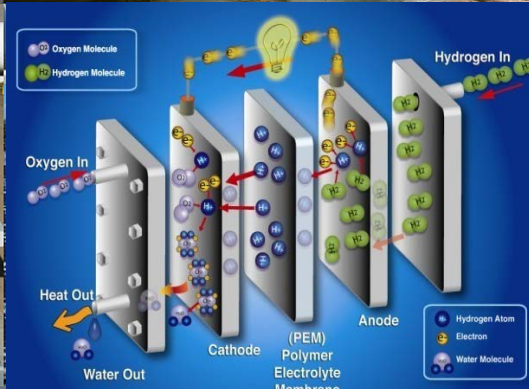


# National Fuel Cell Technology Evaluation Center (NFCTEC)

U.S. DEPARTMENT OF ENERGY

Energy Efficiency & Renewable Energy



Jennifer Kurtz & Sam Sprik

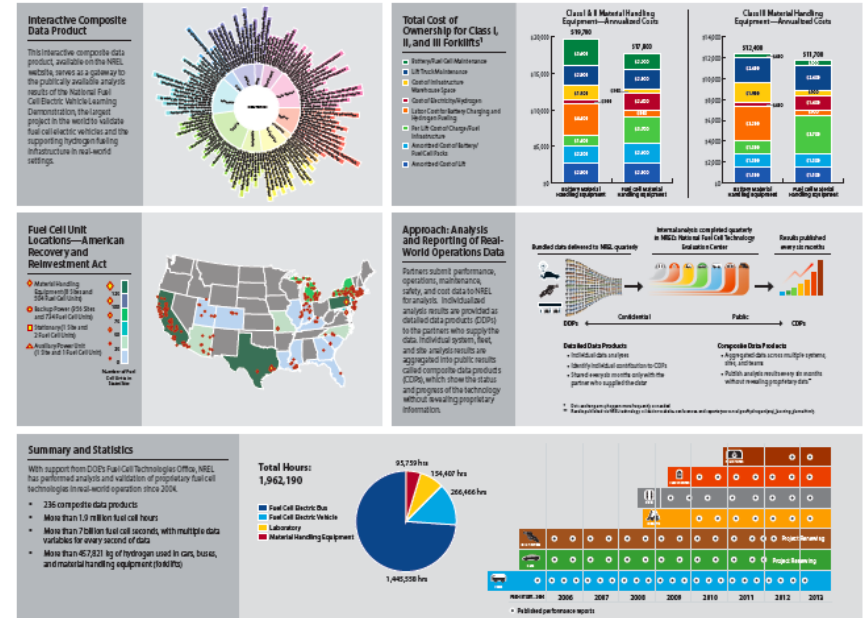
National Renewable Energy Laboratory

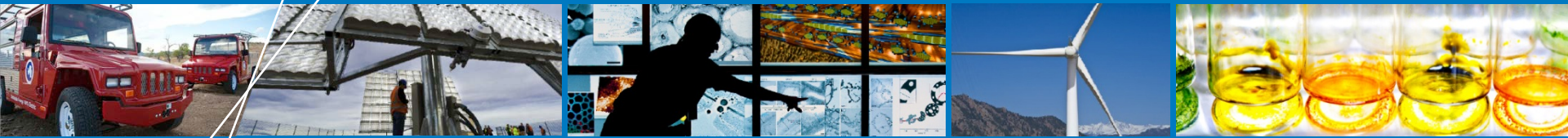
Jim Alkire

U.S. Department of Energy  
Fuel Cell Technologies Office

# Outline

- About NFCTEC
- Benefits to the Hydrogen & Fuel Cell Community
- New Fuel Cell Cost/Price Aggregation Project





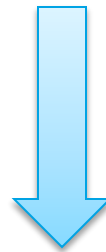
# About NFCTEC

# Energy Department Launches National Fuel Cell Technology Evaluation Center to Advance Fuel Cell Technologies

## September 2013

Source: [http://apps1.eere.energy.gov/news/news\\_detail.cfm/news\\_id=19607](http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=19607)

Rebranding of HSDC



## National Fuel Cell Technology Evaluation Center



*a national resource for hydrogen and fuel cell stakeholders  
supported through Energy Efficiency and Renewable Energy's Fuel Cell Technologies Office*



# NFCTEC Objectives

- Independent, secure analysis
- Industry collaboration & benchmarking
- Confirmation of component and system technical targets
- Technology validation
- Evaluation, optimization, and demonstration in integrated energy systems and real-world operation

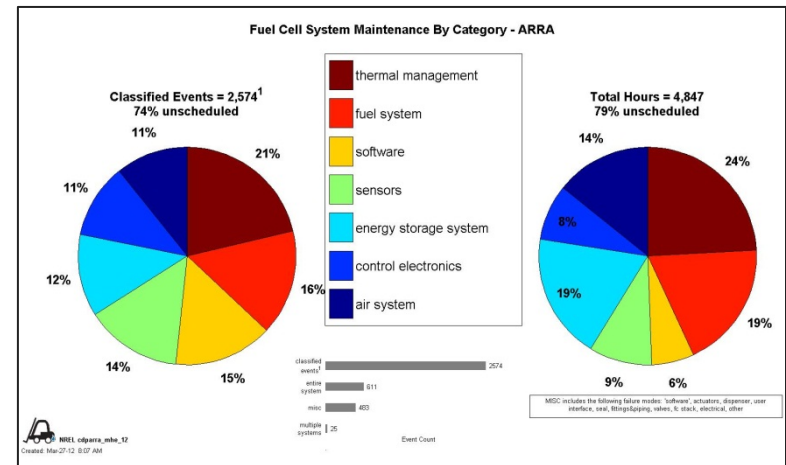
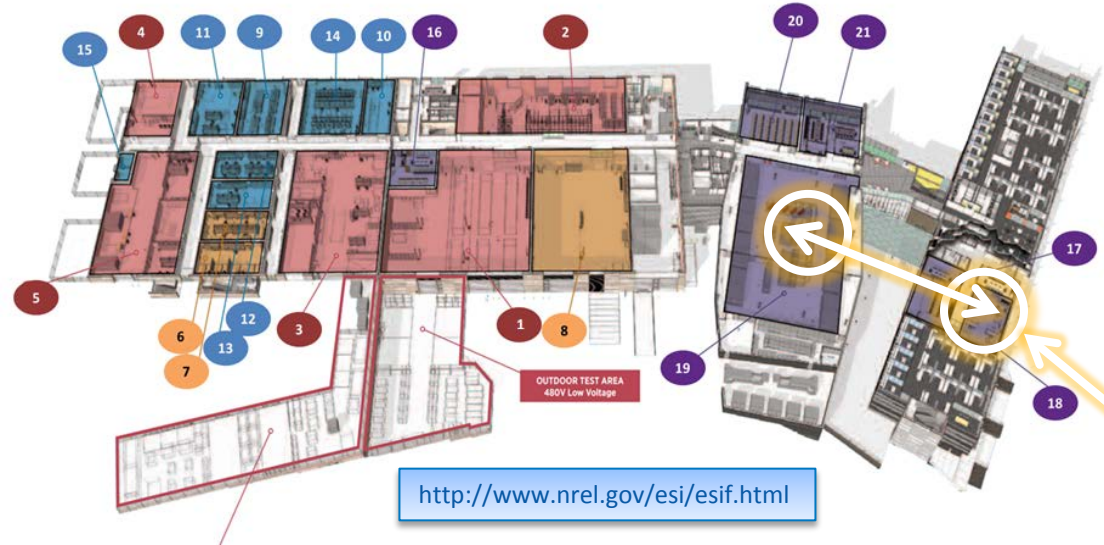


Photo by Dennis Schroeder, NREL  
Figures and illustrations: NREL

# NFCTEC @ Energy Systems Integration Facility



# NFCTEC Security Procedures

National Fuel Cell Technology Evaluation Center  
at  
Energy Systems Integration Facility

Procedures to Protect Proprietary Technical Data Submitted to the  
NREL National Fuel Cell Technology Evaluation Center

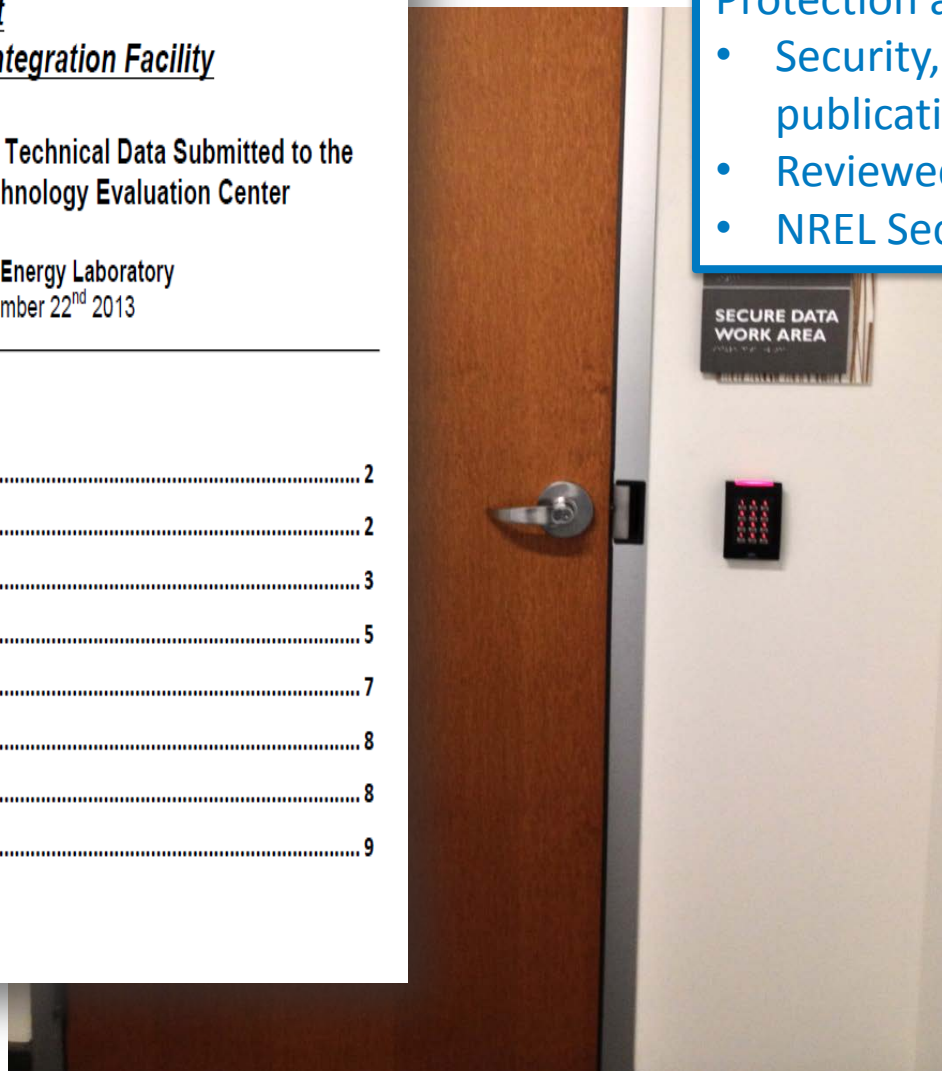
National Renewable Energy Laboratory  
Revision C, November 22<sup>nd</sup> 2013

