NREL
NATIONAL RENEWABLE ENERGY LABORATORY

DEM43-1

FUEL CELL SEMINAR & EXPOSITION

U.S. Fuel Cell Electric Vehicle Demonstration Project 2010 Status Update

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Fuel Cell Seminar
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Outline

- Project Goals
- Vehicle and H2 Station Deployment Status
- Performance Compared to Targets
- Highlights of Latest Vehicle and Infrastructure Analysis Results and Progress
- Conclusions and Future work

Fuel Cell Electric Vehicle Learning Demo 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

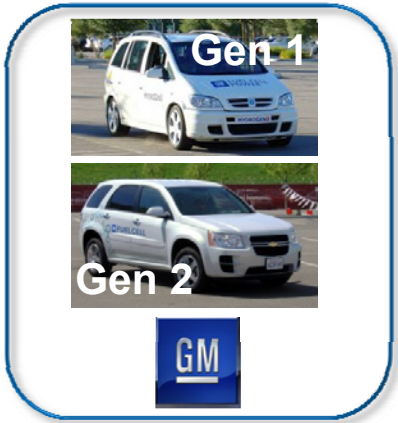
Note: Project extended 2 years to 2011

Burbank, CA station. Photo: NREL

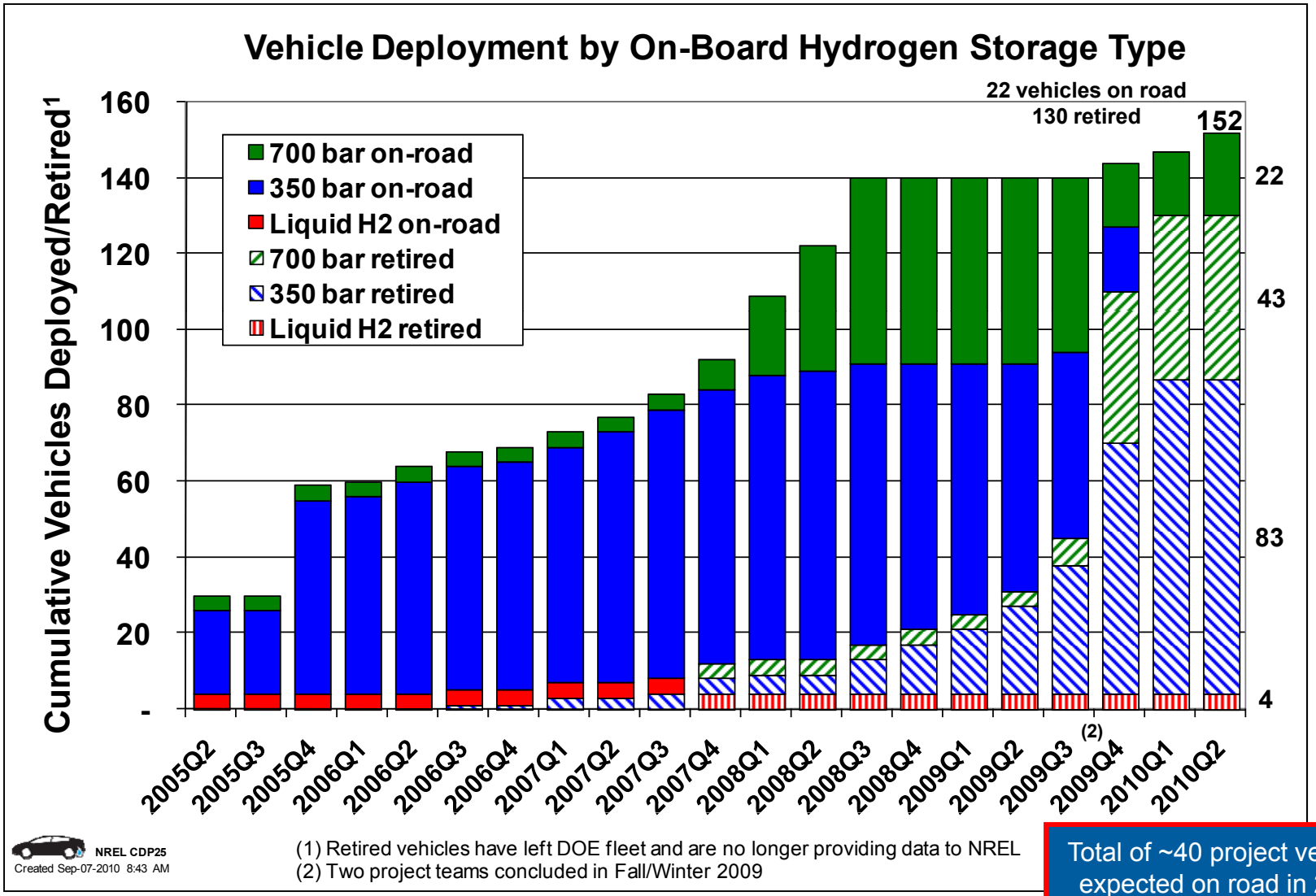
Two Teams Concluded Their Projects in 2009, Three are Continuing through 2011

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

Daimler, GM, and Air Products Continue to Demonstrate Vehicles/Stations within Project through 2011



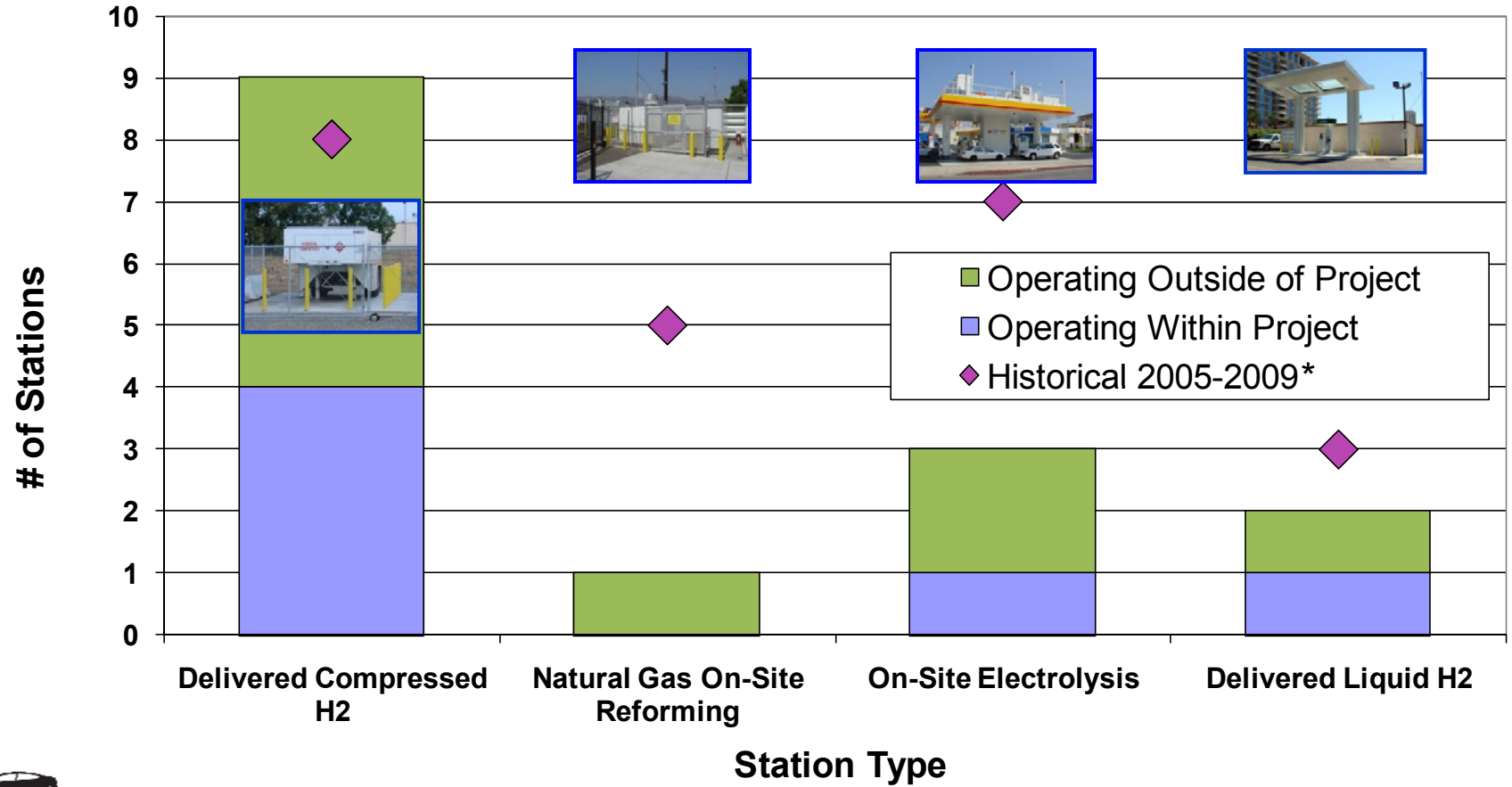
Vehicle Status: All 350 bar Vehicles Retired, Only 700 bar Vehicles Continuing



