NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL Fuel Cell and Hydrogen Technologies Program Overview

Fuel Cell and Hydrogen Energy Expo and Policy Forum

Washington, DC

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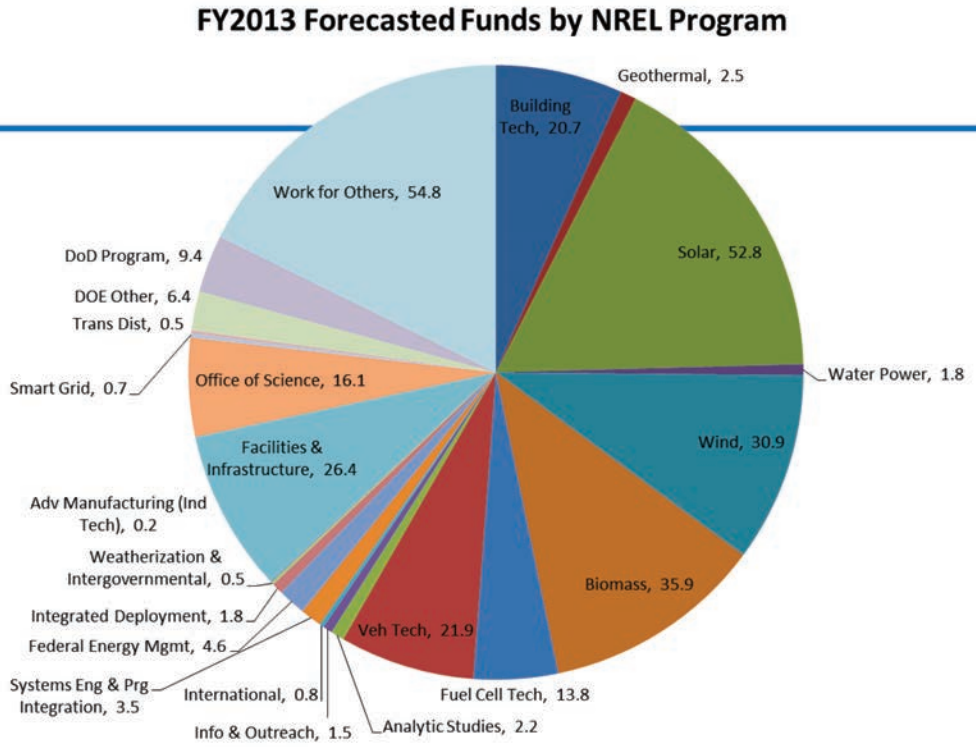
Lab Snapshot

- **35+ years of accomplishments and market impact in energy efficiency and renewable energy technology R&D**
- **2,419 staff (as of 12/2012)**
  - 1,634 employees
  - 785 non-payroll
- **$329.5M total funding in FY12**
- $309M projected for FY13
- **More than 350 partnerships**
- **International benchmark for sustainability**



What Makes NREL Unique?

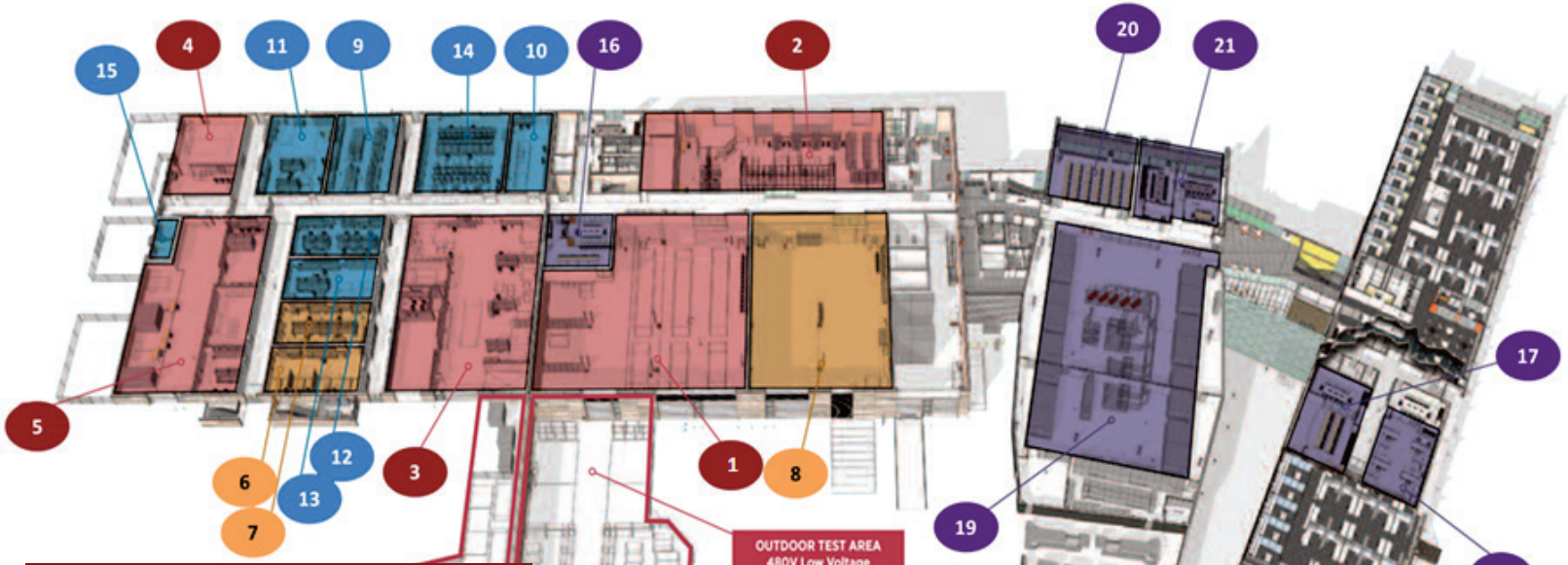
- Only national laboratory dedicated to renewable energy and energy efficiency R&D
- Collaboration with industry and university partners is a hallmark
- Ability to link scientific discovery and product development to accelerate commercialization

