

FCV Learning Demonstration: Project Midpoint Status and First-Generation Vehicle Results

Keith Wipke, Sam Sprik, Jennifer Kurtz, Holly Thomas¹
John Garbak²

ZERO REGIO, Montecatini Terme, Italy
November 6, 2007

¹NREL, ²US Dept. of Energy

This presentation does not contain any proprietary or confidential information

Outline

- Objectives and Partners
- Methodology and Data Analysis
- How to Access Full Results
- Highlighted Results
 - Fuel Cell Efficiency and Power Points
 - FC Voltage Degradation and Factors Affecting it
 - Driving and Refueling Behaviors

Fuel Cell Vehicle Learning Demonstration

Project Objectives and Targets

- Objectives
 - Validate H₂ FC Vehicles and Infrastructure in Parallel
 - Identify Current Status and Evolution of the Technology
 - Assess Progress Toward Technology Readiness
 - Provide Feedback to H₂ Research and Development

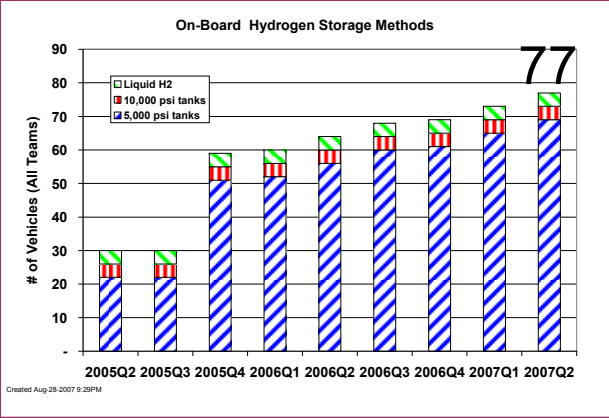
Key Targets

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

* To verify progress toward 2015 targets
** Subsequent projects to validate 2015 targets

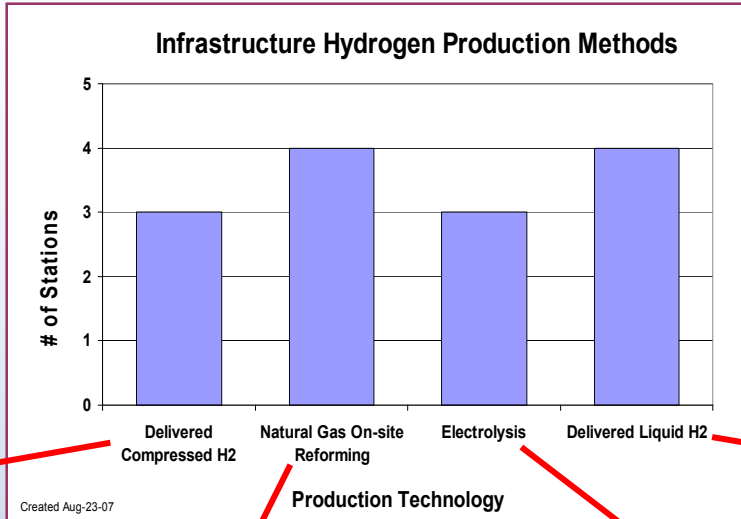


Vehicle Status: All of First Generation Vehicles Deployed, 2nd Generation Initial Introduction in Fall 2007

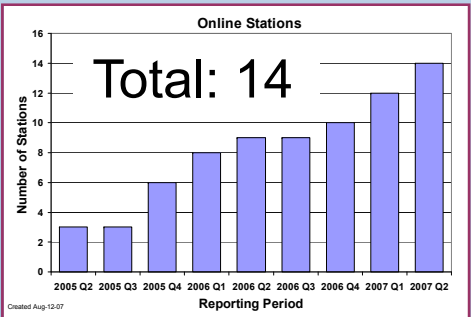


~2/3 of the Project's Infrastructure to Refuel Vehicles Has Been Installed – 4 Types (examples)