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8. Revision History.....	9

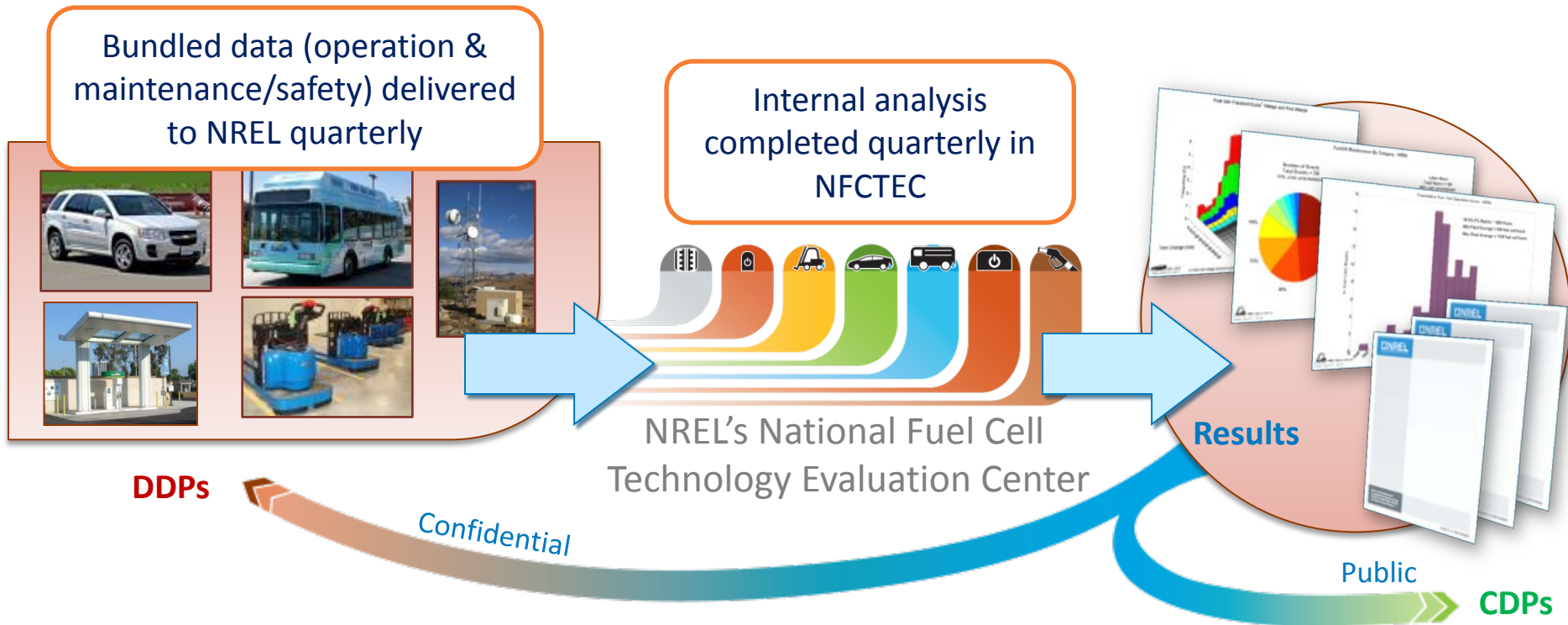
## Protection and use of data

- Security, access, publications, data transfer
- Reviewed every 2 years
- NREL Security response





# NFCTEC 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<sup>1</sup>

## Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publish analysis results every six months without revealing proprietary data<sup>2</sup>

[www.nrel.gov/hydrogen/proj\\_tech\\_validation.html](http://www.nrel.gov/hydrogen/proj_tech_validation.html)



# NFCTEC Data Templates & Tools

## On-Road Vehicle Data<sup>1,2</sup>

Data does not need to be provided via Excel spreadsheet, provided the information below is clearly identified in the data file and formatted the same for Template updated: January 5, 2012 (NREL)

### On-Board Vehicle and Refueling Data<sup>3,4</sup>

Start Time [yyyymmddHHMMSS] Start Time Stamp  
 VEHICLE Number unique vehicle

Footnotes:  
 (1) Data will be delivered to NREL's Hydrod  
 (2) Data must be collected at a minimum fr  
 (3) Values may be calculated rather than di  
 (4) Fueling information is needed to gather

Data files submitted need to contain the unique vehicle name as well as a time stamp (down to the second) for the start of each set of data (example: Veh12\_20111015\_155905.csv)  
 Data will be converted to Matlab \*.mat files

Component	N/A	Vehicle	N/A	Fuel Tank <sup>4</sup>
Measurement	Time <sup>2</sup>	Vehicle Speed	Odometer	Temperature
	Seconds (at least 1 data point per second)	Miles/hour	Miles	Pressure
Units			degrees C	Temperature
			psig	deg C
				%

## Vehicles

Data should include all vehicles since inception of the program

Template updated: January 5, 2012 (NREL)

Date data updated:		insert date updated		
Automaker		insert name of automaker		
Date updated	Unique Vehicle Identifier	Vehicle Configuration (1,2,... from separate template)	Starting Date of Vehicle Operation	Odometer at start of DOE program
mm/dd/yyyy	--	configurationx	mm/dd/yyyy	mile
11/18/11	V24	configuration1	10/30/04	550
11/18/11	V25	configuration2	12/1/04	20

First 2 rows are for example only and should be overwritten with real data.

## Vehicle Descriptive Parameters

Provide one column for each unique vehicle configuration

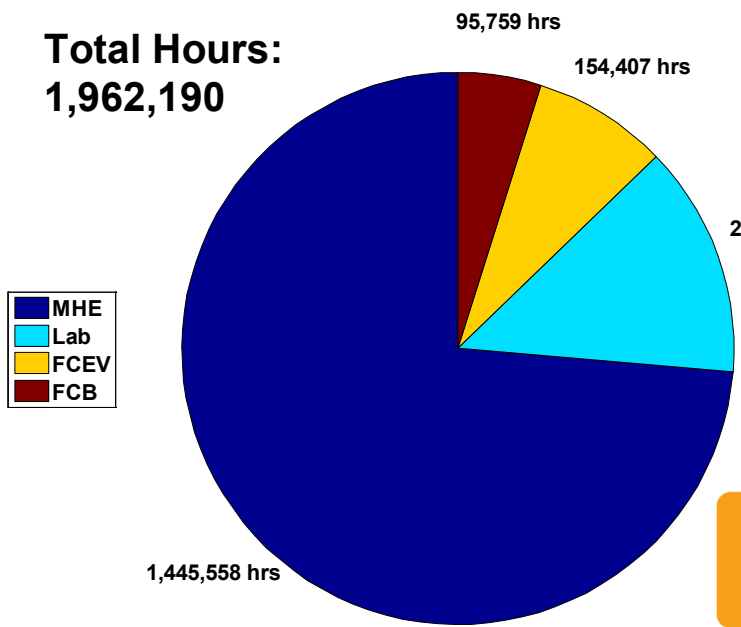
Template updated: January 5, 2012 (NREL)

Parameter	Units	Unique Vehicle Configuration	
		Configuration1	Configuration2
<b>Vehicle</b>			
Date of Input Configuration ID	yyyy/mm/dd		
Year	YYYY		
Make	--		
Model	--		
Technology Generation	--		
Frontal Area	m <sup>2</sup>		
Coefficient of Drag	--		
Curb Weight	kg		
Fuel Economy (EPA rating)	miles/kg		
Range	miles		
Usable Hydrogen Storage	kg		
Top Speed	miles/hour		
Acceleration (0-60 mph)	s		
<b>Fuel Cell System</b>			
Manufacturer	--		
Model	--		
System Net Power Rating	kW		
Fuel Cell Stack Max Power	kW		
Open Circuit Voltage	V		
Idle Current Load	Amp		
Max Operating Current	Amp		
Current Density @ Rated Power	Amp/cm <sup>2</sup>		
Fuel Cell System Mass	kg		
Fuel Cell System Volume	L		
Balance of Plant Mass	kg		
Balance of Plant Volume	L		
Fuel Cell Stack Mass	kg		
Fuel Cell Stack Volume	L		
Number of Cells in Stack			
Calculated Specific Power	W/kg	#DIV/0!	#DIV/0!
Calculated Power Density	W/L	#DIV/0!	#DIV/0!
<b>Fuel Cell System Efficiency (LHV based)</b>			
Gross System Power at idle	kW		
Efficiency at 5% net power	%		
Efficiency at 10% net power	%		
Efficiency at 25% net power	%		
Efficiency at 50% net power	%		
Efficiency at 75% net power	%		
Efficiency at 100% net power	%		
<b>Utility</b>			
Number of Tanks			
Tank Type			
Cycle Life	cycles		
Tank Pressure	bar		
Total H2 Mass	kg		
Total H2 Volume	L		