Energy Systems Integration Facility (ESIF)

- Focused on systems and grid integration
- Complete system modeling, testing and analysis
- High performance computing and visualization capabilities

ESIF Laboratories

ESIF Laboratories



Electrical Systems Laboratories
1. Power Systems Integration
2. Smart Power
3. Energy Storage
4. Electrical Characterization
5. **Energy Systems Integration**

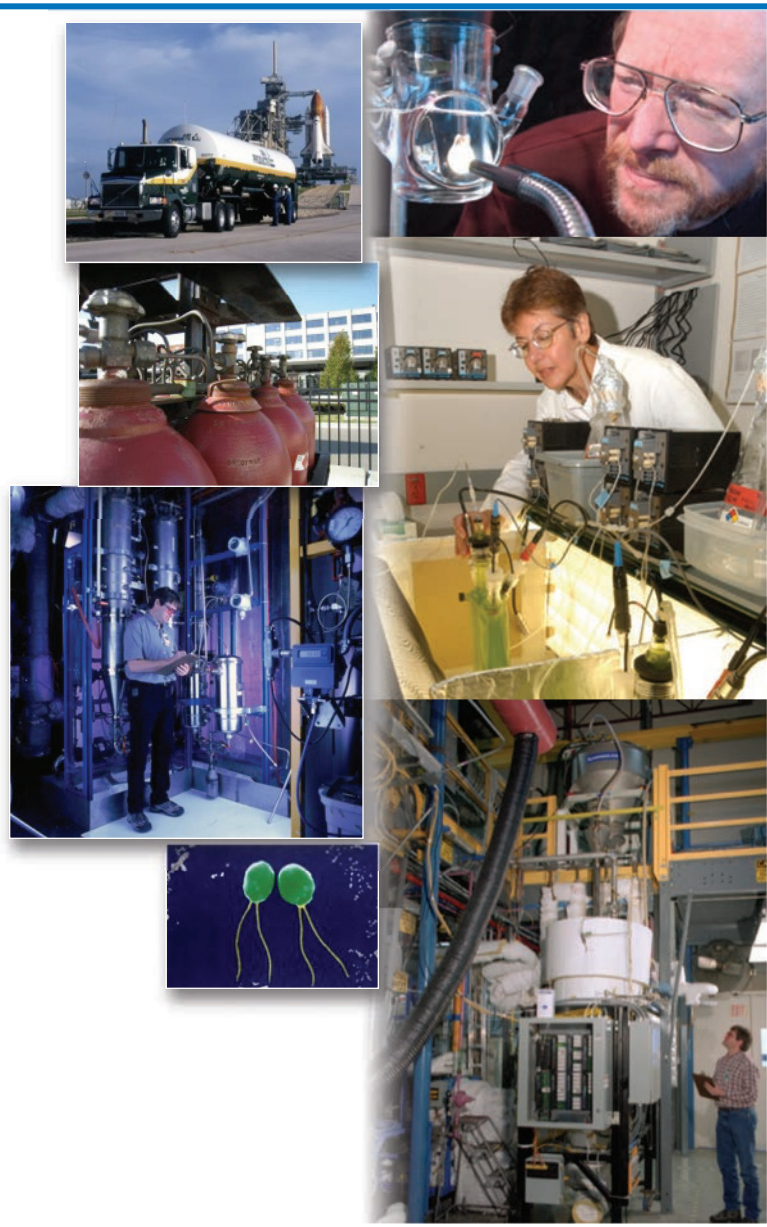
Thermal Systems Laboratories
6. Thermal Storage Process and Components
7. Thermal Storage Materials
8. Optical Characterization

Hydrogen Laboratories
9. Energy Systems Fabrication
10. Manufacturing
11. Materials Characterization
12. Electrochemical Characterization
13. Energy Systems Sensor
14. Fuel Cell Development & Test
15. Energy Systems High Pressure Test