Mobile Refueler Sacramento, CA

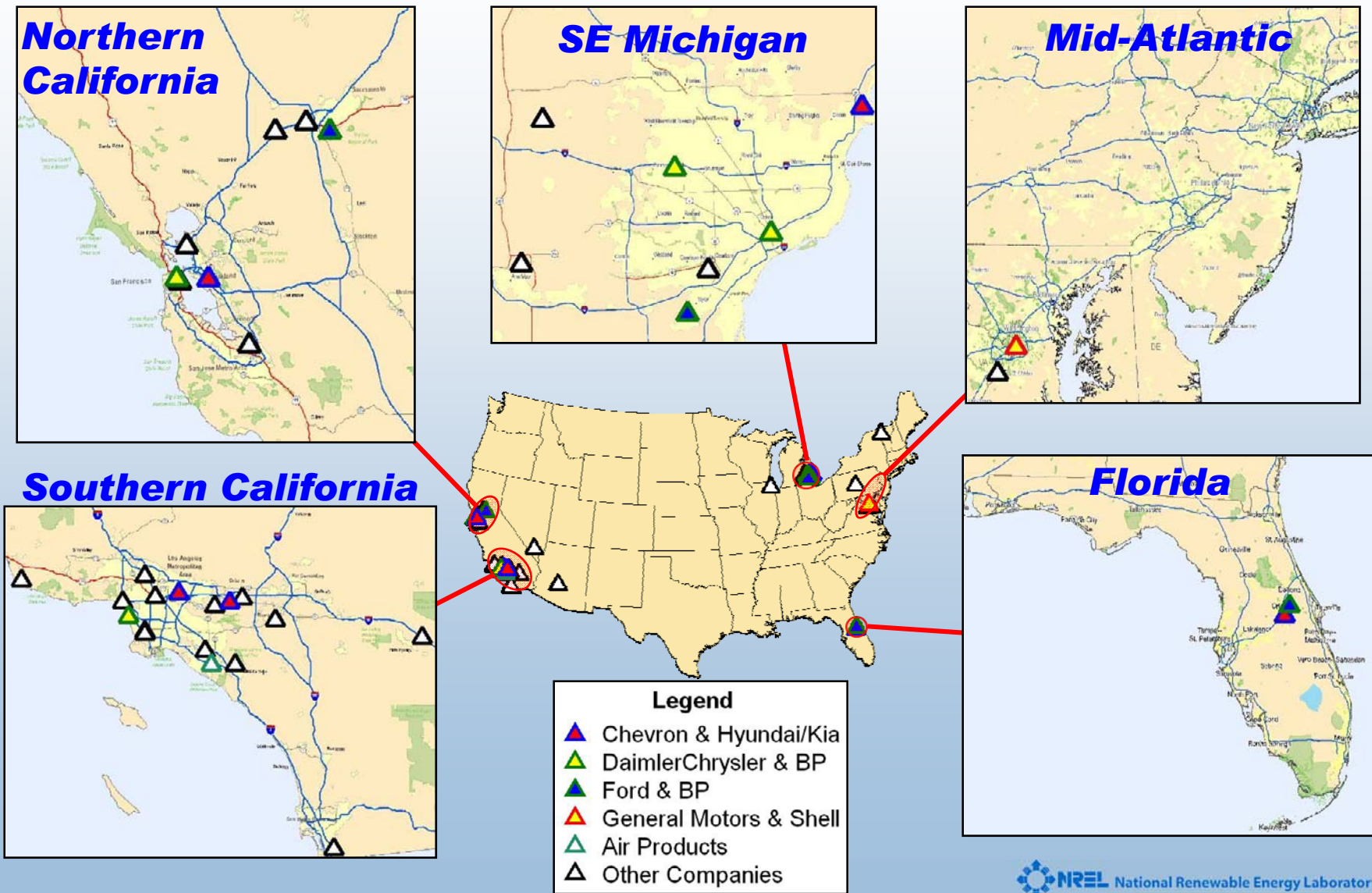


Hydrogen and Gasoline Station Washington, DC

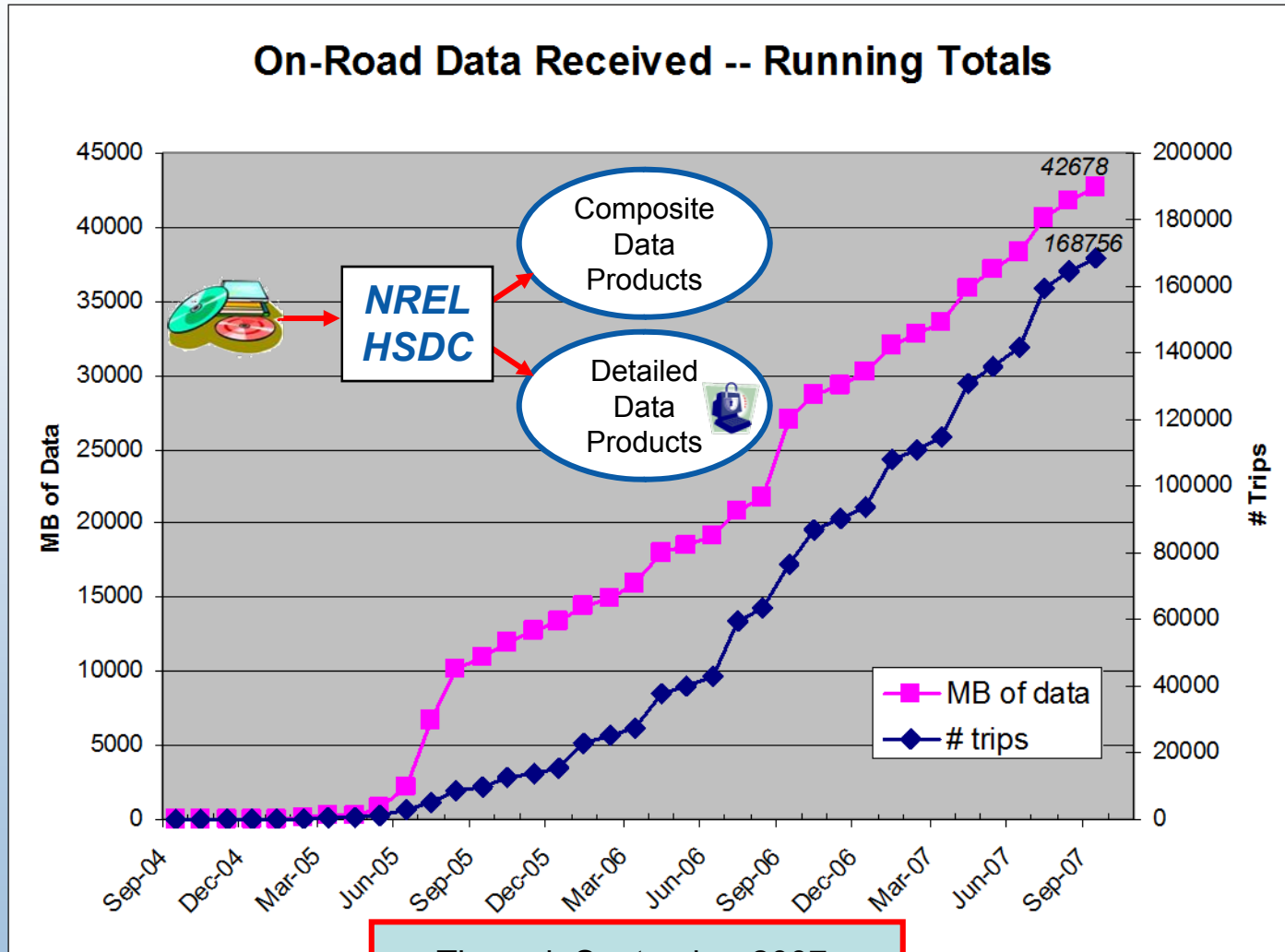


4 stations added in last six months

Refueling Stations from All Four Teams Test Vehicle/Infrastructure Performance in Various Climates