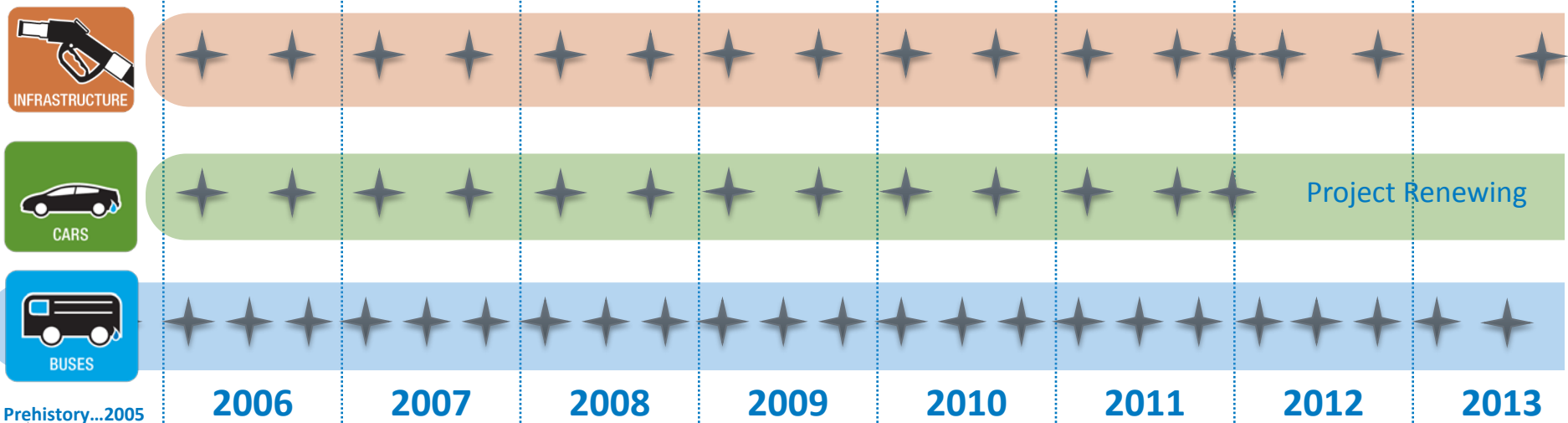
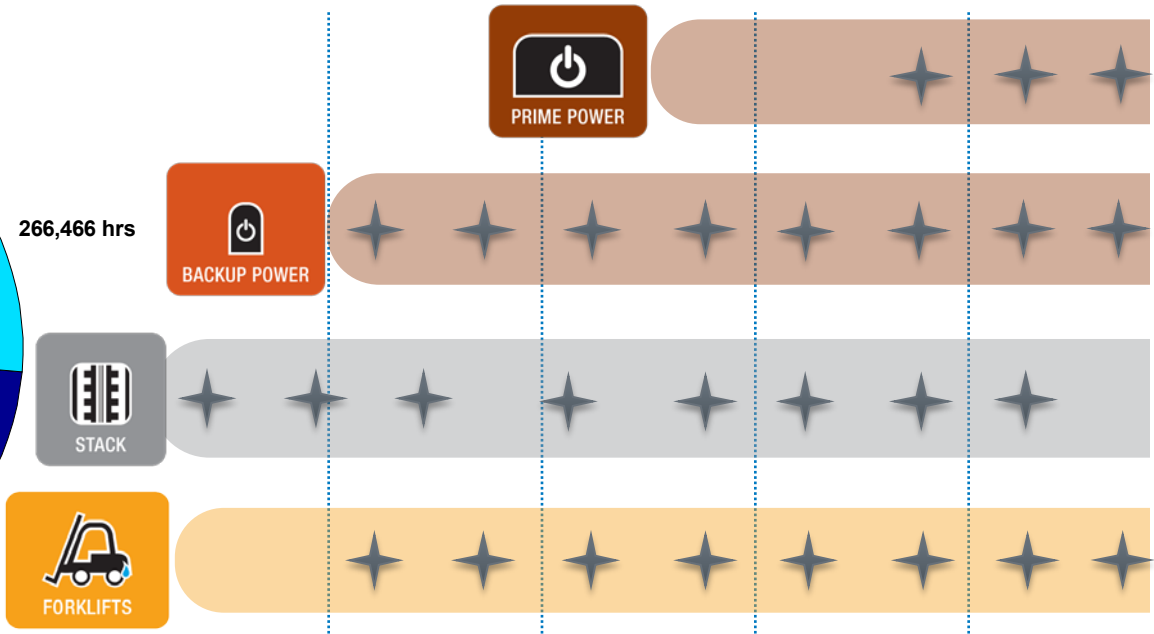
Examples shown for vehicle operation, maintenance, safety, and specification templates

# Leveraging Data Process and Analysis Capabilities Across Technology Validation Projects

Total Hours:  
1,962,190



- MHE
- Lab
- FCEV
- FCB



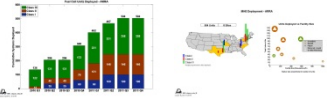
Prehistory...2005

★ Published performance reports

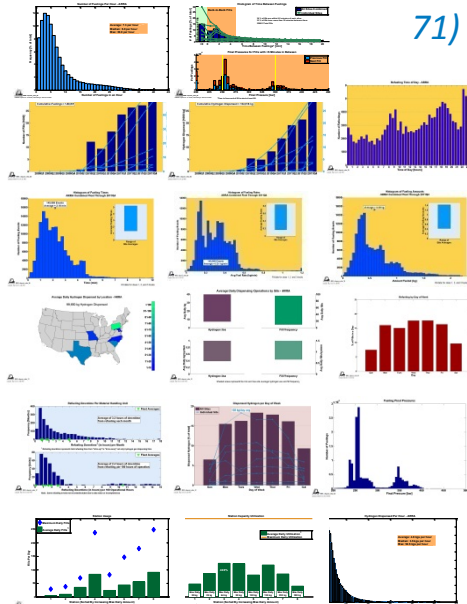
# 74 MHE & Infrastructure CDPs—Count and Category



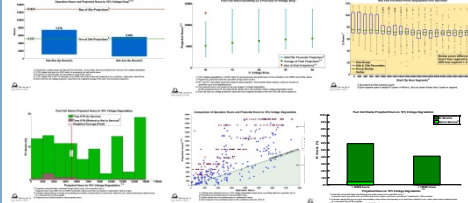
## Deployment & Site Overview (1, 40)



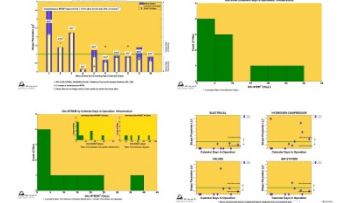
## Infra. Operation (3, 4, 5, 6, 9, 10, 21, 22, 35, 37, 42, 62, 65, 68, 69, 70, 71)



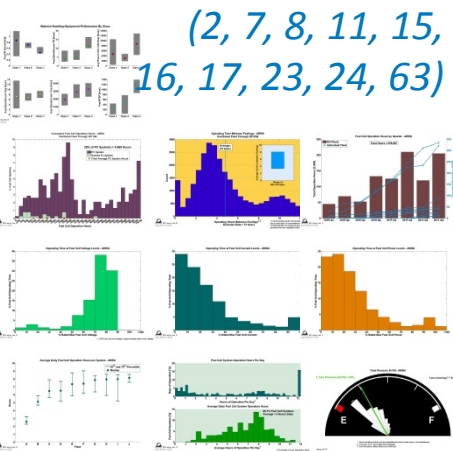
## Fuel Cell Durability (32, 33, 34, 38, 39, 73)



## Infra. Reliability (45, 48, 49, 50)



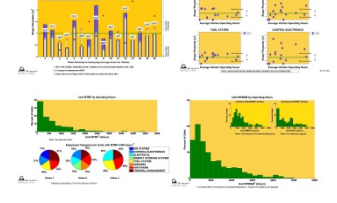
## Fuel Cell Operation (2, 7, 8, 11, 15, 16, 17, 23, 24, 63)



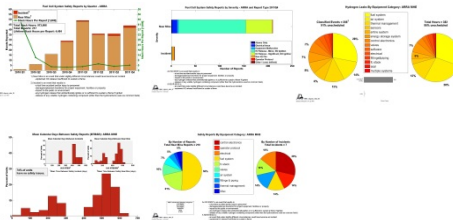
## FC Maintenance (12, 13, 14, 43, 54, 61)



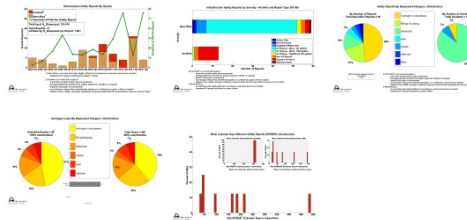
## Fuel Cell Reliability (28, 29, 30, 31)



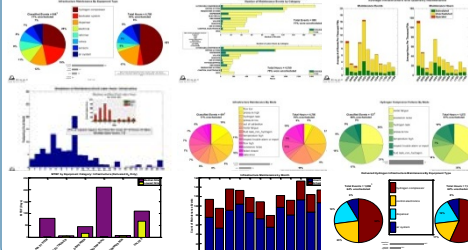
## Fuel Cell Safety (26, 27, 53, 56, 57)