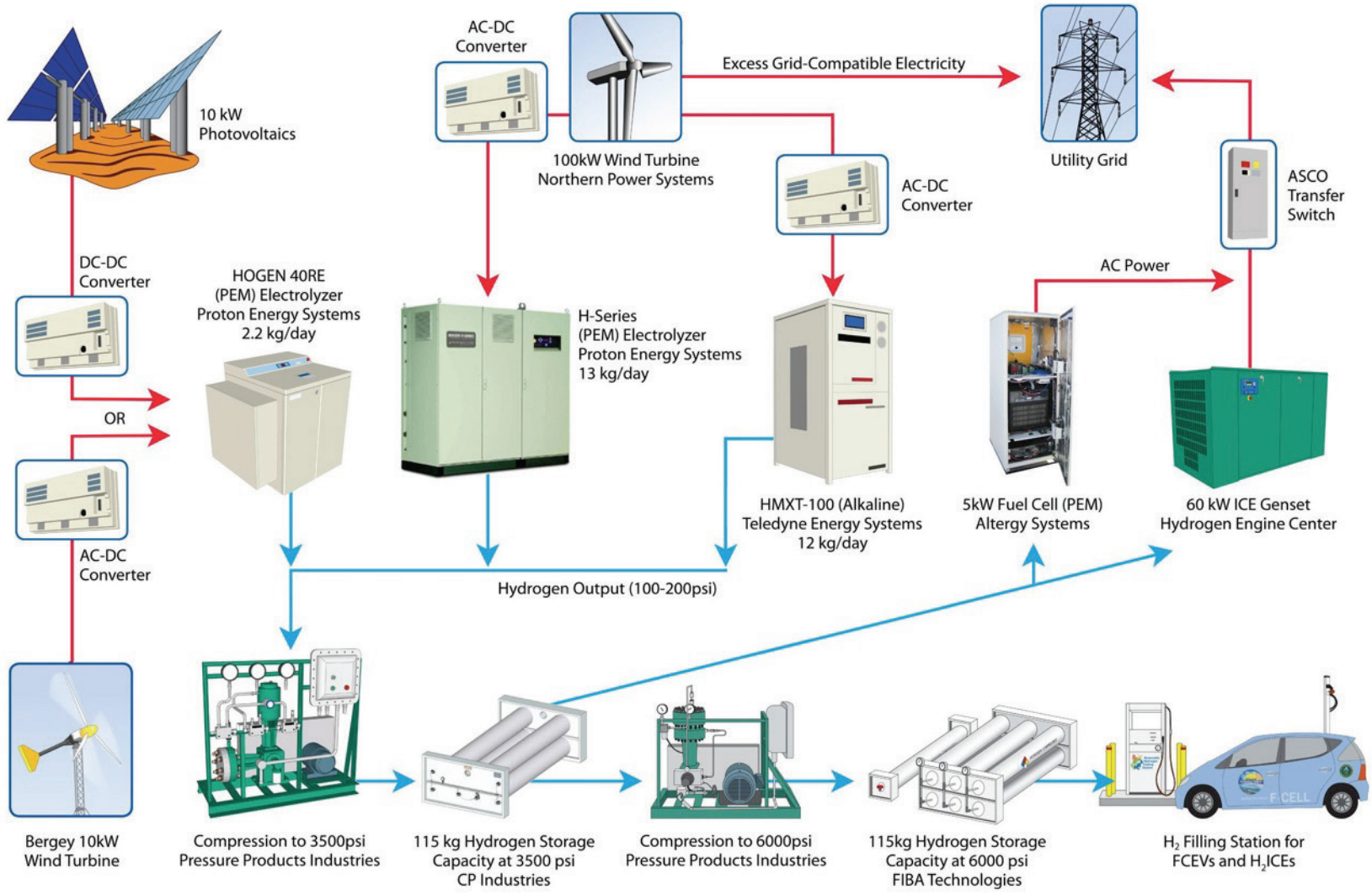
High Performance Computing, Data Analysis, and Visualization
16. ESIF Control Room
17. Energy Integration Visualization
18. **Secure Data Center**
19. High Performance Computing Data Center
20. Insight Center Visualization
21. Insight Center Collaboration

NREL Fuel Cell and Hydrogen Technologies Program

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



Wind-to-Hydrogen at NREL



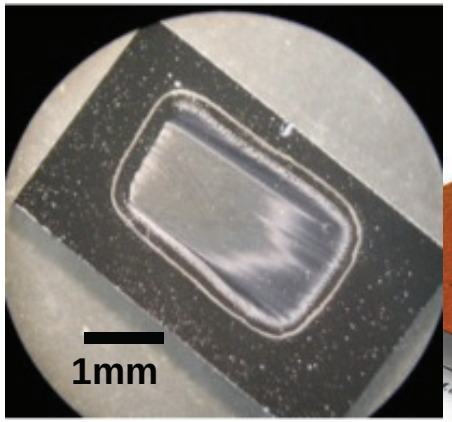
NREL Achieves Breakthrough in Stabilization of High-Efficiency Solar Water-Splitting Electrodes

The **only** demonstrated high-efficiency materials (>10% solar to hydrogen) were developed at NREL. These $GaInP_2$ (III-V) semiconductors are prone to corrosion in less than 24 hours, precluding any market viability.

