NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Exceeding Expectations: Learnings from the FCV Learning Demo

Keith Wipke, Sam Sprik, Jennifer Kurtz, Todd Ramsden

May 5, 2010

NHA Conference
Long Beach, CA

NREL/PR-560-48200

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

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Outline

- Learning Demo Project Overview and Targets
- Vehicle and H2 Station Deployment Status
- Highlights of Latest Vehicle and Infrastructure Analysis Results
- Summary of Key Objectives vs. Targets

Fuel Cell Vehicle Learning Demonstration Project Objectives, Relevance, and Targets

- Objectives
  - Validate H_2 FC Vehicles and Infrastructure in Parallel
  - Identify Current Status and Evolution of the Technology
- Relevance
  - Objectively Assess Progress Toward Technology Readiness
  - Provide Feedback to H_2 Research and Development

Key Targets

Performance Measure	2009	2015
Fuel Cell Stack Durability	2000 hours	5000 hours
Vehicle Range	250+ miles	300+ miles
Hydrogen Cost at Station	$3/gge	$2-3/gge

Outside review panel

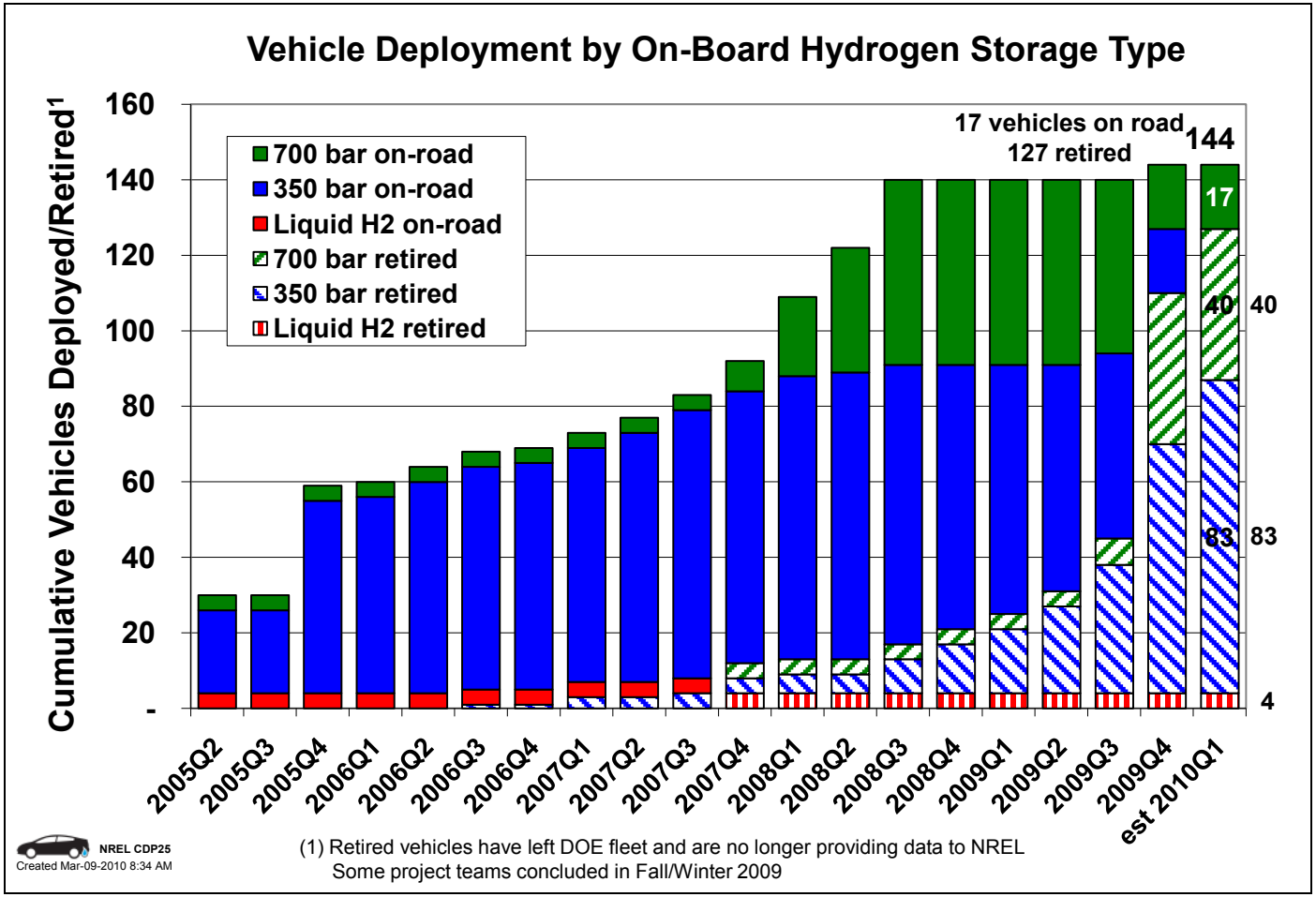
Burbank, CA station. Photo: NREL

Industry Partners Include Automakers and Energy-Suppliers

DAIMLER bp

GM Shell

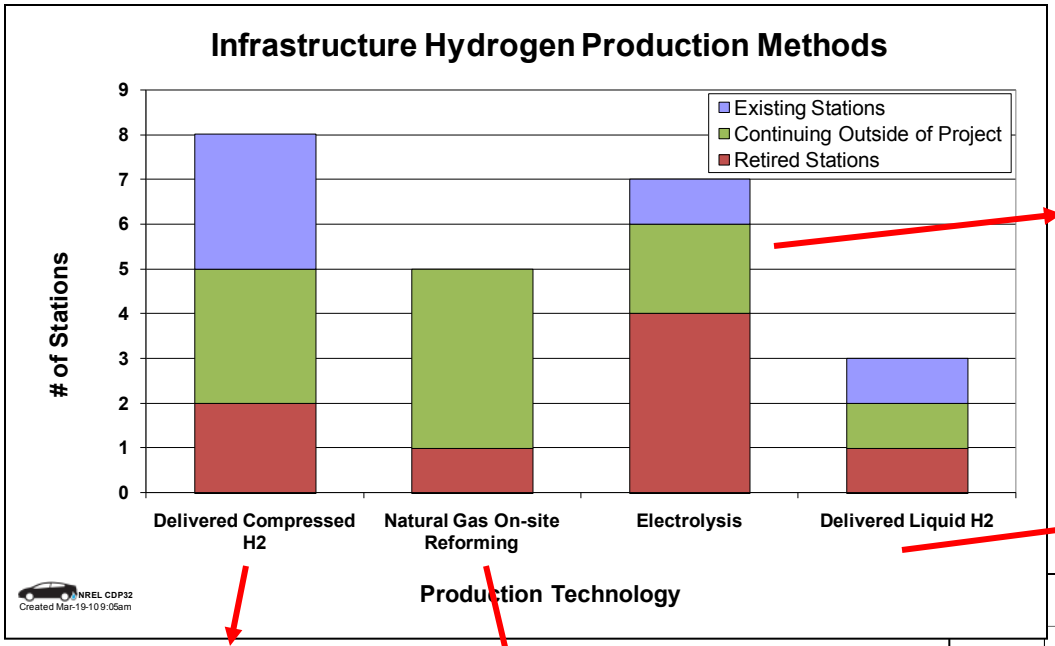
AIR PRODUCTS (CHIP)



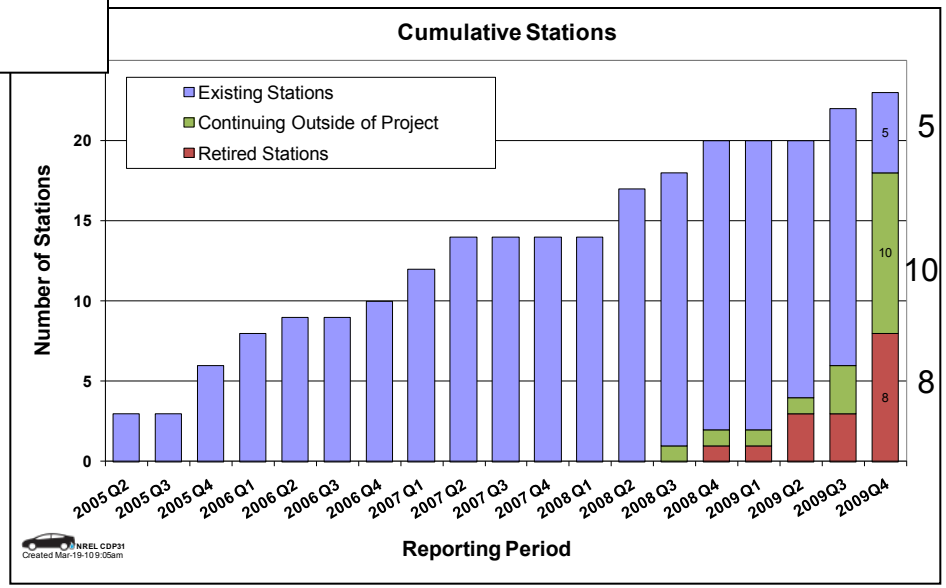
Chevron UTC Power HYUNDAI KIA

Ford bp

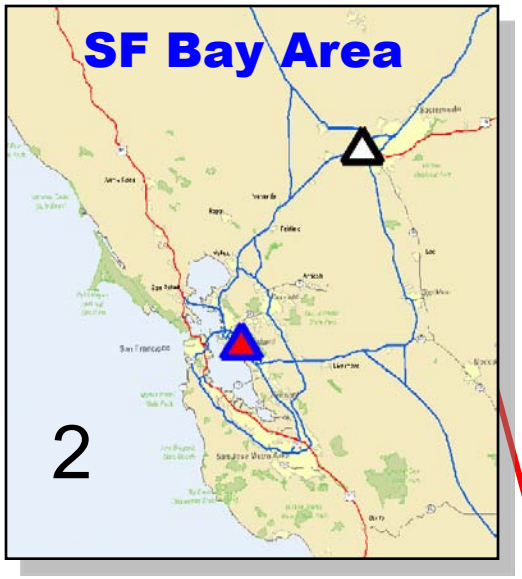
Status: >1/2 Learning Demo Stations Still in Operation; Remainder Decommissioned