Nine Quarters of Data Analyzed Included in Fall 2007 Composite Data Products



Through September 2007:
 >168,000 individual vehicle trips
 42 GB of on-road data

NREL Web Site Provides Direct Access to All Composite Data Products (41) & Reports

The screenshot shows the NREL website's 'Composite Data Products by Topic' page. The page title is 'Hydrogen & Fuel Cells Research'. It features a sidebar with navigation links and a main content area with the following text:

Composite Data Products by Topic
The public technical analysis results from DOE's Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project are generated in the form of composite data products (CDPs). The following CDPs, which are organized by topic, are offered in both PowerPoint and JPEG formats.

If these technical results are reproduced in your own documents or presentations, please provide appropriate reference to the U.S. Department of Energy's National Renewable Energy Laboratory.

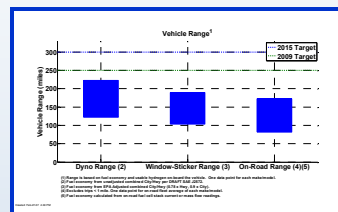
Fuel Cell Stack Durability

- Fuel Cell Stack Hours Accumulated and Projected Hours to 10% Stack Voltage Degradation, CDP #1, 8/23/07 (PowerPoint 39 KB) (JPEG 229 KB)
- Primary Factors Affecting Learning Demo Fleet Fuel Cell Degradation, CDP #49, 8/31/07 (PowerPoint 26 KB) (JPEG 354 KB)
- Primary Factors Affecting Learning Demo Team Fuel Cell Degradation, CDP #49, 8/31/07 (PowerPoint 39 KB) (JPEG 312 KB)

Fuel Cell Vehicle Range and Driving Behavior

- Fuel Cell Vehicle Range, CDP #2, 8/23/07 (PowerPoint 35 KB) (JPEG 136 KB)
- Effective Fuel Cell Vehicle Range, CDP #34, 8/23/07 (PowerPoint 35 KB) (JPEG 85 KB)
- Percentage of Theoretical Driving Range Between Refuelings, CDP #32, 8/23/07 (PowerPoint 39 KB) (JPEG 114 KB)
- Driving Start Time — Day, CDP #44, 9/10/07 (PowerPoint 37 KB) (JPEG 105 KB)
- Driving by Day of Week, CDP #45, 9/10/07 (PowerPoint 35 KB) (JPEG 93 KB)

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



The cover of the 'Learning Demonstration Interim Progress Report - Summer 2007' features the NREL logo and the text: 'Technical Report NREL/TP-560-41848 July 2007'. The authors listed are K. Wipke, S. Sprik, H. Thomas, C. Welch, and J. Kurtz.

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

The screenshot shows the 'Presentations and Publications' page on the NREL website. It lists documents available as Adobe Acrobat PDFs. The page title is 'Presentations and Publications' and it includes the following text:

Some of the following documents are available as Adobe Acrobat PDFs. [Download Adobe Reader.](#)

2007

- FCV Learning Demonstration: First-Generation Vehicle Results and Factors Affecting Fuel Cell Degradation (PDF 1.4 MB), K. Wipke, S. Sprik, J. Kurtz, H. Thomas, J. Garbak. Presentation prepared for the Fuel Cell Seminar, San Antonio, TX. (October 2007)
- Learning Demonstration Interim Progress Report - Summer 2007 (PDF 711 KB), K. Wipke, S. Sprik, H. Thomas, C. Welch, J. Kurtz. NREL/TP-560-41848. (June 2007)
- Controlled Hydrogen Fleet and Infrastructure Analysis (PDF 3.7 MB), K. Wipke. Presentation prepared for the 2007 DOE Hydrogen Program Merit Review, Arlington, Virginia. (May 2007)
- Fuel Cell Vehicle Learning Demonstration: Spring 2007 Results (PDF 1 MB), K. Wipke. Presentation prepared for National Hydrogen Association Conference in San Antonio, Texas. (March 2007)