For generating renewable hydrogen fuel by photoelectrochemical water splitting, materials with high-efficiency **and** durability are required to be commercially attractive.

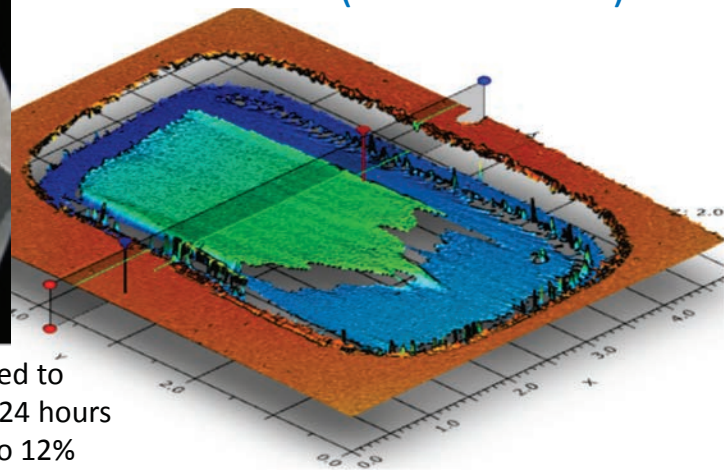
NREL developed a nitrogen ion (N_2^+) implantation surface modification that has **provided protection for several hundred hours without sacrificing efficiency**.

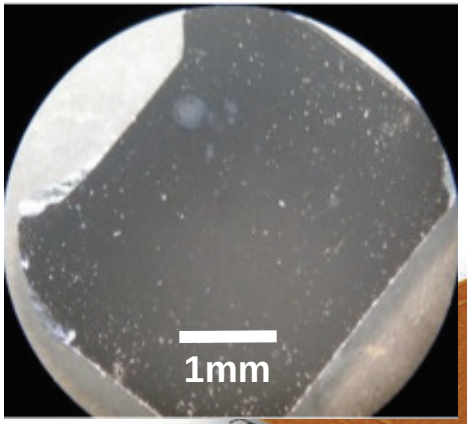
A **provisional patent** application is being drafted on this invention.



The portion of the surface exposed to electrolyte is etched ~1µm after 24 hours passing 10 mA/cm^2 (equivalent to 12% solar-to-hydrogen efficiency) in 3M H_2SO_4

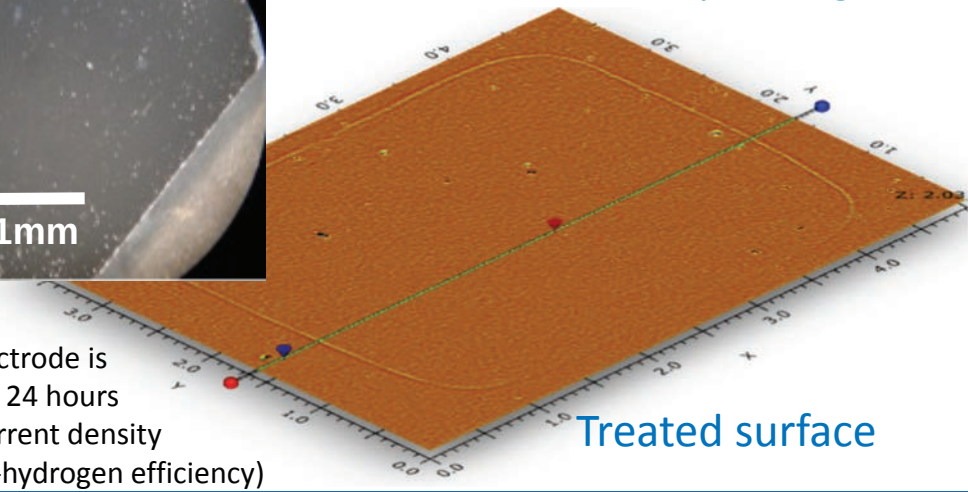
Control (no treatment)