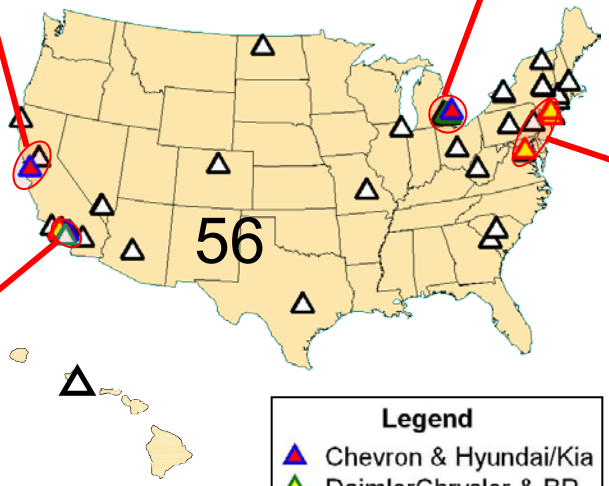


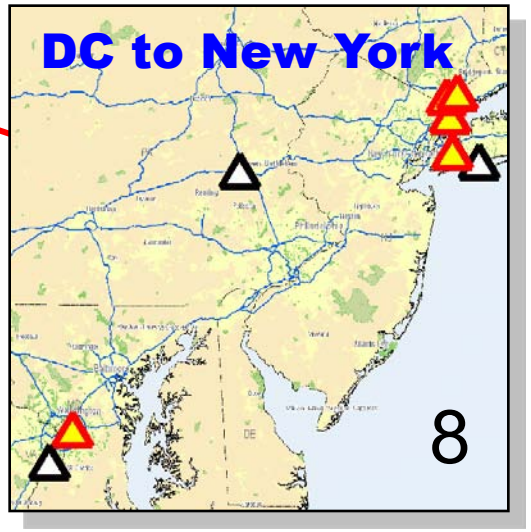
Total of 130,000 kg H_2 produced or dispensed from the 23 stations



Status: Learning Demo & CHIP Stations Still Serving as Critical Backbone of H_2 Infrastructure in LA and Northeast







Legend

- Chevron & Hyundai/Kia
- DaimlerChrysler & BP
- Ford & BP
- General Motors & Shell
- Air Products
- Other Companies

http://mapserve3.nrel.gov/Hydrogen/HydrogenViewer.html

Feb-18-2010

80 Public Composite Data Products Have Been Published; New Results and Updates Every 6 Months

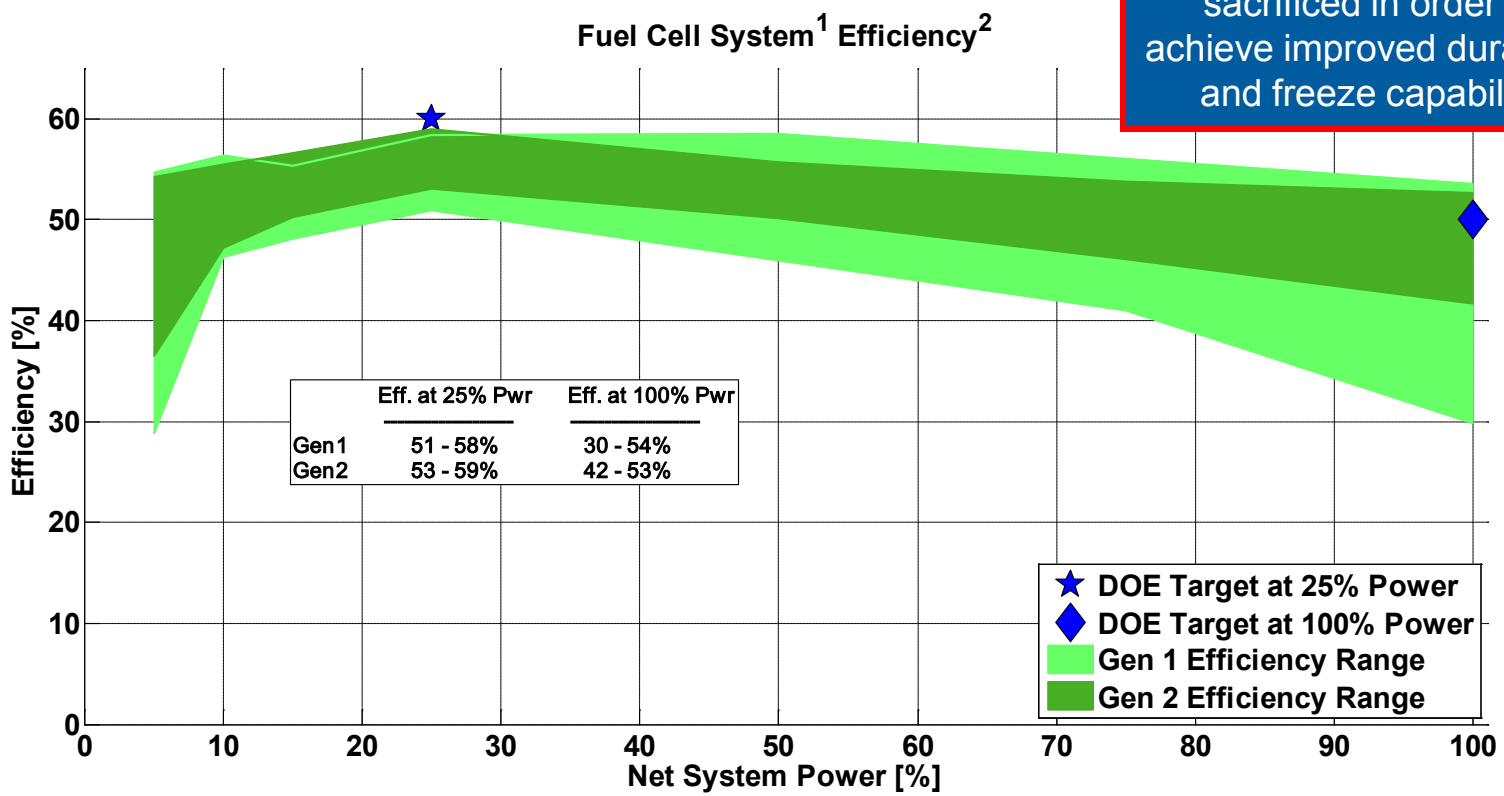
Since last NHA:
20 new + 52 updated + 8 static = 80 results

Results presented at:
FC Seminar, NHA, EVS

Highlights from the 80 latest results follow…

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



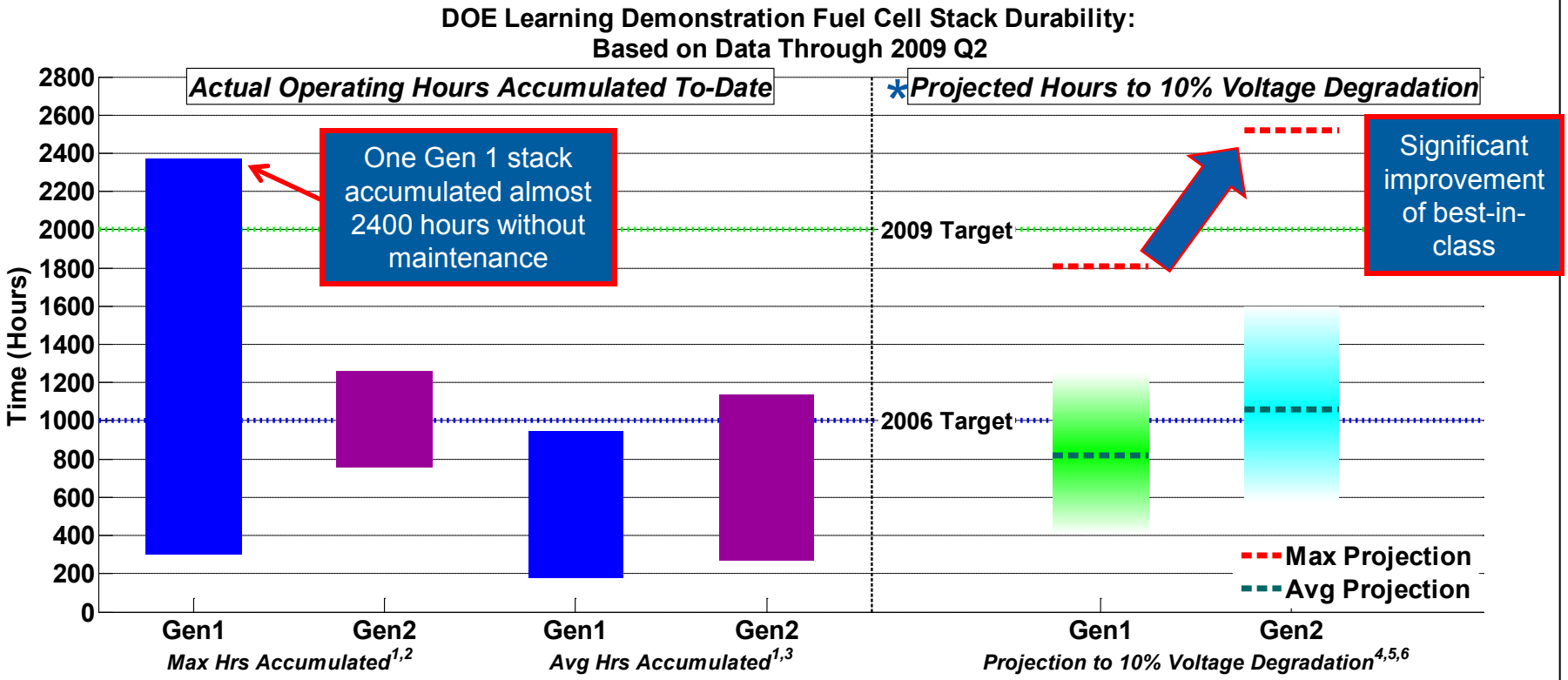
[1] Gross stack power minus fuel cell system auxiliaries, per DRAFT SAE J2615. Excludes power electronics and electric drive.