2006

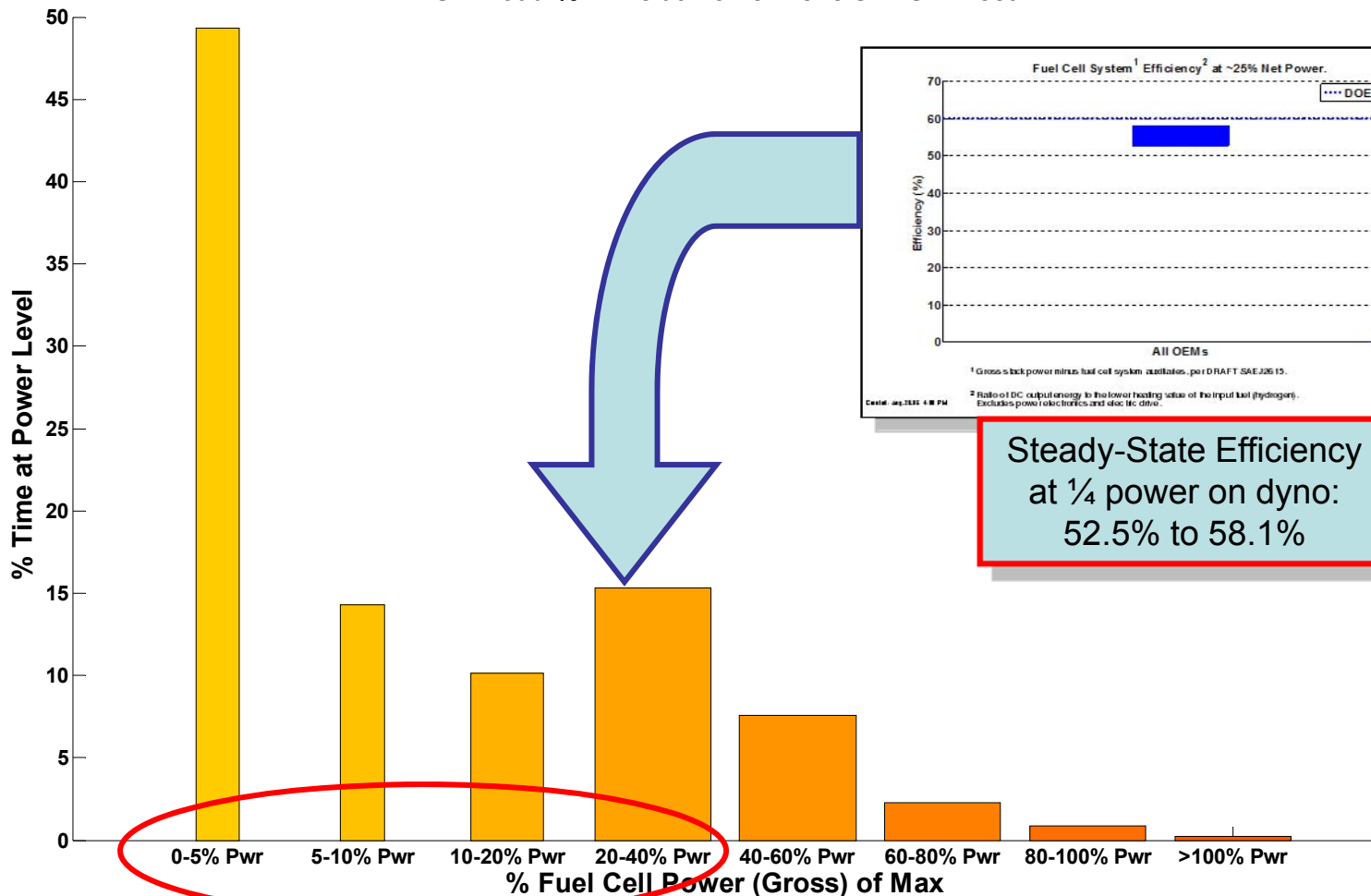
- Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project—Initial Fuel Cell Efficiency and Durability Results (PDF 314 KB), K. Wipke, C. Welch, H. Thomas, S. Sprik, S. Gronich, J. Garbak. Paper prepared for the World Electric Vehicle Association Journal, Vol. 1, 2007. (December 2006)
- 2006 Annual Progress Report for NREL's "Controlled Hydrogen Fleet and Infrastructure Analysis Project," System Analysis Section VI.G.1 (PDF 1.24 MB), K. Wipke, C. Welch, H. Thomas, S. Sprik. (November 2006)
- Hydrogen Learning Demonstration Project: Fuel Cell Efficiency and Initial Durability, K. Wipke. Presentation (PDF 2.3 MB) and abstract (PDF 355 KB) prepared for the 2006 Fuel Cell

The cover of the 'Learning Demonstration Progress Report - September 2007' features the NREL logo and the text: 'Technical Report NREL/TP-560-42264 October 2007'. The authors listed are K. Wipke, S. Sprik, J. Kurtz, H. Thomas.

Select New and Updated Learning Demo Results Follow

On-Road FC Operating Power Points: Dyno Tests Validated High Efficiency at 1/4 Power Point – Key to Overall Efficiency