## Infra. Safety (25, 41, 46, 51, 55)



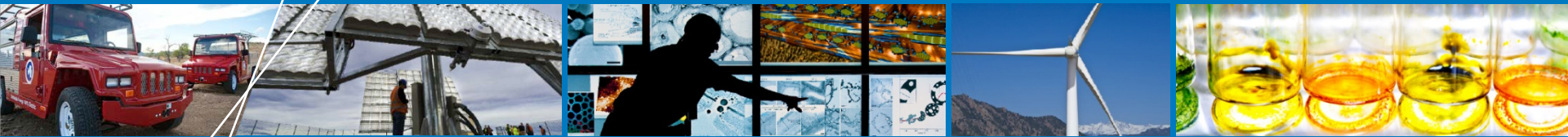
## Infra. Maintenance (18, 19, 20, 44, 47, 52, 66, 67, 72, 76, 77)



## Cost of Ownership (58, 59, 60, 64)







# Benefits to the Hydrogen & Fuel Cell Community

# NFCTEC Real World Operation Analyses

## FCEV Durability

Generation 1  
1,807 hours



Generation 2  
2,521 hours



Next generation  
evaluation starting

## Infrastructure Reliability

Poor MTBF



Key Categories (e.g.  
Compressors)



RD&D Focus on  
Compressors

## Cost of Ownership

Value proposition





Comparison



Annual cost savings of  
~2,000 per Class I/II  
fuel cell lift

# Tracking Future Progress Against Previous Demonstration Results for FCEV Evaluation



Vehicle Performance Metrics	Gen 1 Vehicle	Gen 2 Vehicle	2009 Target	After 2009Q4
<b>Fuel Cell Stack Durability</b>			 2,000 hours	
Max Team Projected Hours to 10% Voltage Degradation	1,807 hours	<u>2,521</u> 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
<b>Driving Range</b>			 250 miles	
Adjusted Dyno (Window Sticker) Range	103-190 miles	196- <u>254</u> 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% – <u>59</u> %	60%	--
Fuel Cell Efficiency at Full Power	30% – 54%	42% – <u>53</u> %	50%	--

Infrastructure Performance Metrics			2009 Target	After 2009Q4
<b>H<sub>2</sub> Cost at Station (early market)</b>	On-Site Natural Gas Reformation \$7.70 – \$10.30/kg	On-Site Electrolysis \$10.00 – \$12.90/kg	\$3/gge	--
Average H <sub>2</sub> 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 1,500 kg/day: **\$2.75-\$3.50/kg** (2006)

Distributed electrolysis at 1,500kg/day: **\$4.90-\$5.70** (2009)

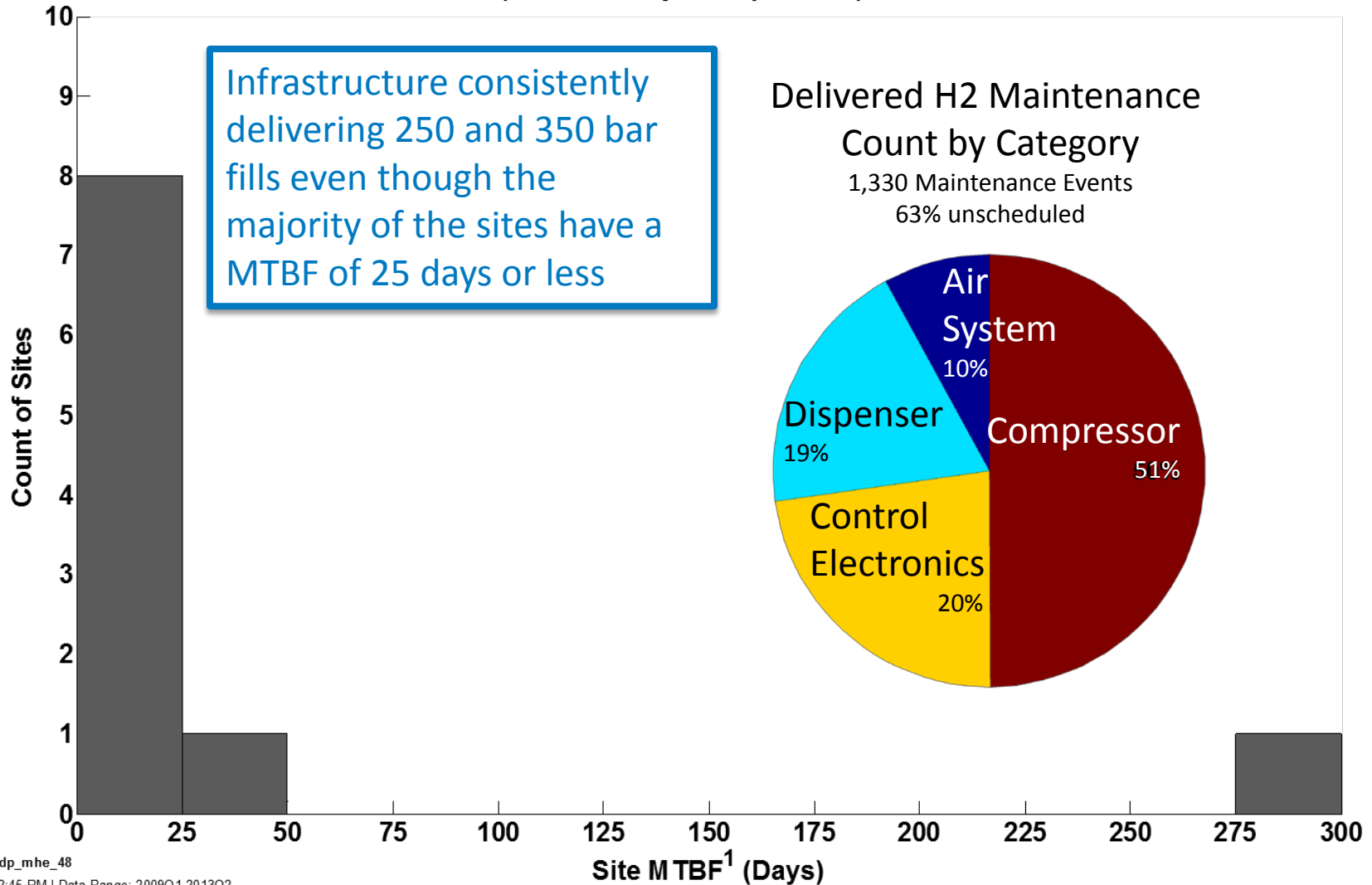




# Infrastructure Reliability Analysis Supports Additional R&D Projects (e.g. Compressors, Hoses)



Site MTBF (Calendar Days In Operation): Infrastructure



NREL cdp\_mhe\_48

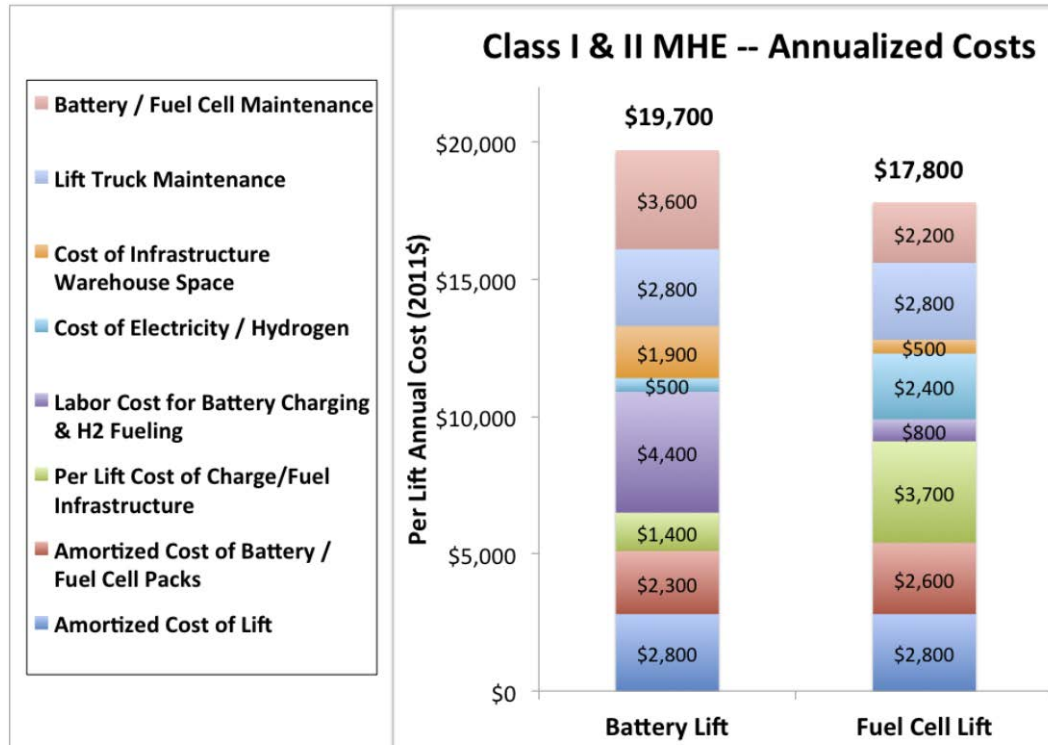
Created: Sep-28-13 12:45 PM | Data Range: 2009Q1-2013Q2

1. Cumulative Mean Time Between Failure

# MHE Cost of Ownership Comparison with Incumbent Technology



Cost advantage per unit is ~\$2,000/year for the average high-use facility with Class I and II fuel cell lift trucks analyzed by NREL.