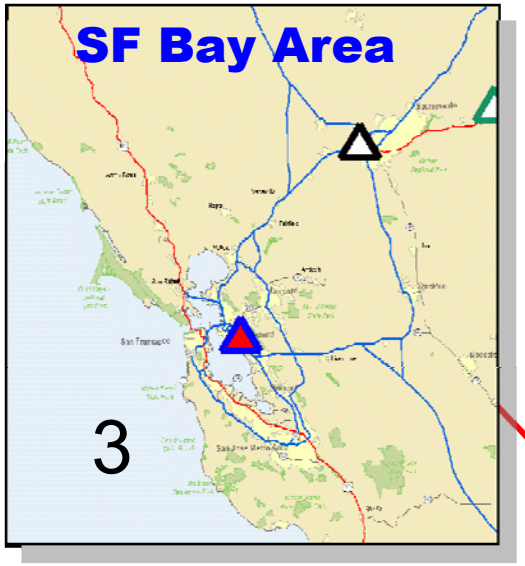
(1) Retired vehicles have left DOE fleet and are no longer providing data to NREL
(2) Two project teams concluded in Fall/Winter 2009

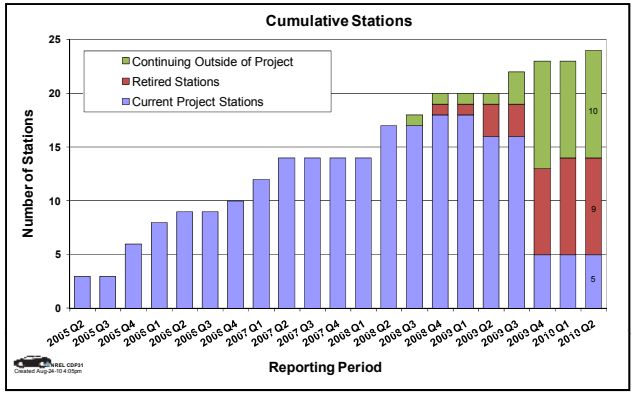
Total of ~40 project vehicles expected on road in 2011, for total of ~170 deployed

Fueling Station Status: Stations that Continue to Operate are Mostly Delivered Compressed Hydrogen



Out of 24 Project Stations, 15 Are Still Operational (2/3 outside of DOE project)





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9

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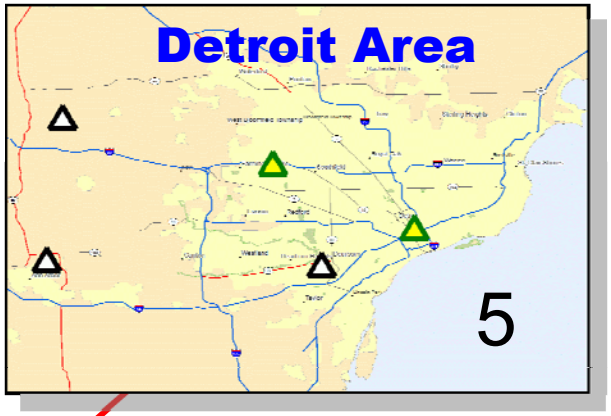
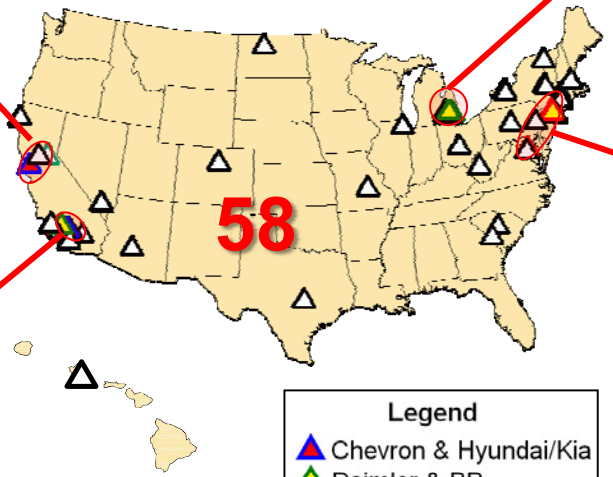
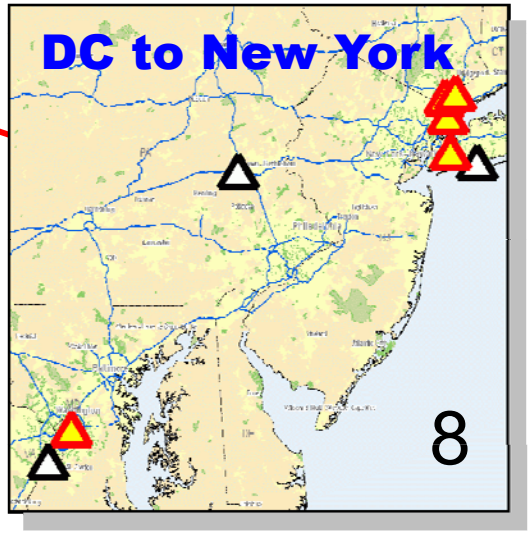






Legend
- Chevron & Hyundai/Kia
- Daimler & BP
- Ford & BP
- General Motors & Shell
- Air Products
- Other Companies

Evaluation Against 3 Primary Metrics

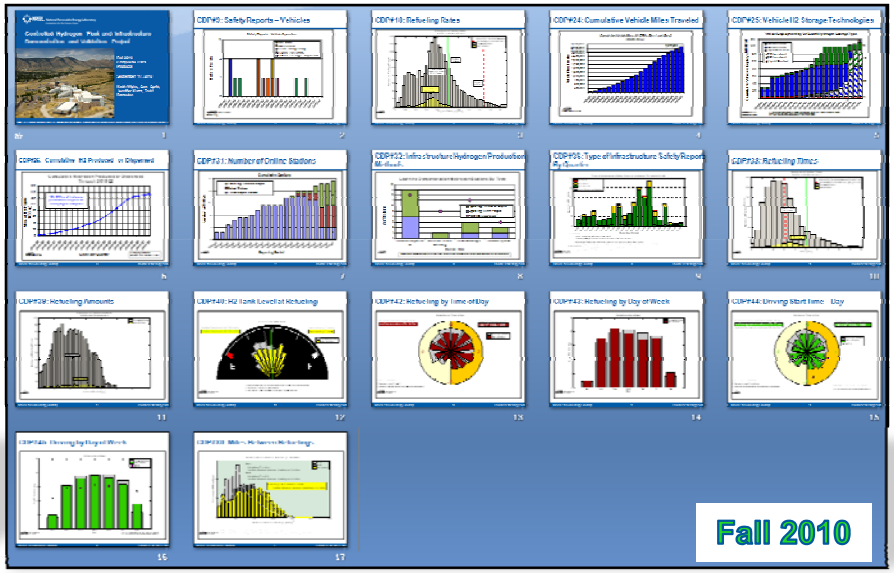
Vehicle Performance Metrics	Gen 1 Vehicle	Gen 2 Vehicle	2009 Target
Fuel Cell Stack Durability			**2000 hours**
Max Team Projected Hours to 10% Voltage Degradation	**1807 hours**	**2521 hours**	
Average Fuel Cell Durability Projection	821 hours	1062 hours	
Max Hours of Operation by a Single FC Stack 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)

Outside review panel

What are the Differences Between the Spring 2010 and Fall 2010 Results?



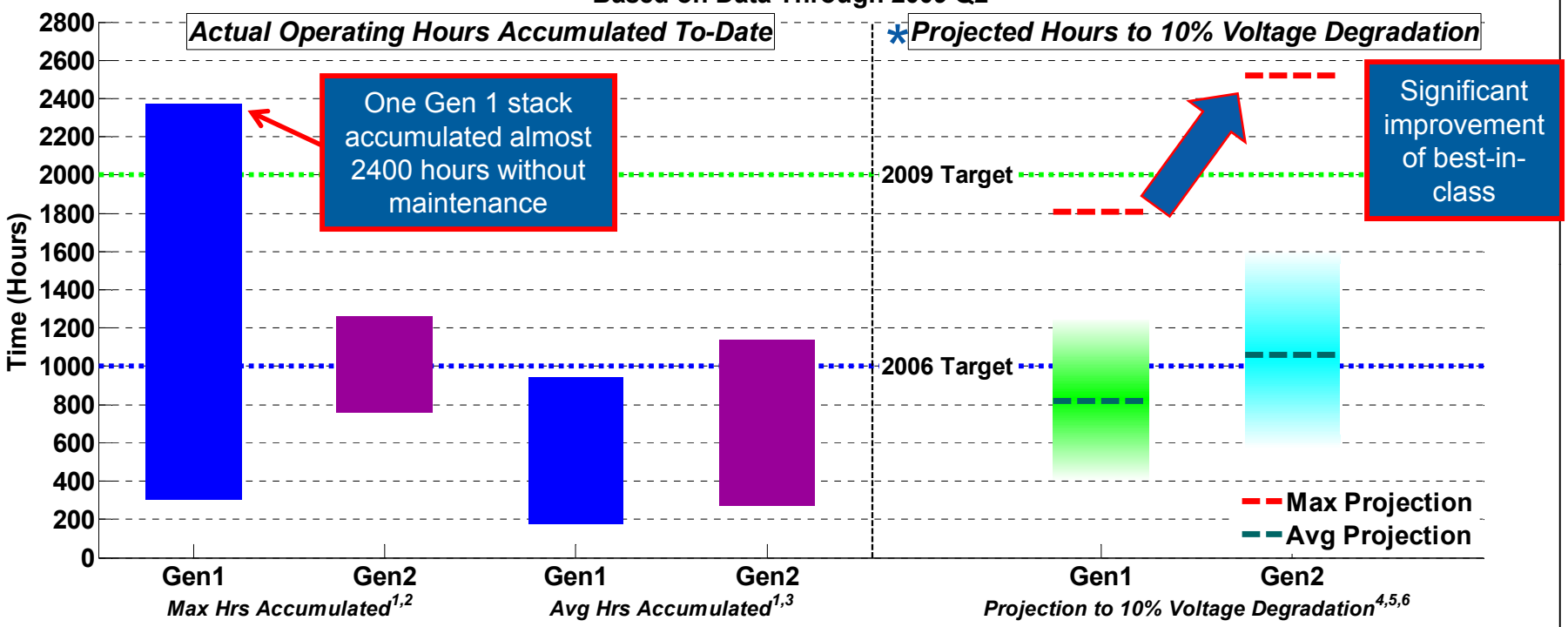
80 Spring 2010 Results

- Most comprehensive set we ever published
- Includes durability, range, fuel economy, etc.
- Covers data from all 4 Learning Demo teams + CHIP project over 5 year period
- Majority of these will now stay static, serving as a historical record of Gen 1 & Gen 2 comparisons.

