National Hydrogen Learning Demonstration Status

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February 6, 2012

DOE's Informational Webinar Series

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Outline

- U.S. DOE Learning Demonstration Project Goals
- Fuel Cell Vehicle and H_2 Station Deployment Status
- Technical Highlights of Vehicle and Infrastructure Analysis Results and Progress
- Next Steps and Project Wrap-up

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Fuel Cell Electric Vehicle Learning Demo Project Objectives, Relevance, and Targets

- Objectives
  - Validate H_2 FC Vehicles and Infrastructure in Real-World Setting
  - Identify Current Status and Evolution of the Technology
- Relevance
  - Objectively Assess Progress Toward Targets and Market Needs
  - Provide Feedback to H_2 Research and Development
  - Publish Results for Key Stakeholder Use and Investment Decisions

Key Targets

Performance Measure	Interim (2009)*	Ultimate (2020)
Fuel Cell Stack Durability	2000 hours	5000 hours
Vehicle Range	250+ miles	300+ miles
Hydrogen Cost at Station	$3/gge	$2-4/gge**

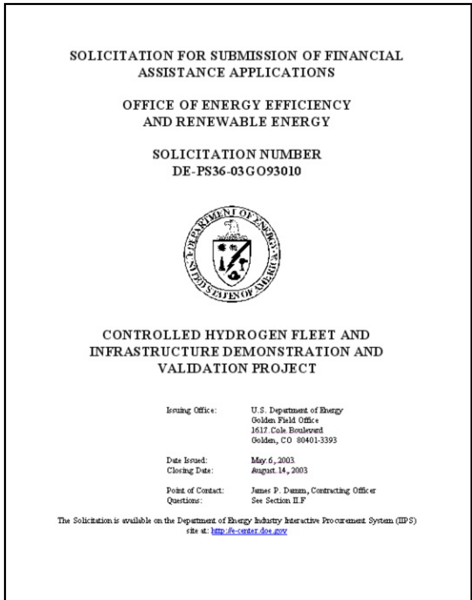
Outside review panel

*Project extended 2 years through 2011; **Previously $2-3/gge for 2015*

Details of each of these 3 results shown later

Burbank, CA station. **Photo: NREL**

History: 4 OEM/Energy Teams Selected Competitively through FOA in 2004



SOLICITATION FOR SUBMISSION OF FINANCIAL ASSISTANCE APPLICATIONS

OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY

SOLICITATION NUMBER DE-PS36-03GO93010

CONTROLLED HYDROGEN FLEET AND INFRASTRUCTURE DEMONSTRATION AND VALIDATION PROJECT

Issuing Office:	U.S. Department of Energy Golden Field Office 1617 Cole Boulevard Golden, CO 80401-3393
Date Issued:	May 6, 2003
Closing Date:	August 14, 2003
Point of Contact:	James P. Damm, Contracting Officer
Questions:	See Section II.F

The Solicitation is available on the Department of Energy Industry Interactive Procurement System (IIPS) site at: http://e-center.doe.gov

ChevronTexaco* / Hyundai / Kia / UTC Fuel Cells** A United Technologies Company

Ford / bp

DaimlerChrysler*** / bp

GM / Shell

DOE funding: $170M

Industry cost share: $189M

Total: $359M

NREL received $6.6M from DOE for analysis and support of this project since FY03

* now Chevron ** now UTC Power A United Technologies Company *** now DAIMLER

Involvement of Industry Teams Over 7 Years

FY03 FY04 FY05 FY06 FY07 FY08 FY09 FY10 FY11 FY12

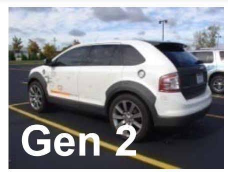
RFP	Startup	Operation, Data Collection, and Analysis

TODAY

♦ Ford/BP and Chevron/Hyundai-Kia Concluded in 2009

Ford

bp



Chevron

UTC Power
A United Technologies Company

HYUNDAI

KIA

Daimler, GM, and Air Products (CHIP) Demonstrated Vehicles/Stations within Project through CY2011

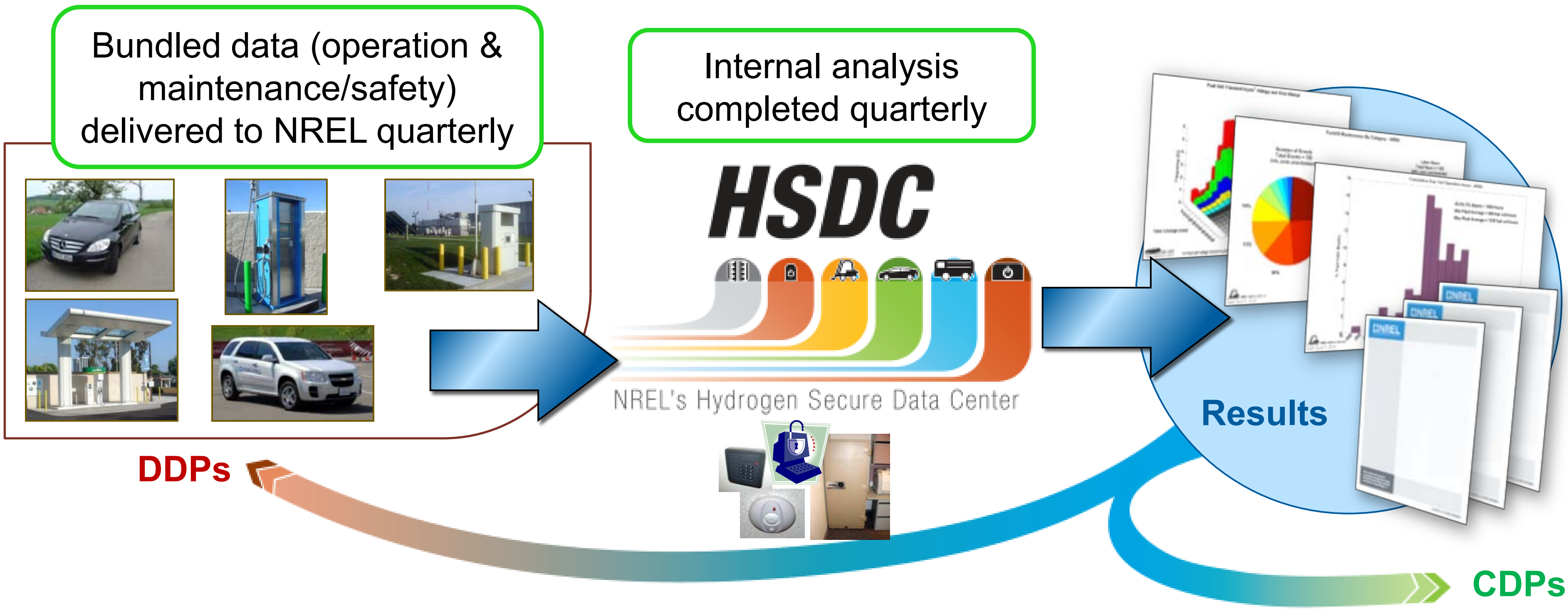
DAIMLER

GM

AIR PRODUCTS (CHIP)

What is NREL's Role? Project Approach

Supporting Both DOE/Public as Well as Fuel Cell Developers



Detailed Data Products (DDPs)

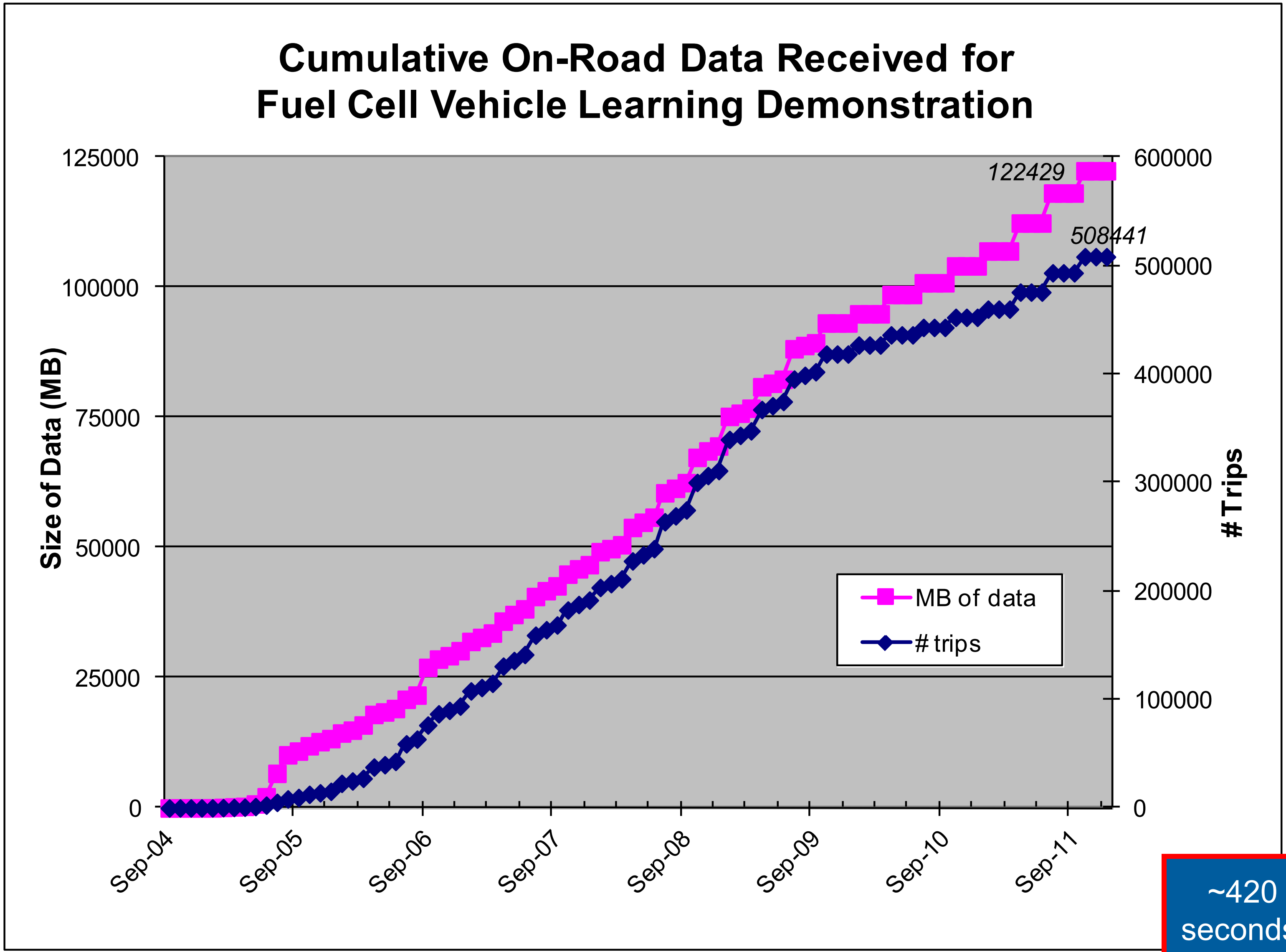
- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data[1]

Composite Data Products (CDPs)

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

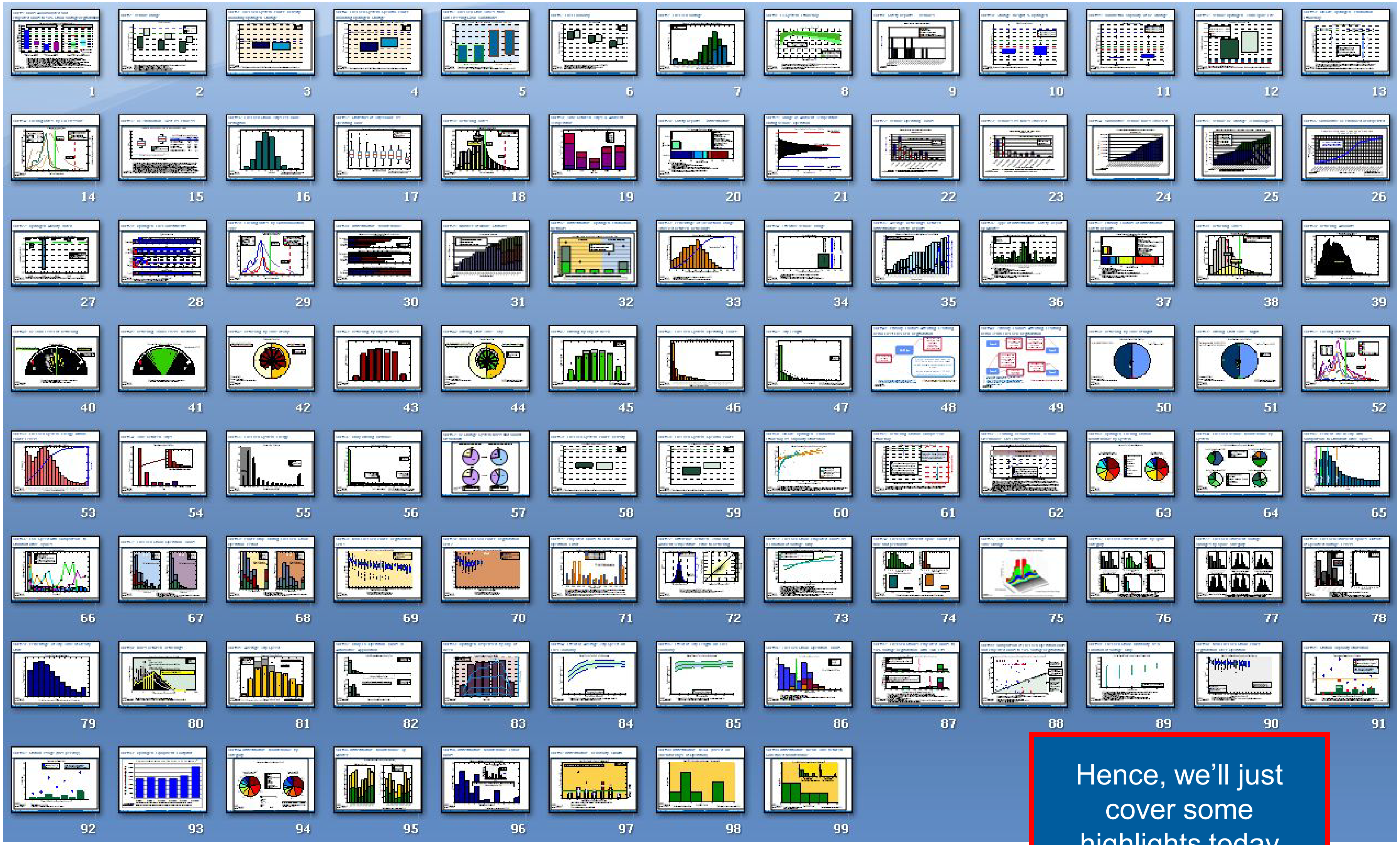
1) Data exchange may happen more frequently based on data, analysis, & collaboration
2) Results published via NREL Tech Val website, conferences, and reports (http://www.nrel.gov/hydrogen/proj_learning_demo.html)

This Project Analyzed Massive Amounts of Data: 3.5 M miles and >500,000 vehicle trips (second-by-second)