On-Road % Time at Power Levels: DOE Fleet

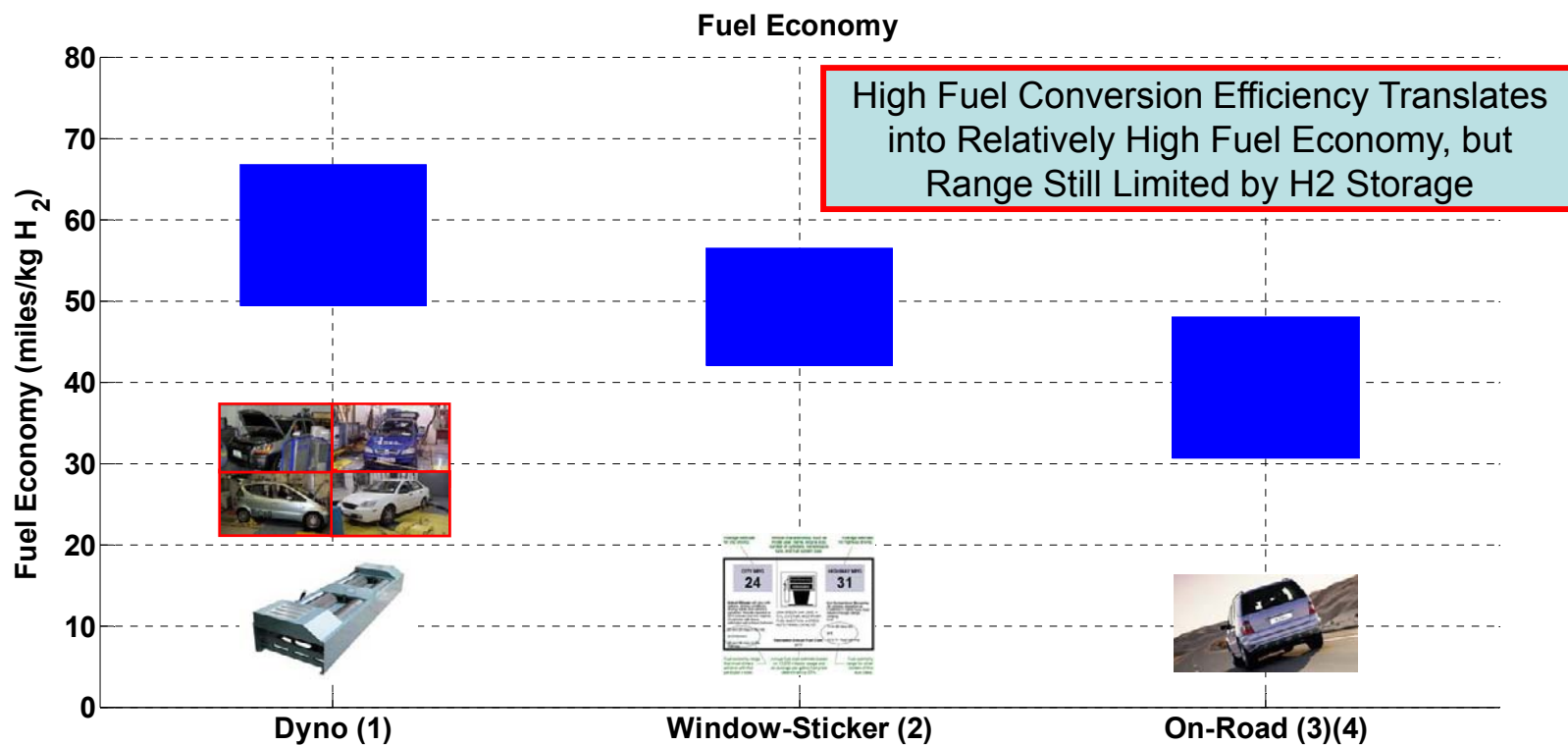


Steady-State Efficiency at 1/4 power on dyno: 52.5% to 58.1%

~85% time spent at <40% power

Created: Sep-10-07 4:31 PM

Dynamometer and On-Road Fuel Economy from Learning Demonstration Vehicles



(1) One data point for each make/model. Combined City/Hwy fuel economy per DRAFT SAE J2572.

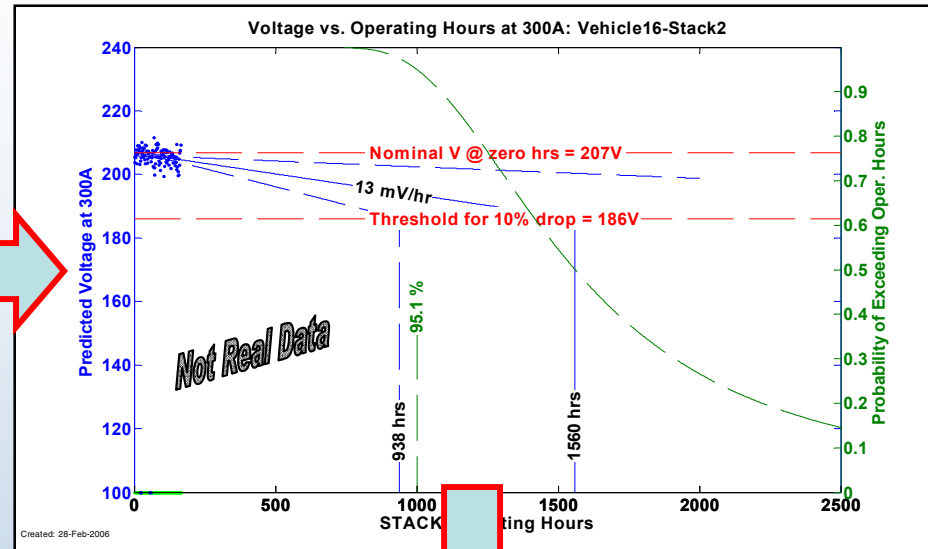
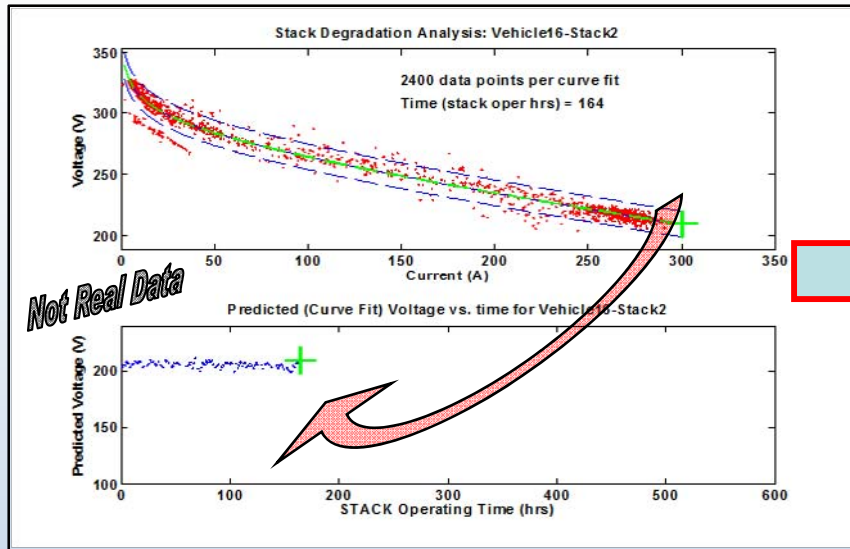
(2) Adjusted combined City/Hwy fuel economy ($0.78 \times \text{Hwy}$, $0.9 \times \text{City}$).