## Key Findings

- Cost advantages dependent on deployment size and use (i.e., multi-shift operation per day)
- H<sub>2</sub> fuel cell cost advantages in maintenance, warehouse infrastructure space, and refueling labor cost
- H<sub>2</sub> fuel cell cost disadvantages in infrastructure and fuel cell cost and hydrogen cost

## Report Sections

- Inputs, assumptions, and results for Class I/II and Class III
- Sensitivity study
- Intensive deployment scenario

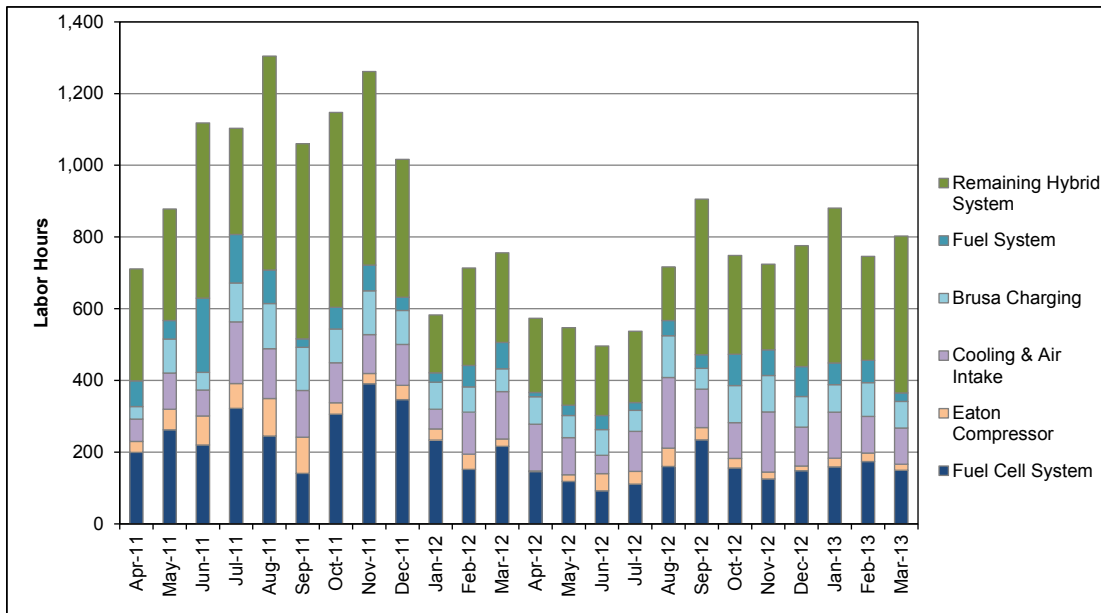
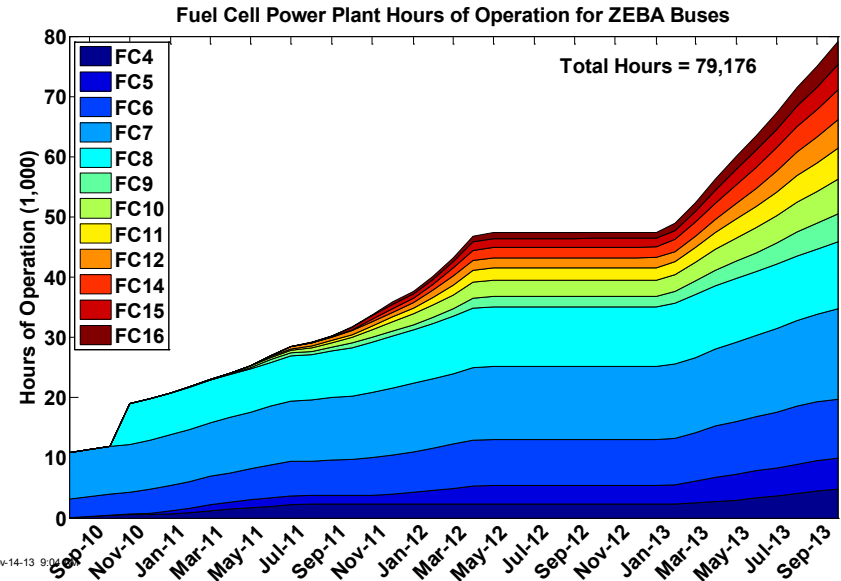
# Fuel Cell Bus Evaluation is an International Effort with Many Different Stakeholders



## ZEBA Fleet Fuel Cell Hours

**Leader at 16,216 hours**  
**2<sup>nd</sup> at 11,908 hours**

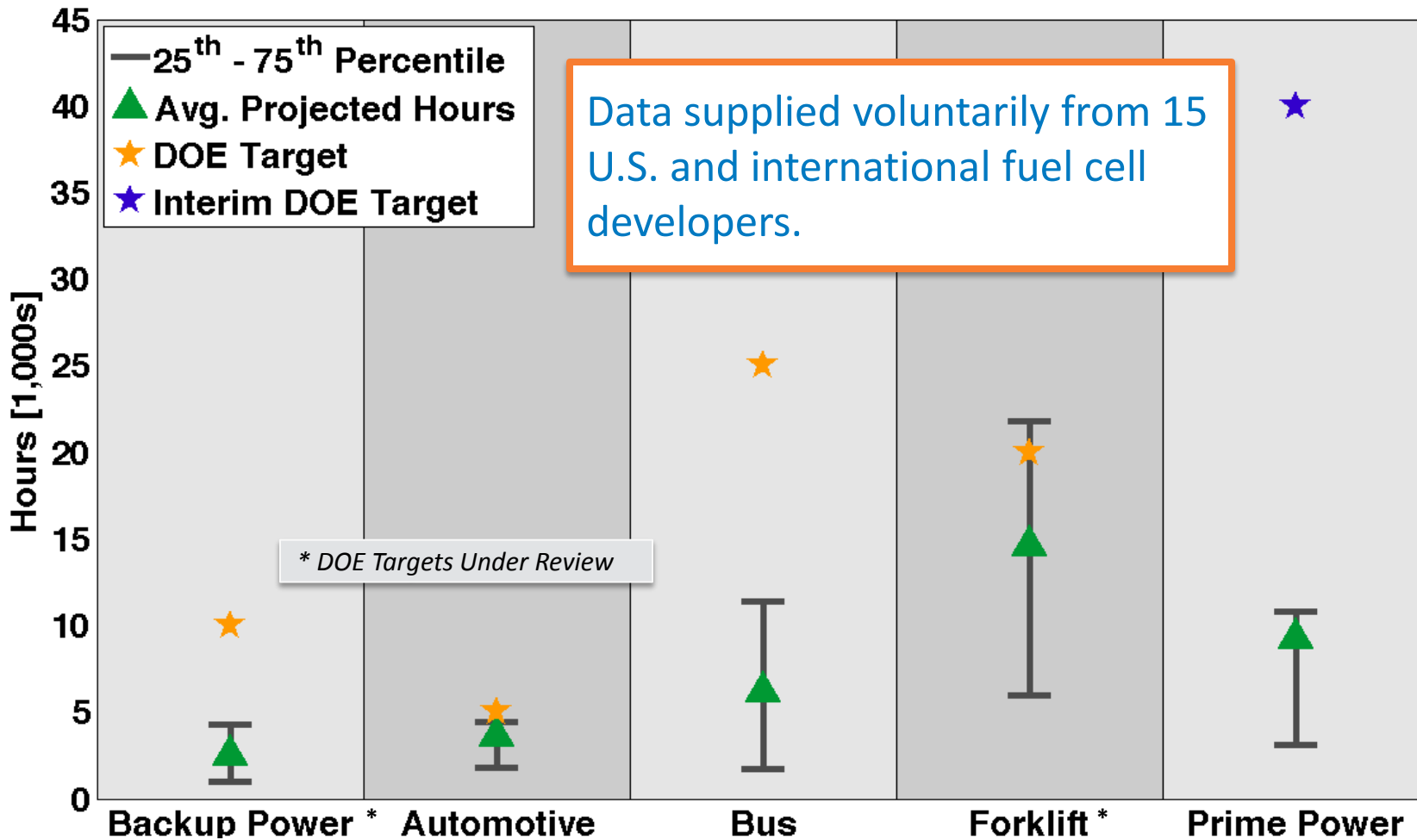
## BC Transit propulsion-related labor hours by category



*Partners:* National Fuel Cell Bus Program, DOE, DOT FTA, California ARB, Public Transit Agencies, Developers & Integrators



# Lab Data - Fuel Cell Technology Status



Analysis – hours to 10% voltage degradation

# Fuel Cell Material Handling Evaluation



Validation of MHE is based on real-world operation data from high-use facilities

**1,859,616**  
Operation hours

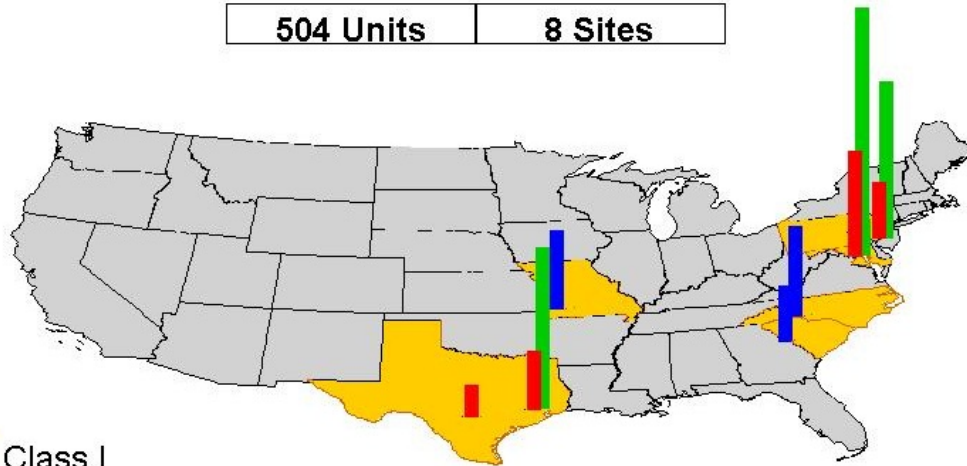
**291,114**  
Hydrogen fills

**490**  
Units in operation\*

**4.4**  
Average operation hours  
between fills

**232,551**  
Hydrogen dispensed  
in kg

504 Units | 8 Sites



- Class I
- Class II
- Class III

Height proportional to units deployed.