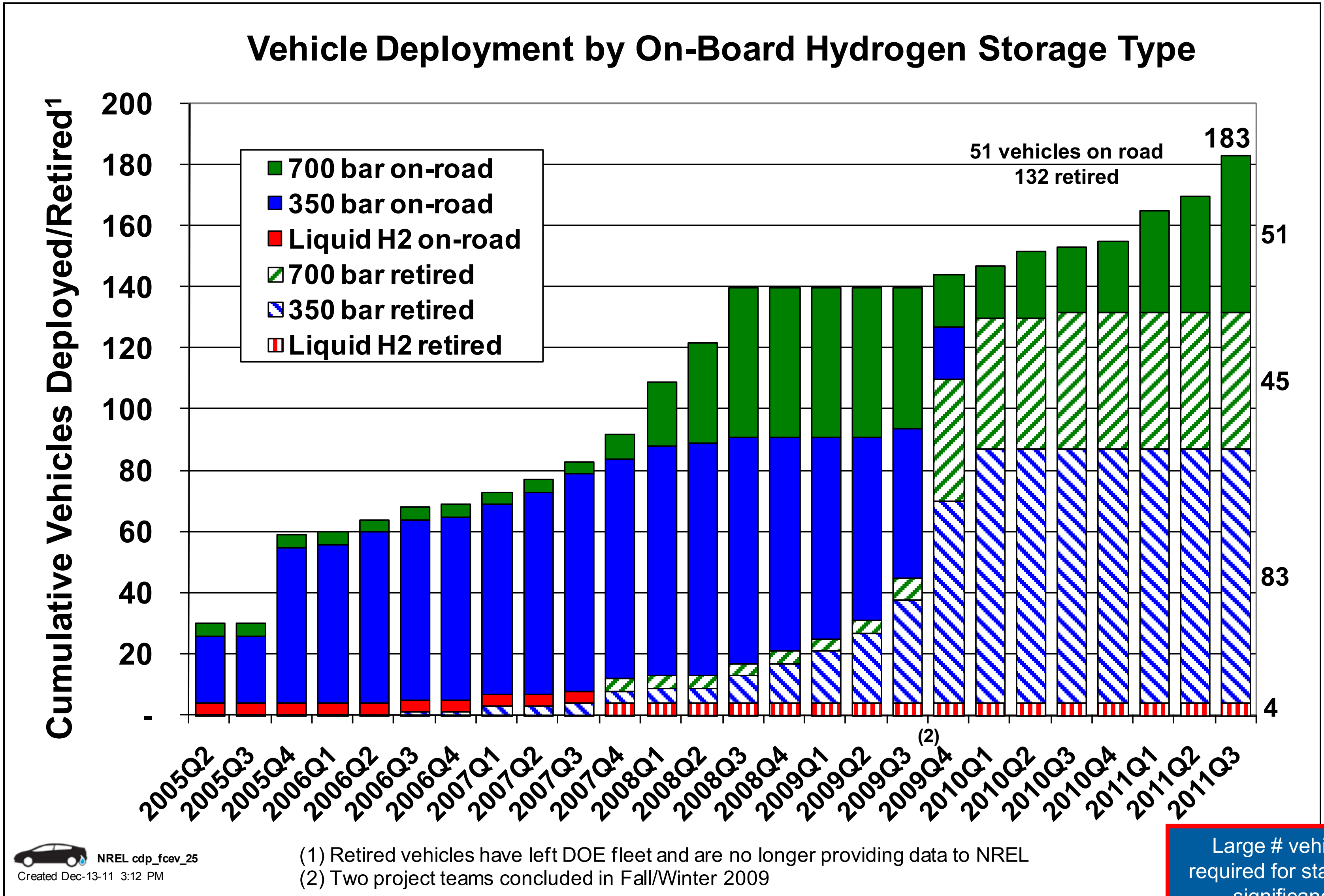
~420 million seconds of data

99 CDPs in Total (40 Winter 2011 CDPs)



Hence, we'll just cover some highlights today

Current Vehicle Deployment Status at End of Evaluation Period (9/30/11)



(1) Retired vehicles have left DOE fleet and are no longer providing data to NREL
(2) Two project teams concluded in Fall/Winter 2009

Large # vehicles required for statistical significance

2nd Generation Vehicles Demonstrated Technology Improvements Over Gen 1

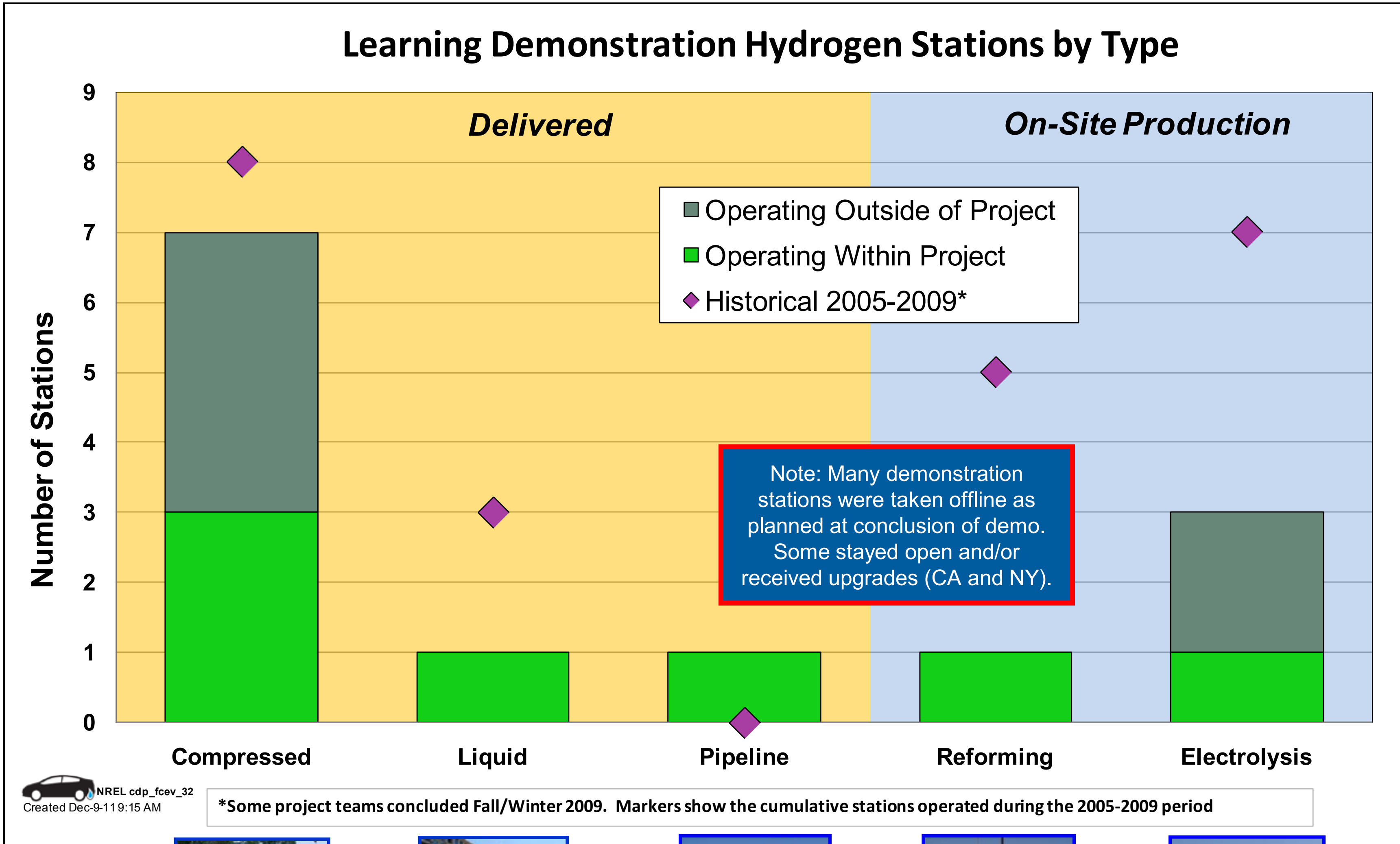
Generation 1 Vehicles

- FC not freeze-capable
- ~2003 stack technology
- Storage: liquid H2 & 350 and 700 bar
- Range: 100-200 miles
- Efficiency: 51-58% at ¼ power

Generation 2 Vehicles

- FC freeze-capable
- ~2007-2009 stack tech.
- Storage: All 700 bar
- Range: 200-250 miles
- Efficiency: 53-59% at ¼ power

Current Infrastructure Status: Demonstration Station Testing Successfully Completed as Planned

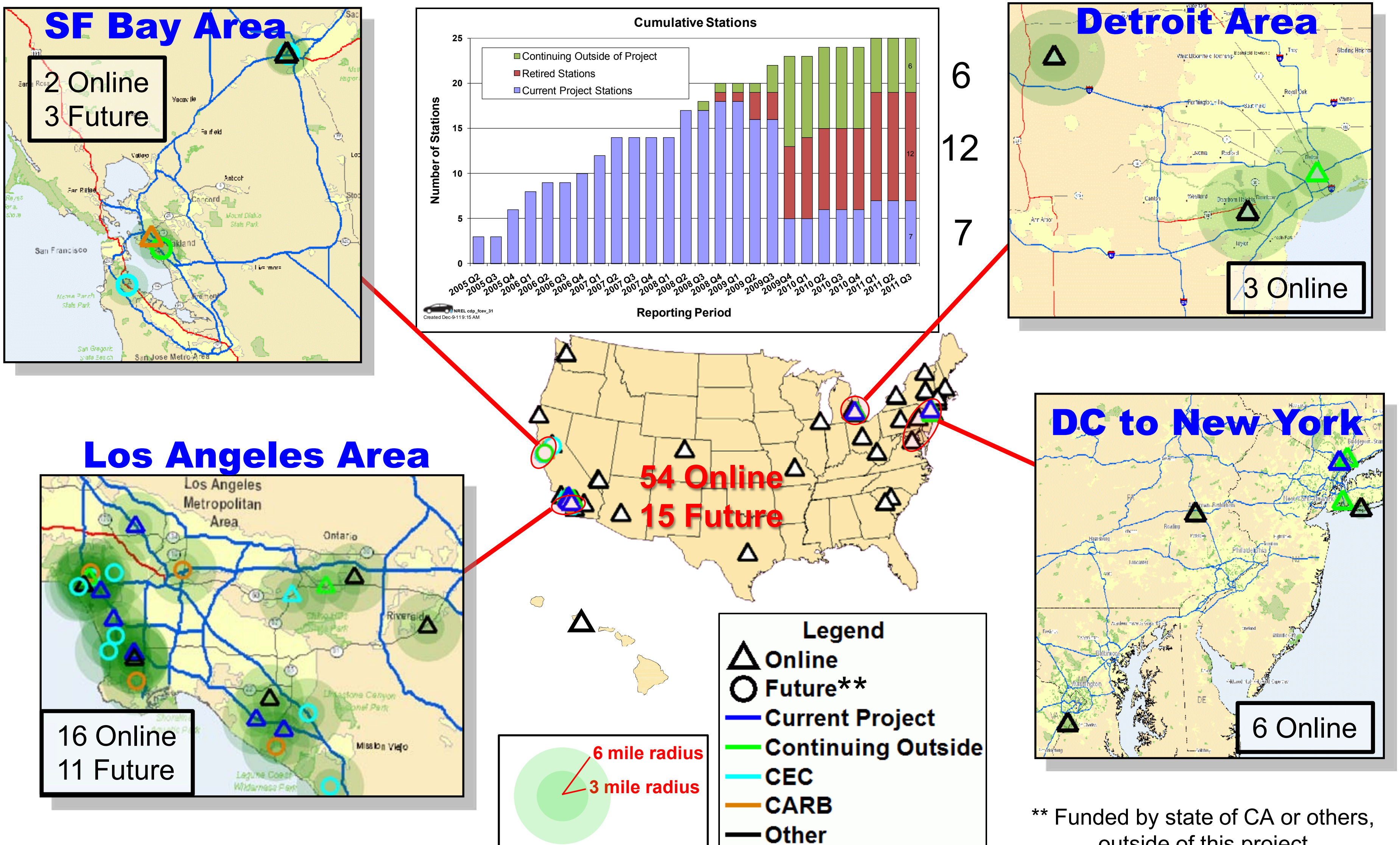






Infrastructure Status: Out of 25 Project Stations, 13 Are Still Operational* (~1/2 outside of DOE project)

* CDP station status is as of 9/30/11



** Funded by state of CA or others, outside of this project

Jan-31-2012

Project Achieved Both Technical Goals; Outside Analysis Used for Cost Evaluation

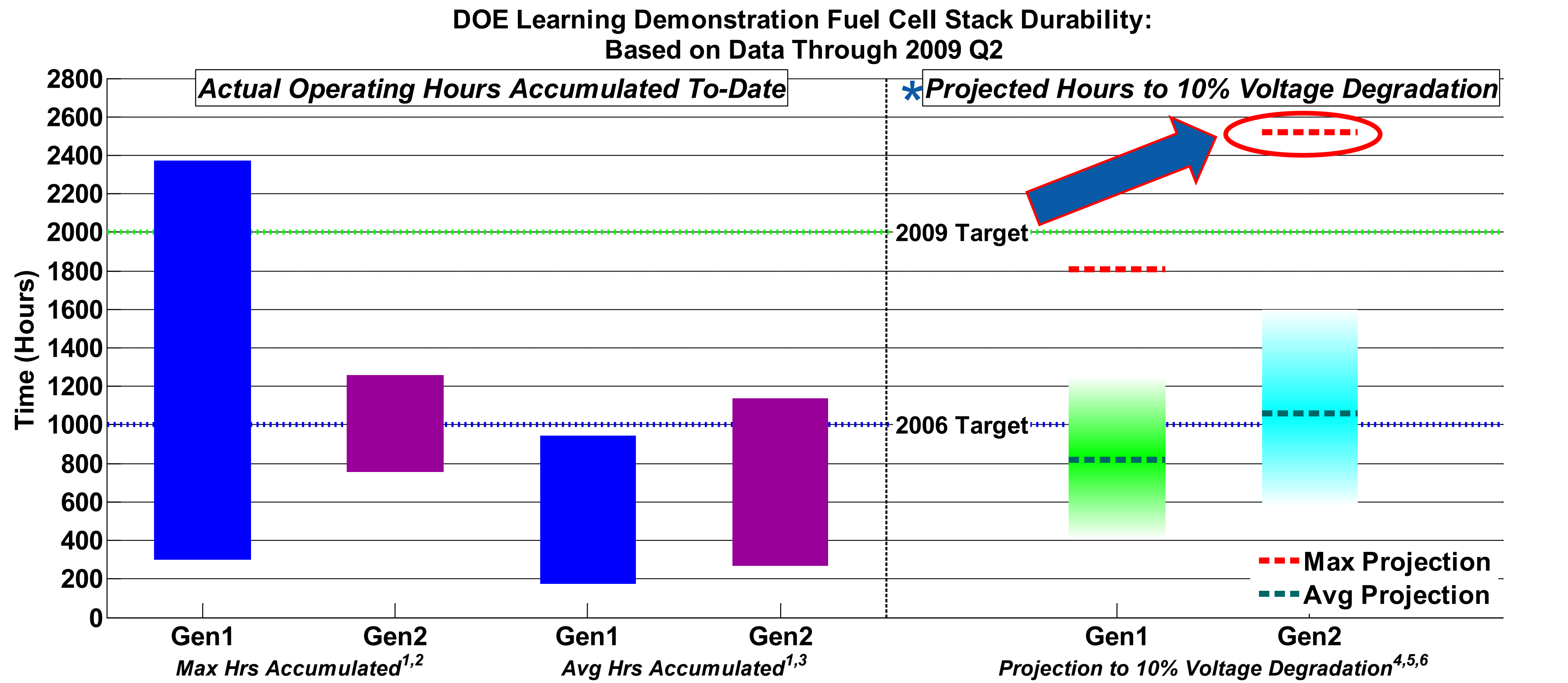
Vehicle Performance Metrics	Gen 1 Vehicle	Gen 2 Vehicle	2009 Target
1) ***Fuel Cell Stack Durability***			**2000 hours**
Max Team Projected Hours to 10% Voltage Degradation	**1807 hours**	**2521 hours**	
Average Fuel Cell Durability Projection	821 hours	1062 hours	
Max Hours of Operation by a Single FC Stack to Date	2375 hours	1261 hours	
2) ***Driving Range***	**103-190 miles**	**196-254 miles**	**250 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
3) ***H_2 Cost at Station (early market)***	On-site natural gas reformation **\$7.70 - \$10.30**	On-site Electrolysis **\$10.00 - \$12.90**	**\$3/gge**
Average H_2 Fueling Rate	0.77 kg/min		1.0 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

1) FC Durability Target of 2000 Hours Met By Gen 2 Projections



(1) Range bars created using one data point for each OEM. Some stacks have accumulated hours beyond 10% voltage degradation.
(2) Range (highest and lowest) of the maximum operating hours accumulated to-date of any OEM's individual stack in "real-world" operation.
(3) Range (highest and lowest) of the average operating hours accumulated to-date of all stacks in each OEM's fleet.
(4) Projection using on-road data -- degradation calculated at high stack current. This criterion is used for assessing progress against DOE targets, may differ from OEM's end-of-life criterion, and does not address "catastrophic" failure modes, such as membrane failure.
(5) Using one nominal projection per OEM: "Max Projection" = highest nominal projection, "Avg Projection" = average nominal projection. The shaded projection bars represents an engineering judgment of the uncertainty on the "Avg Projection" due to data and methodology limitations. Projections will change as additional data are accumulated.
(6) Projection method was modified beginning with 2009 Q2 data, includes an upper projection limit based on demonstrated op hours.

