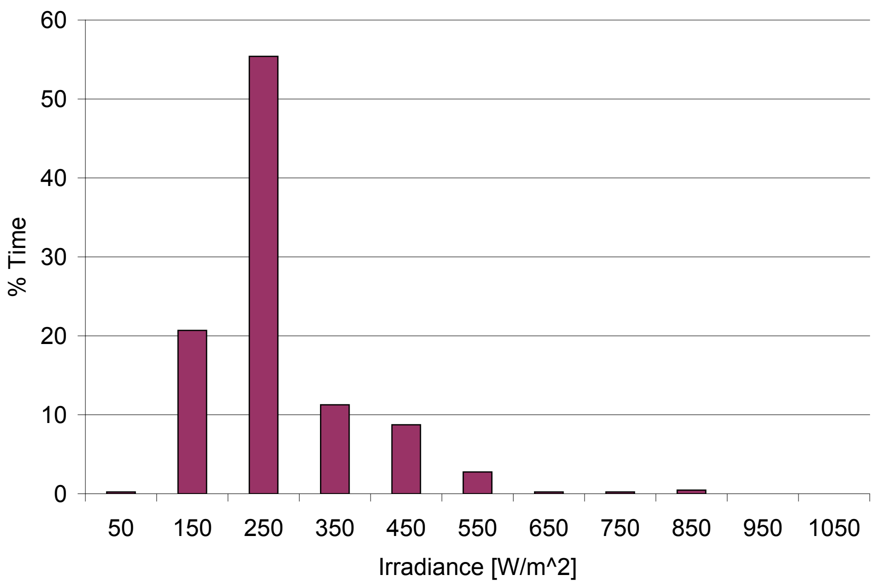


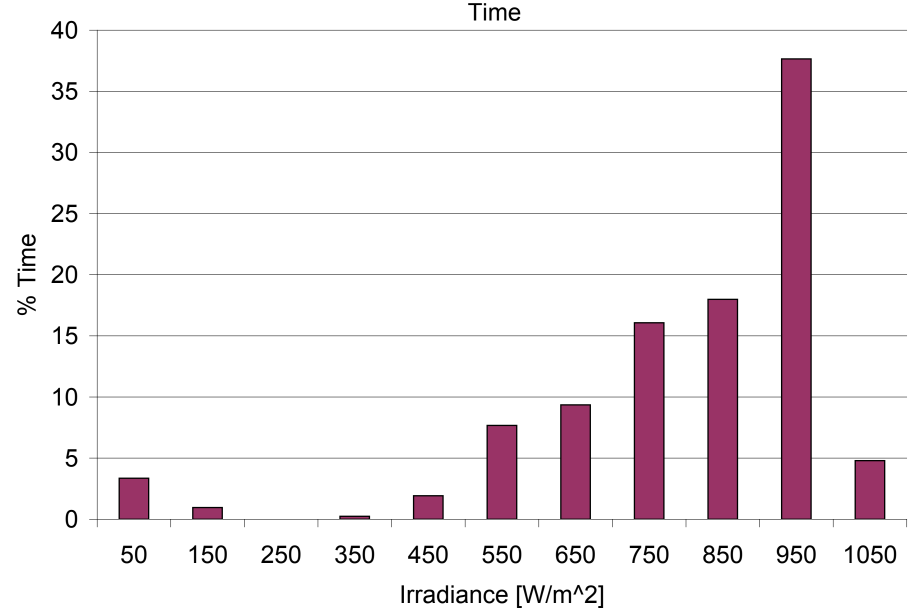
2010 Technical Accomplishment

PV-Powered PEM Electrolysis









2010 Technical Accomplishment

PV-Powered PEM Electrolysis

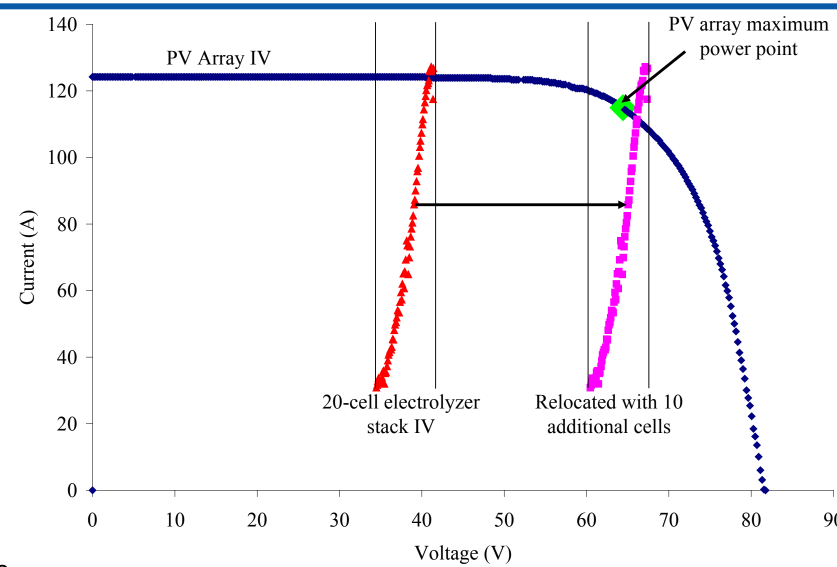
Accomplishment: Completed installation of additional 10 cell stack to better align operating point of photovoltaic (PV) array with series-connected combined stacks

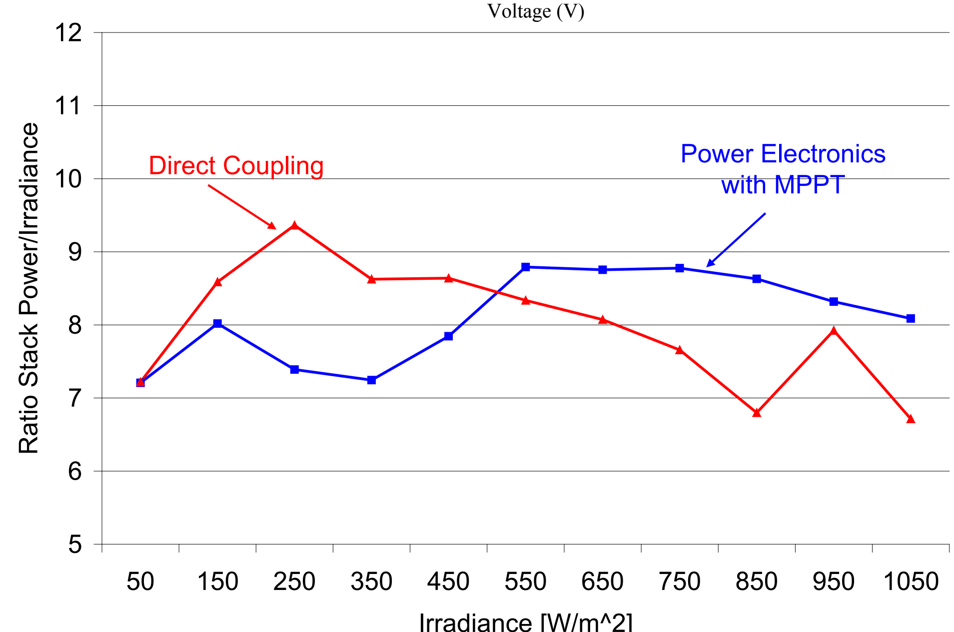
Testing: Performed PV-array-to-stack comparison testing using direct-coupling and power converter utilizing maximum power point tracking (MPPT)

Results: The improved PV-to-stack direct-coupled configuration operated more closely to the MPPT of the PV array without the need for a power converter

Efficiency: The electrical operating point of the stack can be better matched to the renewable resource to improve the energy transfer