[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
Created: Sep-02-09 11:27 AM

Quantified Gen 2 Fuel Cell System Durability* Improvement from Gen 1

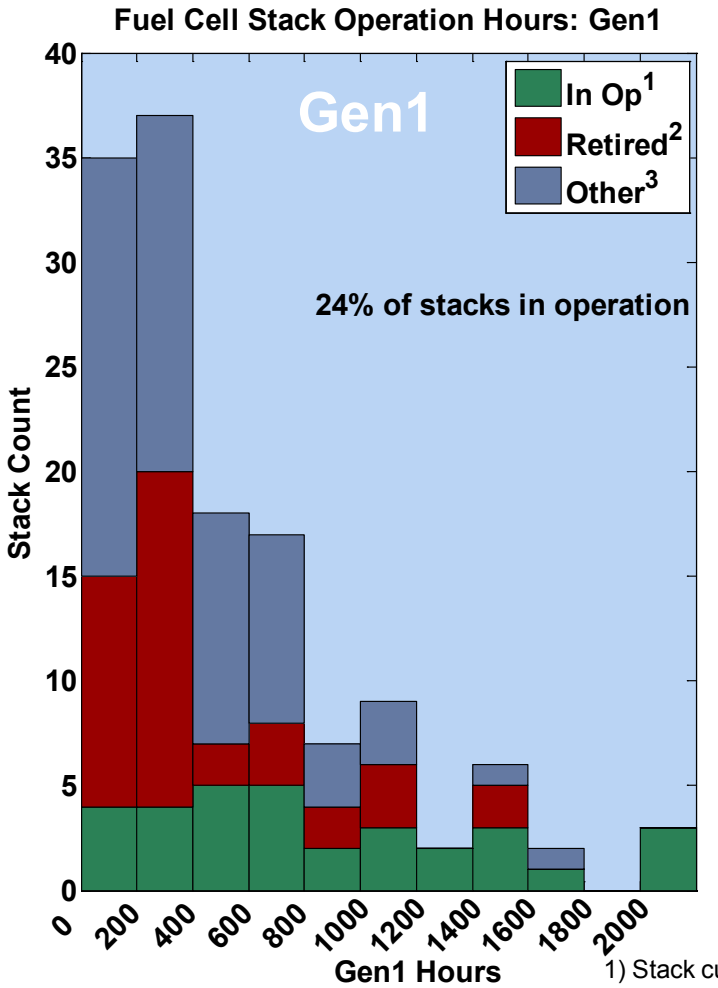


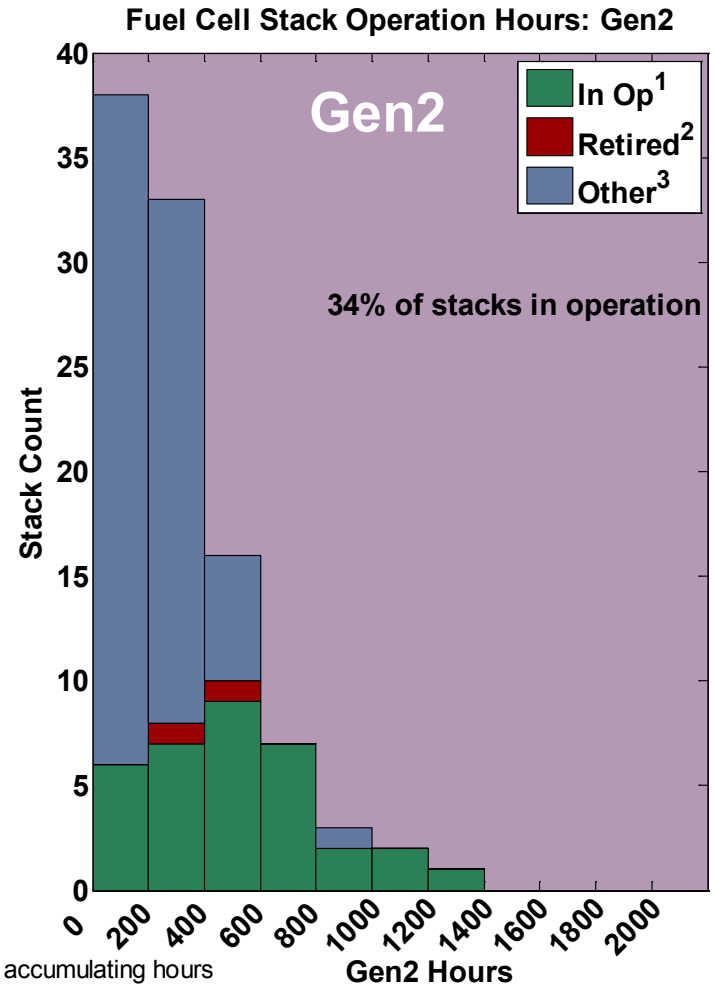
(1) Range bars created using one data point for each OEM. Some stacks have accumulated hours beyond 10% voltage degradation.
(2) Range (highest and lowest) of the maximum operating hours accumulated to-date of any OEM's individual stack in "real-world" operation.
(3) Range (highest and lowest) of the 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
Created: Mar-23-10 10:39 AM