NREL CDP01
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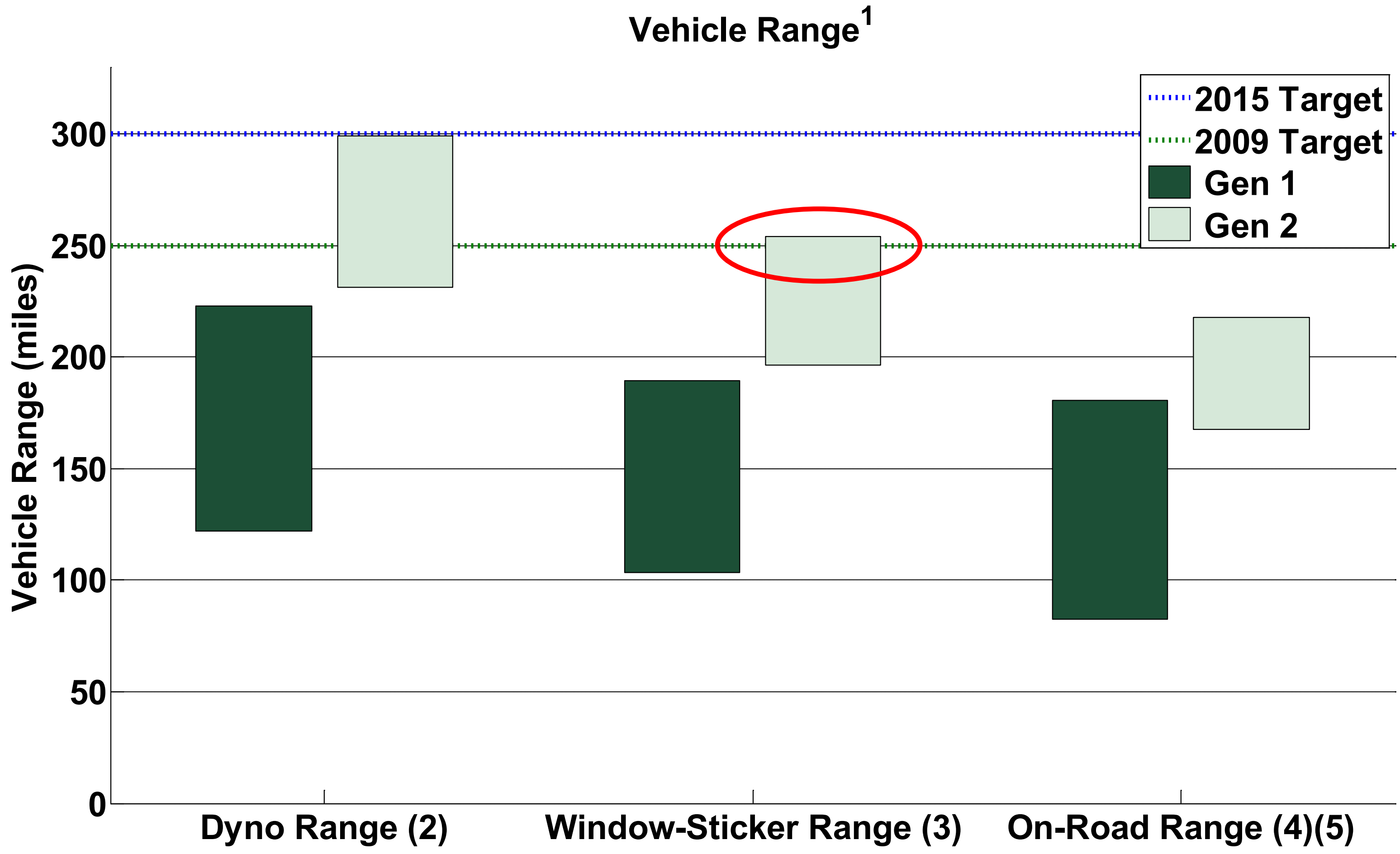
* Durability is defined by DOE as projected hours to 10% voltage degradation

Spring 2010

2) Vehicle Range Achieved 2009 Target of 250 Miles with Gen 2 Adjusted Fuel Economy



(1) Range is based on fuel economy and usable hydrogen on-board the vehicle. One data point for each make/model.
(2) Fuel economy from unadjusted combined City/Hwy per DRAFT SAE J2572.
(3) Fuel economy from EPA Adjusted combined City/Hwy (0.78 x Hwy, 0.9 x City).
(4) Excludes trips < 1 mile. One data point for on-road fleet average of each make/model.
(5) Fuel economy calculated from on-road fuel cell stack current or mass flow readings.

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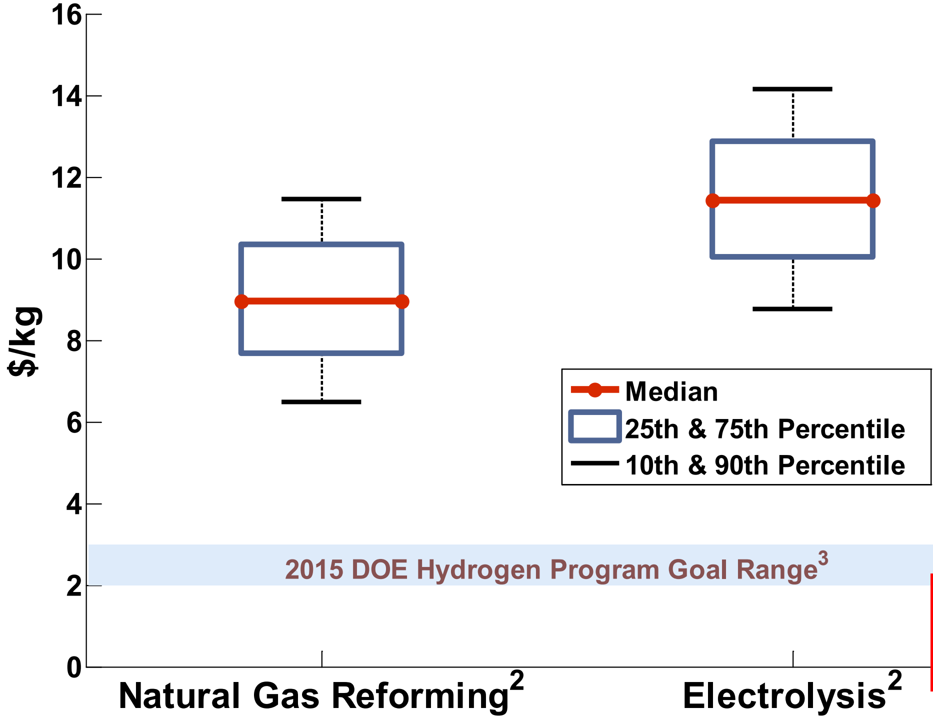
3) Projected Early Market H_2 Production Cost from Learning Demo Energy Partners' Inputs

Projected Early Market 1500 kg/day Hydrogen Cost[1] *



Key H2 Cost Elements and Ranges

Input Parameter	Minimum (P10)	Maximum (P90)
Facility Direct Capital Cost	$10M	$25M
Facility Capacity Utilization	85%	95%
Annual Maintenance & Repairs	$150K	$600K
Annual Other O&M	$100K	$200K
Annual Facility Land Rent	$50K	$200K
Natural Gas Prod. Efficiency (LHV)	65%	75%
Electrolysis Prod. Efficiency (LHV)	35%	62%

This project provides an excellent learning opportunity, but stations are not meant to emulate high volume replicate stations of the future. Permitting was in transition.

(1) Reported hydrogen costs are based on estimates of key cost elements from Learning Demonstration energy company partners and represent the cost of producing hydrogen on-site at the fueling station, using either natural gas reformation or water electrolysis, dispensed to the vehicle. Costs reflect an assessment of hydrogen production technologies, not an assessment of hydrogen market demand.
(2) Hydrogen production costs for 1500 kg/day stations developed using DOE's H2A Production model, version 2.1. Cost modeling represents the lifetime cost of producing hydrogen at fueling stations installed during an early market rollout of hydrogen infrastructure and are not reflective of the costs that might be seen in a fully mature market for hydrogen installations. Modeling uses default H2A Production model inputs supplemented with feedback from Learning Demonstration energy company partners, based on their experience operating on-site hydrogen production stations. H2A-based Monte Carlo simulations (2,000 trials) were completed for both natural gas reforming and electrolysis stations using default H2A values and 10th percentile to 90th percentile estimated ranges for key cost parameters as shown in the table. Capacity utilization range is based on the capabilities of the production technologies and could be significantly lower if there is inadequate demand for hydrogen.
(3) DOE has a hydrogen cost goal of $2-$3/kg for future (2015) 1500 kg/day hydrogen production stations installed at a rate of 500 stations per year.

NREL CDP15
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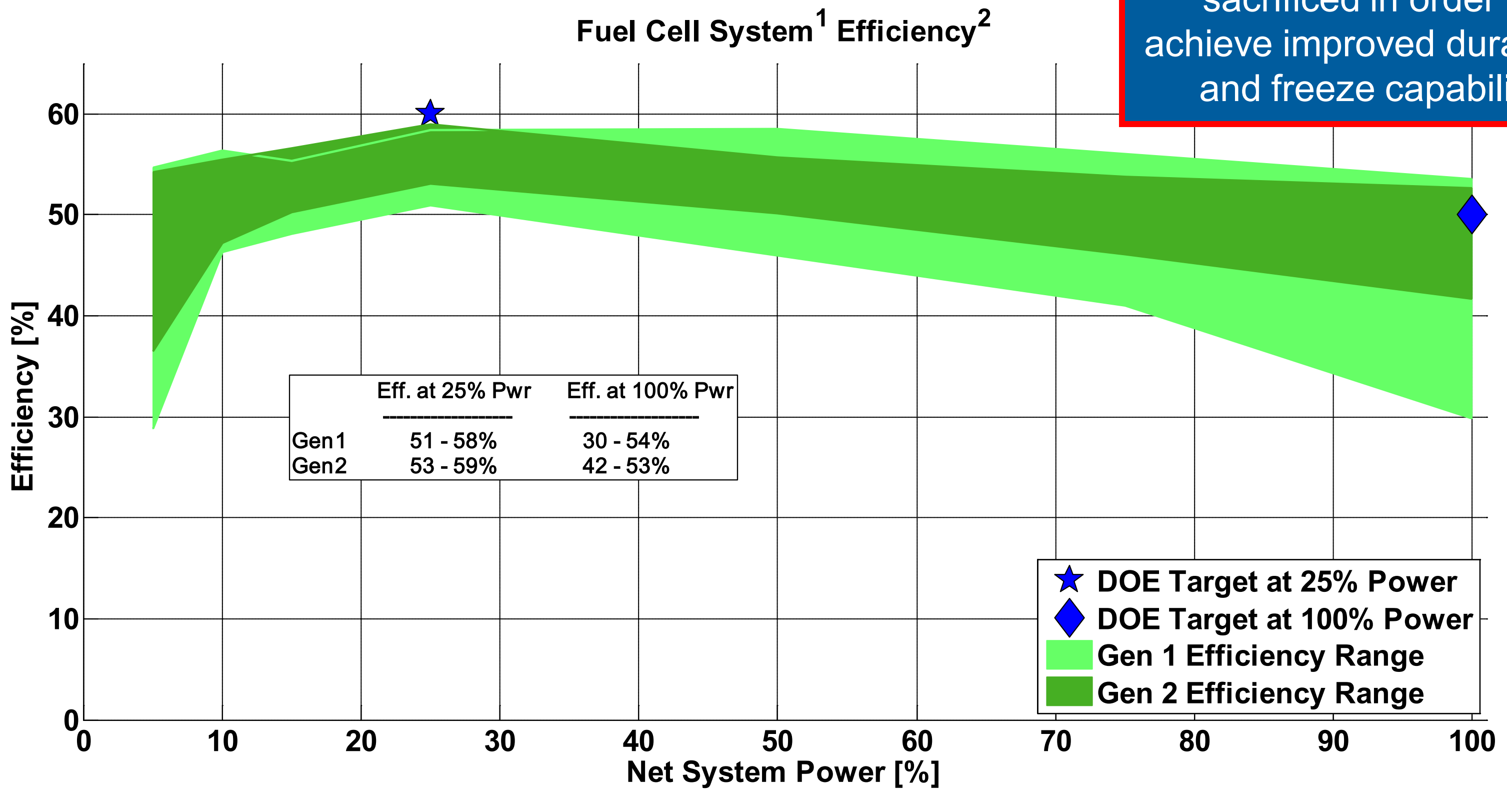
Outside of this project, DOE independent panels concluded at 500 replicate stations/year:
Distributed natural gas reformation at 1500 kg/day: **$2.75-$3.50/kg** (2006)
Distributed electrolysis at 1500kg/day: **$4.90-$5.70** (2009)

EFFICIENCY: Verified High Gen 2 Fuel Cell System Efficiency Maintained (Compared to Gen 1)

Critical result: Efficiency not sacrificed in order to achieve improved durability and freeze capability



[1] Gross stack power minus fuel cell system auxiliaries, per DRAFT SAE J2615. Excludes power electronics and electric drive.

[2] Ratio of DC output energy to the lower heating value of the input fuel (hydrogen).

[3] Individual test data linearly interpolated at 5,10,15,25,50,75,and 100% of max net power. Values at high power linearly extrapolated due to steady state dynamometer cooling limitations.

NREL CDP08

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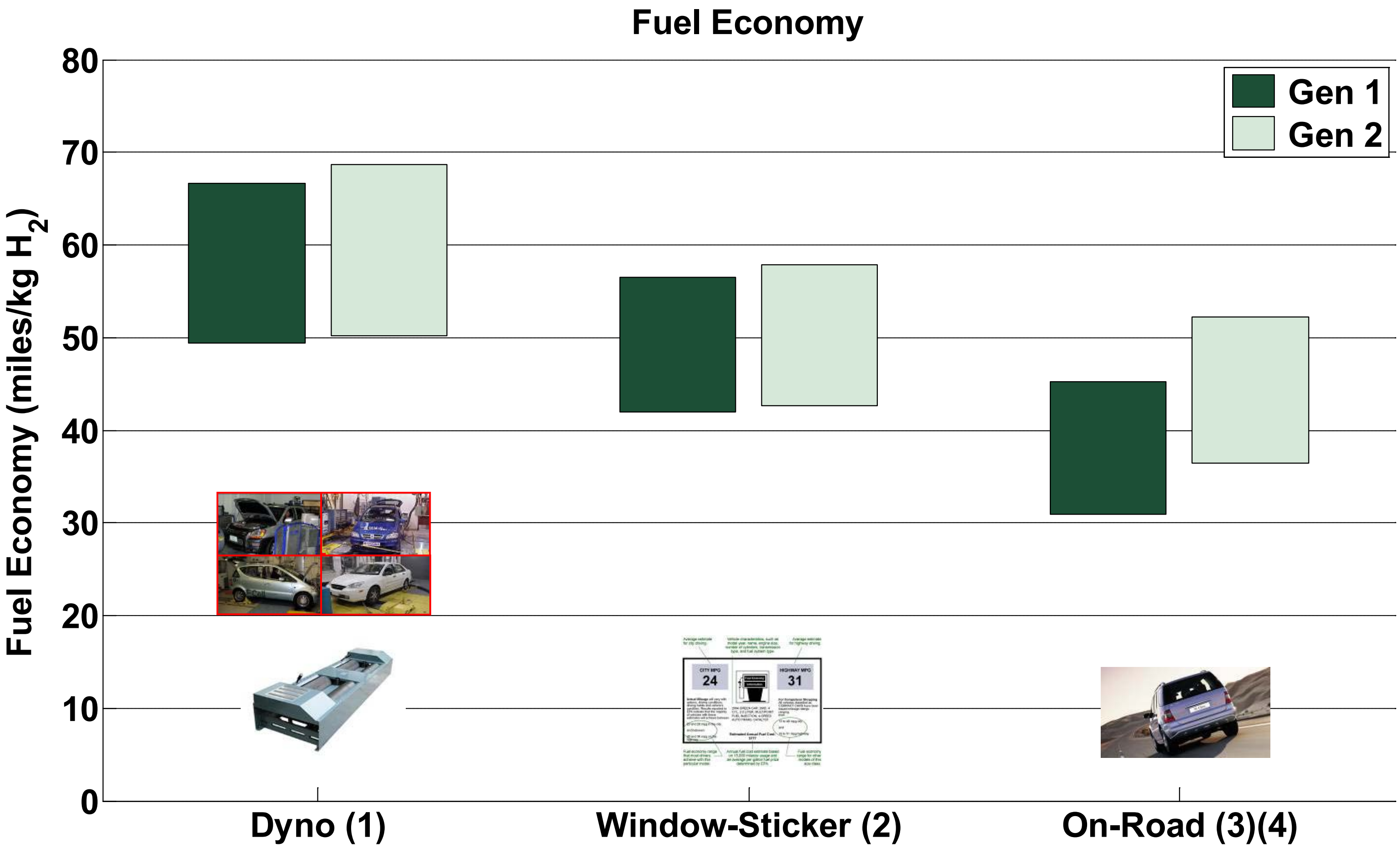
FUEL ECONOMY: Ranges of Fuel Economy from Dynamometer and On-Road Data Similar for Gen 1 & 2



(1) One data point for each make/model. Combined City/Hwy fuel economy per DRAFT SAE J2572.
(2) Adjusted combined City/Hwy fuel economy (0.78 x Hwy, 0.9 x City).
(3) Excludes trips < 1 mile. One data point for on-road fleet average of each make/model.
(4) Calculated from on-road fuel cell stack current or mass flow readings.