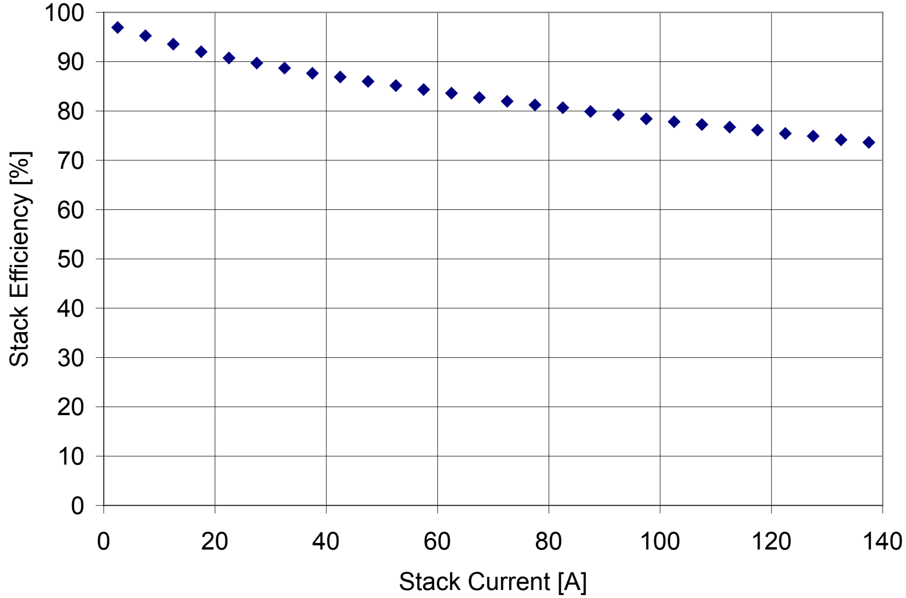
Significance: Data illustrates direct coupling of PV array to stack providing more stack energy at solar irradiances below 500 W/m2, while the power electronics performed better at higher solar levels





2010 Technical Accomplishment

PEM Electrolysis

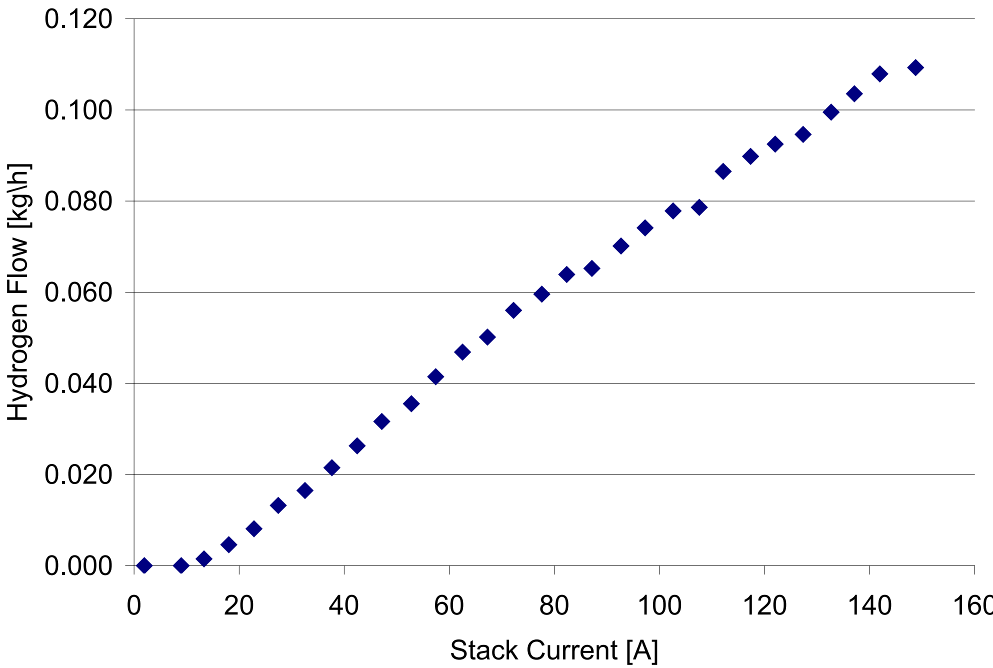


Although stack efficiency is higher at lower current the hydrogen flow (thus system efficiency) is zero at currents below 15 A