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

Fuel Cell Stack Operation Hours Histogram

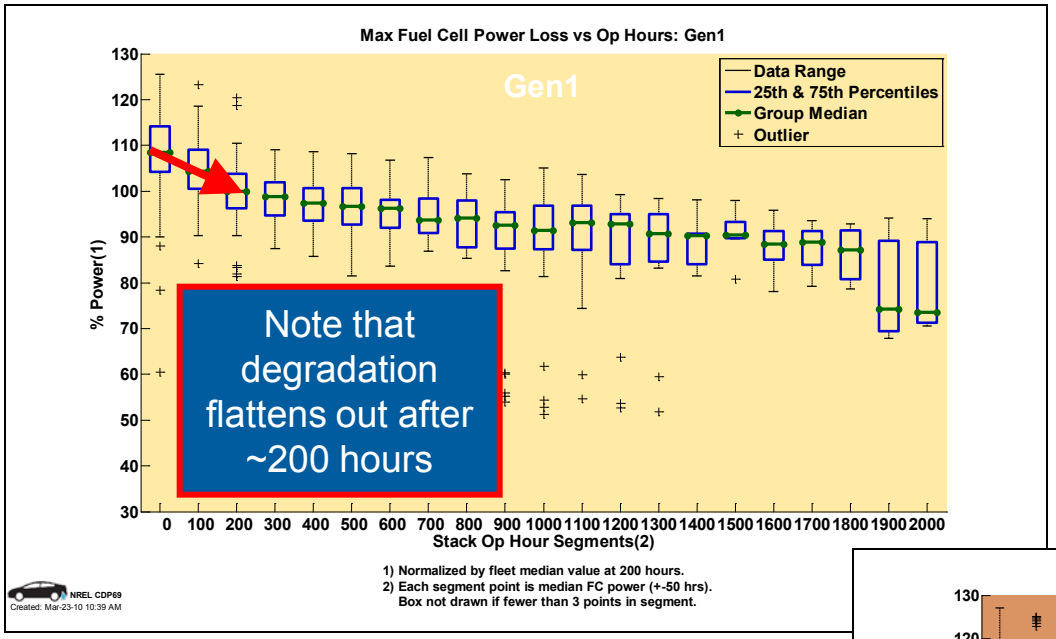


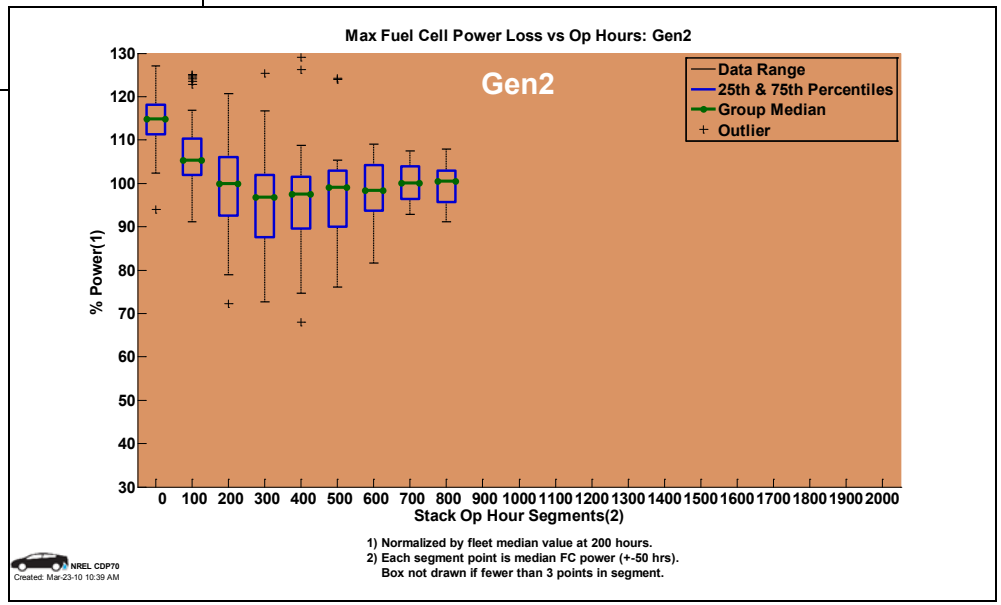


NREL CDP67
Created: Mar-23-10 10:39 AM

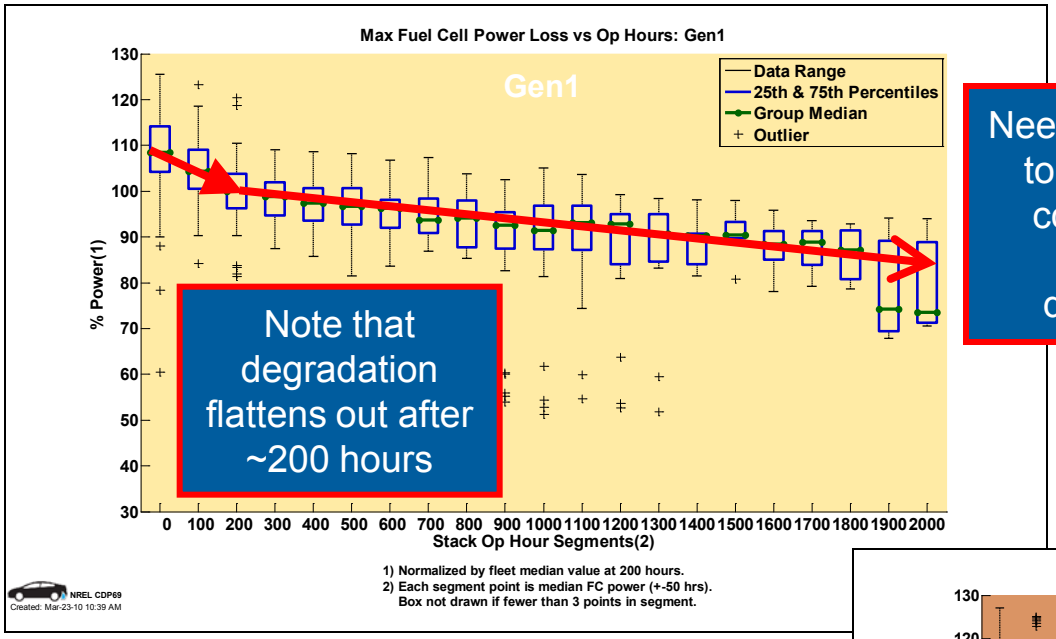
1) Stack currently accumulating hours
2) Stack removed for low performance
3) Stack not currently accumulating hours, but not removed because of low performance. Some project teams concluded in Fall/Winter 2009

Completed Final Analysis of Gen 1 Fuel Cell System Power Degradation



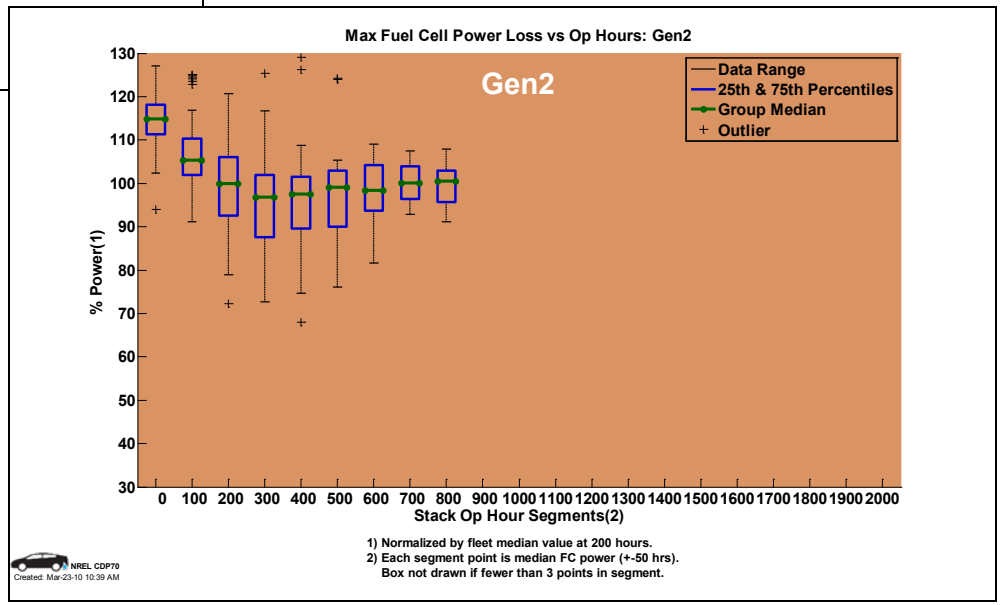


Completed Final Analysis of Gen 1 Fuel Cell System Power Degradation

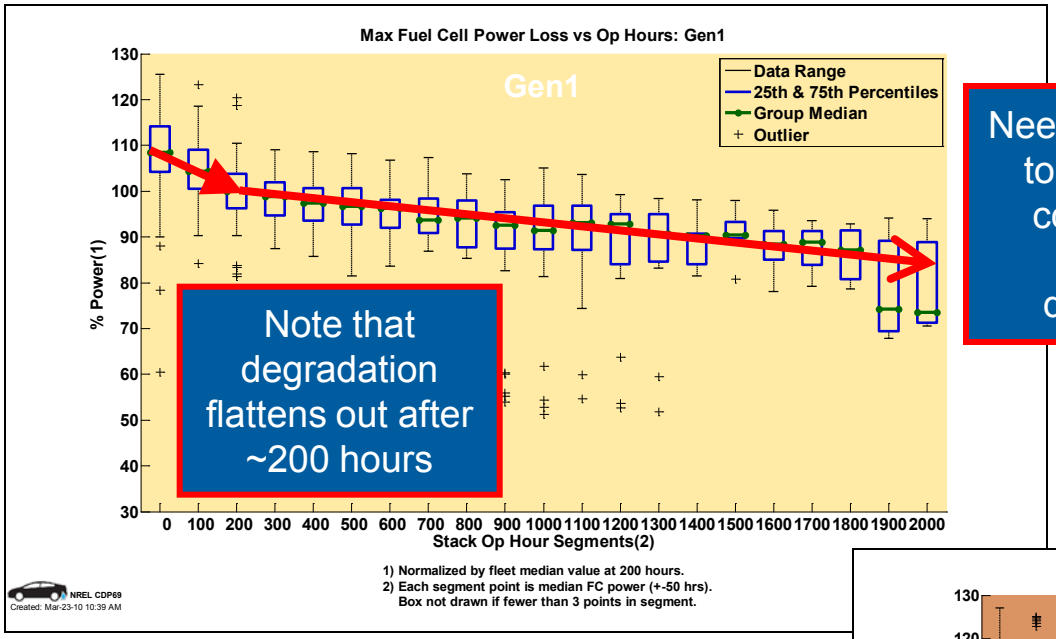


Note that degradation flattens out after ~200 hours

Need ~1000 hours to have higher confidence in slope of degradation



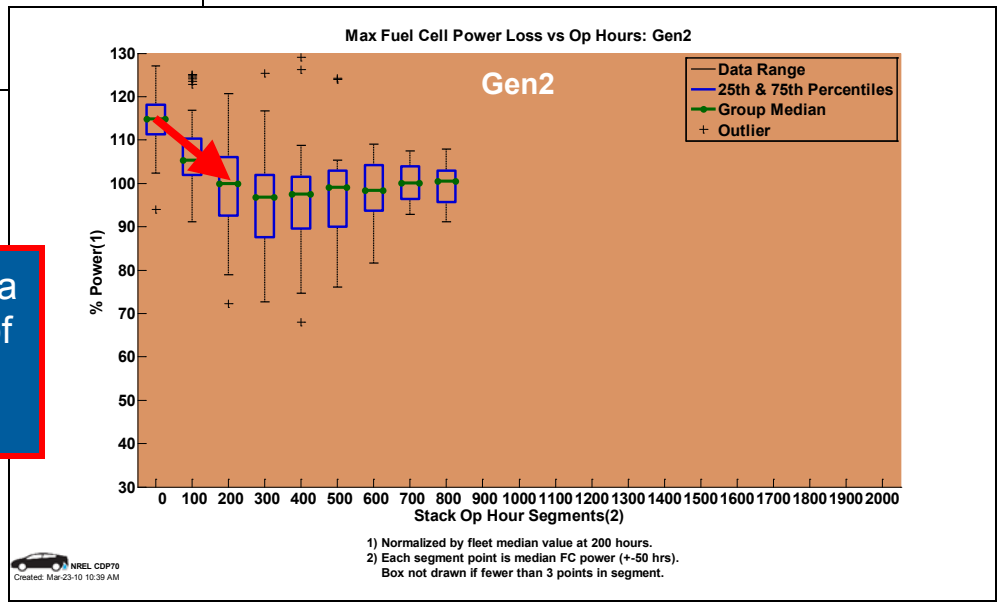
Completed Final Analysis of Gen 1 Fuel Cell System Power Degradation