(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.

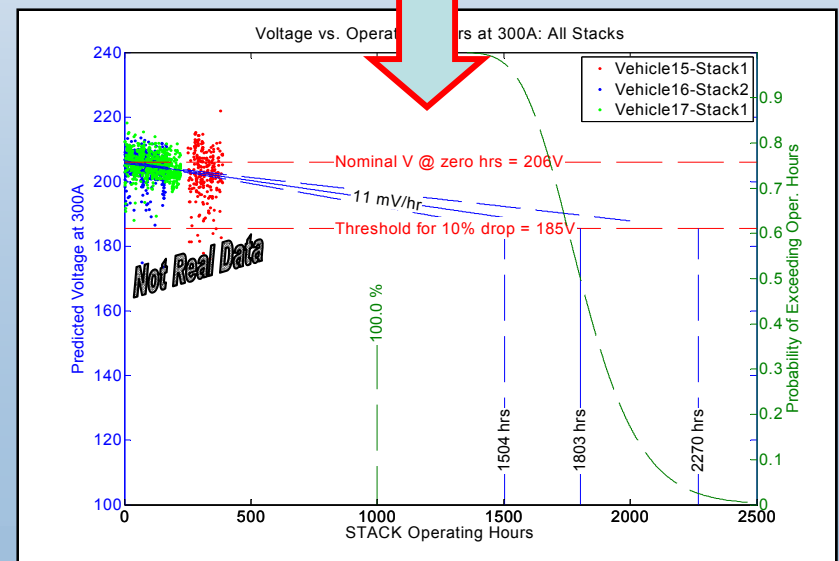
Created: Aug-23-07 2:48 PM

Method for Projecting Time to 10% Fuel Cell Stack Voltage Degradation



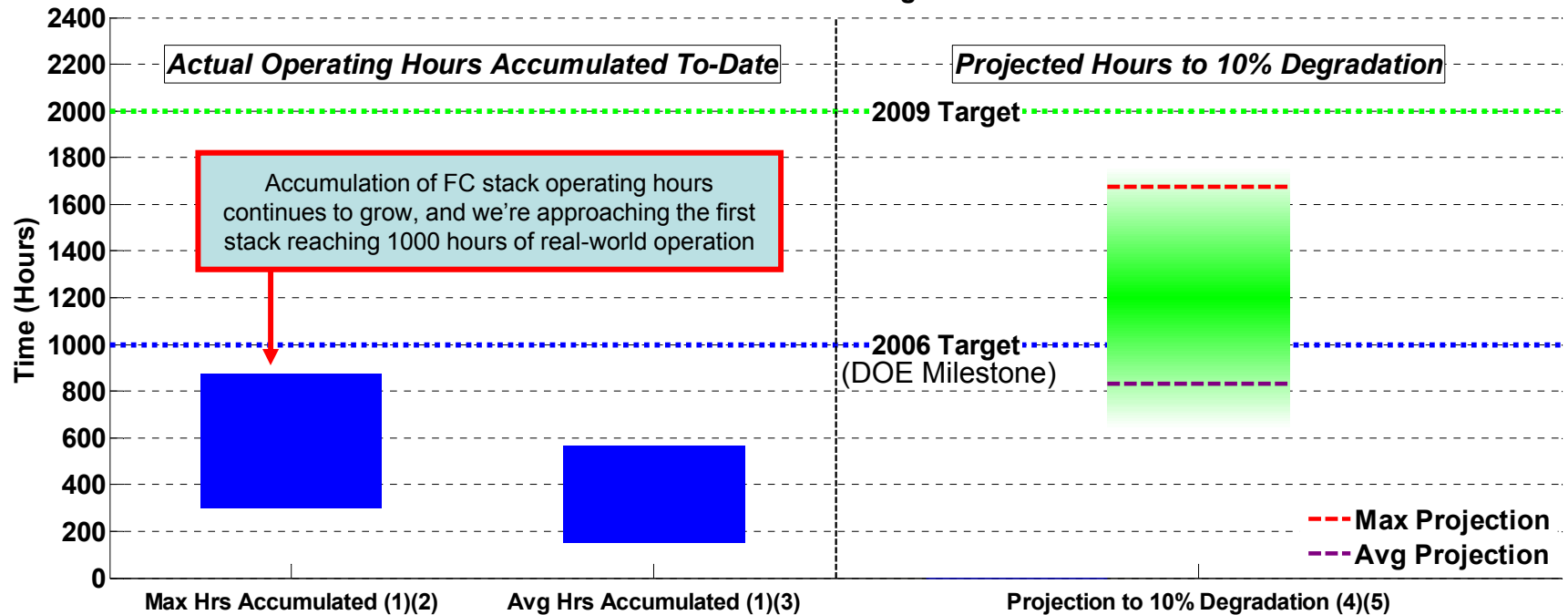
Note: 10% is an R&D metric for FC stack degradation. It does not necessarily indicate an end-of-life condition. OEMs may use other values or indicators.