Electrolyzer consumes hydrogen to maintain the desiccant drying system

New techniques and incremental improvements in drying systems will improve system efficiency

Higher pressure electrolyzers will dissolve more hydrogen that is also wasted



2010 Technical Accomplishment

Unattended Operation & Long Duration Testing

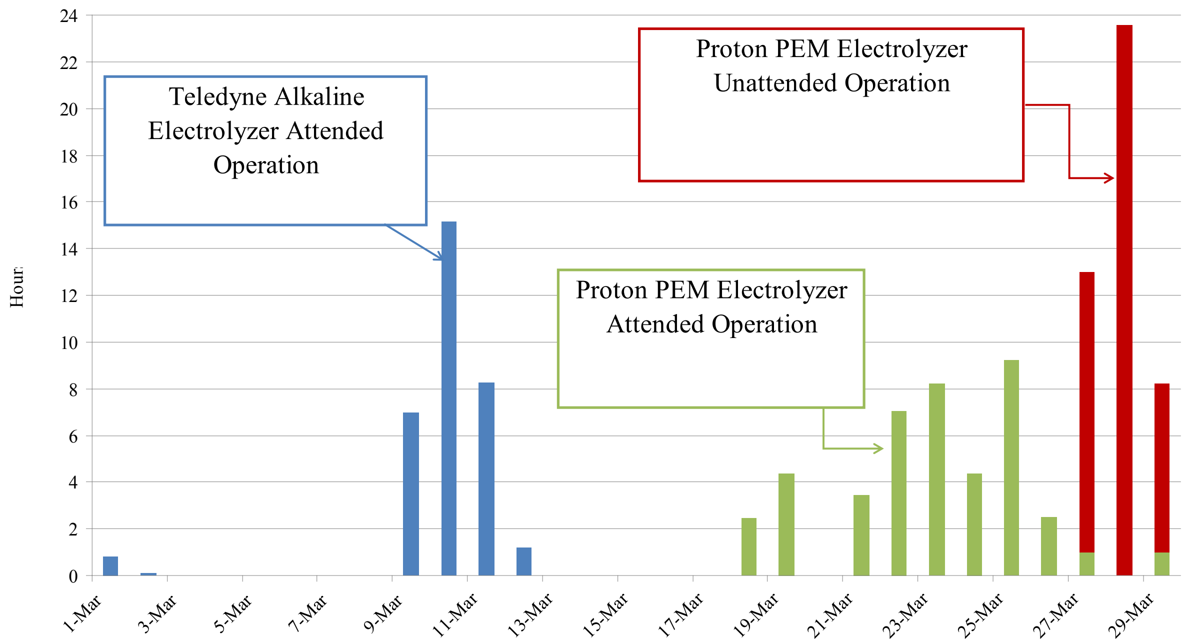
Accomplishments: Operated both the alkaline and PEM systems in unattended mode of operation.

Completed installation, commissioning and testing of 13 kg/day polymer electrolyte membrane (PEM) electrolyzer.

Results: Long-duration testing of similarly sized alkaline and PEM systems (40-50 kW).

Significance: Demonstration of integrated renewable electrolysis system operating in an unattended mode, enabling 24/7 operation.

Next: Enables comparison testing of alkaline and PEM technologies under wind-energy-driven operation.



2010 Technical Accomplishment

350 bar Compression, Storage and Refueling

Accomplishment: Completed installation of 350 bar compressor, storage and dispensing system (NREL funded)

Testing: 9 months of refueling A-Class Mercedes (~2 kg) and Proterra fuel cell bus (20 kg filled, 30 kg capacity)

Results: Critical refueling data from refueling being collected.

Significance: Station data will be included with the 23 stations currently being tracked by the Technology Validation team.