16 Fall 2010 Results

- No “new” CDPs, but we updated 16 previously published CDPs with data from last 6 months
- Results on most recent durability, range, fuel economy, not yet possible to publish until more data accumulated (in 2011)
- Covers data from 2 Learning Demo OEMs + CHIP project
- Emphasized changes observed in last 6 months through use of gray (old) and colors (new)

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.

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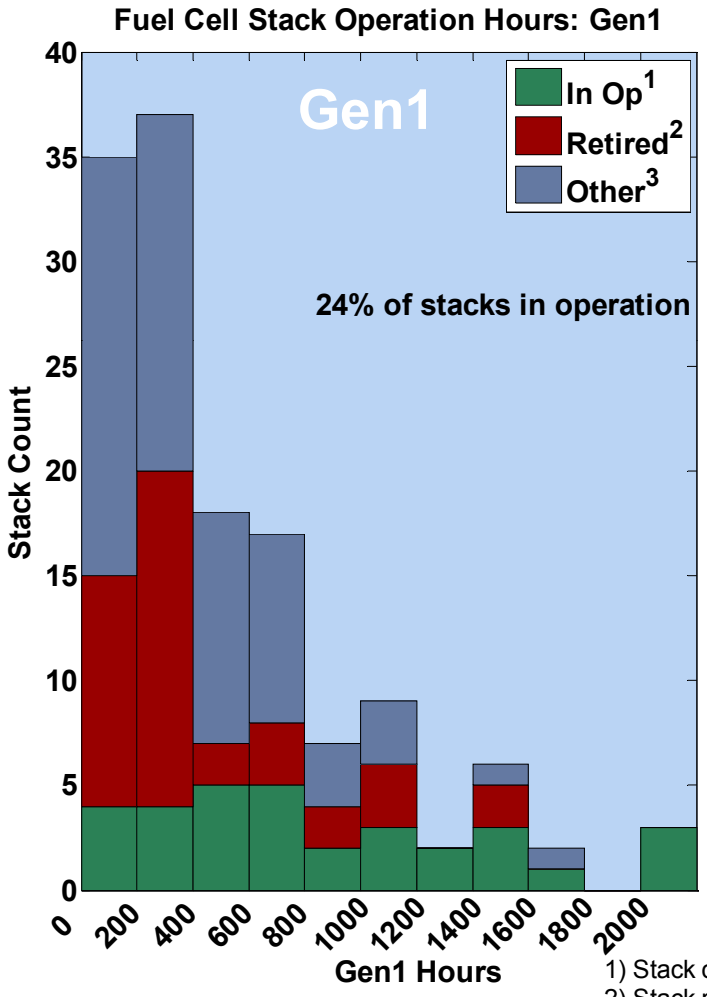
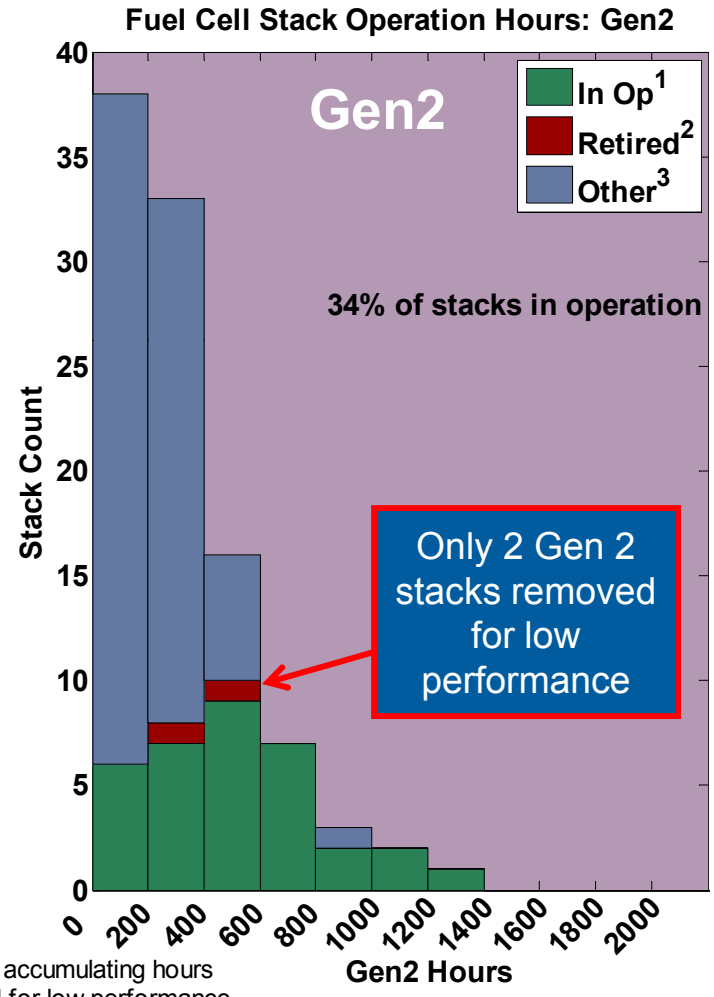
* Durability is defined by DOE as projected hours to 10% voltage degradation

Spring 2010

Fuel Cell Stack Operation Hours Histograms Show Differences Between Gen 1 and Gen 2





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

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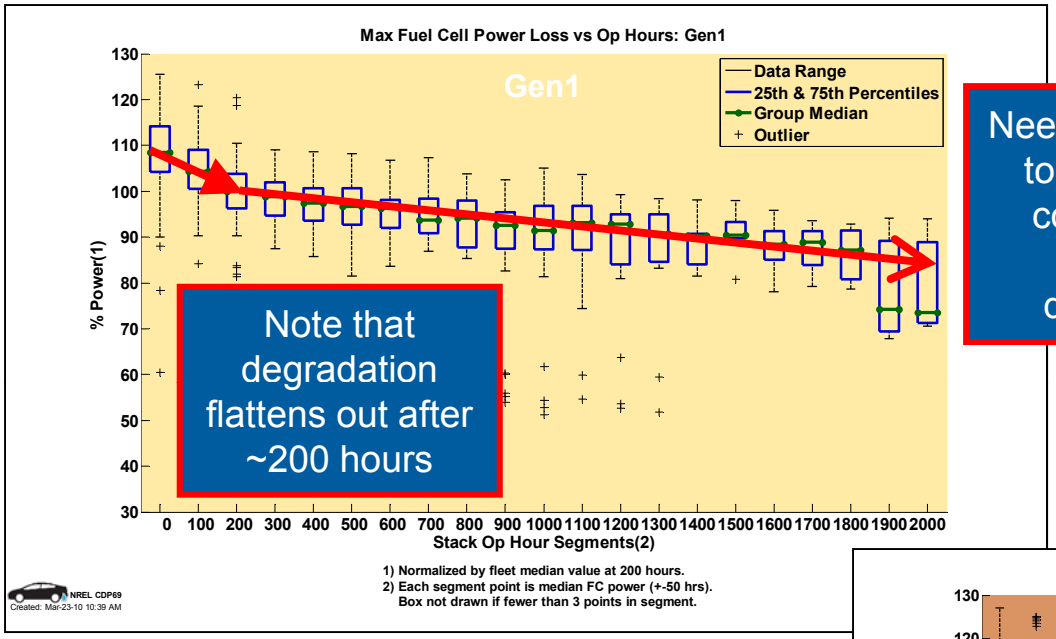
Spring 2010

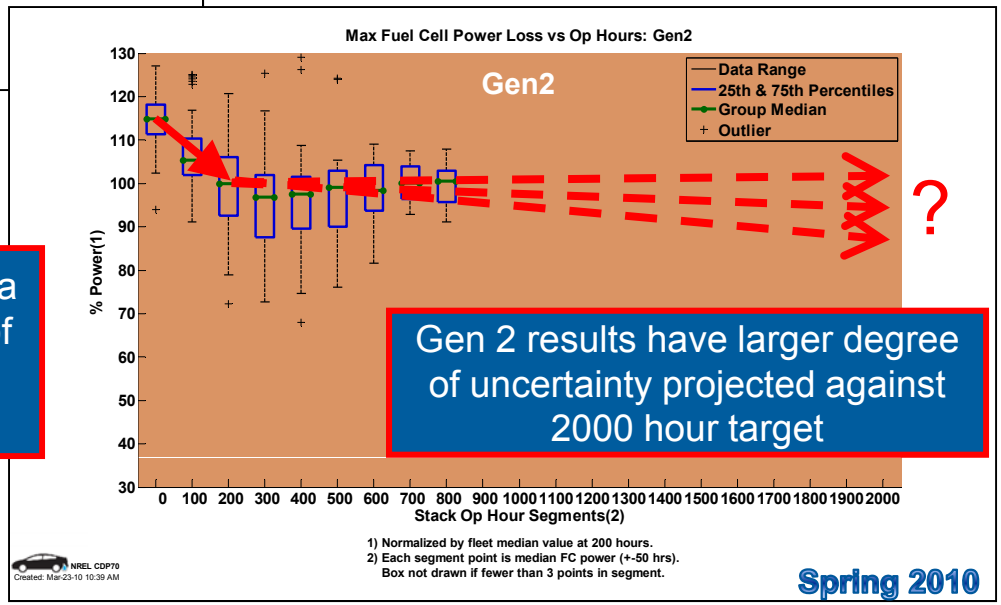
Completed Final Analysis of Gen 1 Fuel Cell System Power Degradation