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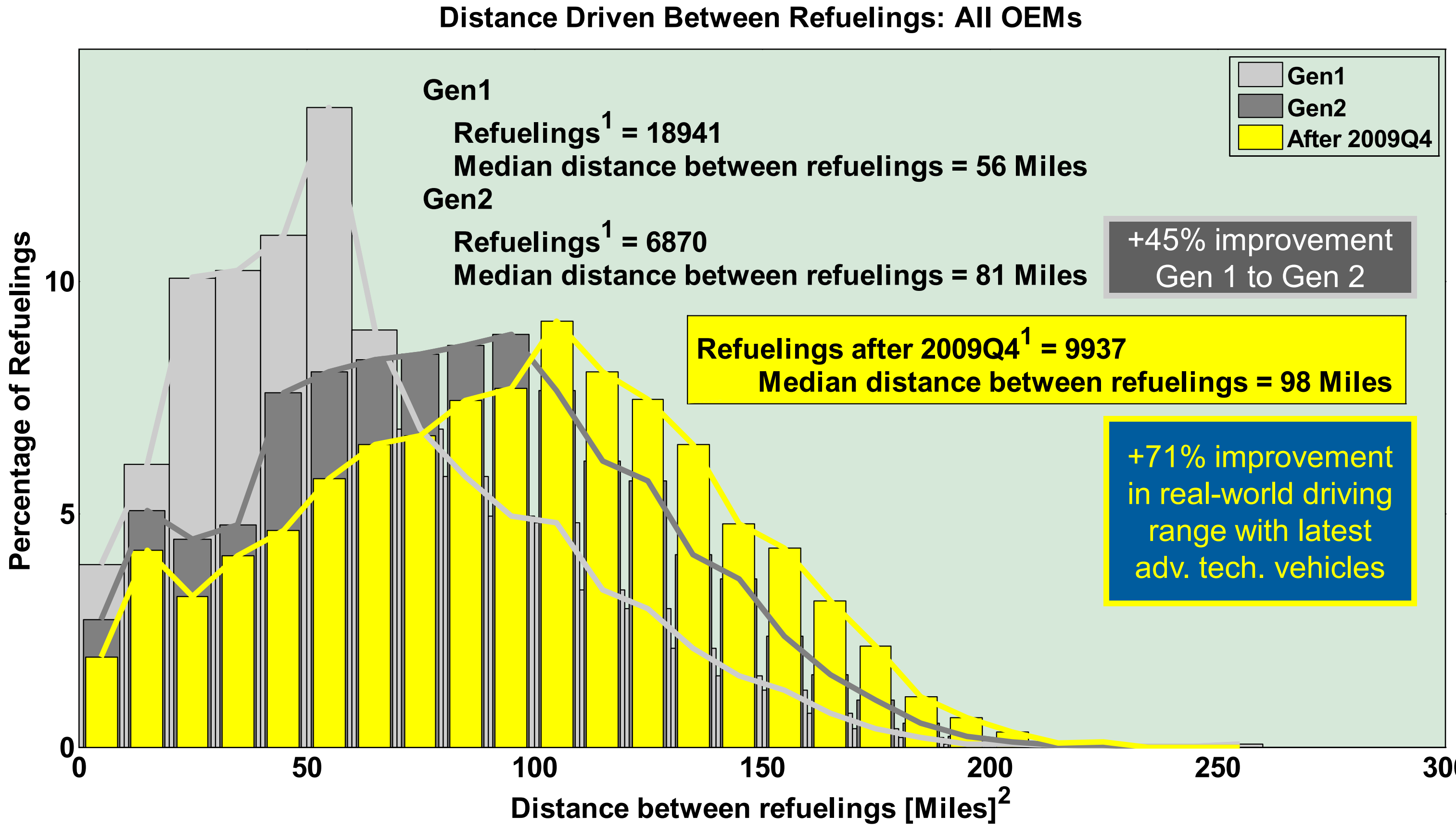
RANGE: Results Show Significant Improvement in Real-World Driving Range Between 3 Sets of Vehicles



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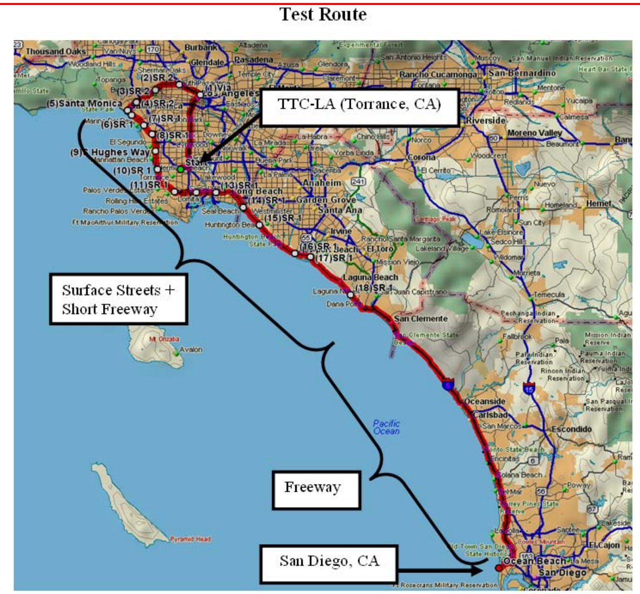
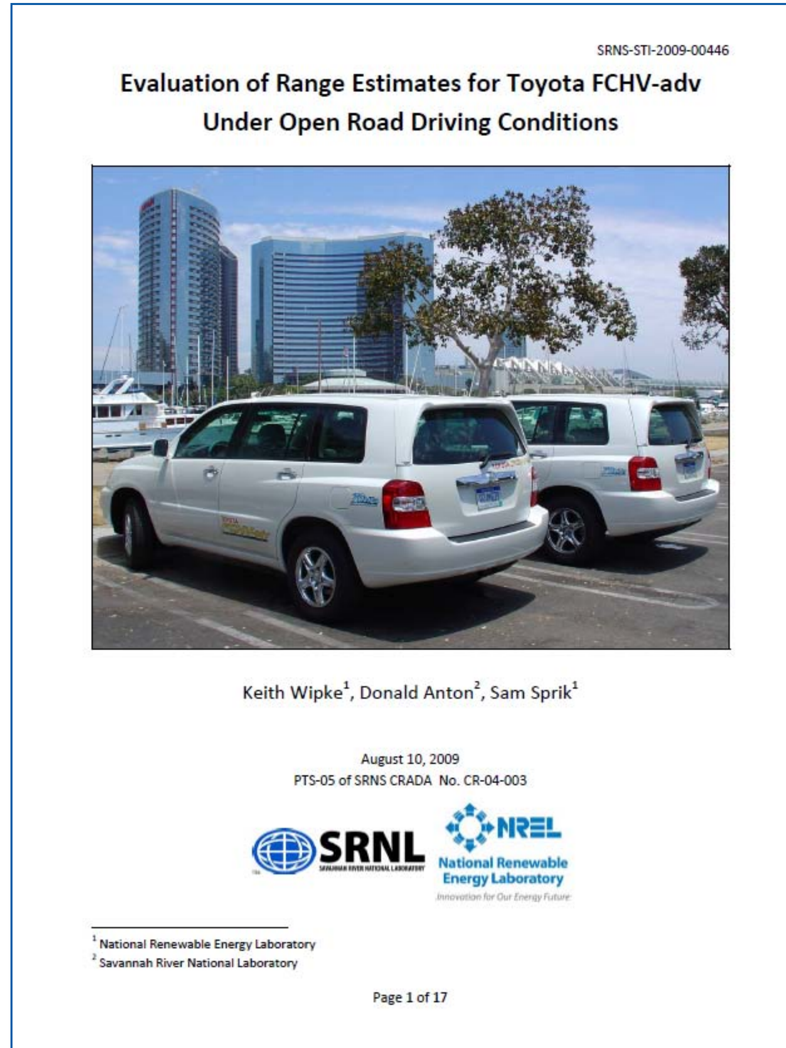
1. Some refueling events are not detected/reported due to data noise or incompleteness.
2. Distance driven between refuelings is indicative of driver behavior and does not represent the full range of the vehicle.

Note: Actual range possible >200 miles

RANGE: NREL/SRNL Experiment Verified Toyota FCHV-adv Capable of up to 430-Mile Driving Range Without Refueling on June 30, 2009



	Average trip distance (miles)	H_2 consumed (kg)	Remaining usable H_2 (kg)	Calculated remaining range (miles)	(miles)	(miles)
Vehicle #1	331.50	4.8255	1.4854	102.04	433.55	**431**
Vehicle #2	331.45	4.8751	1.4328	97.41	428.87	


SRNS-STI-2009-00446

Evaluation of Range Estimates for Toyota FCHV-adv Under Open Road Driving Conditions

Keith Wipke[1], Donald Anton[2], Sam Sprik[1]

August 10, 2009

PTS-05 of SRNS CRADA No. CR-04-003

SRNL

NREL National Renewable Energy Laboratory

[1] National Renewable Energy Laboratory

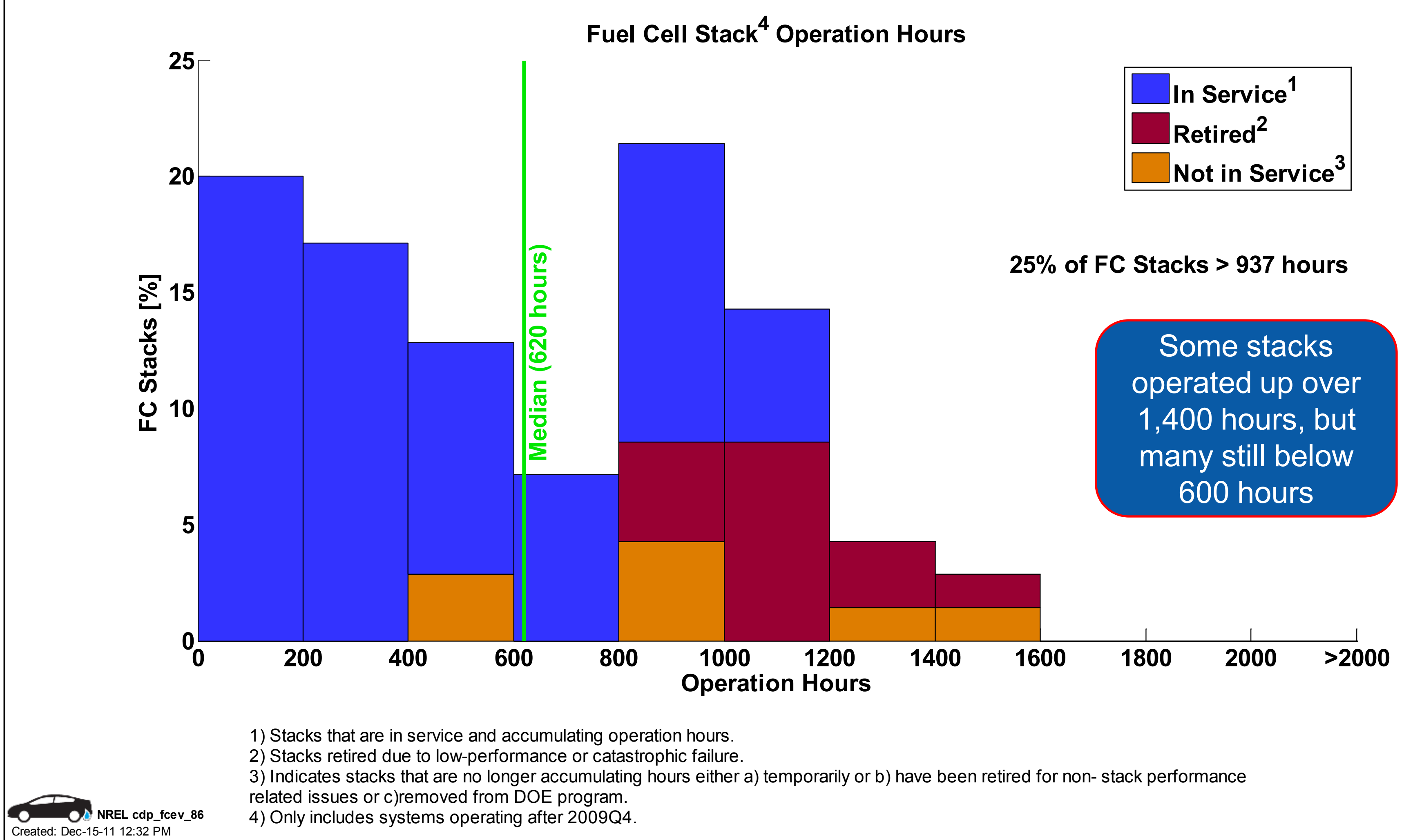
[2] Savannah River National Laboratory

Page 1 of 17

Toyota video: http://www.youtube.com/watch?v=iz0vD5E7glA

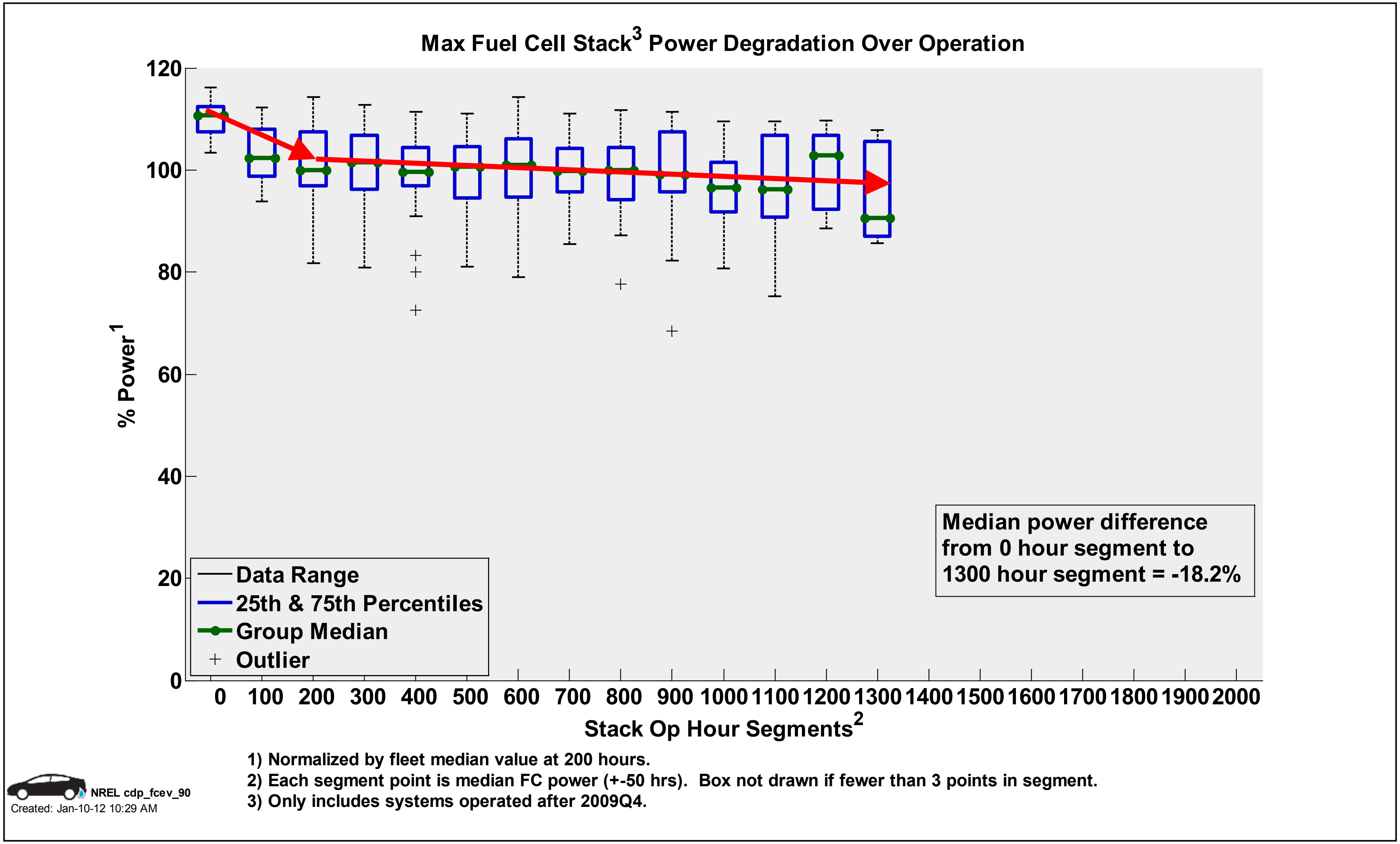
Report: http://www.nrel.gov/hydrogen/pdfs/toyota_fchv-adv_range_verification.pdf