Next: Additional 350 bar storage, cascade fill capability and NREL H2ICE shuttle in 2010 to expand lessons learned, data collection and improved safety.

2010 Technical Accomplishment

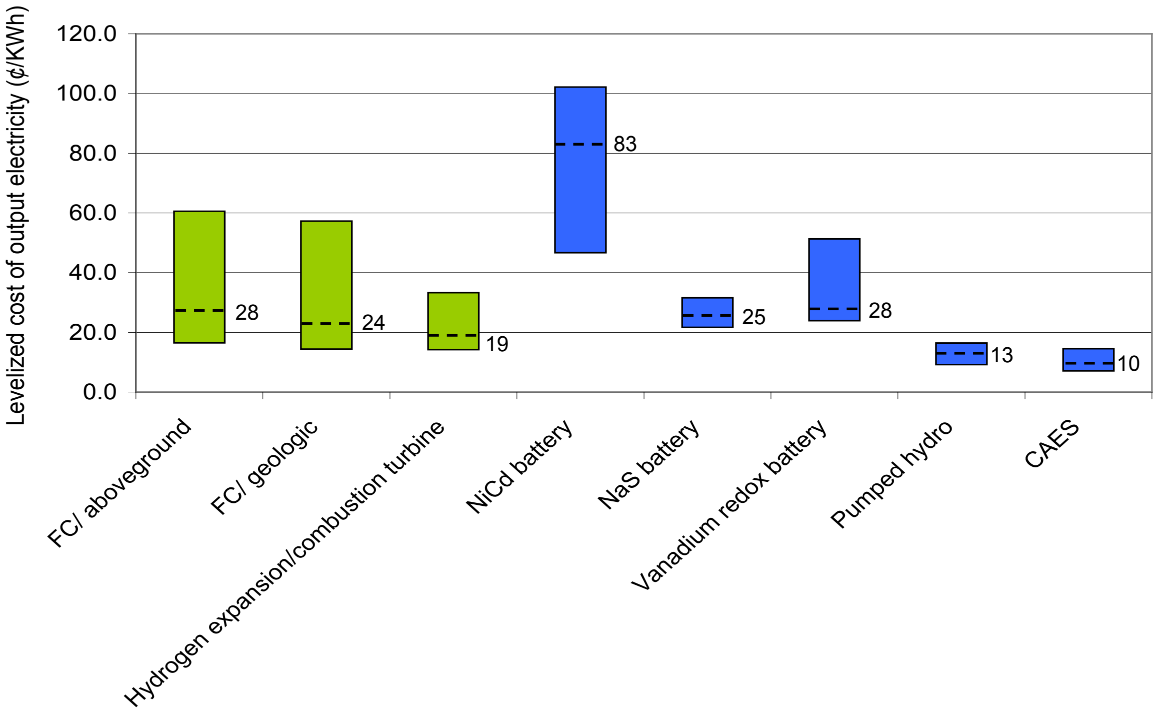
Cost & Performance Modeling

Completed the hydrogen-based energy storage analysis and companion energy storage benchmarking study.

– Final report delivered to DOE

The study included full sets of analyses of hydrogen-based energy storage systems, including PEM fuel cell based systems and hydrogen expansion-combustion turbine based systems

The study found that hydrogen-based systems were competitive with battery based systems, with hydrogen expansion-combustion turbine systems providing stored electricity for as little as 17 cents/kWh.