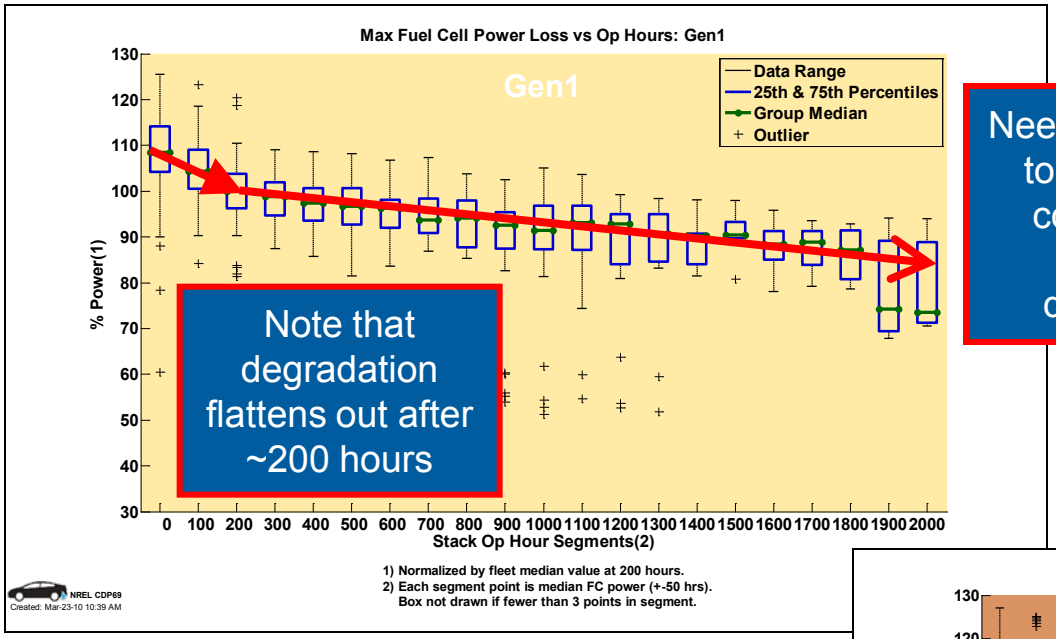
Need ~1000 hours to have higher confidence in slope of degradation

Note that degradation flattens out after ~200 hours

From limited Gen 2 data received so far, trend of flattening after 200 hours appears similar



Completed Final Analysis of Gen 1 Fuel Cell System Power Degradation

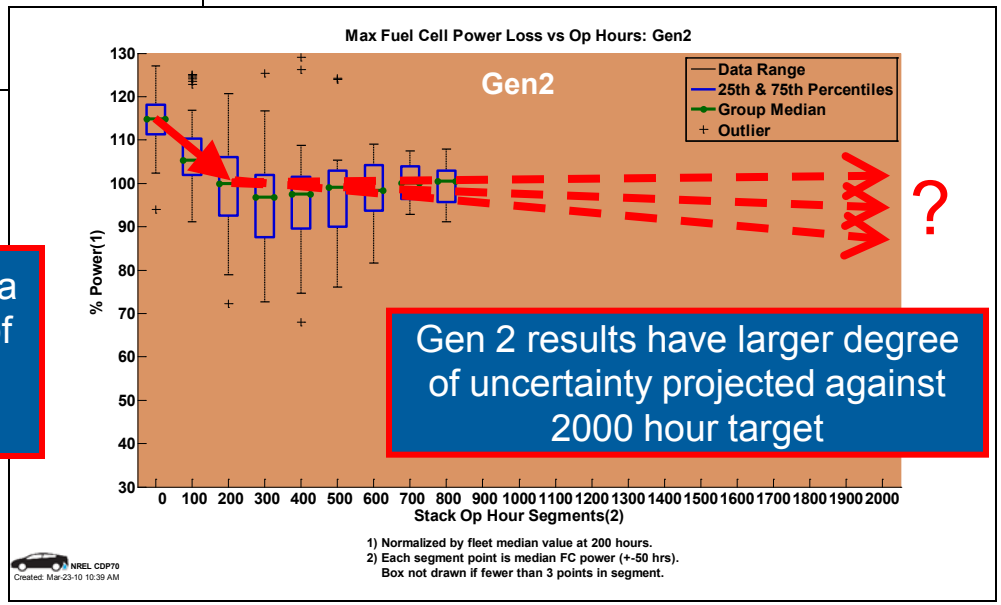


Need ~1000 hours to have higher confidence in slope of degradation

Note that degradation flattens out after ~200 hours

All vehicles continuing in the project will be Gen 2 vehicles

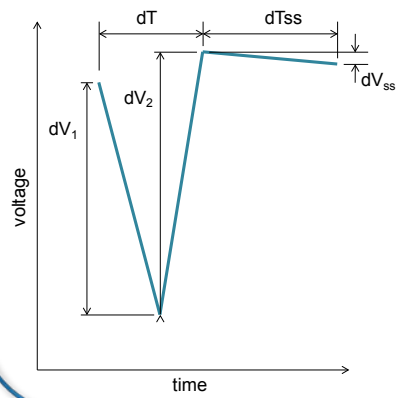
From limited Gen 2 data received so far, trend of flattening after 200 hours appears similar



Gen 2 results have larger degree of uncertainty projected against 2000 hour target

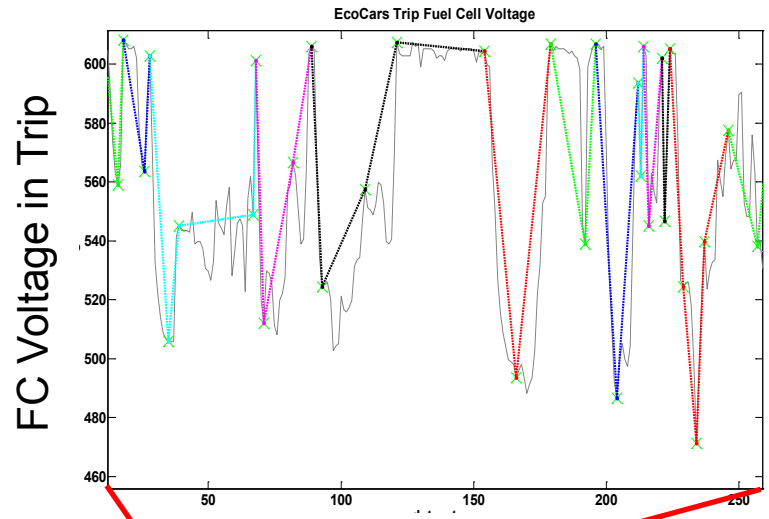
Accomplishment: Developed Methodology for Tracking FC System Voltage Transients