DURABILITY: Data from FCEVs After 2009 Q4
Fuel Cell Stack Operation Hours

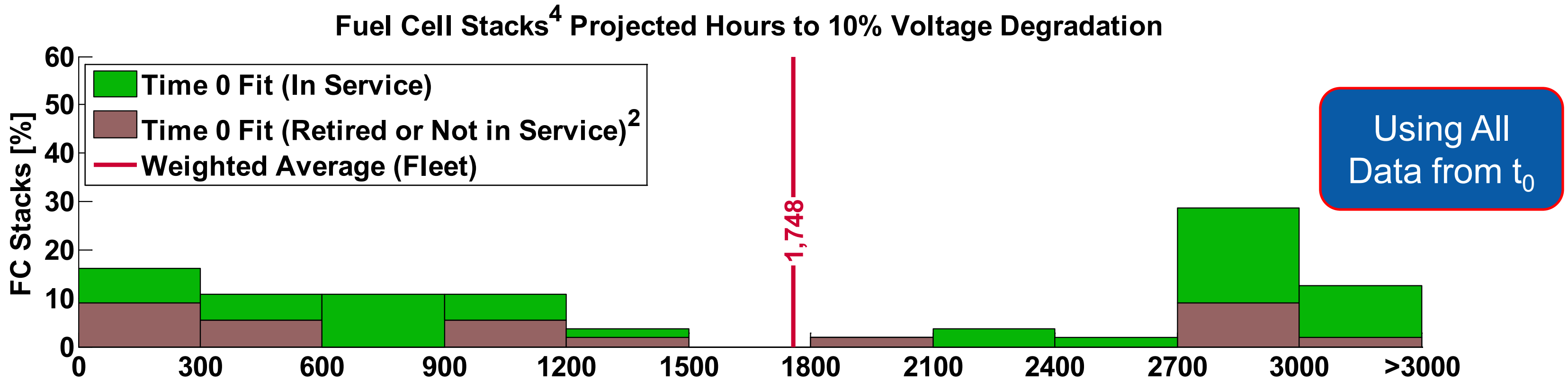


1) Stacks that are in service and accumulating operation hours.
2) Stacks retired due to low-performance or catastrophic failure.
3) Indicates stacks that are no longer accumulating hours either a) temporarily or b) have been retired for non- stack performance related issues or c)removed from DOE program.
4) Only includes systems operating after 2009Q4.

DURABILITY: What Does the Stack Aging Look Like? Max FC Power Degradation Rate Drops with Aging



DURABILITY: Fuel Cell Stacks Projected Hours to 10% Voltage Degradation; Two Fits



1) Projection using field data, calculated at high stack current, from operation hour 0 or a steady operation period. Projected hours may differ from an OEM's end-of-life criterion and does not address "catastrophic" failure modes.
2) Indicates stacks that are no longer accumulating hours either a) temporarily or b) have been retired for non- stack performance related issues or c) removed from DOE program.
3) Projected hours limited based on demonstrated hours.
4) Only includes systems operating after 2009Q4.
5) Not all stacks have a steady operation fit which is calculated from data after 200 hr break-in period. The steady operation starting hour is an approximation of the period after initial break-in where degradation levels to a more steady rate.

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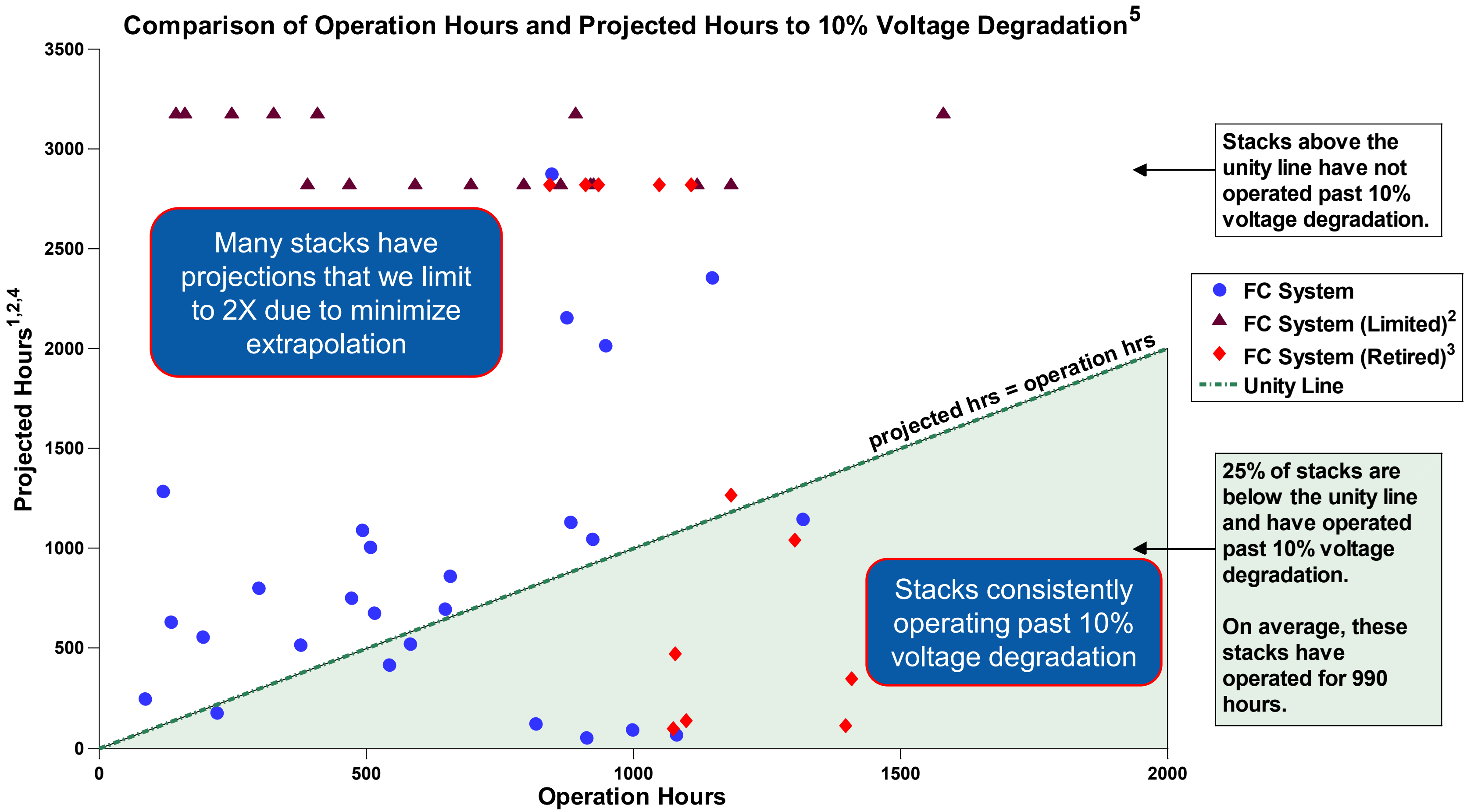
DURABILITY: Comparison of Fuel Cell Operation Hours and Projected Hours to 10% Voltage Degradation



1) Indicates the projected hours to a 10% voltage degradation based upon curve fitting data from operation hour 0.
2) Projected hours limited based on demonstrated hours.
3) Stacks retired due to low-performance or catastrophic failure.
4) Each projection has uncertainty based on the confidence intervals of the fit.
5) Only includes systems operated after 2009Q4.

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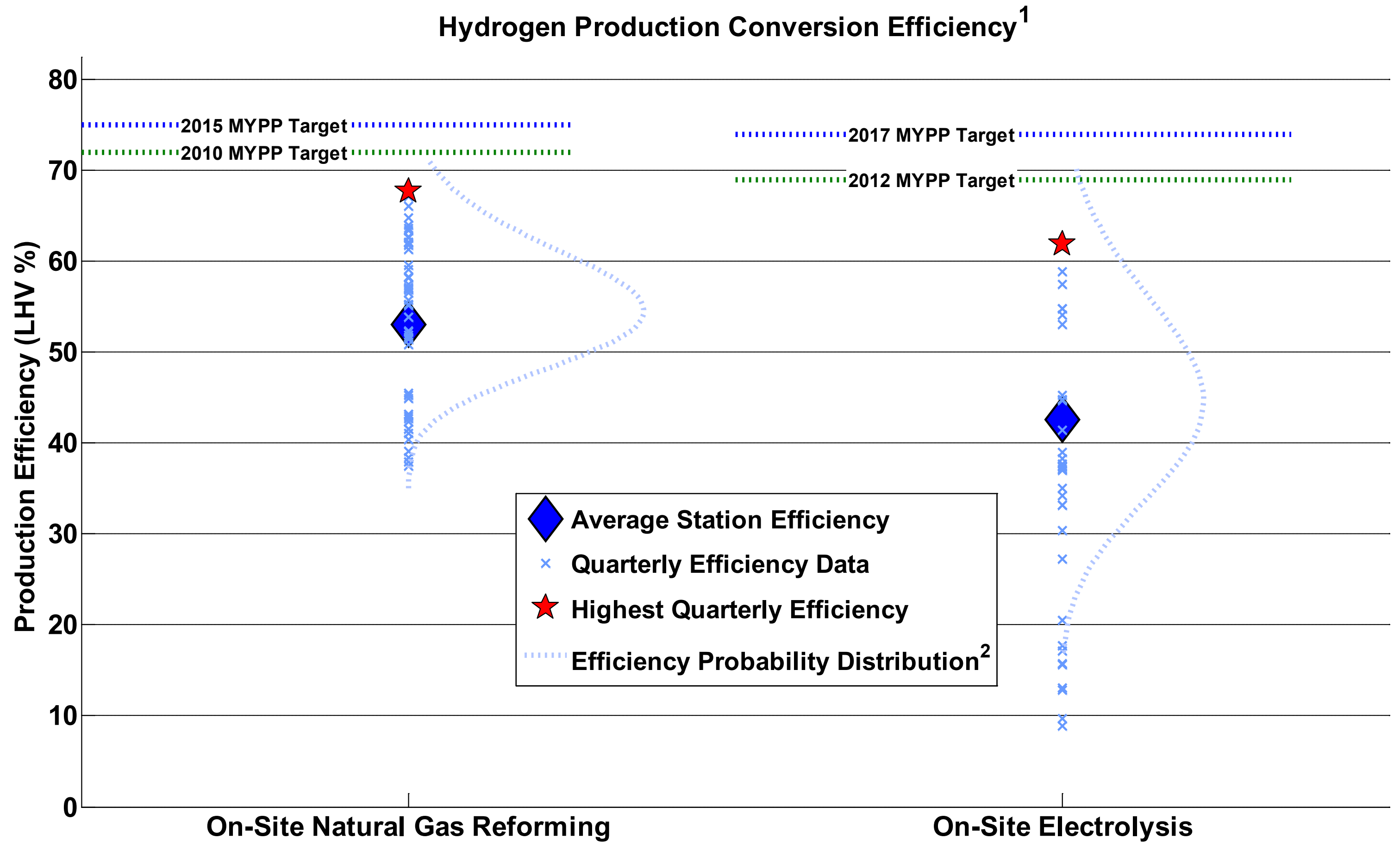
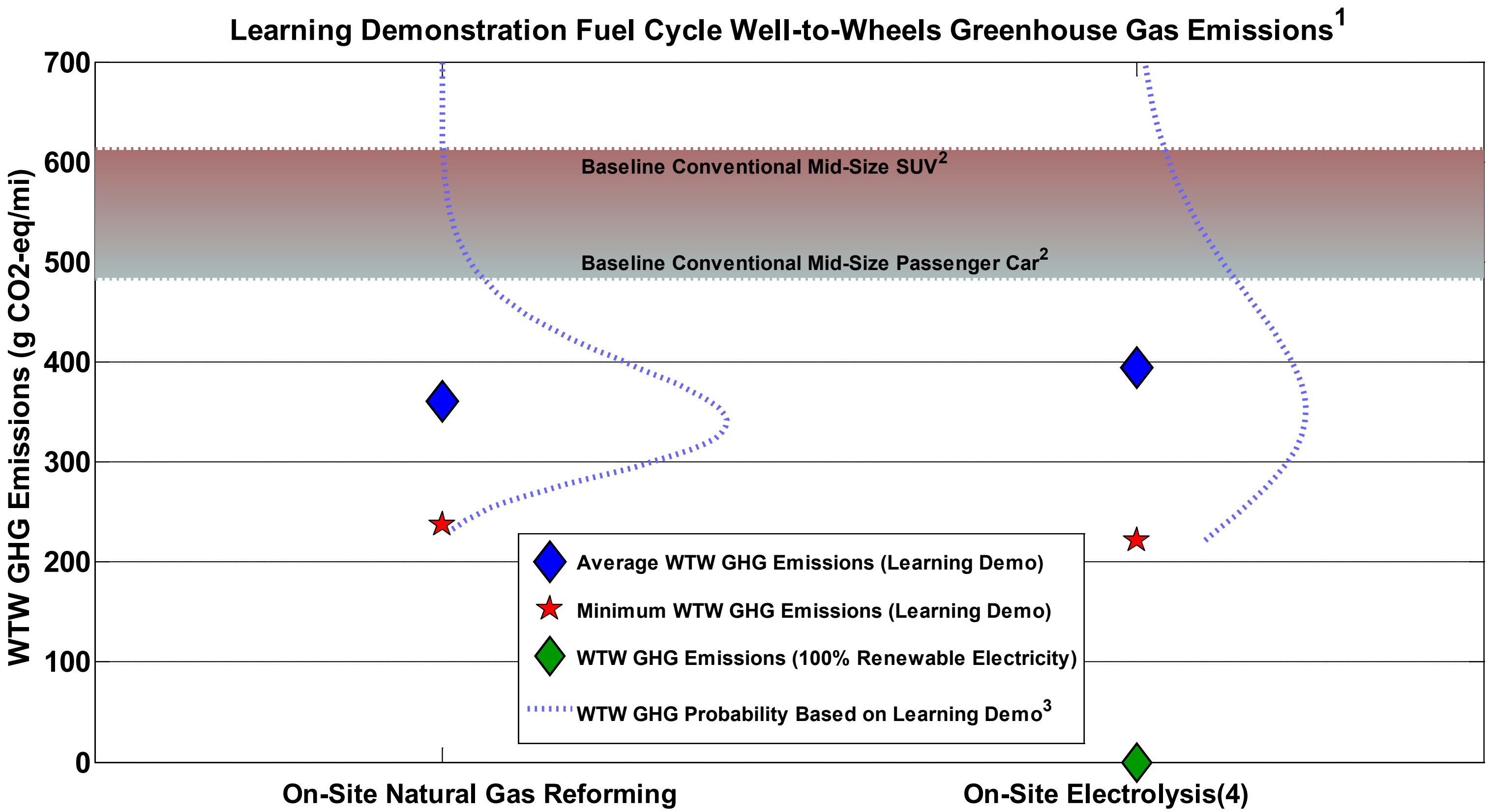
INFRASTRUCTURE: Evaluated On-Site Hydrogen Production Efficiency



[1]Production conversion efficiency is defined as the energy of the hydrogen out of the process (on an LHV basis) divided by the sum of the energy into the production process from the feedstock and all other energy as needed. Conversion efficiency does not include energy used for compression, storage, and dispensing.