Technique makes performance projection based on all available FC data; Includes reporting confidence in results



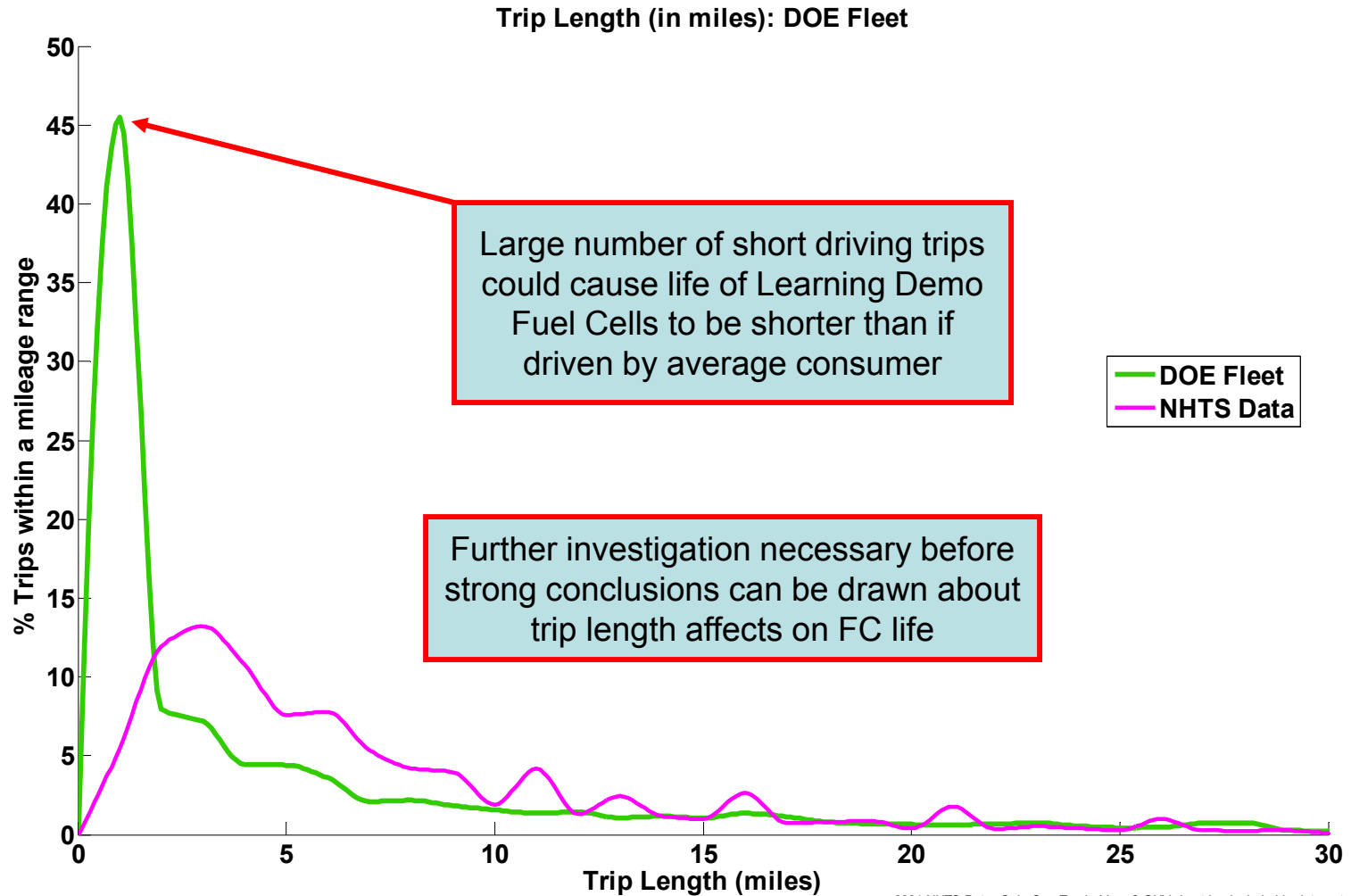
As More Gen 1 Data Is Accumulated, Some Teams Are Demonstrating Long FC Durability

DOE Learning Demonstration Fuel Cell Stack Durability:
Based on Data Through 2007 Q2



- (1) Range bars created using one data point for each OEM.
- (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 green bar represents an engineering judgment of the uncertainty due to data and methodology limitations. Projections will change as additional data are accumulated.