**0.6**  
Average fill amount  
in kg

**2.3**  
Average fill time  
in minutes

\*One project has completed

# Fuel Cell Backup Power Evaluation



**1.94**

Installed capacity  
in MW

Systems are operating reliably in 23 states. Reasons for unsuccessful starts include an e-stop signal, no fuel, and other system failures.

**99.7%**

Successful starts

**842**

Systems in operation\*

**4-6**

Average site  
capacity in kW

**2,579**

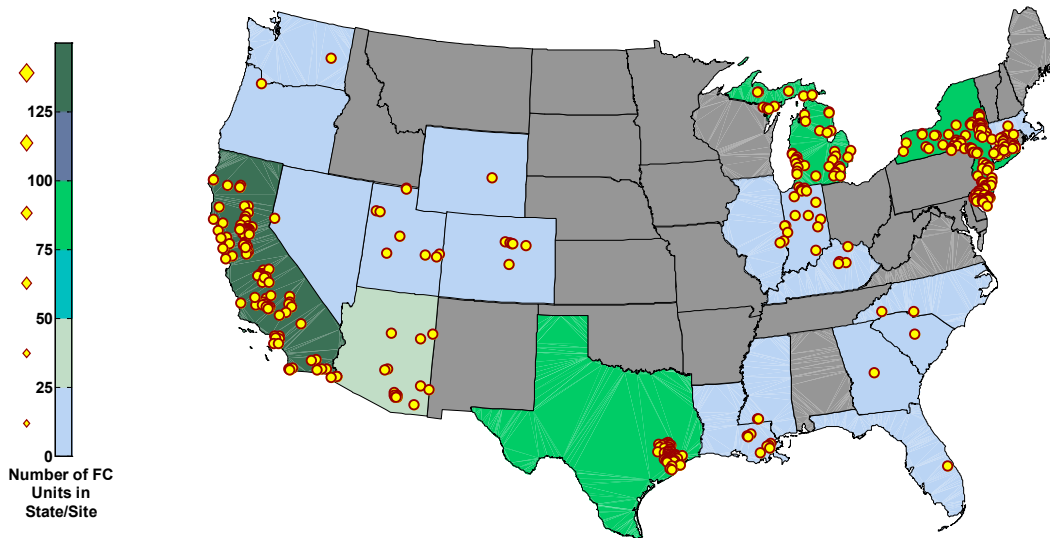
Start attempts

**65**

Continuous run  
hours demonstrated

**1,683**

Operation hours



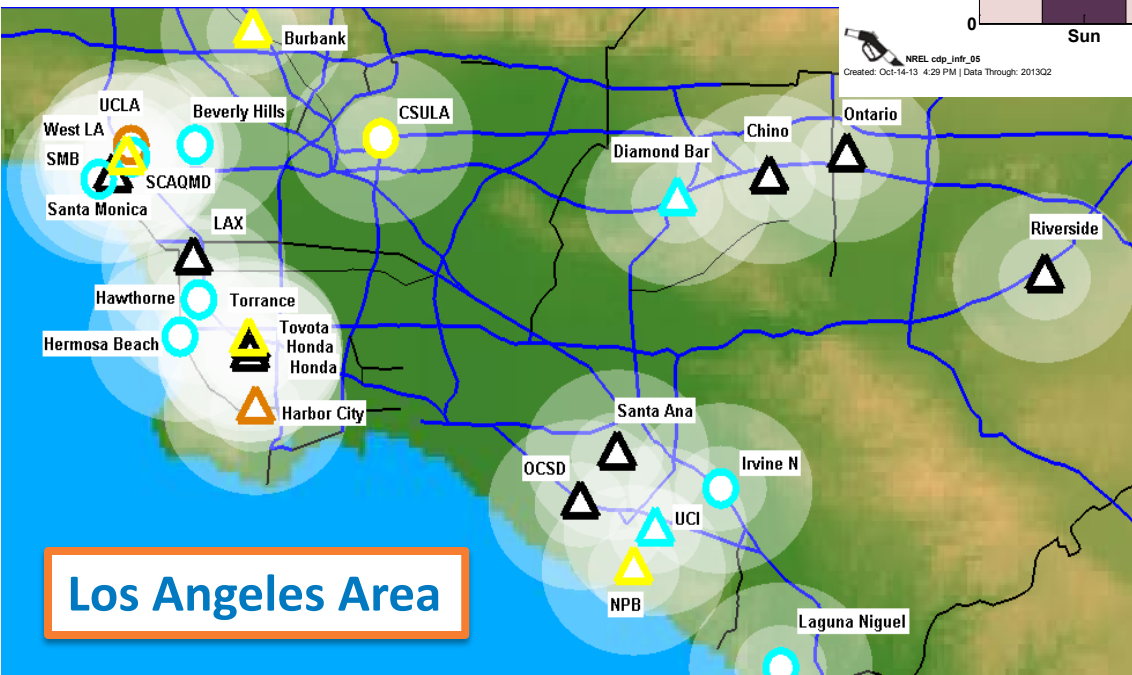
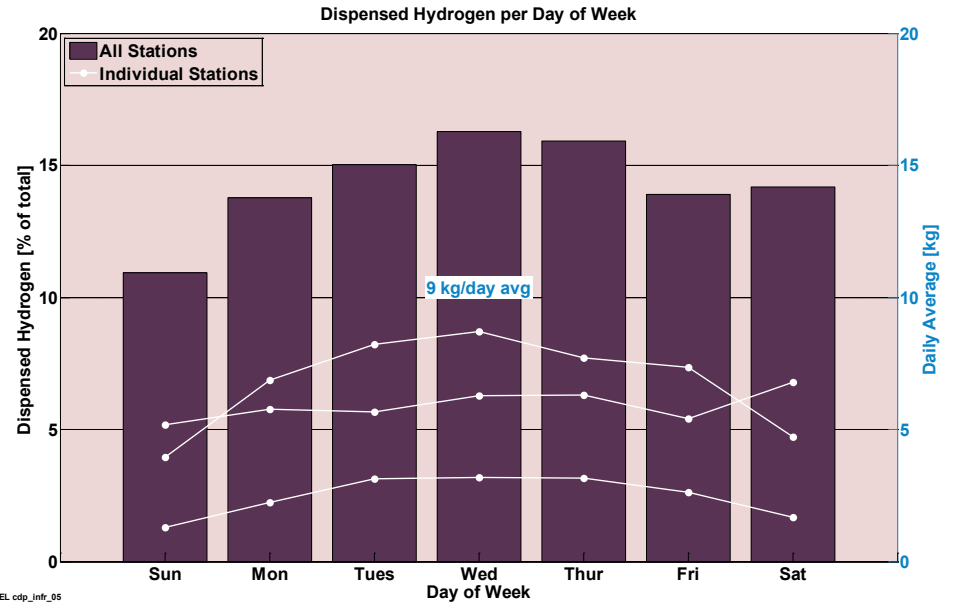
\*Not all systems have detailed data reporting to NREL



# H<sub>2</sub> Infrastructure Evaluation



Hydrogen Station Location Data Available through AFDC Mobile App (iPhone)



# Data Supports DOE Updates/Records/Status

Examples:

## Early Market Fuel Cells for Material Handling Fact Sheet

[http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/early\\_markets\\_mh\\_e\\_fact\\_sheet.pdf](http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/early_markets_mh_e_fact_sheet.pdf)

## Fuel Cell Bus Targets Record

[http://hydrogen.energy.gov/pdfs/12012\\_fuel\\_cell\\_bus\\_targets.pdf](http://hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf)

## Fuel Cell Backup Power Deployments Record

[http://hydrogen.energy.gov/pdfs/13007\\_industry\\_bup\\_deployments.pdf](http://hydrogen.energy.gov/pdfs/13007_industry_bup_deployments.pdf)

**FUEL CELL TECHNOLOGIES OFFICE**

**Early Markets: Fuel Cells for Material Handling Equipment**

**Overview**

Fuel cells can be used to produce power for many end-uses in stationary, transportable, and portable power applications. By directly converting the chemical energy in fuels such as hydrogen, natural gas, or biogas to electricity, fuel cells can efficiently provide power while at the same time producing almost no harmful air pollutants.


Fuel cell systems are commercially available today for several applications. One of these emerging markets is in material handling equipment (MHE) including counterbalanced forklifts, narrow aisle lift trucks, pallet jacks, and stack pickers. MHE can use Polymer Electrolyte Membrane (PEM) fuel cell systems, which can be fueled with hydrogen, or by using compressed air. Direct Methanol Fuel Cells (DMFCs) are also used in MHE, while but degrade.

**The Case for Fuel Cells**

Typically MHE is powered by gasoline, propane, or diesel. These fuels require outdoor operations or by using lead-acid batteries for indoor applications where emissions must be controlled. The logistics of battery lift truck operations present several challenges, especially for high freight volume throughput with multiple daily shifts. Fuel cells include special and maintenance requirements including the fuel battery changes, which must be made cool down. Also, they require indirect battery storage, battery charging maintenance (e.g. watering equipment).

Unlike batteries, fuel cells are refueled, boost, eliminating the need to wait for the battery to be recharged. Fuel cell power the labor cost of up to 30% and as compared with infrastructure investments, fuel cells have a shorter payback period.

With their proven reliability, fuel cells are a viable alternative to gasoline, propane, or diesel.