Technical Accomplishments

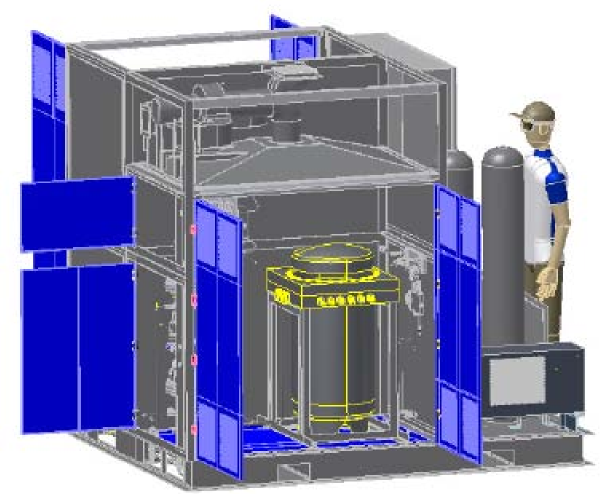
Experimental Results & Operational Lessons Learned

IMPLICATIONS FOR ELECTRIC UTILITIES', COMPONENT SUPPLIERS AND HYDROGEN-BASED ENERGY STORAGE SYSTEMS INTEGRATORS

- NREL continues to feedback experimental results and operational lessons learned to system integrators and electrolyzer industry
- Our experience with the wind-to-hydrogen production facility has been consistent with operations at similar facilities
- Participation in the International Energy Agency, Annex 24 (Wind Energy and Hydrogen Integration) has provided valuable cross-pollination of similarly designed and operating systems

DOE Awarded System Testing

Update



Giner Electrochemical Systems:

- Completed preliminary design review
  - Started to procure & fabricate the stack/system
- Begin assembly of the system late this year
- Ship system to NREL in 2011

Avalence, LLC:

- Testing 6500 psi system pressure to maintain safe H_2 in O_2 levels
- System delivery schedule to NREL uncertain

Future Work

PEM and Alkaline Comparison Testing

- Similar capacities (12 kg/day)
- Alkaline stack repair/replace

Side-by-Side Stack Testing

- Fundamental understanding of decay rate with varying stack current
- Operational characterization of system
- Two stacks operating with wind profile
- Third stack constant current

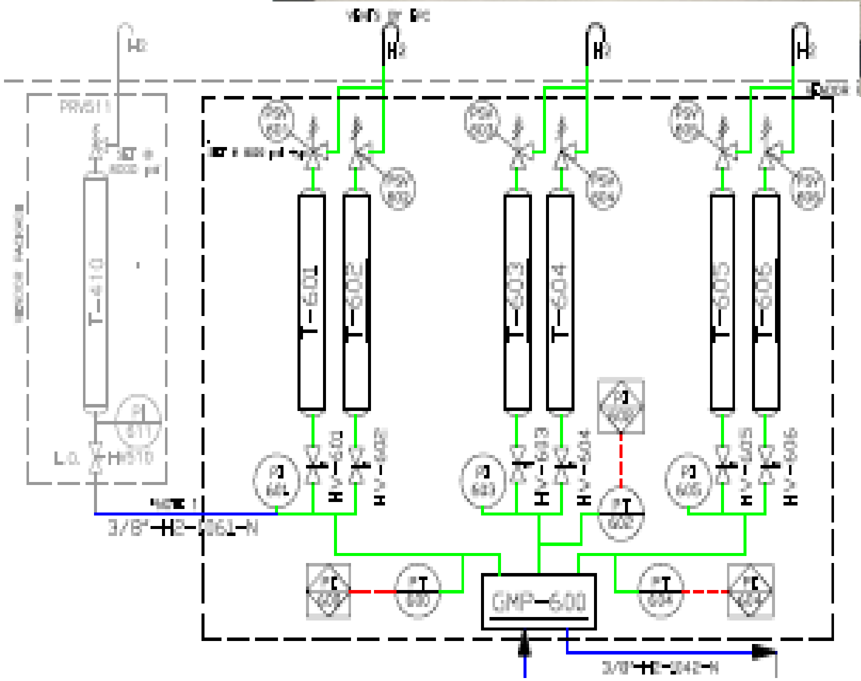
Future Work

Integrated Renewable Energy System

- Dynamic response of 5 kW fuel cell with PV and wind
- Long-duration operation

High Pressure Tank Installation

- Raising total to 250 kg capacity
- Cascade filling
- Enabling refueling of NRELs H2 ICE shuttle bus (30 kg capacity)
- Increasing interest from FCEV OEMs