Note that degradation flattens out after ~200 hours

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

All vehicles continuing in the project will be Gen 2 vehicles

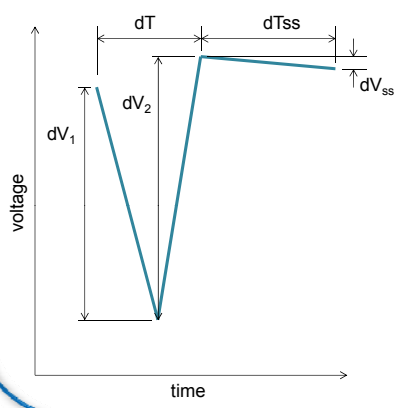


From limited Gen 2 data received so far, trend of flattening after 200 hours appears similar

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

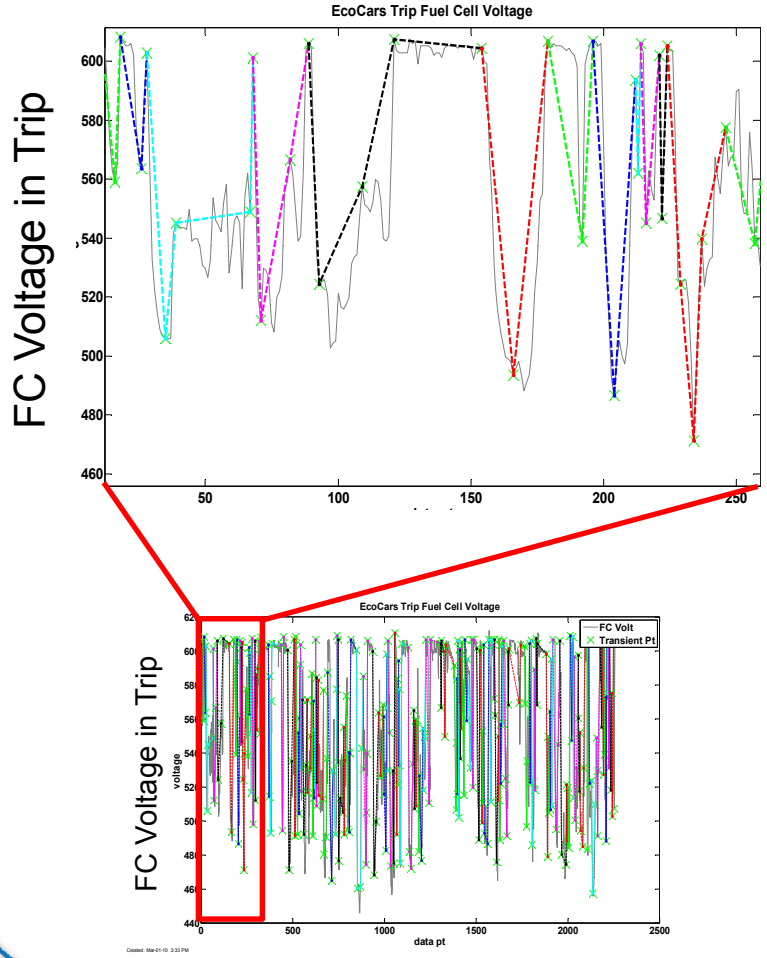
Developed Methodology for Tracking FC System Voltage Transients

1) Define a voltage transient cycle

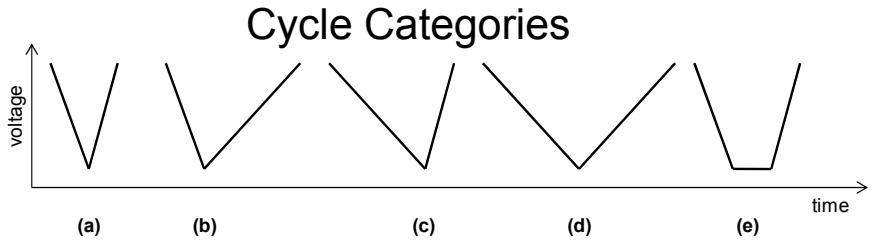


Cycle Definition:
dV >= 10% Nom Stack V
dTss >= 10 sec
dVss <= 5% Nom Stack V

2) Find voltage transient cycles

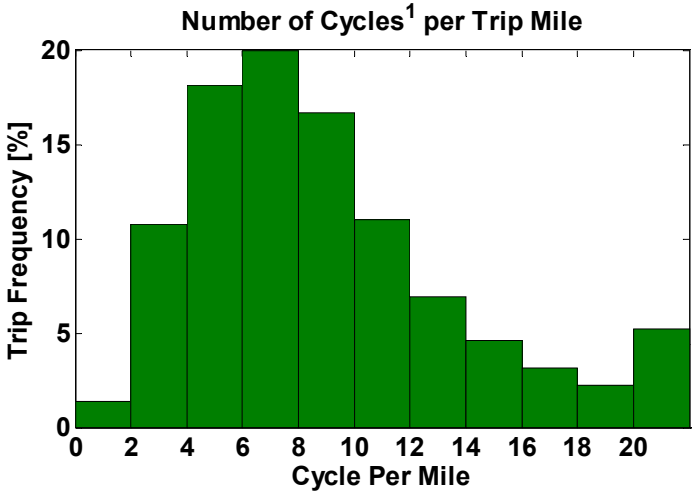


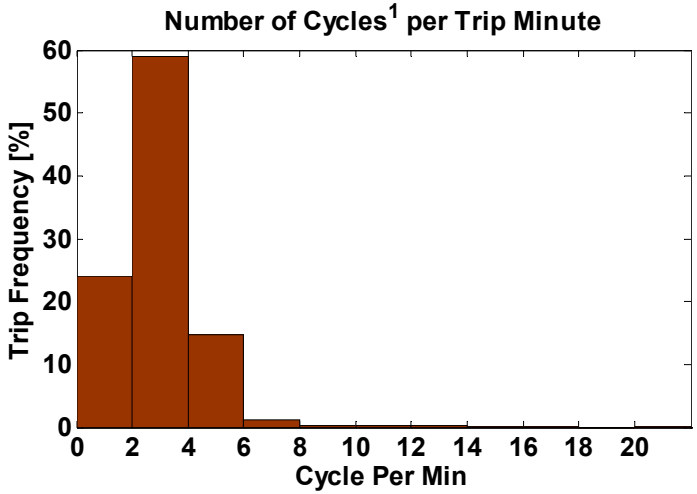
3) Categorize and collect voltage transient cycle details