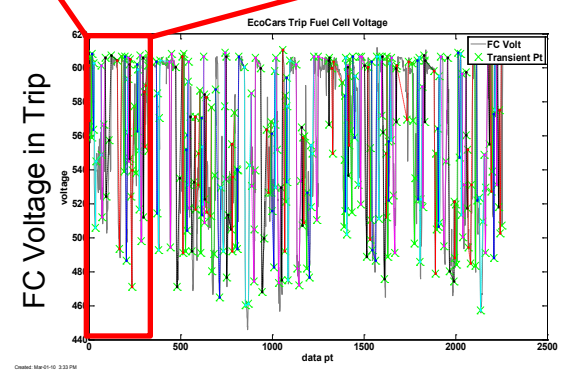
1) Define a voltage transient cycle



Cycle Definition:
dV >= 10% Nom Stack V
dTss >= 10 sec
dVss <= 5% Nom Stack V

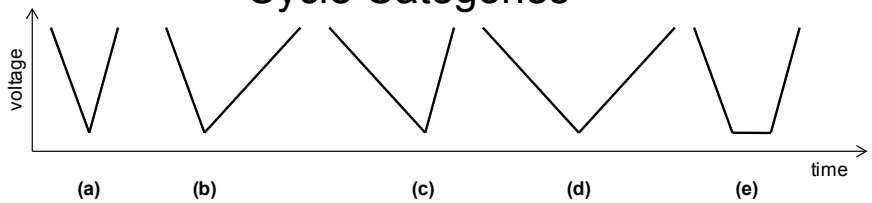
2) Find voltage transient cycles



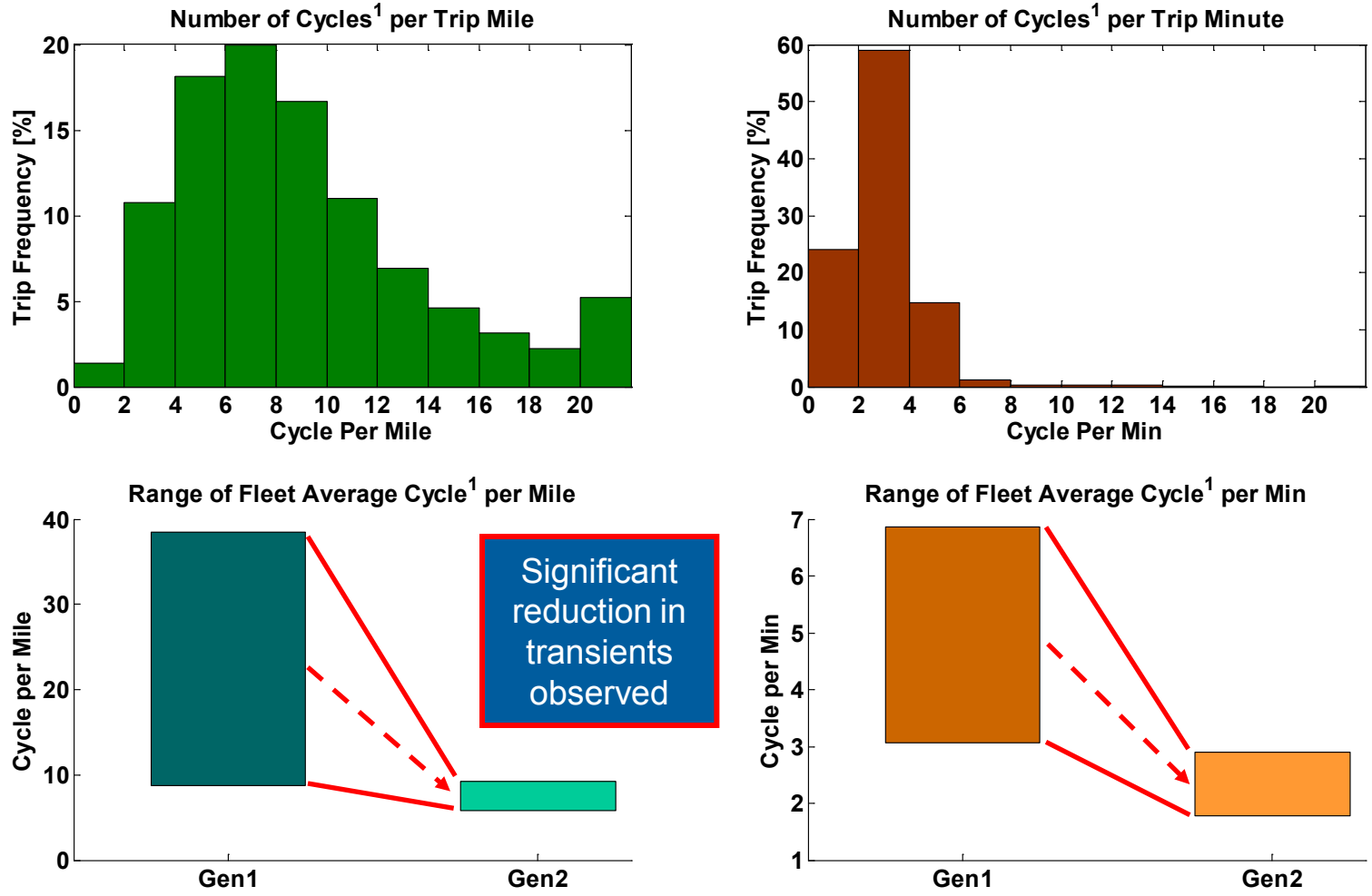


3) Categorize and collect voltage transient cycle details

Cycle Categories



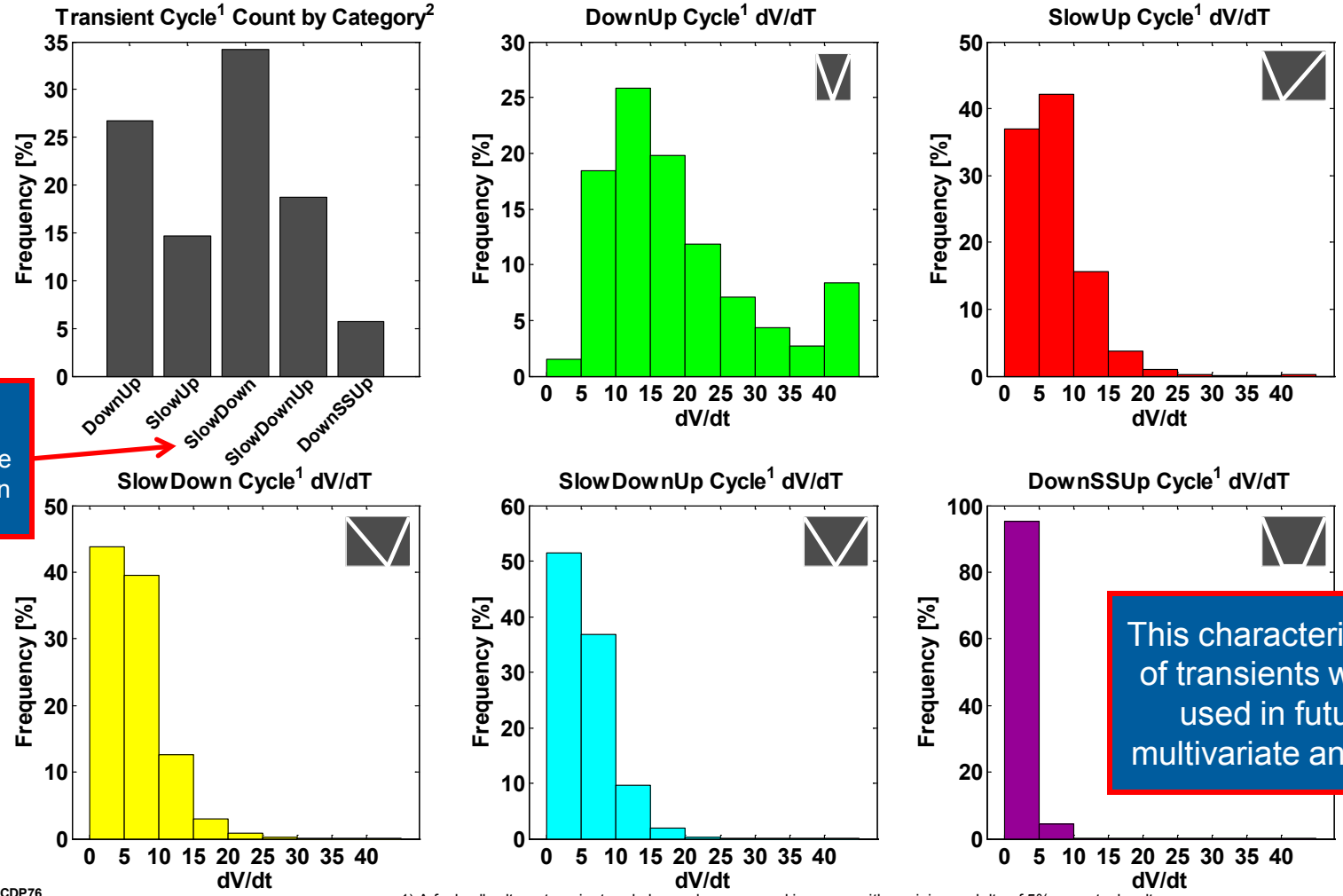
Quantified Transient Cycle Reduction Between Gen 1 and Gen 2 FC Systems



NREL CDP74
Created: Mar-22-10 4:46 PM

1) A fuel cell voltage transient cycle has a decrease and increase with a minimum delta of 5% max stack voltage.

Characterized Fuel Cell Transient Rates by Cycle Category



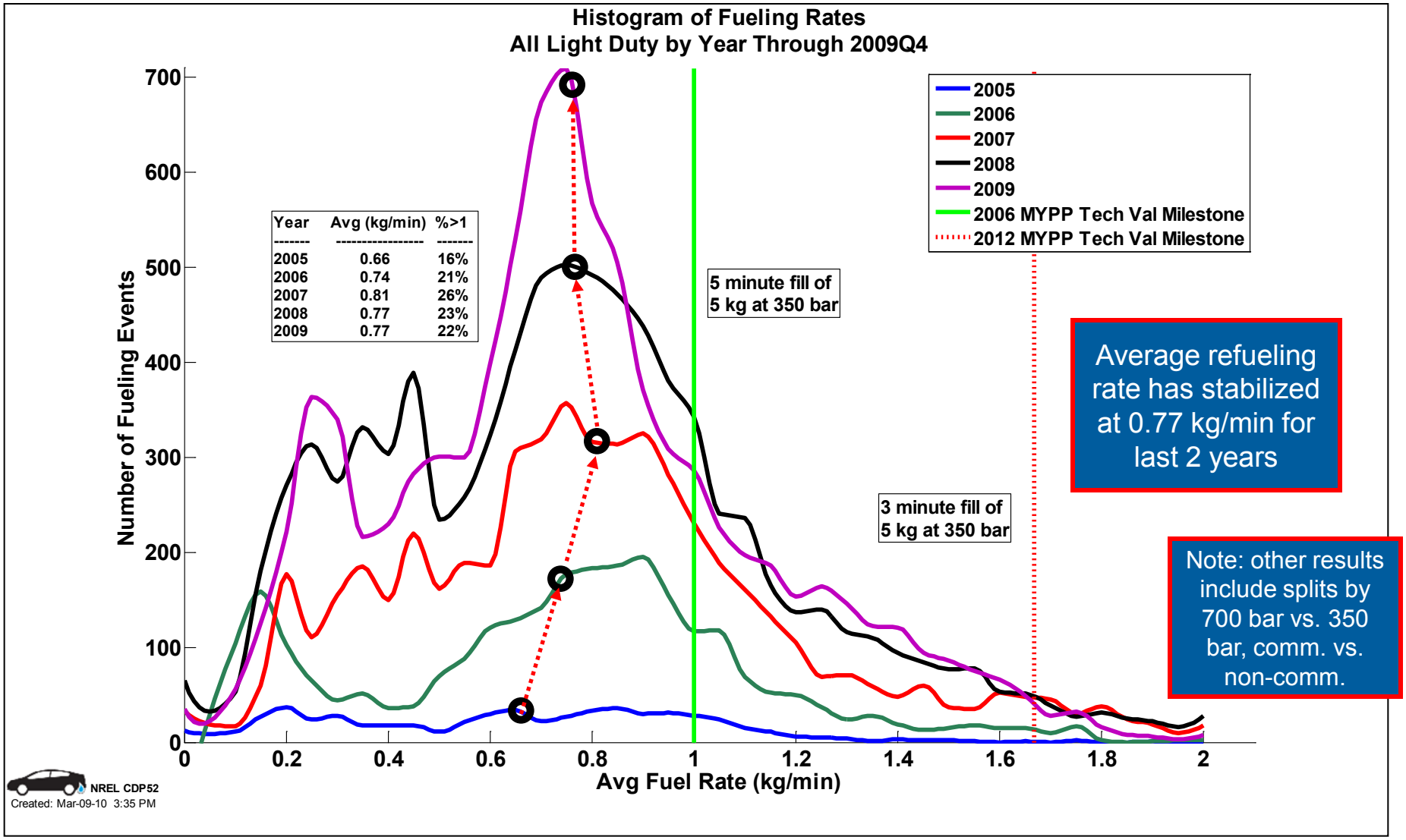
Type: The slow down, fast up are the most common transients