[2]The efficiency probability distribution represents the range and likelihood of hydrogen production conversion efficiency based on monthly conversion efficiency data from the Learning Demonstration.

GHG: Learning Demonstration Vehicle Greenhouse Gas Emissions (WTW)



1. Well-to-Wheels greenhouse gas emissions based on DOE's GREET model, version 1.8b. Analysis uses default GREET values except for FCV fuel economy, hydrogen production conversion efficiency, and electricity grid mix. Fuel economy values are the Gen 1 and Gen 2 window-sticker fuel economy data for all teams (as used in CDP #6); conversion efficiency values are the production efficiency data used in CDP #13.
2. Baseline conventional passenger car and light duty truck GHG emissions are determined by GREET 1.8b, based on the EPA window-sticker fuel economy of a conventional gasoline mid-size passenger car and mid-size SUV, respectively. The Learning Demonstration fleet includes both passenger cars and SUVs.
3. The Well-to-Wheels GHG probability distribution represents the range and likelihood of GHG emissions resulting from the hydrogen FCV fleet based on window-sticker fuel economy data and monthly conversion efficiency data from the Learning Demonstration.
4. On-site electrolysis GHG emissions are based on the average mix of electricity production used by the Learning Demonstration production sites, which includes both grid-based electricity and renewable on-site solar electricity. GHG emissions associated with on-site production of hydrogen from electrolysis are highly dependent on electricity source. GHG emissions from a 100% renewable electricity mix would be zero, as shown. If electricity were supplied from the U.S. average grid mix, average GHG emissions would be 1330 g/mile.

NREL CDP62
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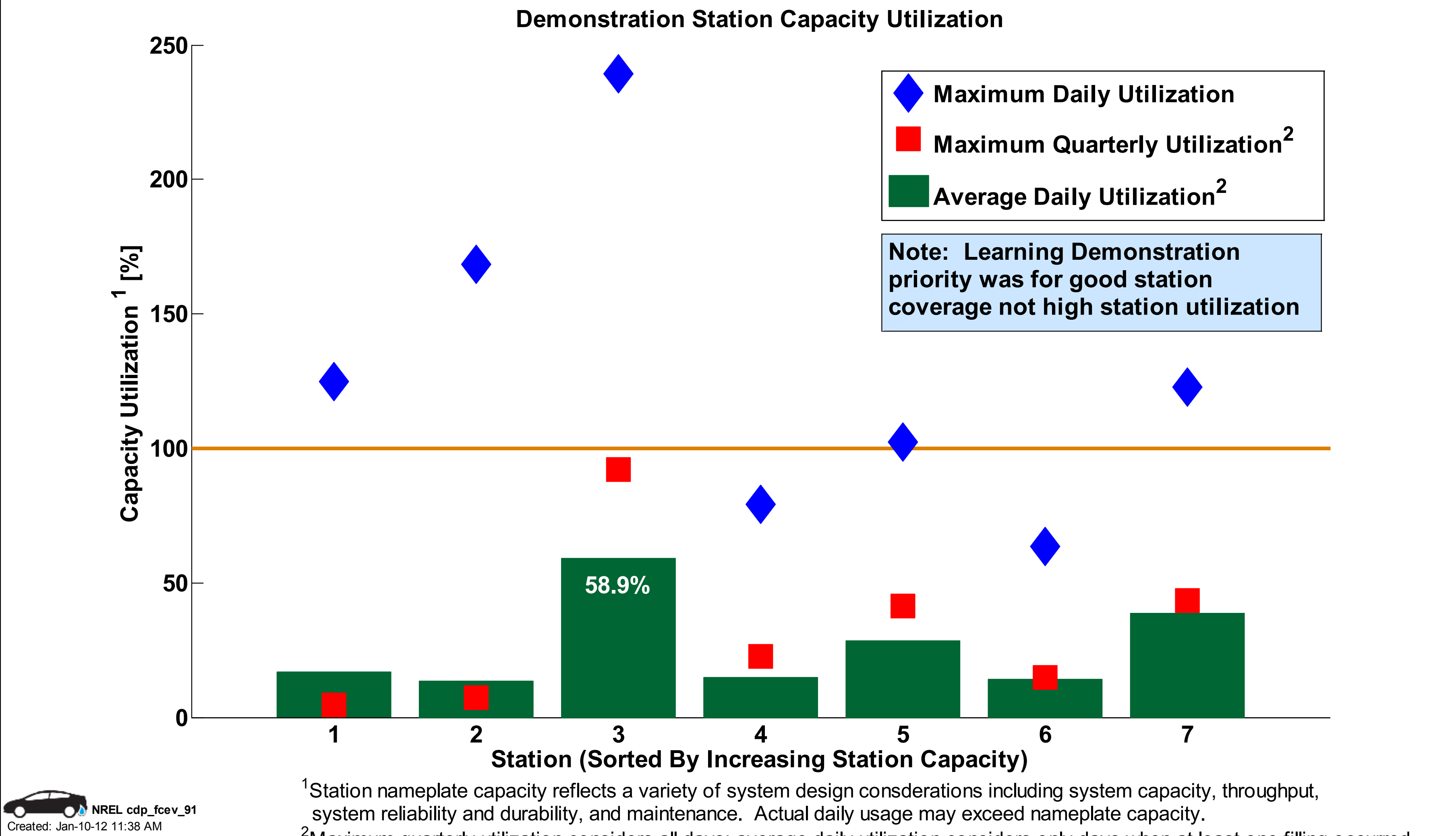
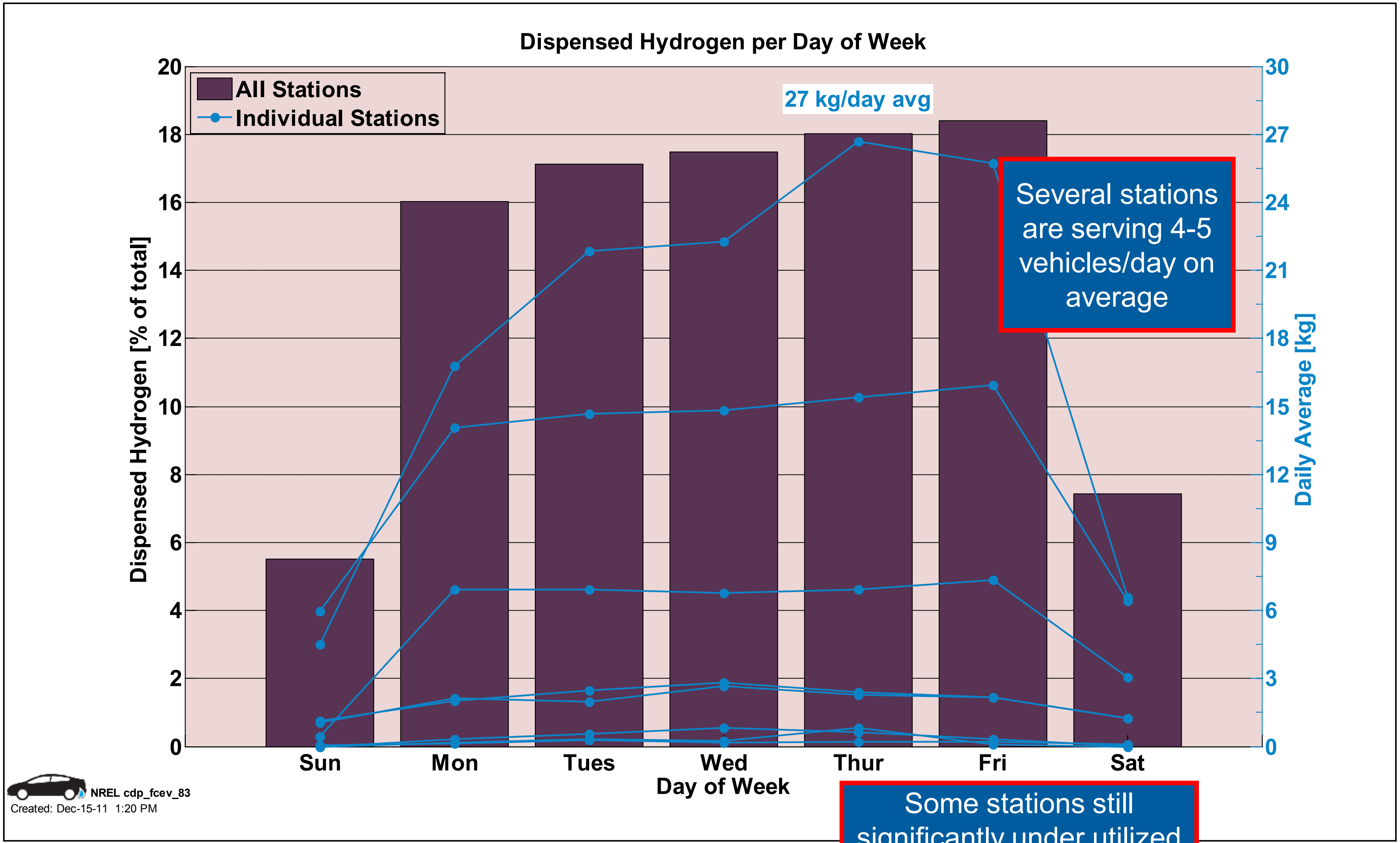
INFRASTRUCTURE: Station Capacity Utilization



[1]Station nameplate capacity reflects a variety of system design consderations including system capacity, throughput, system reliability and durability, and maintenance. Actual daily usage may exceed nameplate capacity.

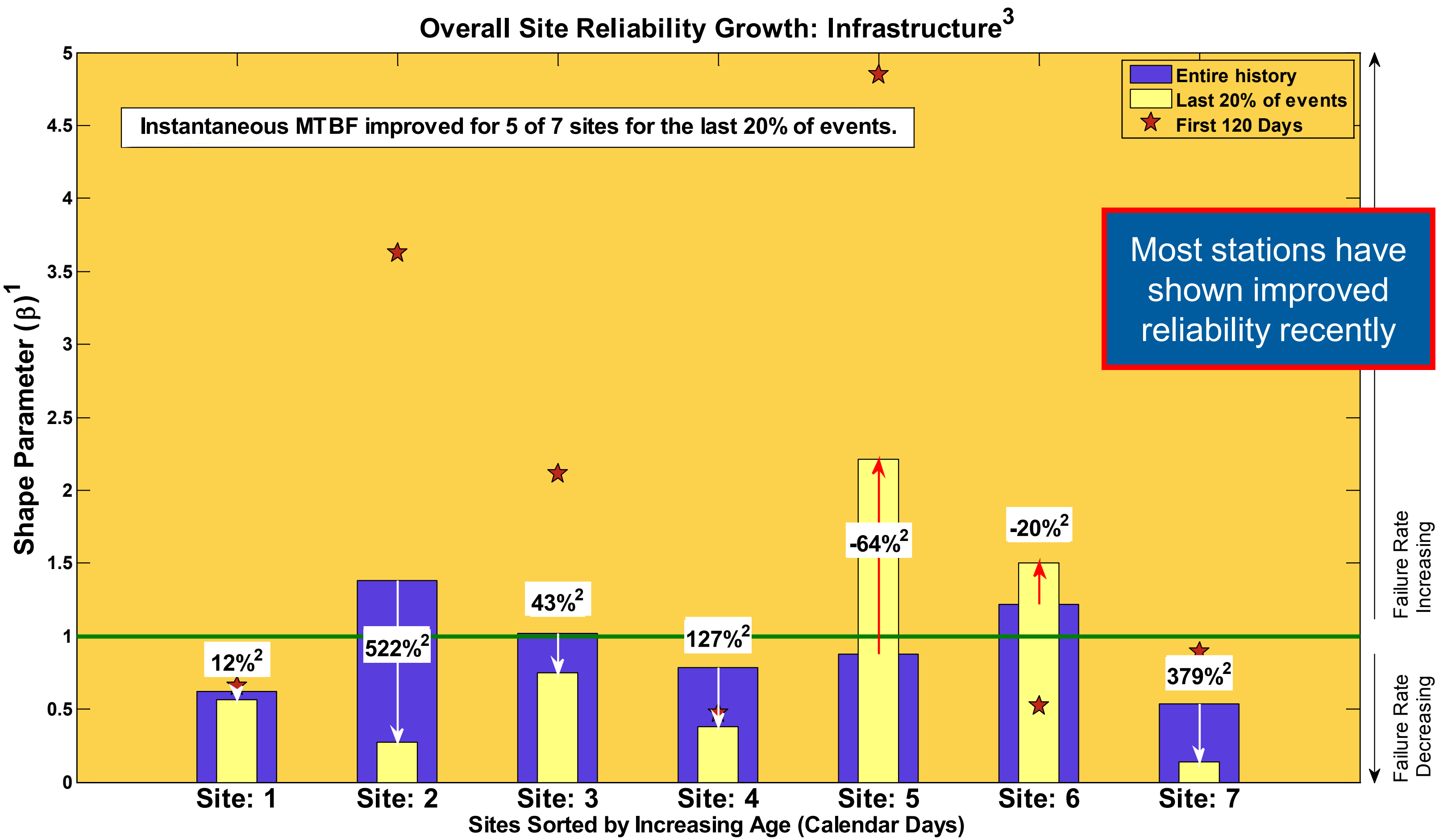
[2]Maximum quarterly utilization considers all days; average daily utilization considers only days when at least one filling occurred

INFRASTRUCTURE: Some CDPs Are Now Looking at the Transition from Demo to Early Market – Utilization is Important