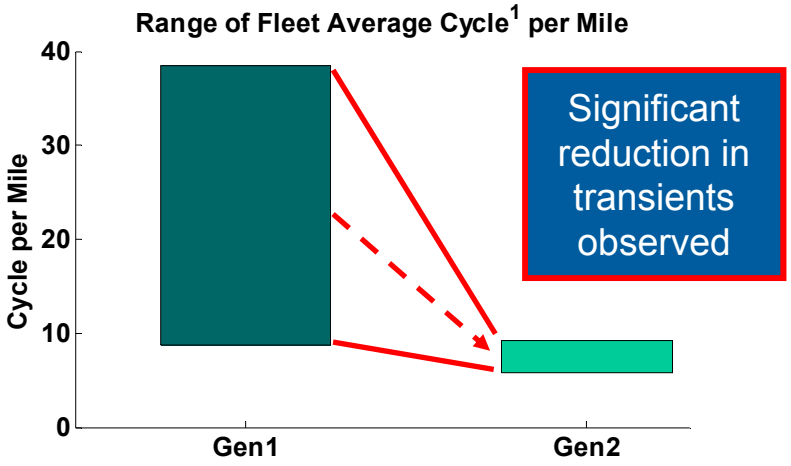


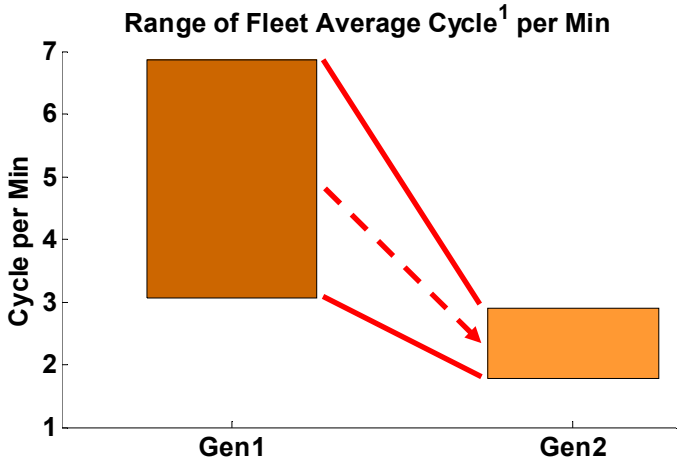
Spring 2010

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









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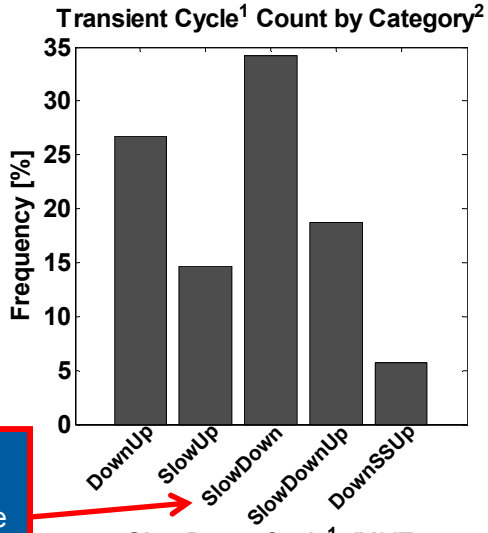
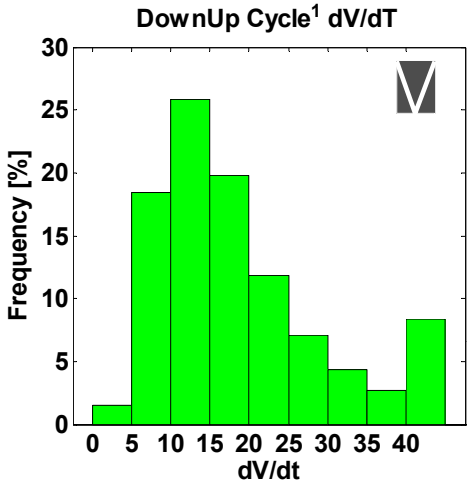
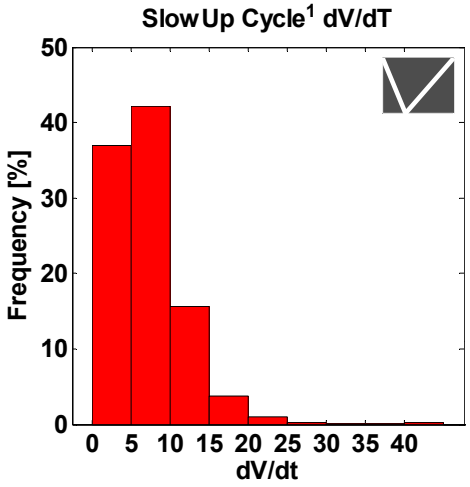
1) A fuel cell voltage transient cycle has a decrease and increase with a minimum delta of 5% max stack voltage.

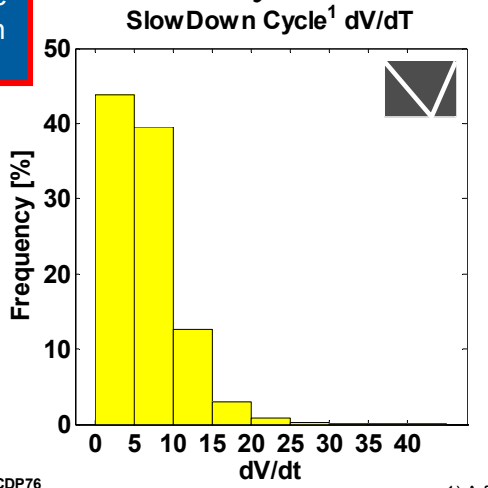
Characterized Fuel Cell Transient Rates by Cycle Category

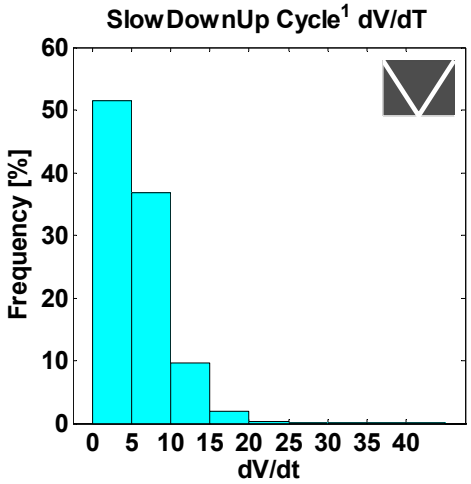


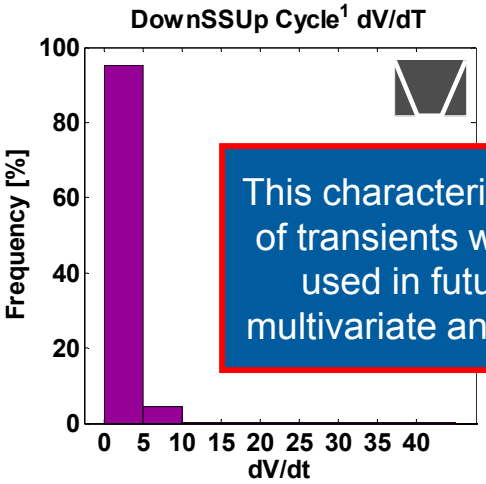




Type: The slow down, fast up are the most common transients







This characterization of transients will be used in future multivariate analysis

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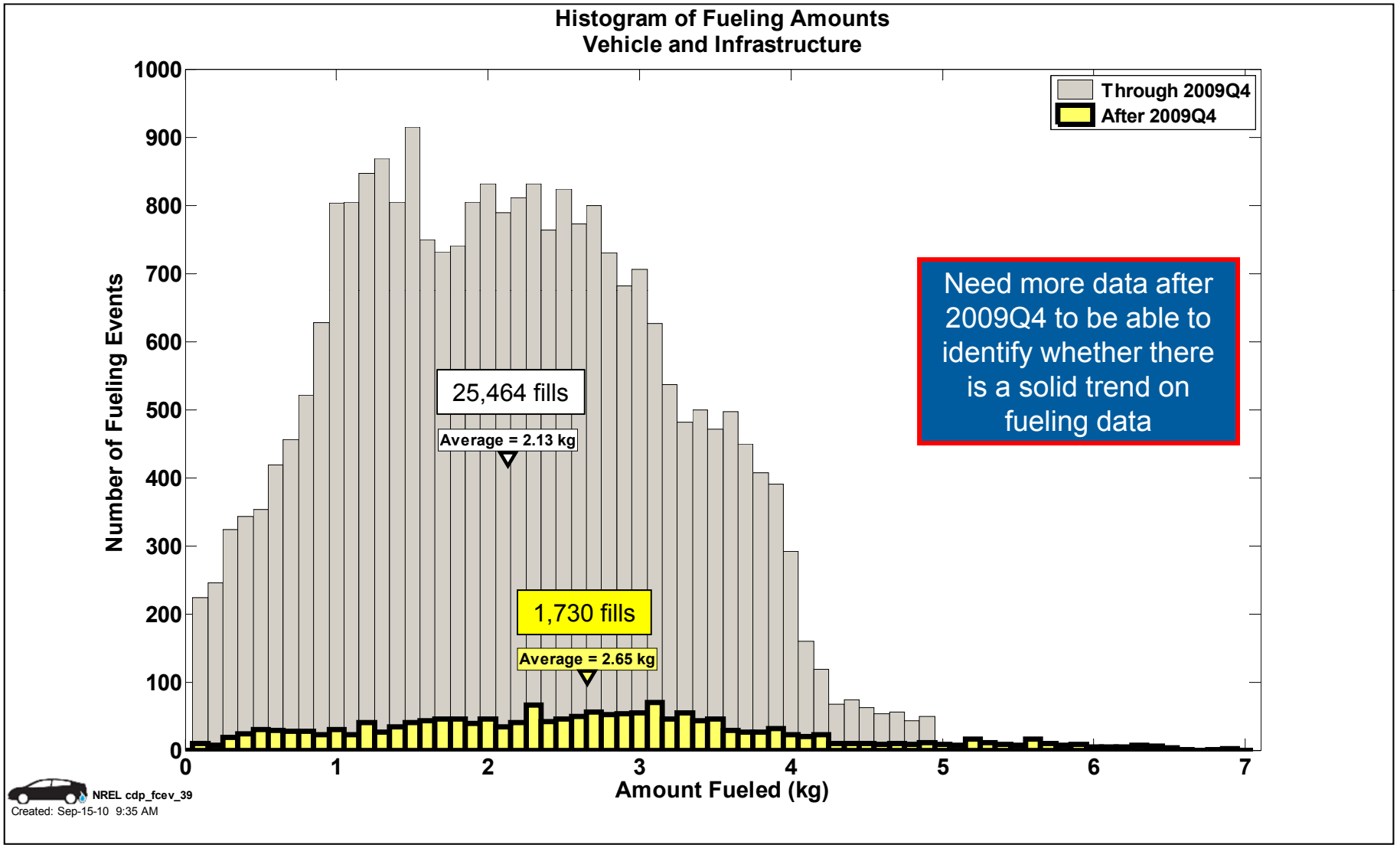
1) A fuel cell voltage transient cycle has a decrease and increase with a minimum delta of 5% max stack voltage.
2) Cycle categories based on cycle up and down times. A slow up or down transient has a time change >= 5 seconds.
SS = Steady State, where the time change is >= 10 seconds and the voltage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