Collaborations

Cooperative Research and Development Agreement

- Xcel Energy – Wind2H2 demonstration project
- Proton Energy Systems (pending) – Advanced electrolyzer sub-system engineering, energy storage and All Renewable Electrolyzer

Information sharing

- Hydrogen Utility Group
- Electrolyzer manufacturers
- University of North Dakota
- Energy & Environmental Research Center (Grand Forks, ND)
- Ft. Collins Utility (Ft. Collins, CO)

International

- International Energy Agency, Annex 24 “Wind Energy and Hydrogen Integration”
- Risø-DTU (Denmark) – Modeling and experimental verification of enhanced energy storage systems

Summary

Relevance: Addressing capital cost, efficiency and renewable energy source integration to reduce the cost per kg of hydrogen

Approach: Demonstrating advanced controls, system-level improvements and integration of renewable energy sources to electrolyzer stack

Technical Accomplishments:

- Unattended long-duration operation of both PEM and alkaline systems
- Testing results of more optimal PV-to-stack sizing
  - Testing compared direct coupling with maximum power point tracking power electronics
- Completed the hydrogen-based energy storage analysis and companion energy storage benchmarking study
- Completed commissioning and operated 350 bar refueling station

Technology Transfer & Collaborations: Gathering feedback from and transferring results to industry to enable improved renewable and electrolyzer integration and performance. Active and informal partnerships with industry, academia and domestic/international researchers.

Proposed Future Research:

- PEM and alkaline comparison testing
- Side-by-Side stack testing
- Integrated Renewable Energy System investigating FC, PV and wind dynamic response

Publications

Harrison, K. W.; Remick, R.; Hoskin, A.; Martin, G. D. (2010). Hydrogen Production: Fundamentals and Case Study Summaries; Preprint. 21 pp.; NREL Report No. CP-550-47302.

Ramsden, T.; Harrison, K.; Steward, D. (2009). NREL Wind to Hydrogen Project: Renewable Hydrogen Production for Energy Storage & Transportation (Presentation). 26 pp.; NREL Report No. PR-560-47432.

Harrison, K. W.; Martin, G. D.; Ramsden, T. G.; Kramer, W. E.; Novachek, F. J. (2009). Wind-To-Hydrogen Project: Operational Experience, Performance Testing, and Systems Integration. 95 pp.; NREL Report No. TP-550-44082.