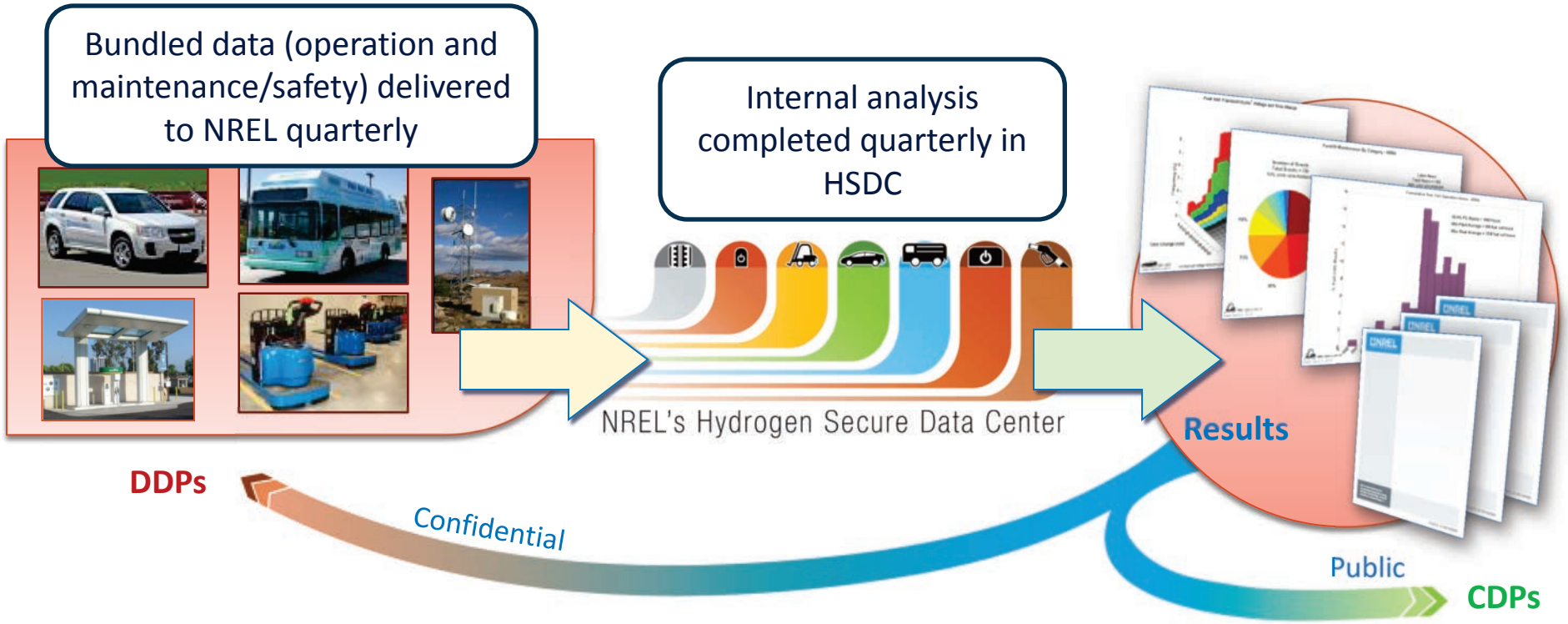
The surface of the treated electrode is unaltered after 24 hours at twice the current density (~23% solar-to-hydrogen efficiency)

Optical (interference) profilometry after durability testing



Treated surface

Analysis and Reporting of Real-World Operation Data



Detailed Data Products (DDPs)

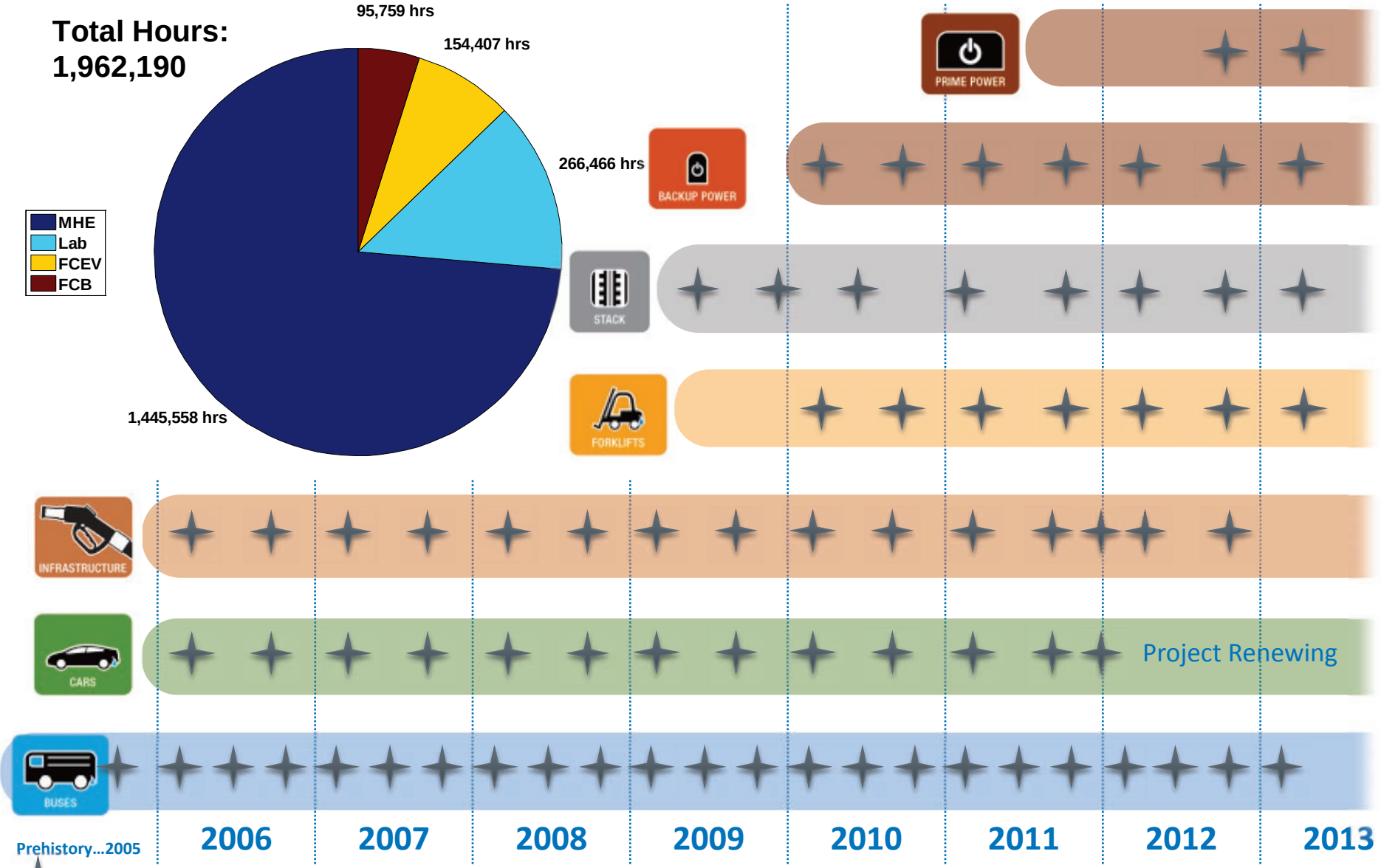
- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data[1]

Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publish analysis results every six months without revealing proprietary data[2]

1) Data exchange may happen more frequently
2) Results published via NREL technology validation website, conferences, and reports (http://www.nrel.gov/hydrogen/proj_learning_demo.html)

Technology Validation Projects



Transportation – Validation of Fuel Cell Vehicles

Vehicle Performance Metrics	Gen 1 Vehicle	Gen 2 Vehicle	2009 Target	After 2009Q4
Fuel Cell Stack Durability			**2,000 hours**	
Max Team Projected Hours to 10% Voltage Degradation	**1,807 hours**	**2,521 hours**		--
Average Fuel Cell Durability Projection	821 hours	1,062 hours		1,748 hours
Max Hours of Operation by a Single FC Stack to Date	2,375 hours	1,261 hours		1,582 hours
Driving Range			**250 miles**	
Adjusted Dyno (Window Sticker) Range	**103-190 miles**	**196-254 miles**		--
Median On-Road Distance Between Fuelings	56 miles	81 miles		98 miles
Fuel Economy (Window Sticker)	42 – 57 mi/kg	43 – 58 mi/kg	no target	--
Fuel Cell Efficiency at ¼ Power	51 – 58%	53 – 59%	60%	--
Fuel Cell Efficiency at Full Power	30 – 54%	42 – 53%	50%	--

Infrastructure Performance Metrics			2009 Target	After 2009Q4
H_2 Cost at Station (early market)	On-site natural gas reformation **$7.70 – $10.30/kg**	On-site Electrolysis **$10.00 – $12.90/kg**	**$3/gge**	--
Average H_2 Fueling Rate	0.77 kg/min		1.0 kg/min	0.65 kg/min

Outside of this project, DOE independent panels concluded at 500 replicate stations/year:
Distributed natural gas reformation at 1500 kg/day: **$2.75-$3.50/kg** (2006)
Distributed electrolysis at 1500kg/day: **$4.90-$5.70** (2009)

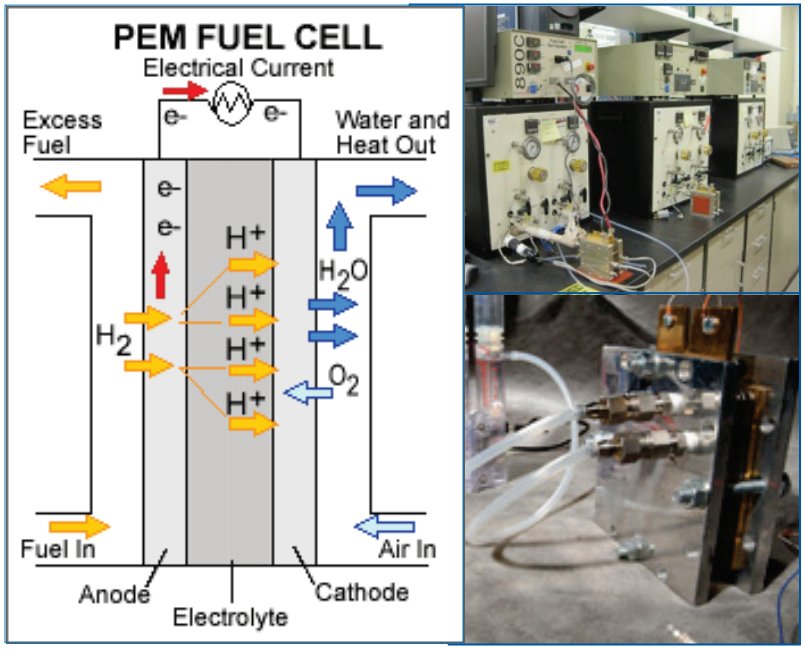
Outside review panel

Fuel Cell R&D at NREL

Improving the cost performance, and durability of fuel cell systems and their subsystems and components