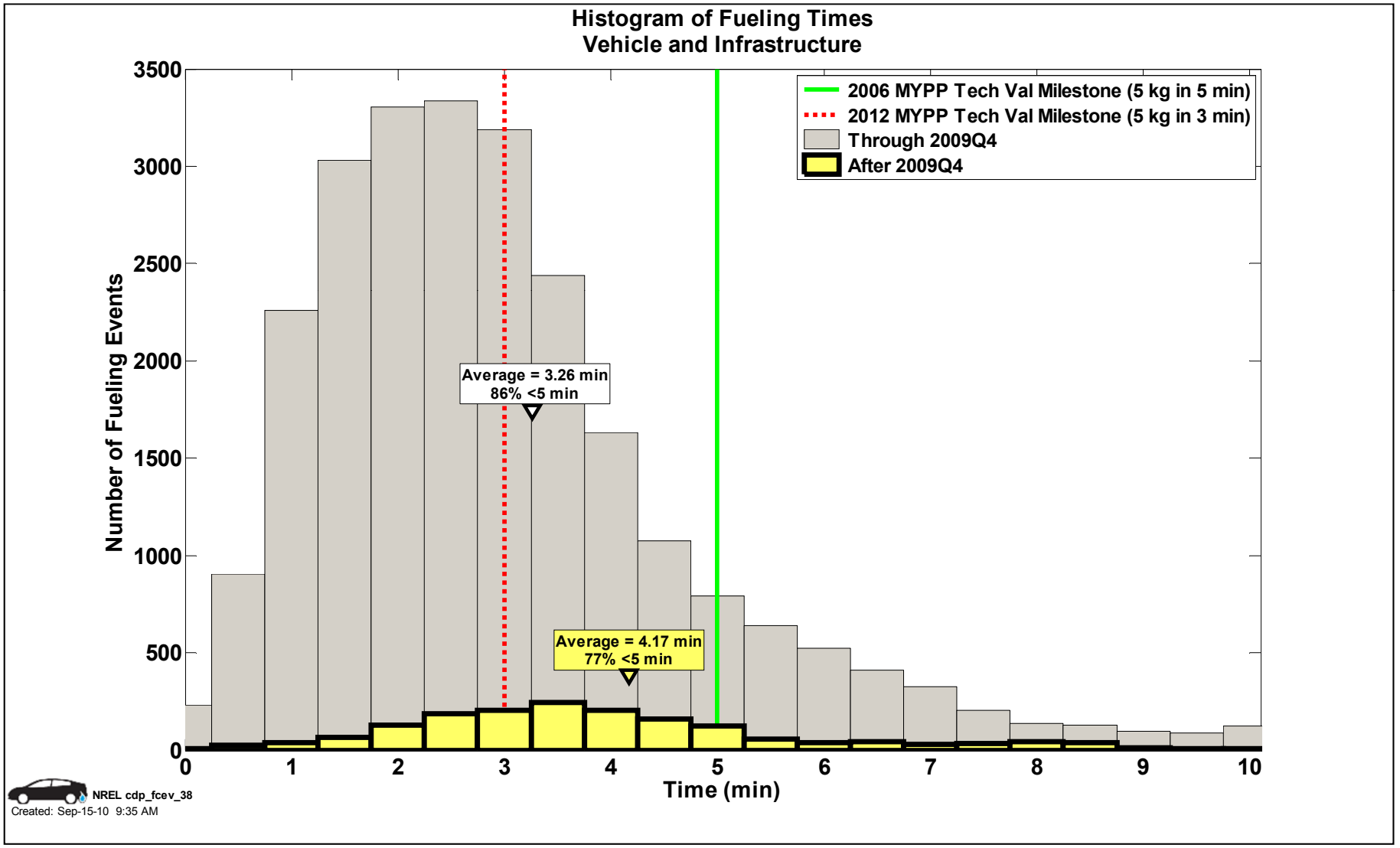
Spring 2010

Average Hydrogen Per Fill Has Increased 24%, But Based on Much Smaller Sample



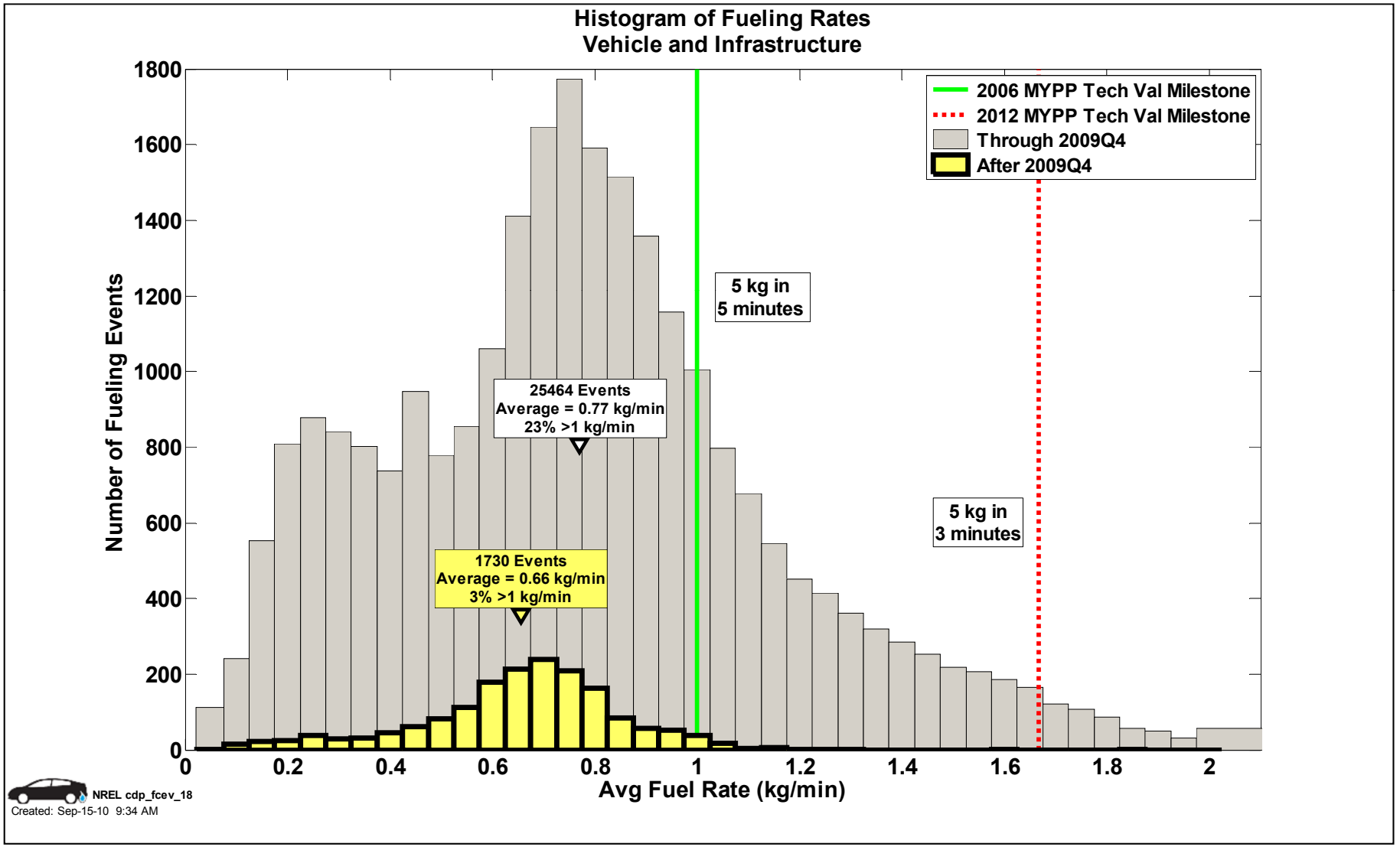
Fall 2010

Fueling Times Also Increased: +28%



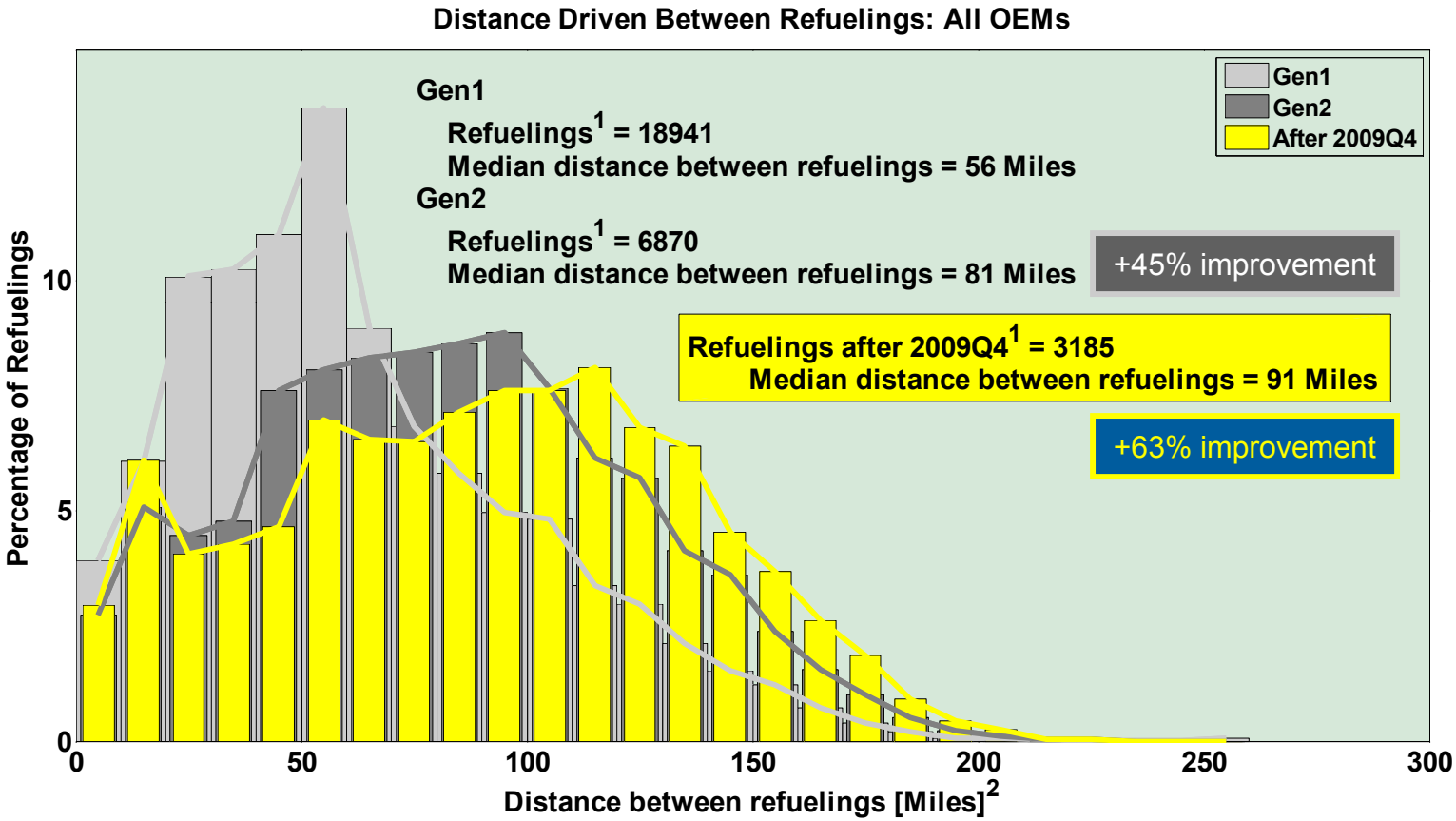
Fall 2010

Putting Those Together: Average Refueling Rate Decreased 14%



Fall 2010

Real-World Driving Range Between Refuelings Continues to Improve as Demonstration Progresses