Some stations still significantly under utilized

INFRASTRUCTURE: Infrastructure Reliability Growth



1. IEC 61164:2004(E)., Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.

2.% change in instantaneous MTBF

3. Includes data from stations operating after 2009 Q4.

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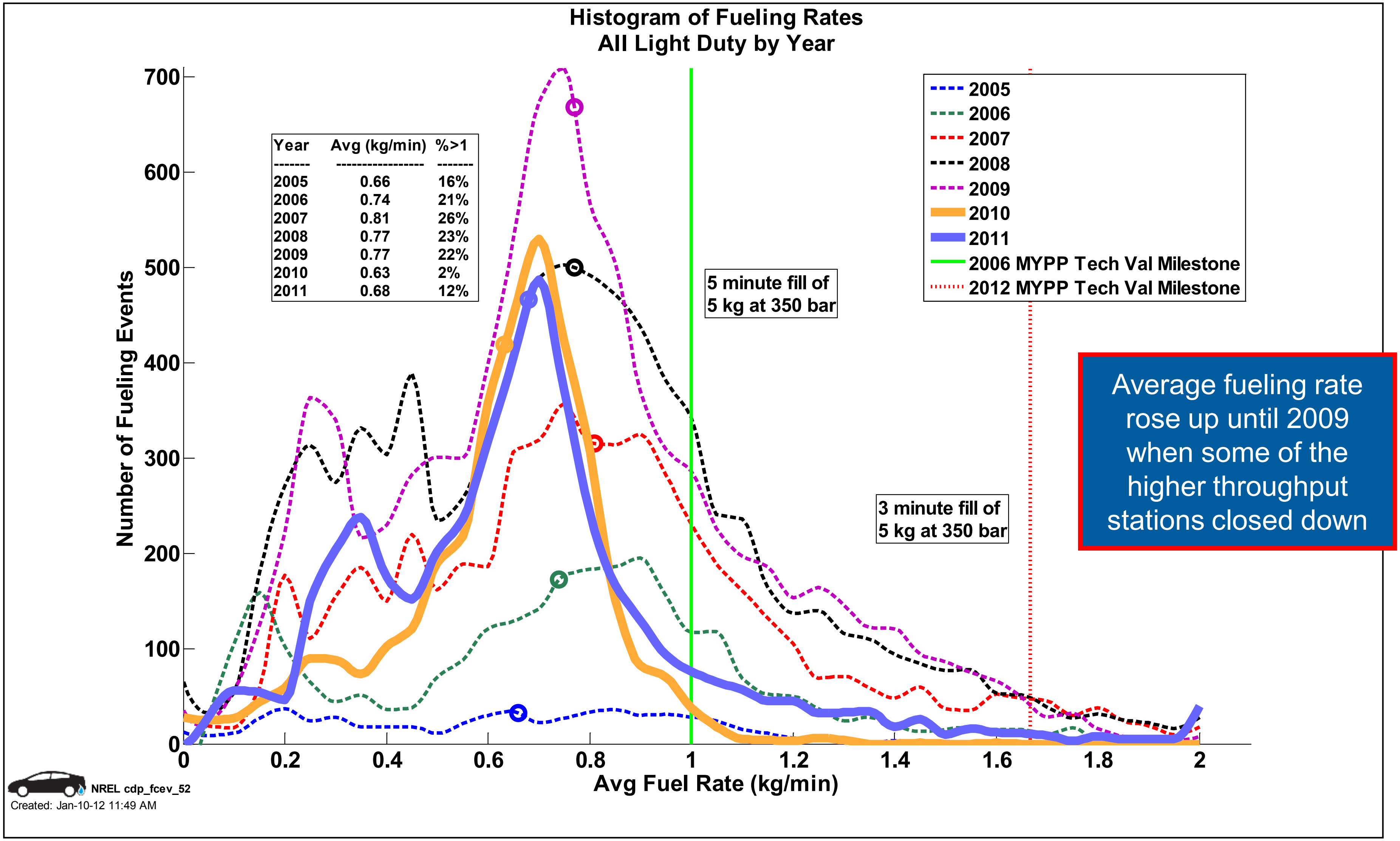
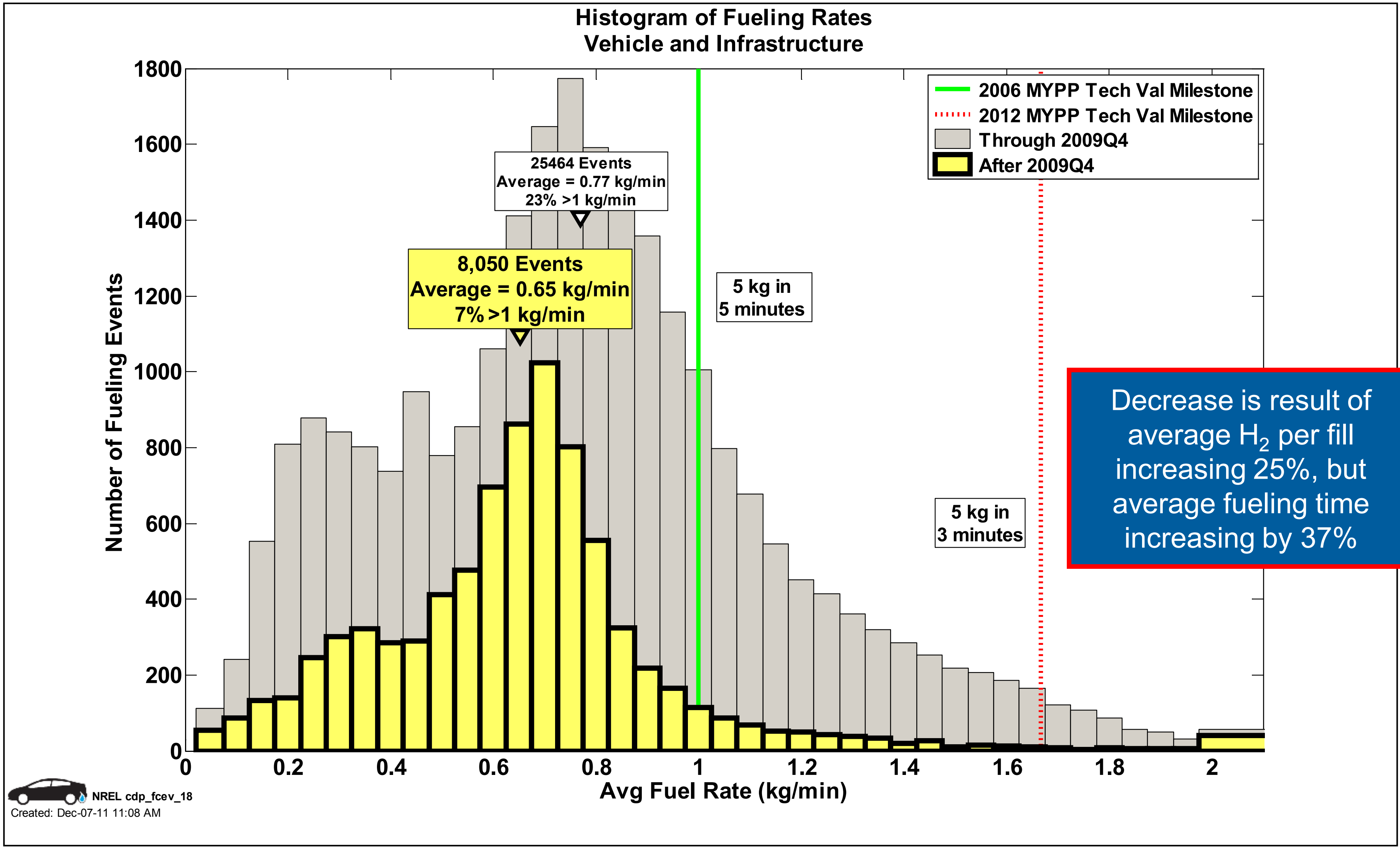
FUELING: Tracking Fueling Rates by Year



Average fueling rate rose up until 2009 when some of the higher throughput stations closed down

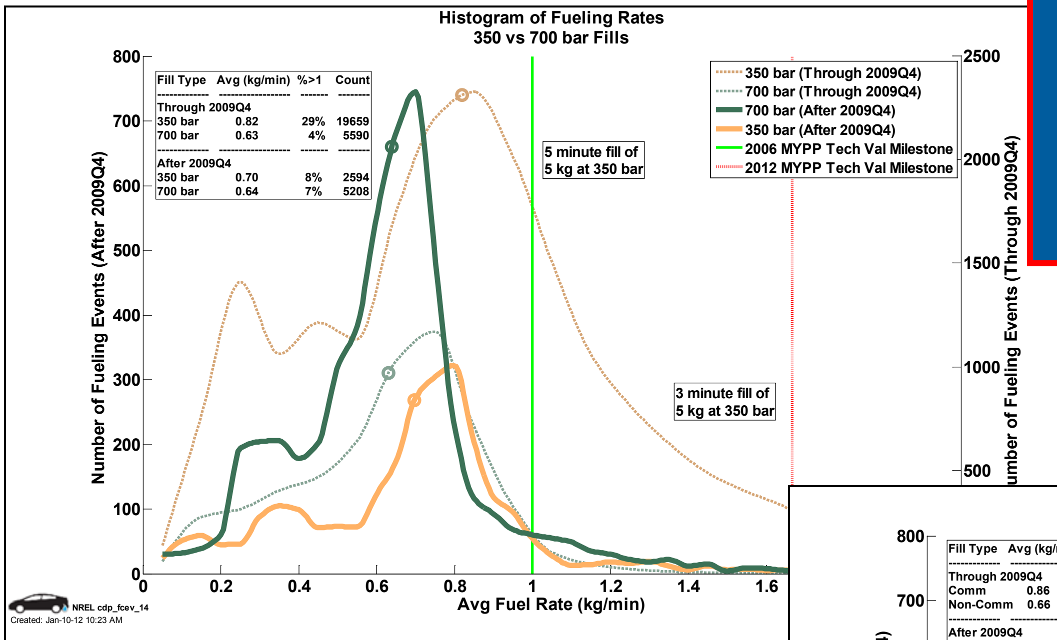
FUELING: Changes in Refueling Rate Trends – Average Refueling Rate Decreased 16%



Decrease is result of average H_2 per fill increasing 25%, but average fueling time increasing by 37%

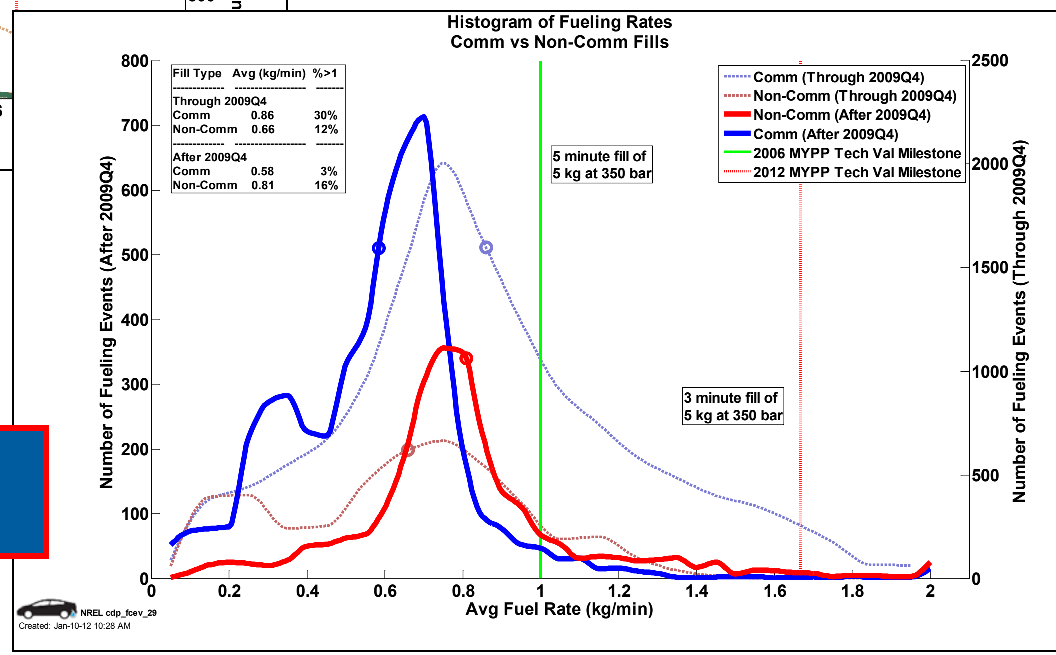
Fall 2010

FUELING: Fueling Rates by Fill Pressure and Communication vs. Non-communication – Fueling infrastructure in transition



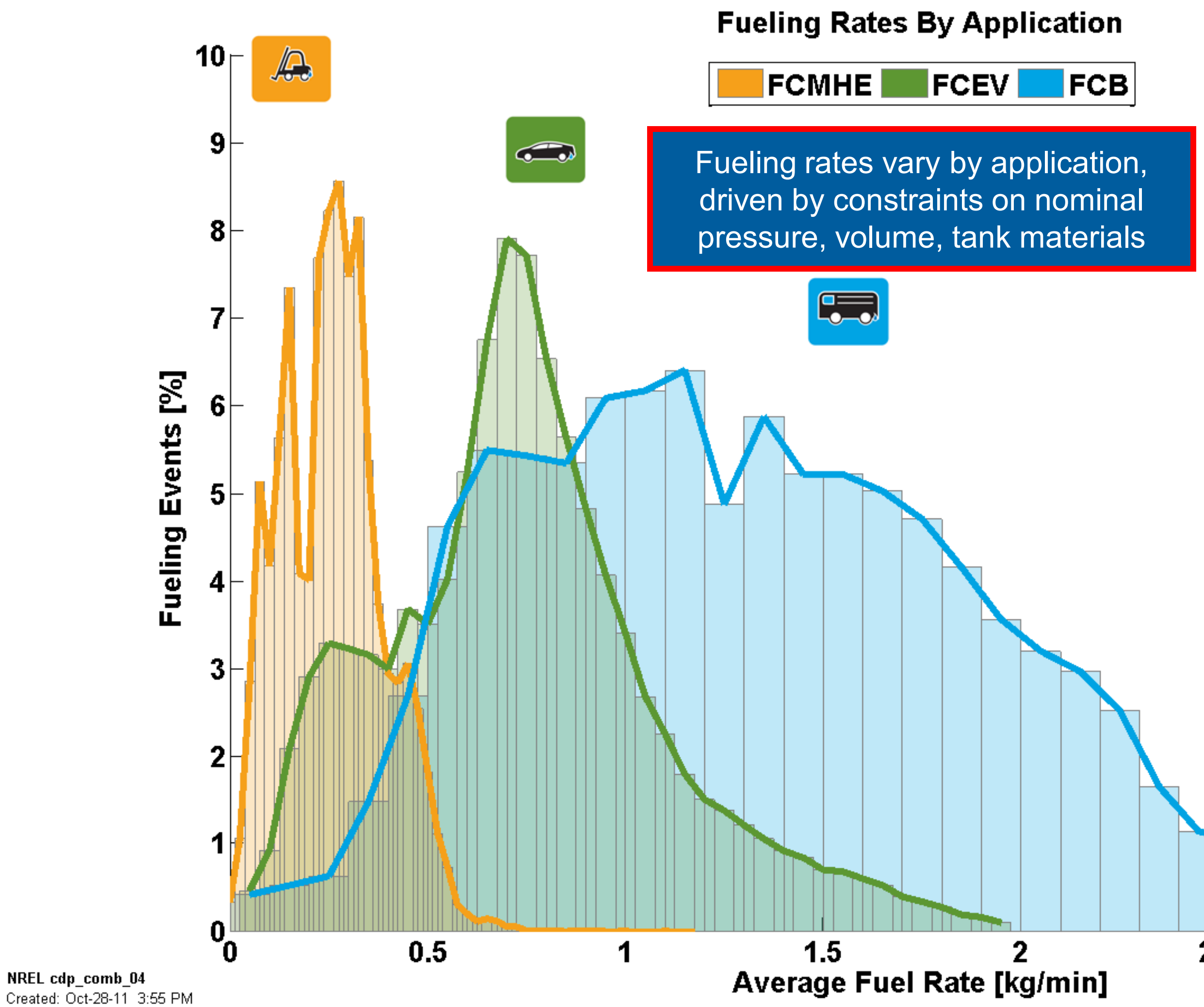
700 bar fueling rates holding constant at ~0.63 kg/min

350 bar fueling rates dropped from 0.82 to 0.70 kg/min

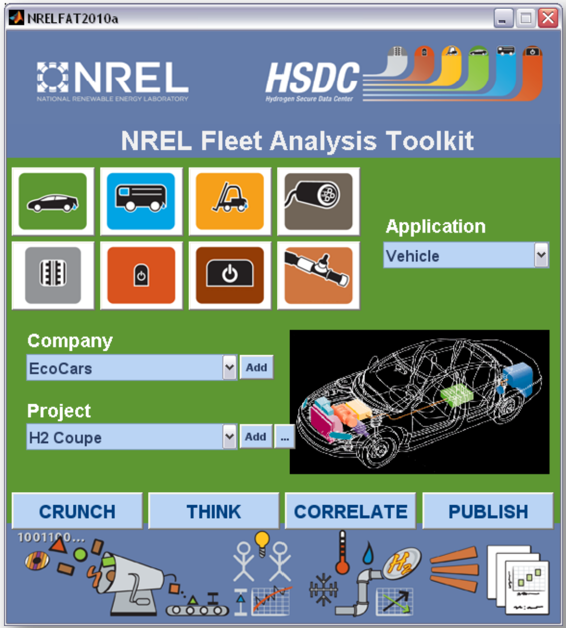


Comm fill rates dropped while non-comm fill rates increased

Analysis at NREL Leveraged Across Applications; Being Applied to Compare Similarities/Differences