Fuel Cell Technologies Program Record	
Record #: 12012	Date: March 2, 2012
Title: Fuel Cell Bus Targets	
Originator: Jacob Spindelov and Dimitrios Papageorgopoulos	
Approved by: Sunita Satyapal	Date: September 12, 2012

**Item:**

Performance, cost, and durability targets for fuel cell transit buses are presented in Table 1. These market-driven targets represent technical requirements needed to compete with alternative technologies. They do not represent expectations for the status of the technology in future years.

**Table 1. Performance, cost, and durability targets for fuel cell transit buses.**

	Units	2012 Status	2016 Target	Ultimate Target
Bus Lifetime	years/miles	5/100,000 <sup>1</sup>	12/500,000	12/500,000
Power Plant Lifetime <sup>2,3</sup>	hours	12,000	18,000	25,000

DOE Hydrogen and Fuel Cells Program Record	
Record #: 13007	Date: 09/05/2013
Title: Industry Deployed Fuel Cell Backup Power (BuP)	
Originators: Pete Devlin, Jim Atkins, Sara Dillich, Dimitrios Papageorgopoulos	
Approved by: Rick Farmer and Sunita Satyapal	Date: 09/09/13

**Table 1: Number of fuel cells deployments (current and planned) for applications in backup power.**

	DOE Funded <sup>1</sup> (ARRA) as of 5/2013	DOE Funded (Appropriations) <sup>2,3</sup> as of 9/1/2013	DOE Total	Industry Funded or on Order (Globally) <sup>4,5</sup> From 2009 – Record Date	DOE and Industry Total From 2009 – Record Date
Number of Backup Power Deployments (current & planned)	820	83	903	3,593	4,496

The funding of 903 Department of Energy (DOE) fuel cell backup power systems has led to over 3,500 industry installations and on-order backup power units with no DOE funding.

**Data Assumptions/Calculations:**

The manufacturers providing the fuel cells for the deployments (current and planned) mentioned in Table 1 above are:

Alteryx	Ballard/ Idia Tech
Hydrogenics	ReliOn, Inc.

Total DOE American Recovery and Reinvestment Act (ARRA) investment for these fuel cell projects is \$18.5M, with an industry cost share of \$30.8M.<sup>1</sup> While publicly available sales

<sup>1</sup>ARRA funding supported deployments in backup power for: ReliOn with deployments at AT&T and PG&E sites, Spent Nezel with deployments at Spent sites, and Plug Power with deployments at Warner Robins Air Force Base and Fort Irwin. Funds included units as well as other aspects of the project such as installation, pre-testing, data collection, analysis, maintenance, and reporting.

# Examples of Peer Review Feedback

“Other areas of strength include industry’s confidence and trust in NREL’s team and approach to the project, and the continuous improvement and enhancement of project products, particularly CDPs and DDPs...”

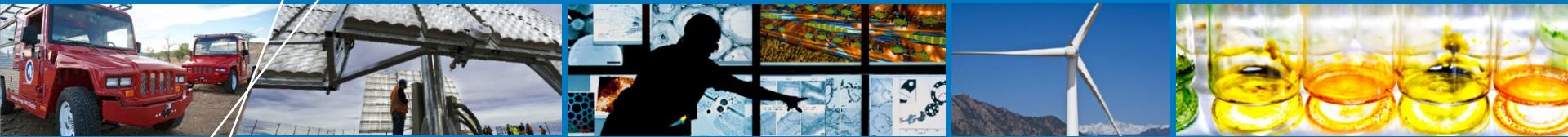
“This is a good national approach to fuel cell analysis. There are early warnings of commercial problems, such as compressors...”

The ability to leverage the capabilities established by NREL for its implementation of other technology validation projects is a strength of this project...”

“NREL is uniquely set up to compare data sets from a variety of fuel cell developers for a range of applications. Without this project, such comparative analysis would not be available.”

“This project is essential to benchmarking the progress of fuel cell systems over time and across industries.”

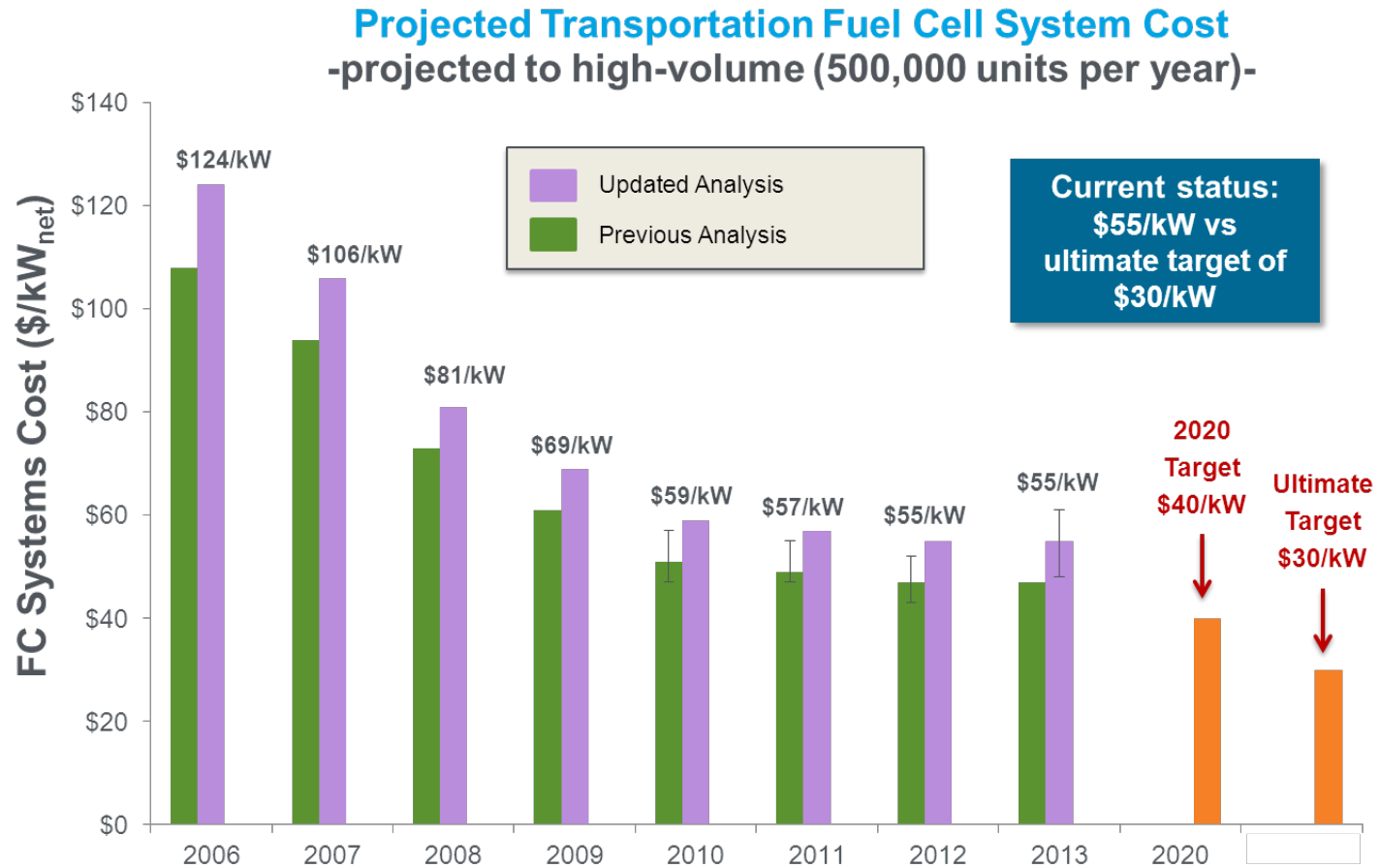
“This is a great way to put all the data together and get information back to the industry and potential customers.”



# Fuel Cell Cost & Price Aggregation Project



# DOE Fuel Cell System Cost Based on Models for High Volume

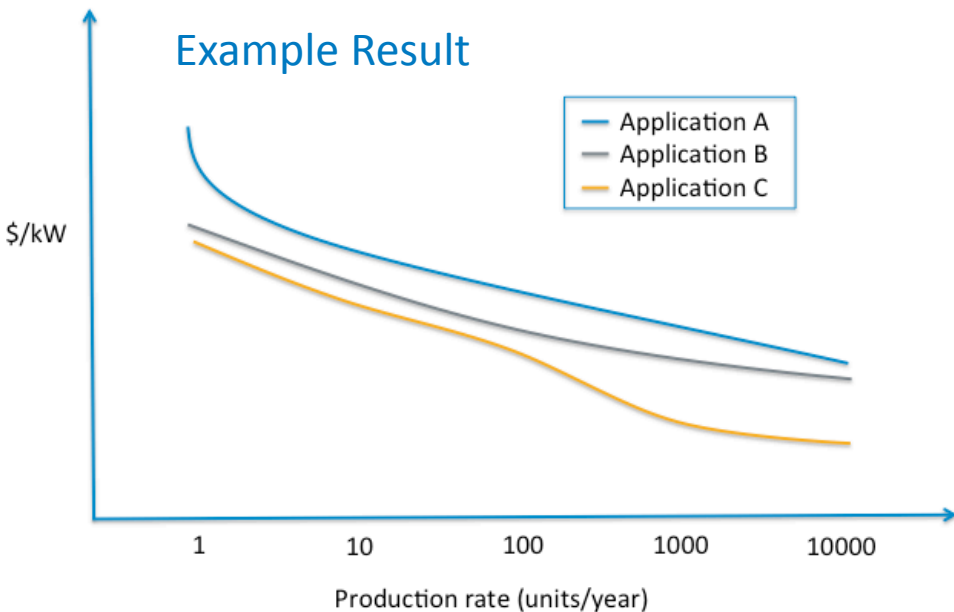


Record Source: [http://www.hydrogen.energy.gov/pdfs/13012\\_fuel\\_cell\\_system\\_cost\\_2013.pdf](http://www.hydrogen.energy.gov/pdfs/13012_fuel_cell_system_cost_2013.pdf)