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.

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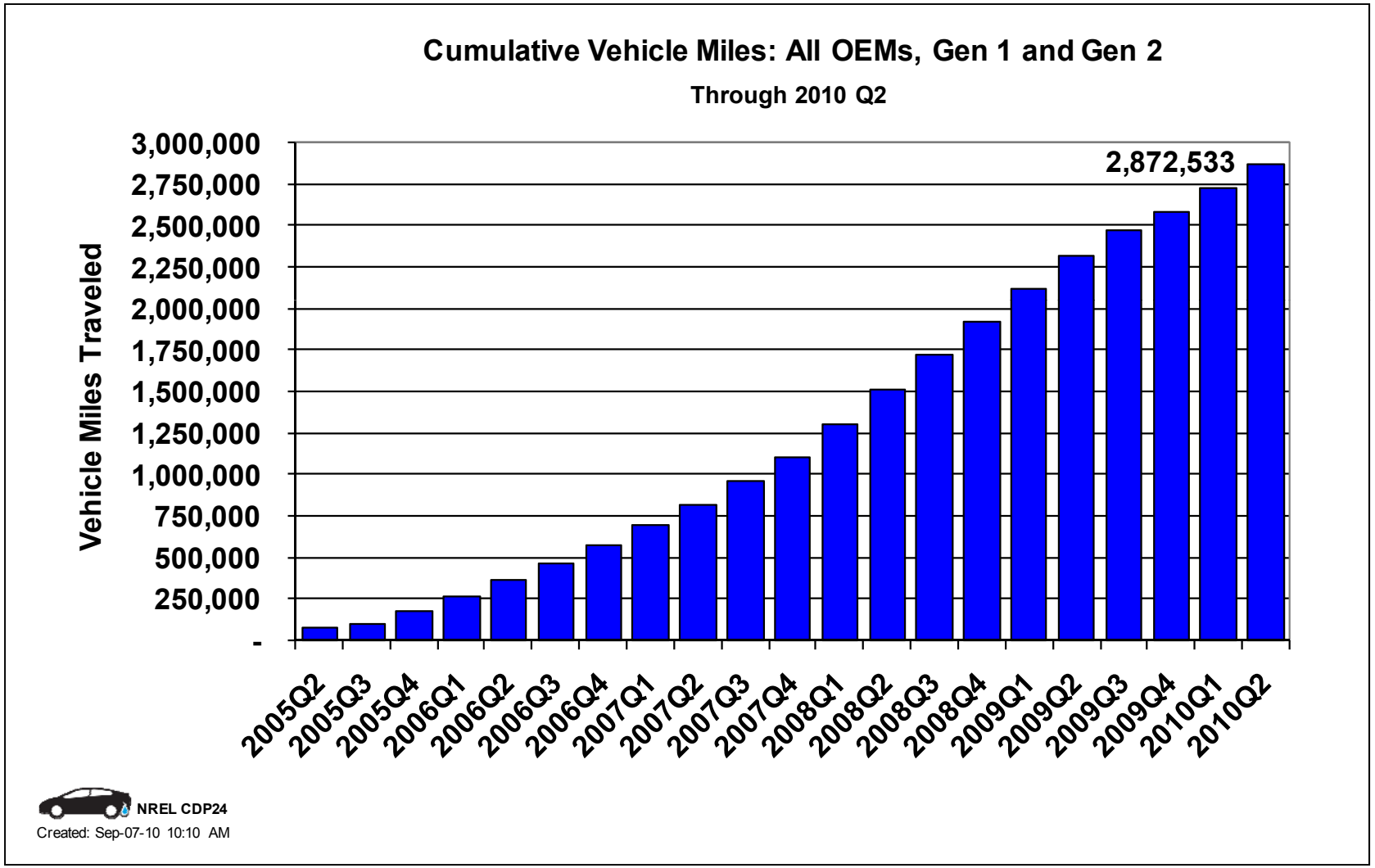
"window-sticker" range from adjusted dyno tests is 196-254 miles

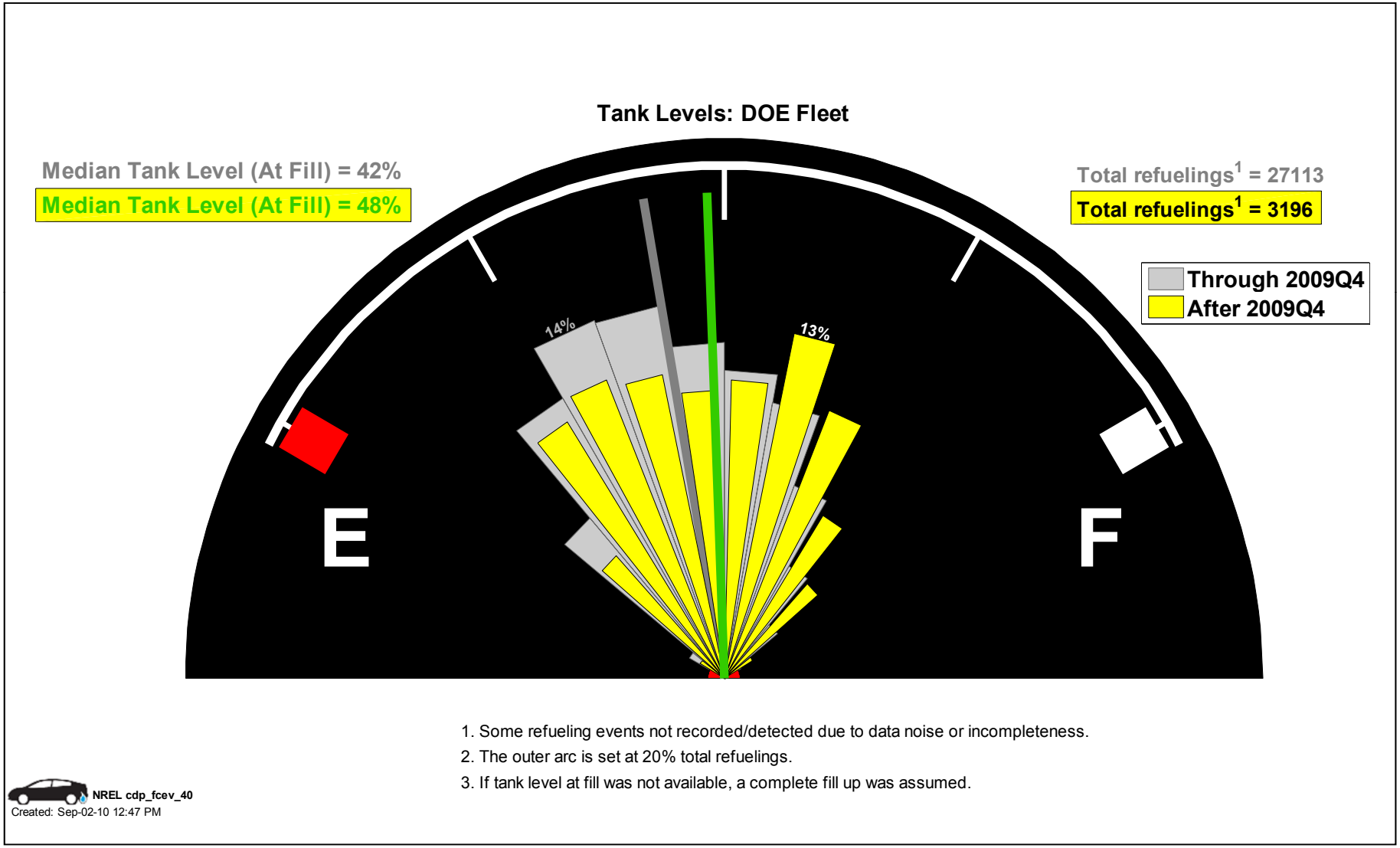
Fall 2010

Rate of Mileage Accumulation Has Decreased in the Last Year, But Vehicles Still Added 550,000 Miles