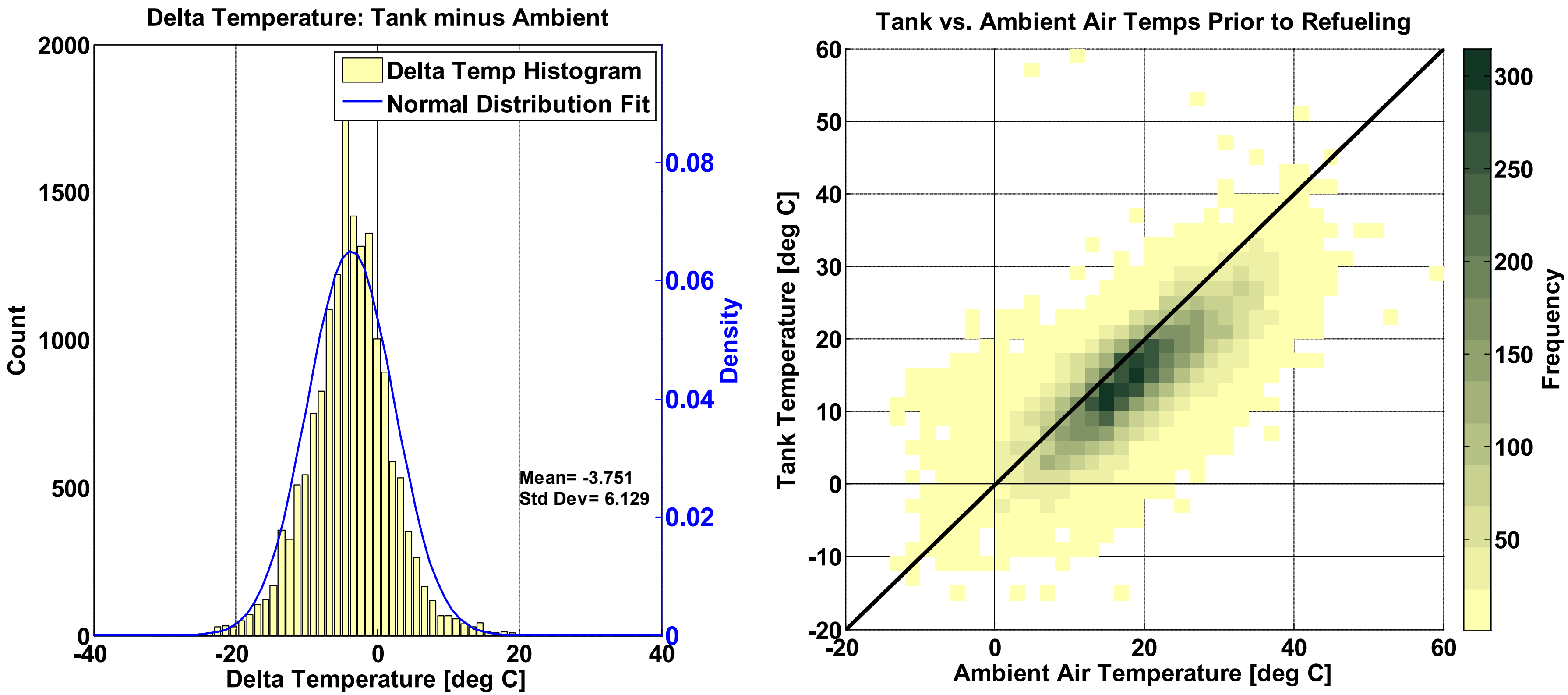


Fueling rates vary by application, driven by constraints on nominal pressure, volume, tank materials



Other data sources:
FC bus, forklift, lab data, and backup power

Example of Analysis Results Informing R&D Activities and Codes and Standards Development



-This CDP created in support of SAE J2601 related to refueling
-Temperatures are prior to refueling and exclude data within 4 hours of a previou
-The plot to the left excludes ambient temperatures less than -5 deg C

NREL CDP72
Created: Mar-11-10 10:24 AM

FCEVs arrive at station with a tank temperature that is 3.8 degrees C colder than ambient temp

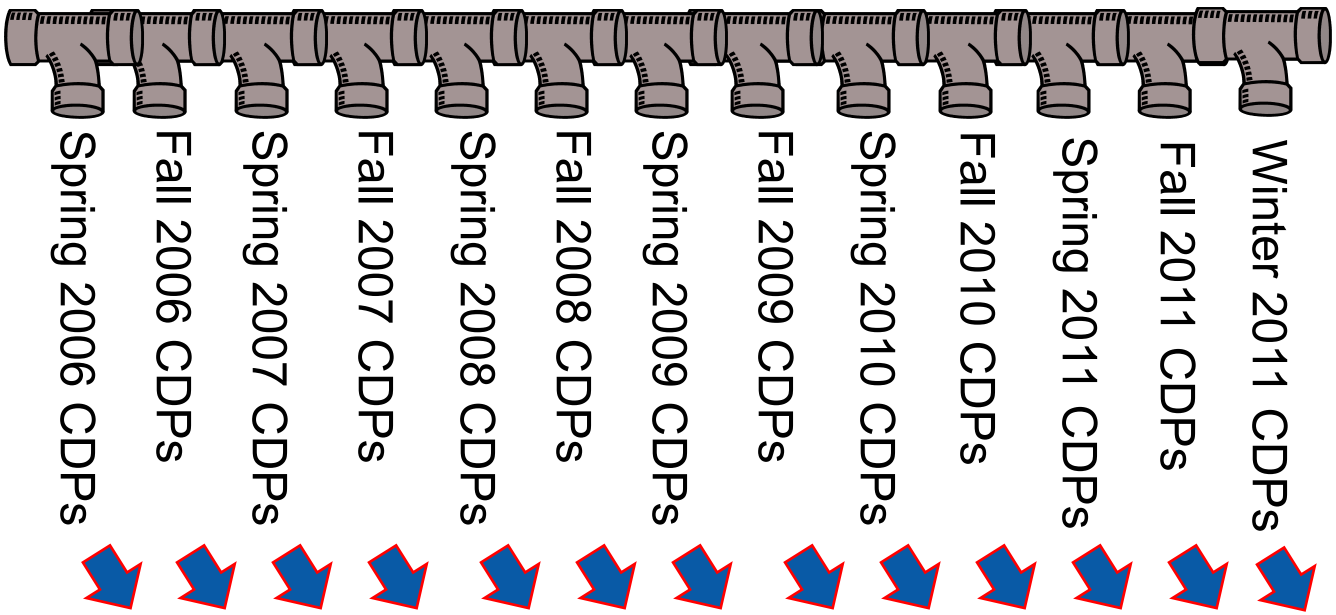
Technical Summary

- Project has completed ~7 years of real-world validation
- Vehicle operation: 183 vehicles, 154,000 hours, 3.5 million miles, 500,000 trips
- H_2 station operation: 25 stations, 151,000 kg produced or dispensed, 33,000 fuelings
- DOE Key Technical Targets Validated and Met:
  - FC Durability >2,000 hours and Range >250 miles

Learning Demo Project Wrap-Up

- Winter 2011 CDPs just posted on NREL web site
- Draft final report in March 2012, to be published in April
- Continuing to receive data on H2 infrastructure with support from DOE (primarily in CA: stations funded by CEC and ARB). New results to follow.
- In discussions with how to continue to assess FCEV progress in the coming years
- This project is the 1st time such comprehensive data was collected by an independent 3rd-party and consolidated for public dissemination
  - Successful framework being used for other projects

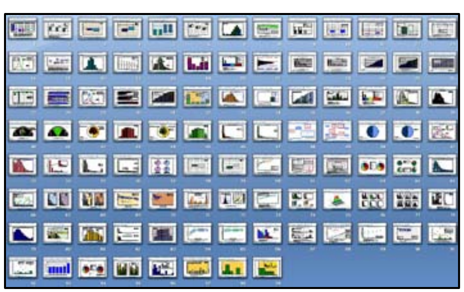
NREL Has Built the Infrastructure and Framework for Other Projects to Follow



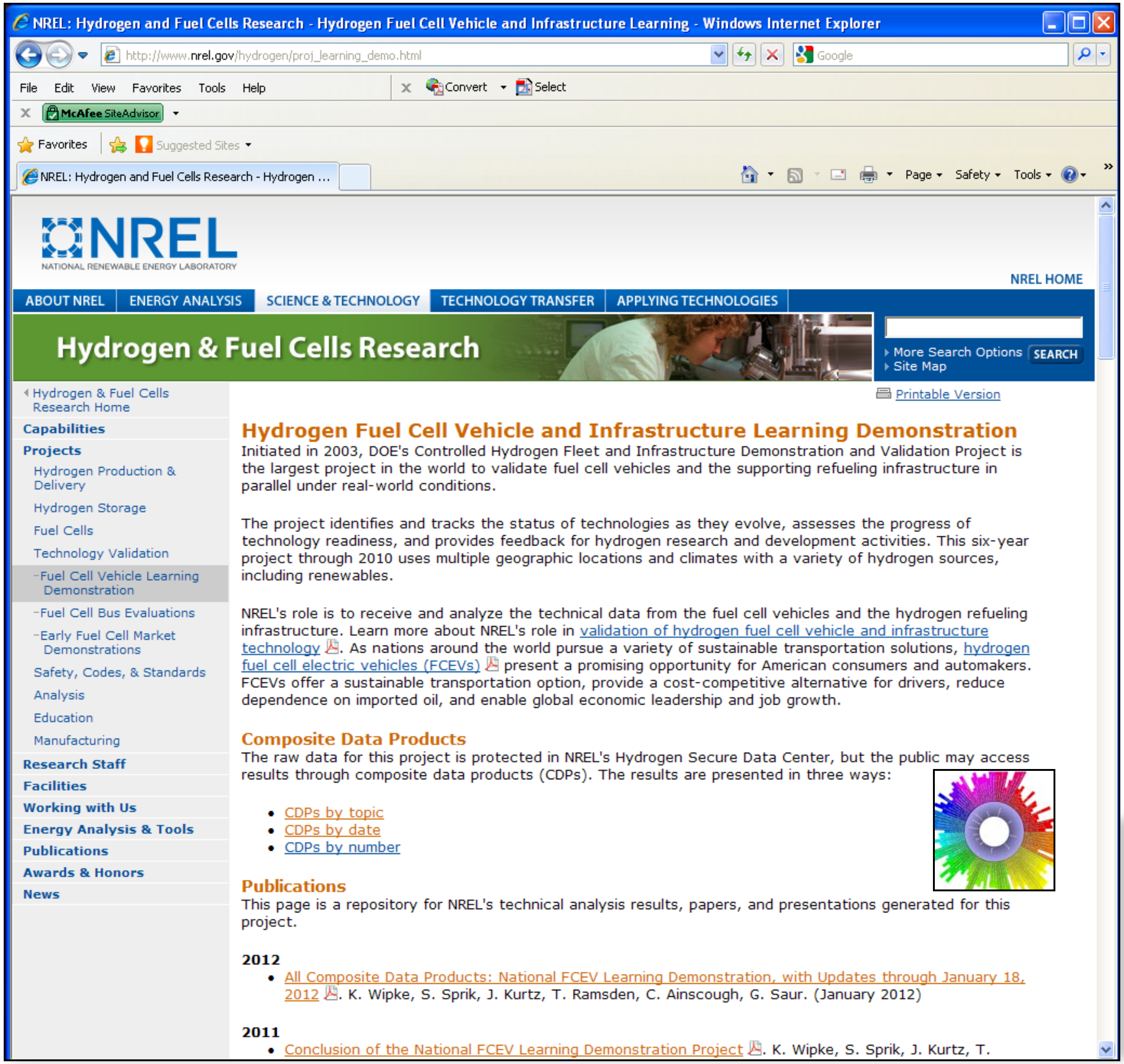
Learning Demo Conclusion

Final Public Report

OBJECTIVE CREDIBLE EVALUATIONS HELPED LEAD TO INFORMED DECISIONS



To Learn More on Your Own…
It's All Online on NREL's web site



NREL: Hydrogen and Fuel Cells Research - Hydrogen Fuel Cell Vehicle and Infrastructure Learning - Windows Internet Explorer

http://www.nrel.gov/hydrogen/proj_learning_demo.html

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Hydrogen Fuel Cell Vehicle and Infrastructure Learning Demonstration

Initiated in 2003, DOE's Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project is the largest project in the world to validate fuel cell vehicles and the supporting refueling infrastructure in parallel under real-world conditions.

The project identifies and tracks the status of technologies as they evolve, assesses the progress of technology readiness, and provides feedback for hydrogen research and development activities. This six-year project through 2010 uses multiple geographic locations and climates with a variety of hydrogen sources, including renewables.

NREL's role is to receive and analyze the technical data from the fuel cell vehicles and the hydrogen refueling infrastructure. Learn more about NREL's role in validation of hydrogen fuel cell vehicle and infrastructure technology. As nations around the world pursue a variety of sustainable transportation solutions, hydrogen fuel cell electric vehicles (FCEVs) present a promising opportunity for American consumers and automakers. FCEVs offer a sustainable transportation option, provide a cost-competitive alternative for drivers, reduce dependence on imported oil, and enable global economic leadership and job growth.

Composite Data Products

The raw data for this project is protected in NREL's Hydrogen Secure Data Center, but the public may access results through composite data products (CDPs). The results are presented in three ways:

- CDPs by topic
- CDPs by date
- CDPs by number

Publications

This page is a repository for NREL's technical analysis results, papers, and presentations generated for this project.

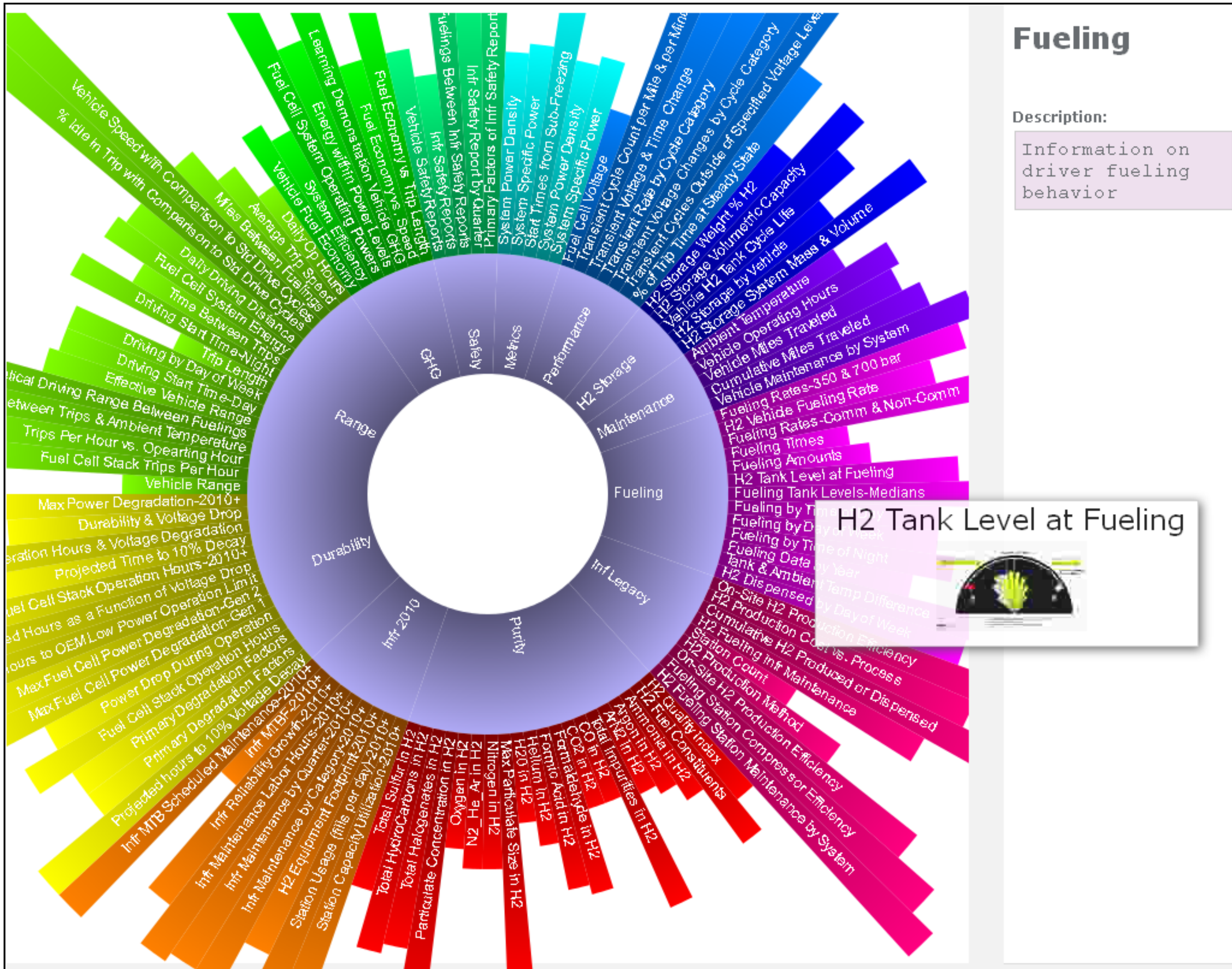
2012

- All Composite Data Products: National FCEV Learning Demonstration, with Updates through January 18, 2012. K. Wipke, S. Sprik, J. Kurtz, T. Ramsden, C. Ainscough, G. Saur. (January 2012)

2011

- Conclusion of the National FCEV Learning Demonstration Project. K. Wipke, S. Sprik, J. Kurtz, T.

New Graphical Way of Viewing Results Will Soon Be Online



Web demo

Sunburst temporarily located at http://nreldev.nrel.gov/hydrogen/_noctp/demo/source/sunburst.html

Online Questions and Discussion

Project Contact: Keith Wipke, National Renewable Energy Lab
303.275.4451 keith.wipke@nrel.gov

All public Learning Demo papers and presentations are available online at http://www.nrel.gov/hydrogen/proj_tech_validation.html

DOE FCT Program website:
http://www1.eere.energy.gov/hydrogenandfuelcells/index.html