This characterization of transients will be used in future multivariate analysis

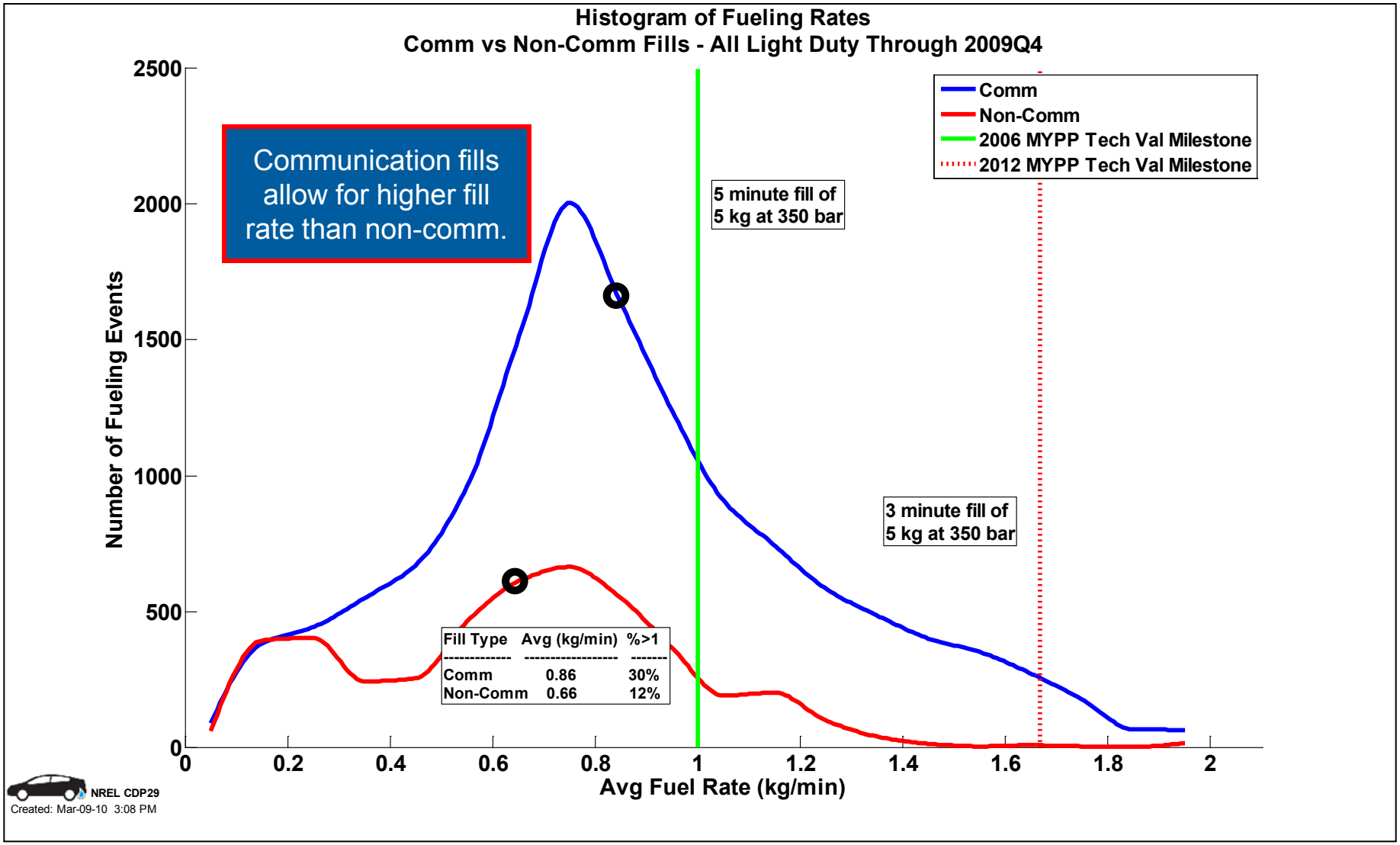
NREL CDP76
Created: Mar-22-10 4:46 PM

1) A fuel cell voltage transient cycle has a decrease and increase with a minimum delta of 5% max stack voltage.
2) Cycle categories based on cycle up and down times. A slow up or down transient has a time change >= 5 seconds.
SS = Steady State, where the time change is >= 10 seconds and the voltage change is <= 2.5% max stack voltage.

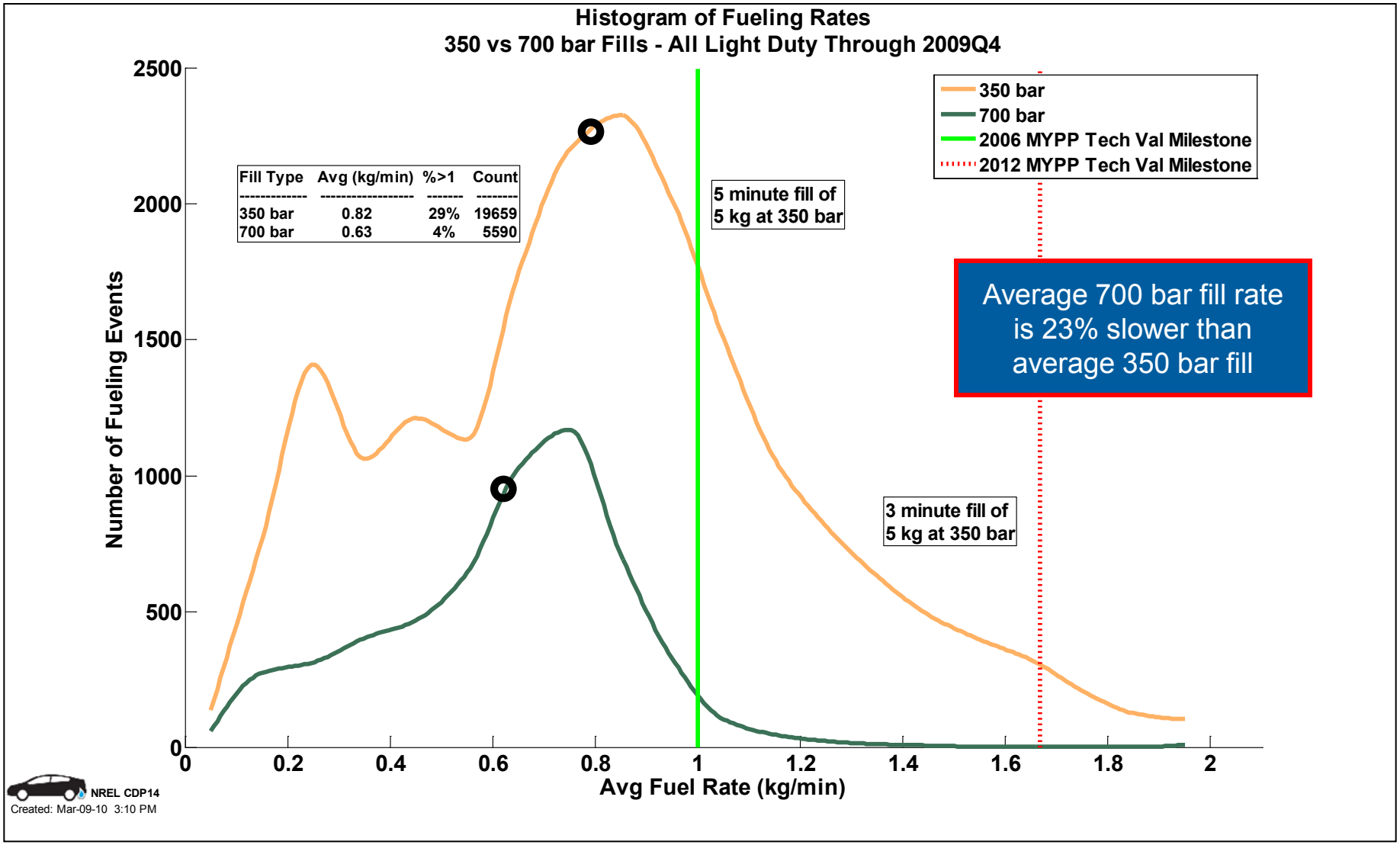
Tracked Refueling Rates Over 5 Year Period of Project