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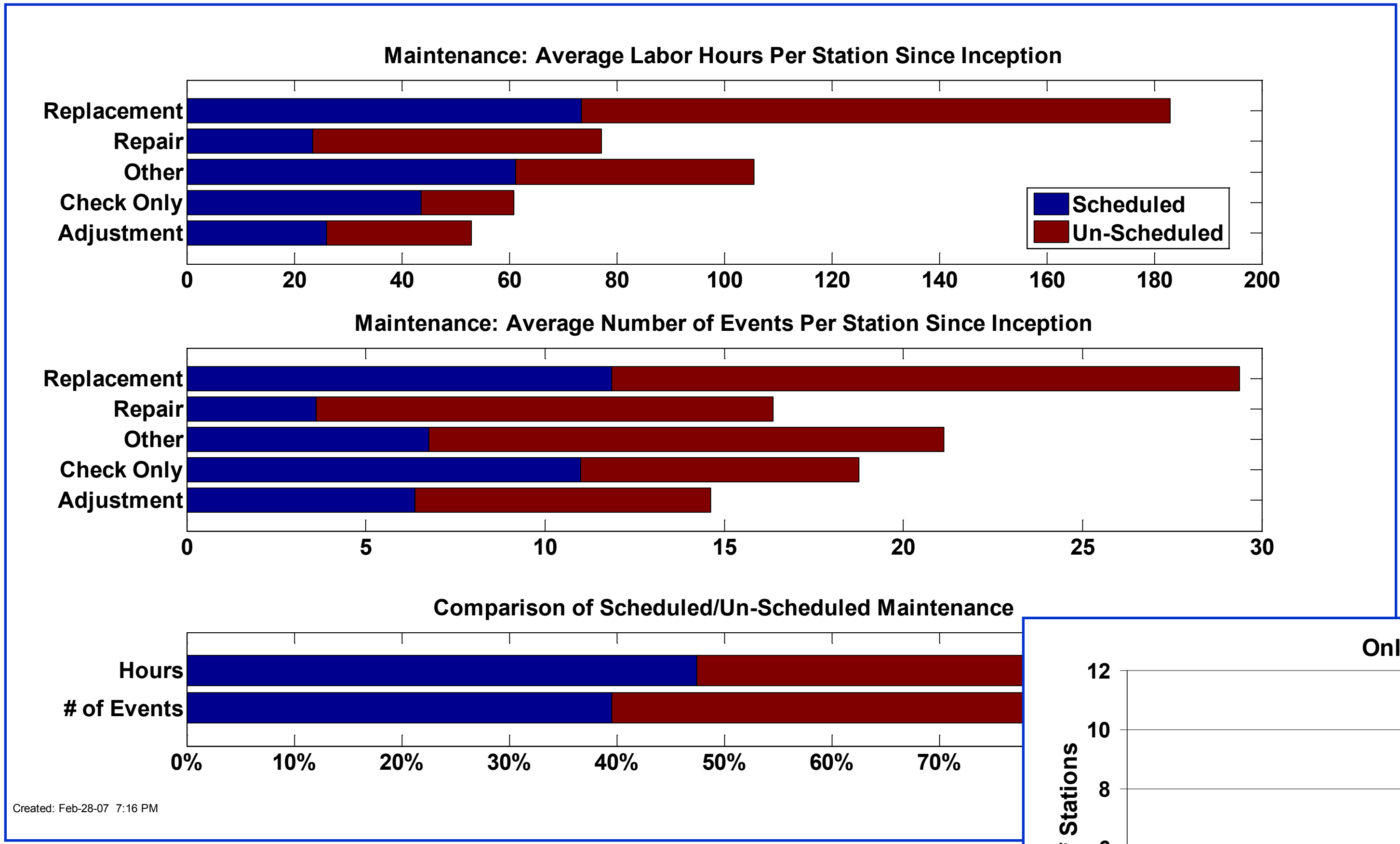
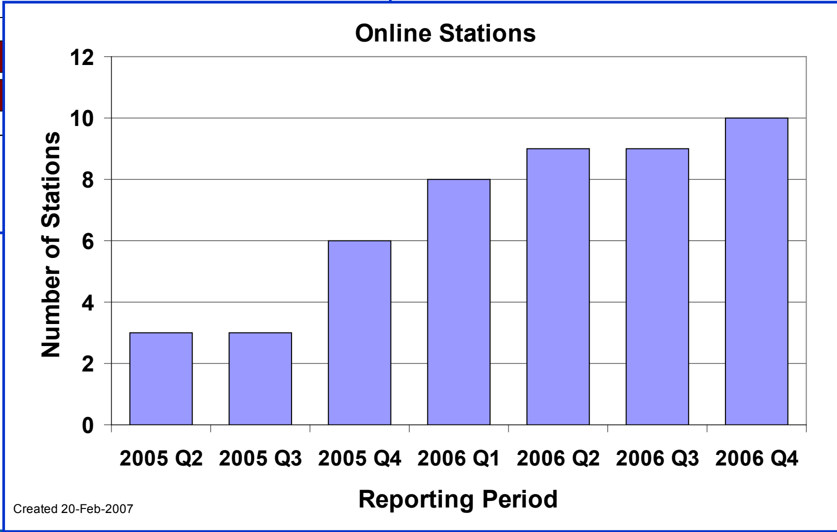
Supplemental Slides

DOE FCV Learning Demo

Spring 2007 Results





DOE FCV Learning Demo

Spring 2010 Results