- Projects include proton exchange membrane fuel cells (PEMFCs), direct methanol fuel cells (DMFCs), and alkaline exchange membrane fuel cells (AEMFCs):
  - Catalysts
  - Membrane
  - Membrane electrode assemblies (MEA)
  - Bipolar plates
  - Effects of contaminants

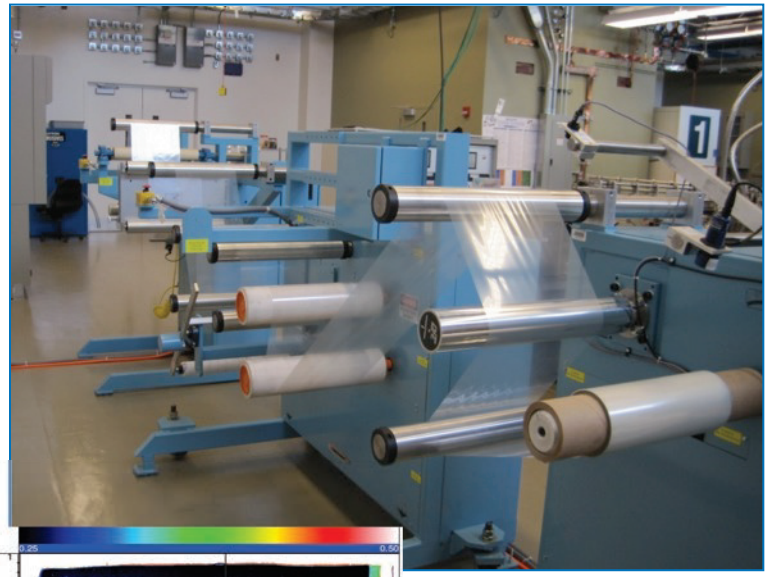
- Maintain focus on low temperature PEM fuel cells for transportation with R&D on materials and integration of membrane electrode assemblies (MEAs)

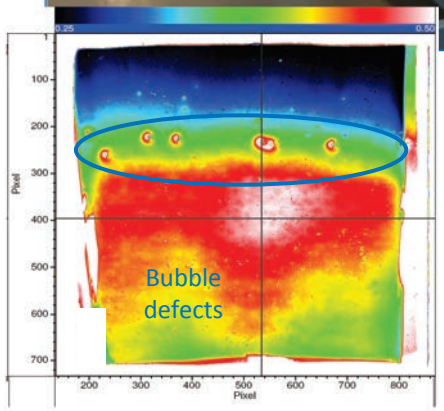


Fuel Cell Manufacturing R&D at NREL

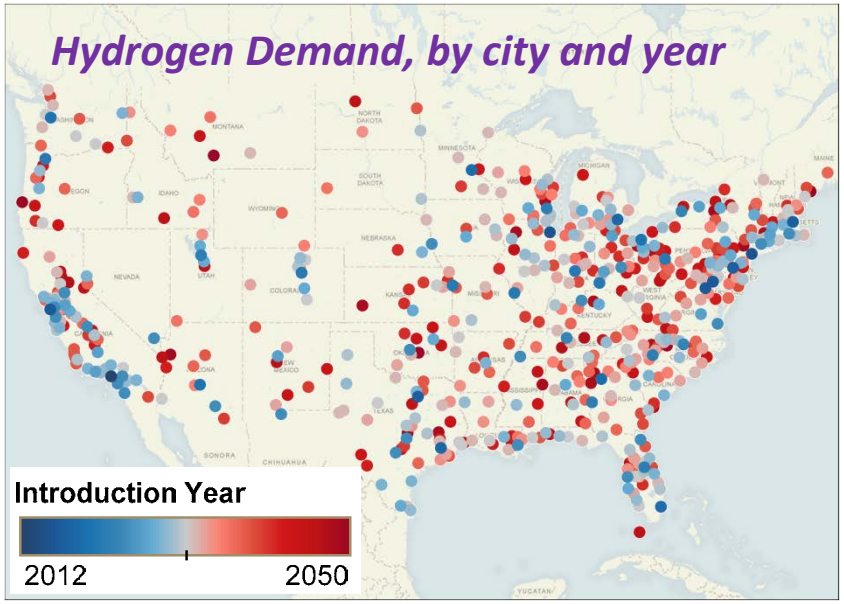
Assessing industry manufacturing methods and developing improved processes