Fall 2010

Based on Limited Number of Fuelings in Last 6 Months, Higher Level of Tank at Refueling Observed



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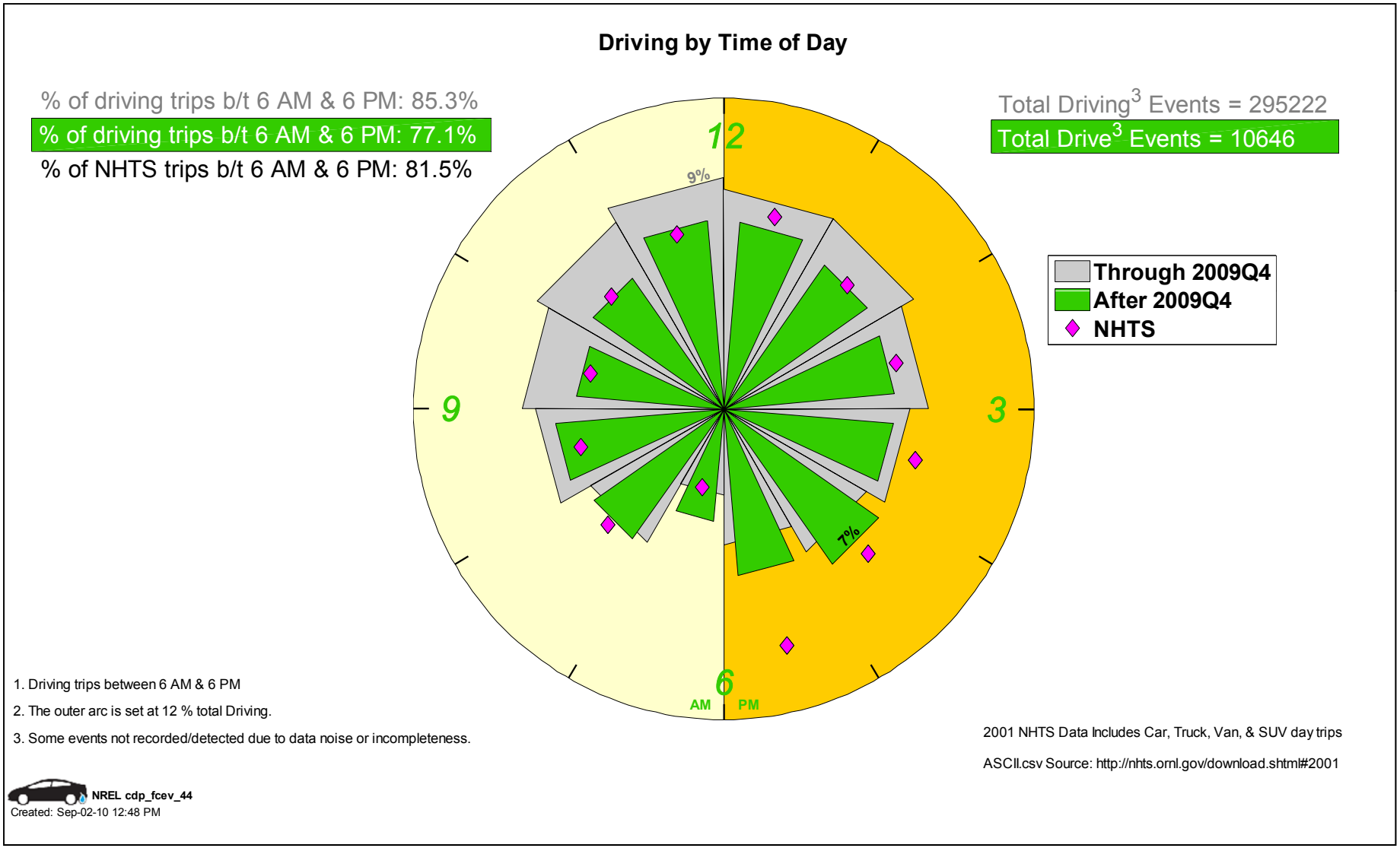
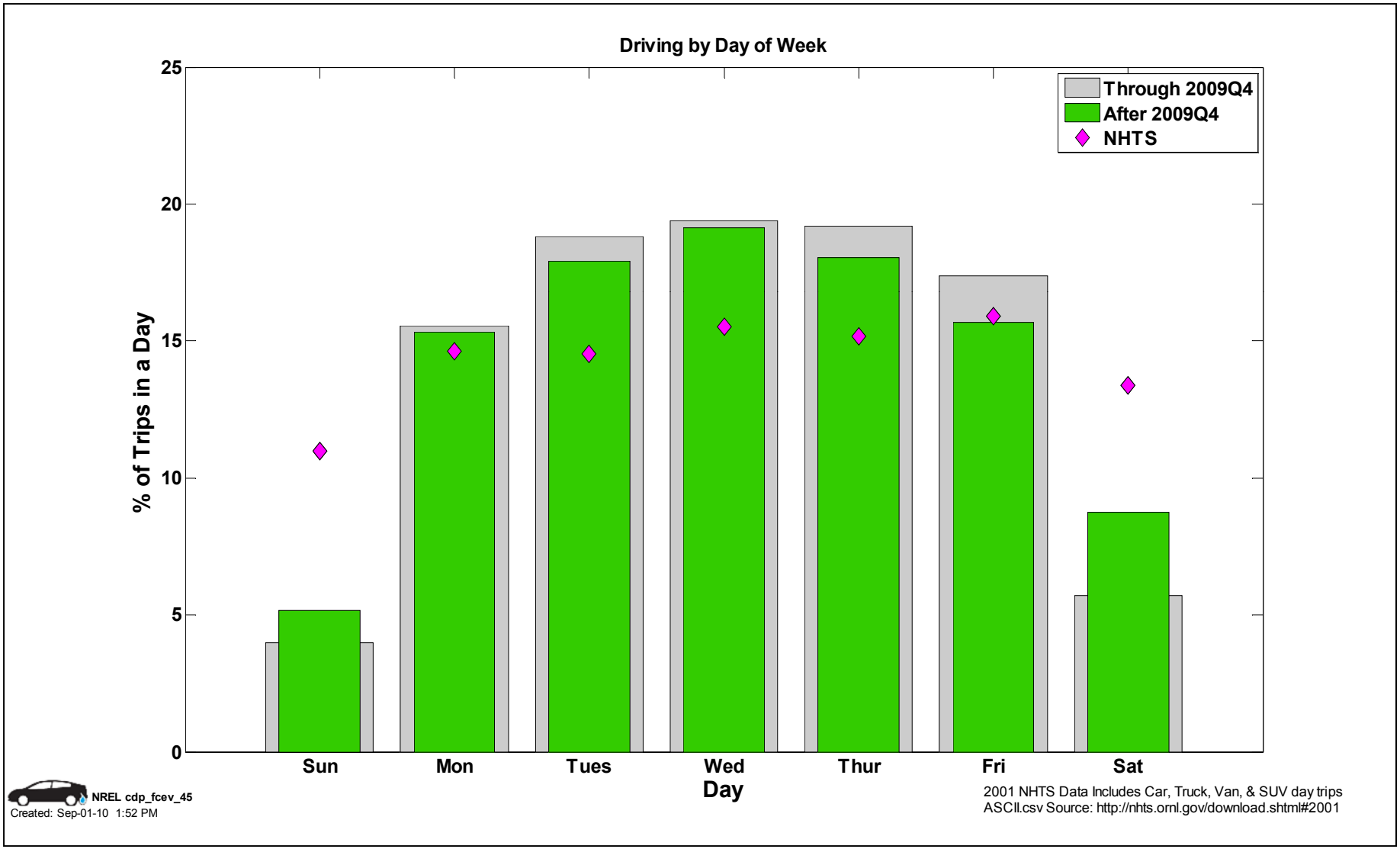
Driving Behavior in Last 6 Months Much More Similar to National Average



Fall 2010

More Weekend Driving Observed in Last Six Months – Still Much Less than National Avg.



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Summary

- Project has completed >5 full years of operation
- Vehicle operation: 114,000 hours, 2.87 million miles, 436,000 trips
- H2 station operation: 134,000 kg produced or dispensed, 27,000 refuelings
- DOE Key Technical Targets Met: FC Durability and Range
- Two of the OEMs will be continuing operation of Gen 2 vehicles through end of 2011; *progress will be tracked*
- Future work: Additional collaboration with remaining auto OEM teams to make analyses useful for technology evolution and preparation for 2014-2015 market entry
- New CA fueling stations planned for inclusion in future results as they come online

Questions and Discussion

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