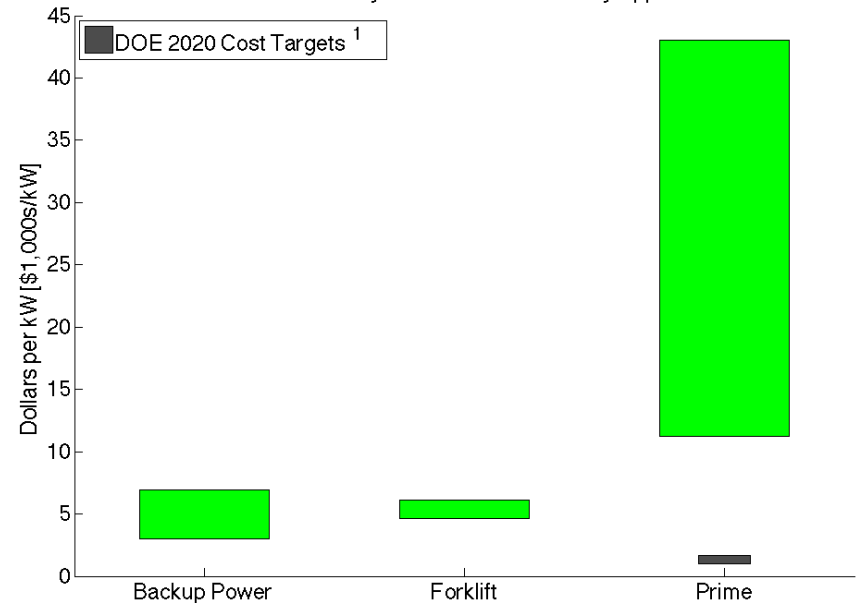
# Fuel Cell Technology Status – Cost/Price

The U.S. Department of Energy's National Renewable Energy Laboratory is seeking fuel cell industry partners from the United States and abroad to participate in an objective and credible analysis of commercially available fuel cell product cost/price to benchmark the current state of the technology and support industry growth.

Current fuel cell price by application and production rate



Current Fuel Cell System Price Estimates by Application



# Cost/Price Data Template

	A	B	C	D
7	System <input type="text" value="ProductName1"/>	Product Name 1 <input type="text" value="ProductName2"/>	Product Name 2 <input type="text" value="ProductName32"/>	Product Name 32 <input type="text"/>
8	Current Price (US \$)			
9	Availability			
10	Market			
11	Application			
12	Fuel Cell Type	PEMFC	PEMFC	
13	Fuel			
14	Comments			
15	Power Rating (kW)			
16	Other features			
17	# systems sold to date			
18	2010 Price (US \$)			
19	2011 Price (US \$)			
20	2012 Price (US \$)			
21	Current system cost (US \$)			
22	Current fuel cell stack cost (US \$)			
23	Cell count			
24	Active area			
25	Turndown capability			
26	Spec sheet link or Product brochure PDF attached			

# Benefits of Cost/Price Analysis

## External

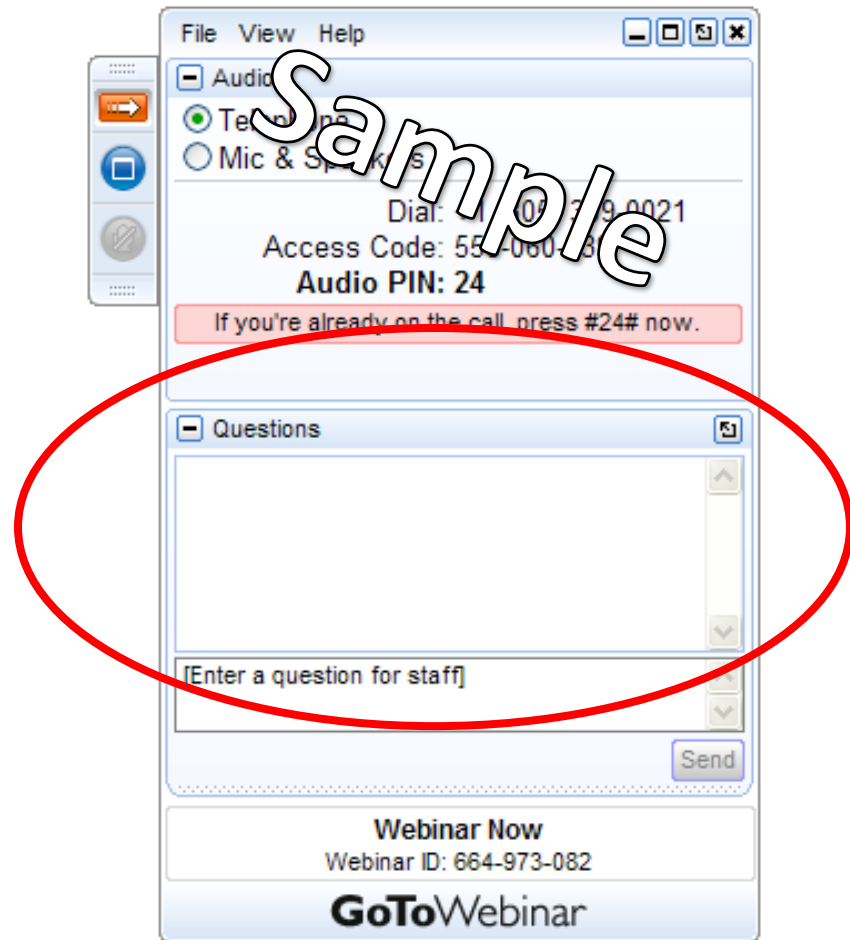
- Provide current cost status of fuel cell products that fill the gap with high volume cost numbers
- Help set realistic price expectations at small volume production
- One source of realistic cost/price status for DOE from the leading fuel cell developers
- Highlights technology successes
- Helps adoption of fuel cell technology

## Internal

- Provide independent, credible and consistent product cost/price information that is very useful for external partners (e.g. DOE and industry) without revealing proprietary information
- Benchmarking against CDPs
- Collaboration with NREL's technology validation team; dedicated analysis team with experience in multiple fuel cell applications

# Question and Answer

- Please type your question into the question box



[hydrogenandfuelcells.energy.gov](http://hydrogenandfuelcells.energy.gov)



# NFCTEC Contacts

## Website

[http://www.nrel.gov/hydrogen/proj\\_tech\\_validation.html](http://www.nrel.gov/hydrogen/proj_tech_validation.html)

**Hydrogen & Fuel Cell Research**

### Fuel Cell and Hydrogen Technology Validation

Technology validation is defined as confirmation that component and system technical targets have been met under realistic operating conditions. The NREL technology validation team works on validating hydrogen fuel cell electric vehicles; hydrogen fueling infrastructure; and fuel cell use in early market applications such as material handling, backup power, and prime power applications. The team also analyzes the current status of state-of-the-art laboratory fuel cell technologies, with a focus on performance and durability. This work supports the Department of Energy's hydrogen and fuel cell technology validation activity.

Technology validation projects involve gathering extensive data from the systems and components under real-world conditions, analyzing this detailed data, and then comparing results to technical targets. While the raw data is protected by NREL, analysis results are aggregated into public results called composite data products. These public results show the status and progress of the technology, but don't identify individual companies.

Visit the following pages to see project highlights, analysis results, and detailed reports and presentations from the hydrogen and fuel cell technology validation efforts underway at NREL:

- Hydrogen Fuel Cell Electric Vehicle Learning Demonstration
- Hydrogen Fuel Cell Bus Evaluations
- Early Fuel Cell Market Demonstrations
- Fuel Cell Technology Status Analysis
- Hydrogen Fueling Infrastructure Analysis
- Stationary Fuel Cell Systems Analysis

Subscribe to the biannual Fuel Cell and Hydrogen Technology Validation newsletter, which highlights recent technology validation activities at NREL.



## Email

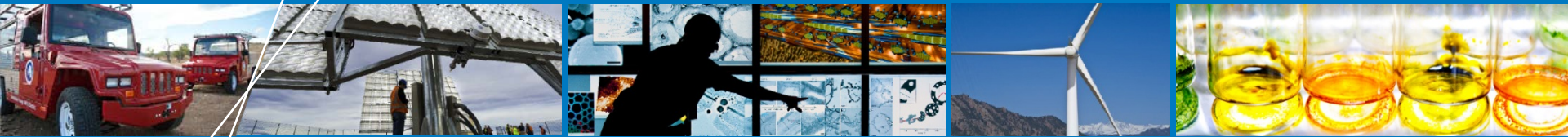
[techval@nrel.gov](mailto:techval@nrel.gov)

[jennifer.kurtz@nrel.gov](mailto:jennifer.kurtz@nrel.gov)

# Thank You

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# Backup

# NFCTEC Partners

AC Transit	FedEx	Proterra
Auto OEMs	GENCO	Proton OnSite
Ballard Power Systems	Golden Gate Transit	ReliOn Inc.
Bluways	GTI	San Francisco Metropolitan Transit Agency
CaFCP	H2 Frontier	San Mateo Transit Authority
California Stationary Fuel Cell Collaborative (CaSFCC)	H2Pump	Santa Clara Valley Transportation Authority
CARB/Shell	H2USA	SCAQMD
CEC	Hydrogenics	Sprint Communications
CHBC	Linde	SunLine Transit Agency
City of Burbank	National Fuel Cell Research Center (NFCRC)	Sysco of Houston
ClearEdge Power	Nuvera Fuel Cells	US Hybrid
CSULA	PDC Machines	
FCHEA	Plug Power	