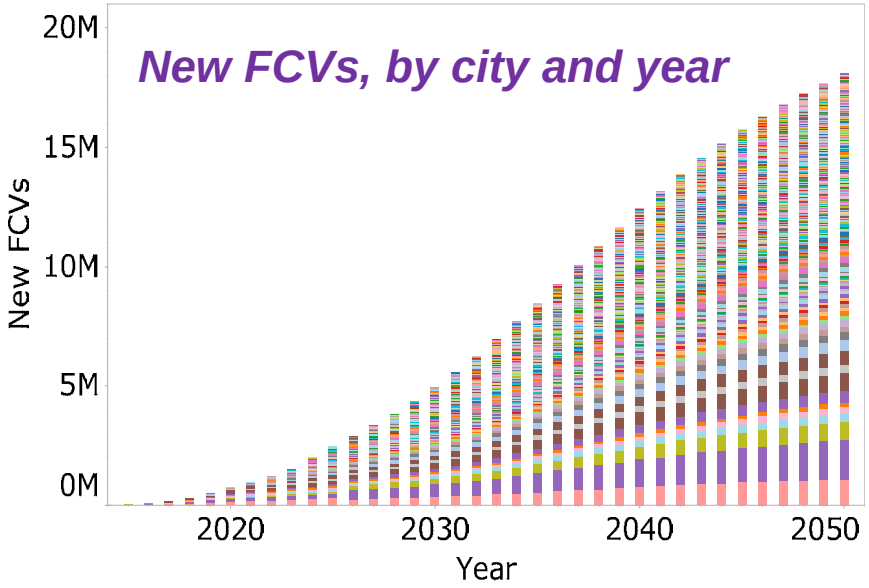
- Focus fuel cell manufacturing R&D on industry-wide solutions for in-line quality control during manufacturing across leading fuel cell technologies
- Provide assessments of the state of technology and manufacturing readiness for fuel cell products



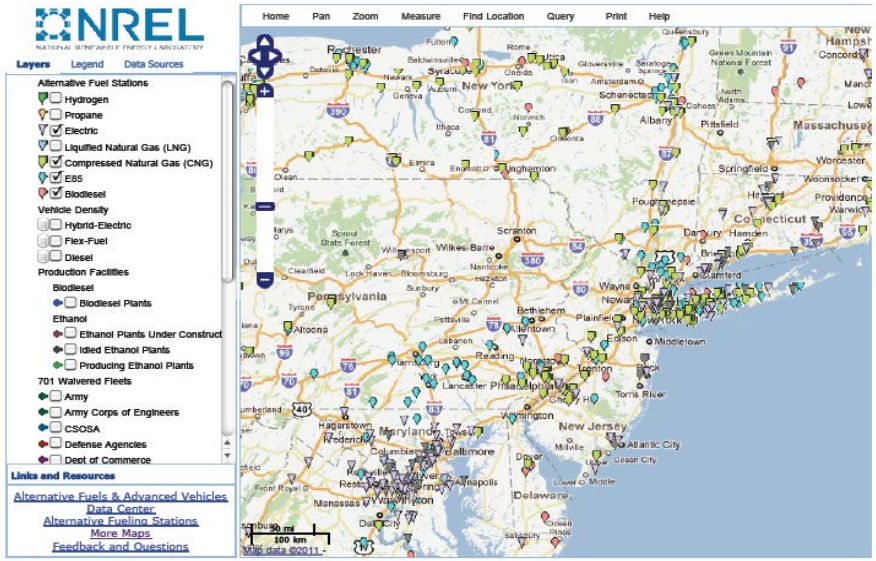


Hydrogen Station Rollout: Integration Contributes to Scenario Analyses & Market Assessments





- Travel time requirements for early markets can improve analytic basis for rollout scenario
- Results can also be used to monitor market development when combined with empirical market data
- Realizing and anticipating niche markets and regional variability



TransAtlas: http://maps.nrel.gov/transatlas

Key Messages

- Hydrogen FCEVs are clean, efficient, refuel quickly, and provide long driving range
- Auto OEMs are coming to market with commercial vehicles in the 2015–2017 timeframe
- Additional support for H_2 infrastructure is needed for these vehicles
- Abundant supplies of clean domestic sources (including natural gas and renewables) make fuel cells a good choice for the future
- Remaining research challenges on fuel cells focus on cost and durability, which are interrelated
- NREL is involved in most aspects of bringing hydrogen fuel cell technologies closer to market (production, storage, fuel cells, etc.)

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Backup

Safety, Codes and Standards

Ensuring safe operation, handling, and use of hydrogen and hydrogen systems through safety sensors and codes and standards for buildings and equipment

- Provide guidance to organizations that are developing model codes and standards
- Test fuel cell and hydrogen components for operation and safety
- Assist the United States in harmonizing codes and standards worldwide

Hose Reliability Testing and Analysis

Automated Cycling of Fueling Hoses

- School of Mines – SEM of hose material
- NREL – Evolved gas analysis of hose material
- Hydrogen recycle system at Wind-to-Hydrogen