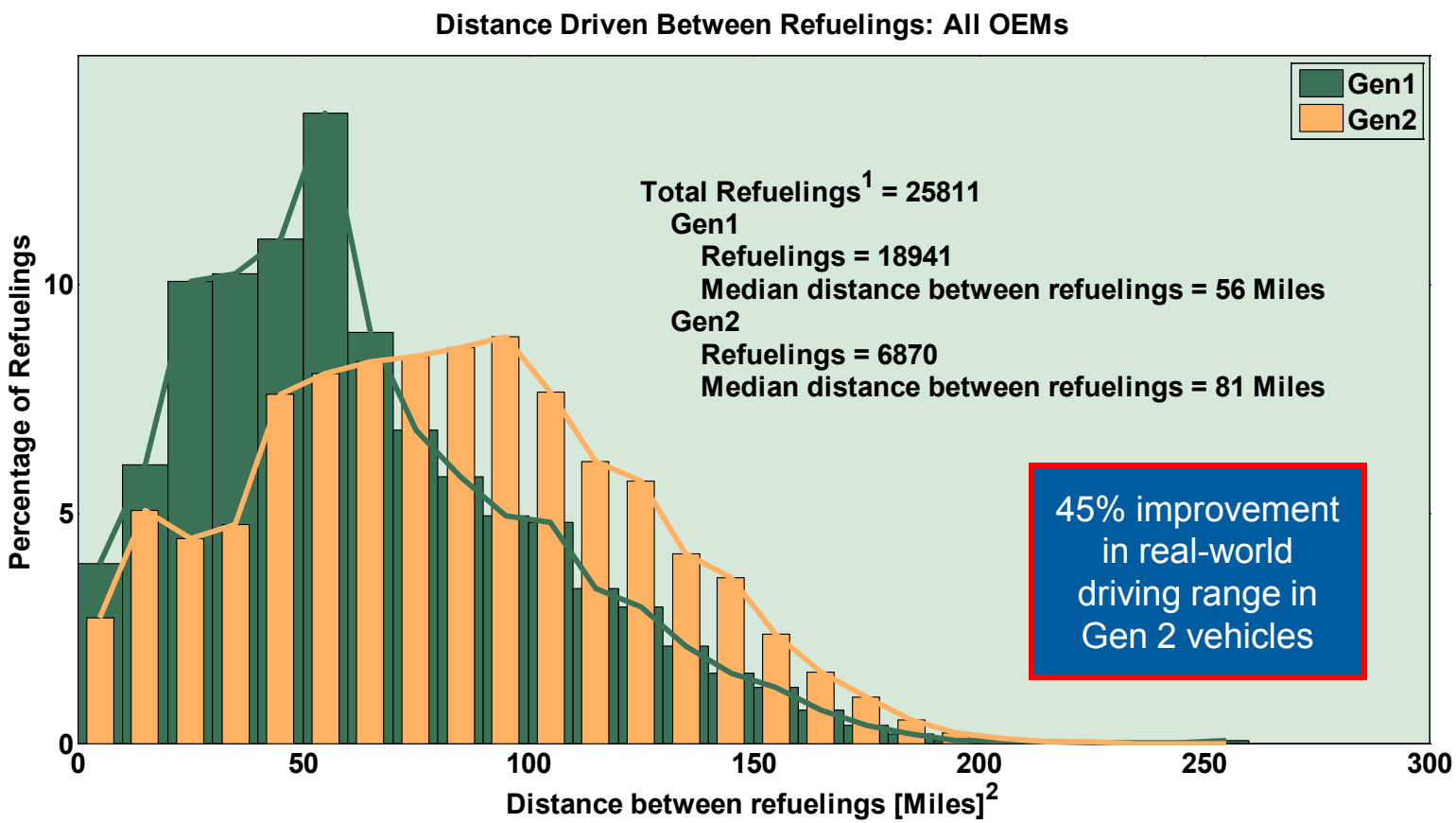
Fueling Rates Communication and Non-Communication Fills



Fueling Rates – 350 and 700 bar



Range: Quantified Real-World Improvement in Driving Range Between Gen 1 and Gen 2 Vehicles



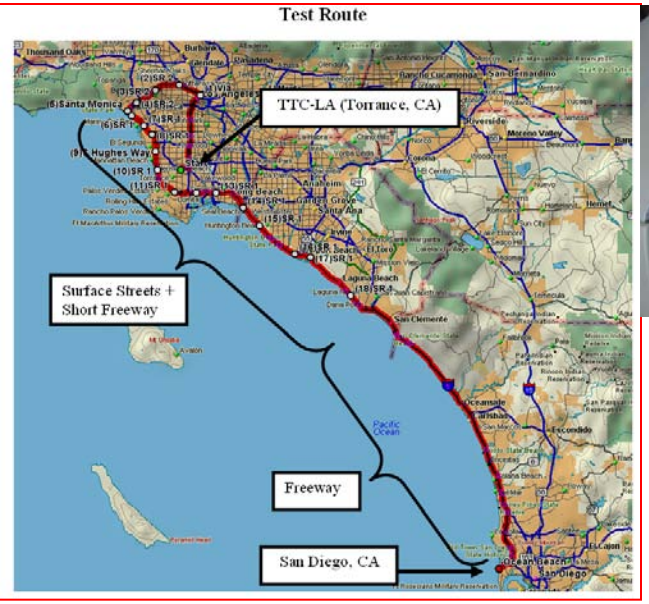
45% improvement in real-world driving range in Gen 2 vehicles

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.

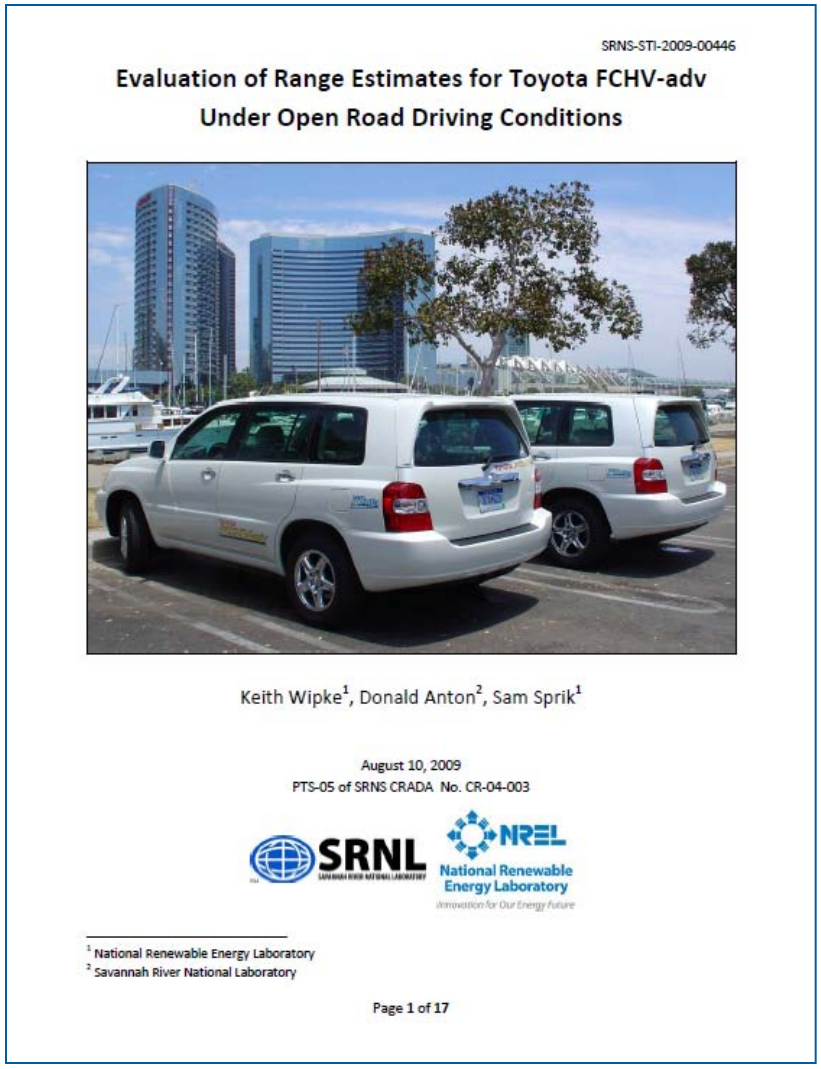
NREL CDP80
Created: Mar-23-10 10:53 AM

NREL 2009 NHA results showed "window-sticker" range of 196-254 miles

Range: NREL/SRNL Verified Toyota FCHV-adv Driving Range >400-Mile (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
Innovation for Our Energy Future

[1] National Renewable Energy Laboratory
[2] Savannah River National Laboratory

Page 1 of 17

Summary – Key Performance Metrics

Vehicle Performance Metrics	Gen 1 Vehicle	Gen 2 Vehicle	2009 Target
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	
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
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)

Summary

- Project has completed 5 full years of operation
- Vehicle operation: 106,000 hours, 2.5 million miles, 427,000 trips
- H2 station operation: 130,000 kg produced or dispensed, 25,000 refuelings
- DOE FC Durability and Range Targets Met
- Two of the OEMs will be continuing operation of Gen 2 vehicles through end of 2011; *more results to come*
- Future work: Additional collaboration with remaining auto OEM teams to make analyses useful for technology evolution and preparation for 2014-2015 market entry

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