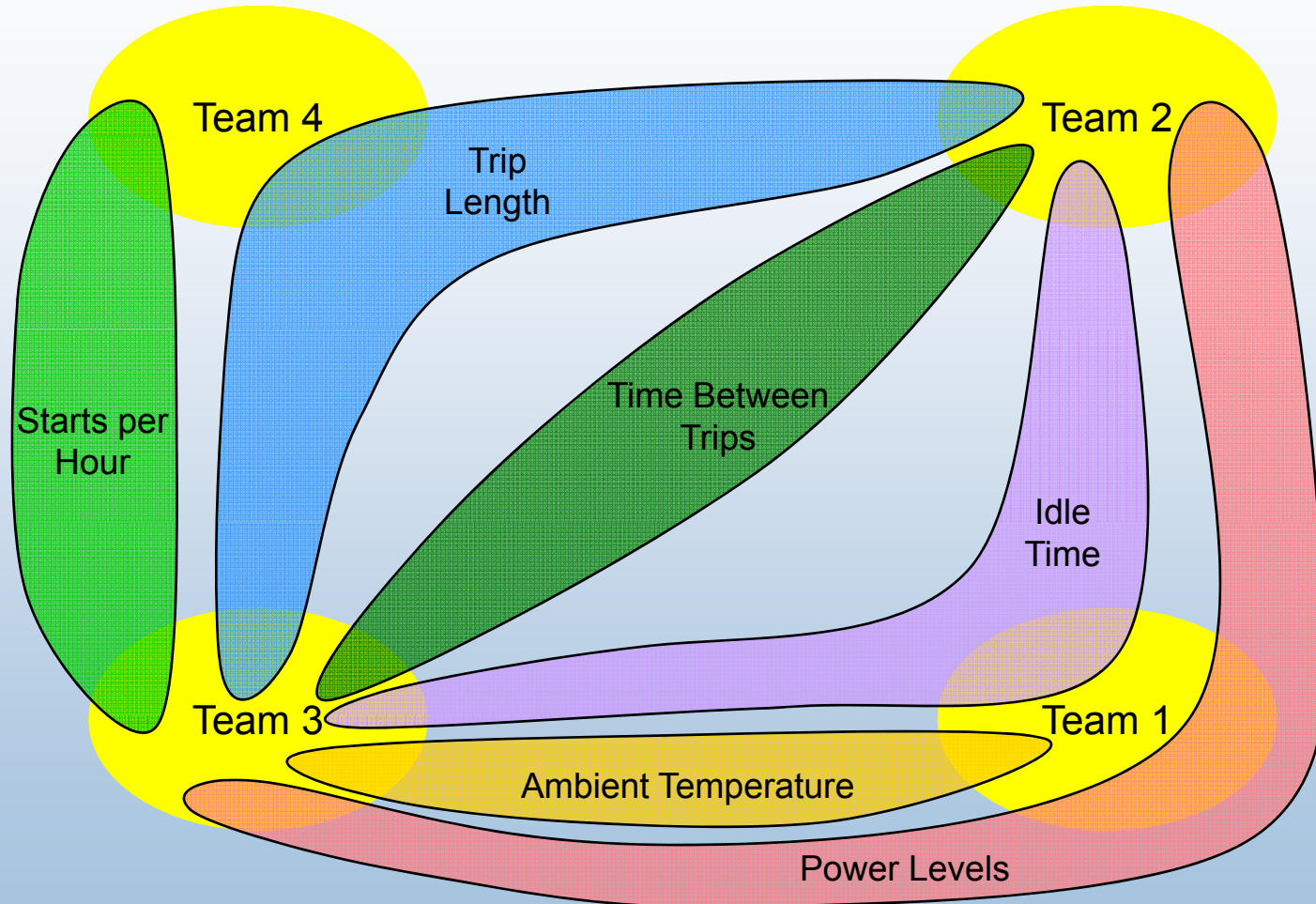
Learning Demo FCVs Tend to Take Many More Trips <2 Miles Than Compared to National Average



Created: Sep-10-07 4:31 PM

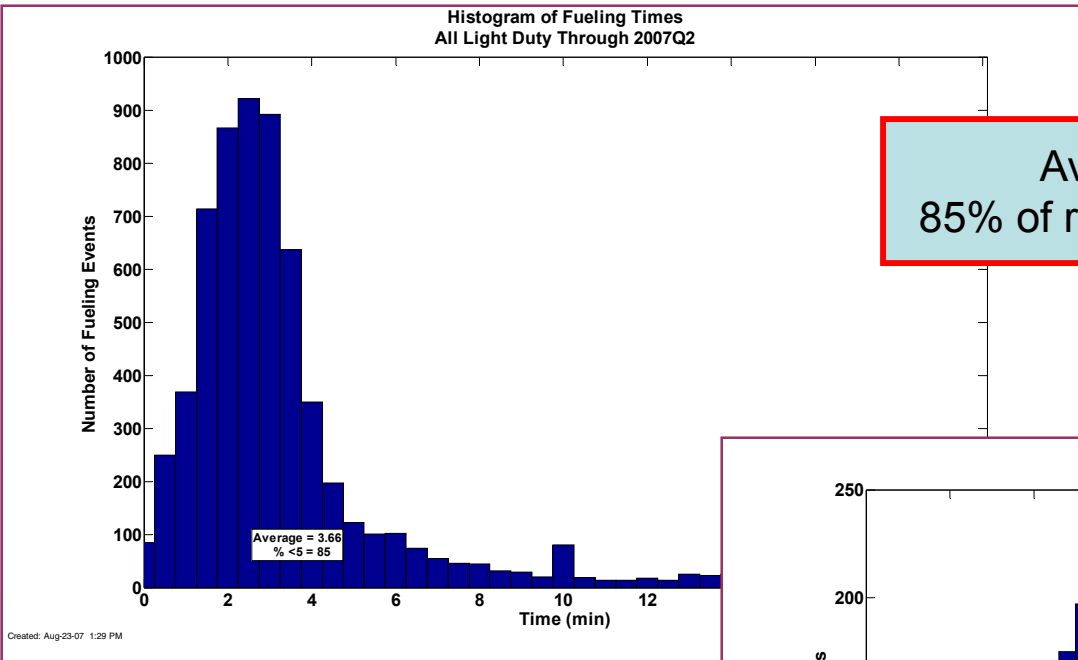
2001 NHTS Data: Only Car, Truck, Van, & SUV day trips included in data set shown here
Source: <http://nhts.ornl.gov/download.shtml#2001>, ASCII.csv

Preliminary Analysis of Dominant Factors Affecting Degradation: Each Team's Stacks Have Different Sensitivity to These Factors

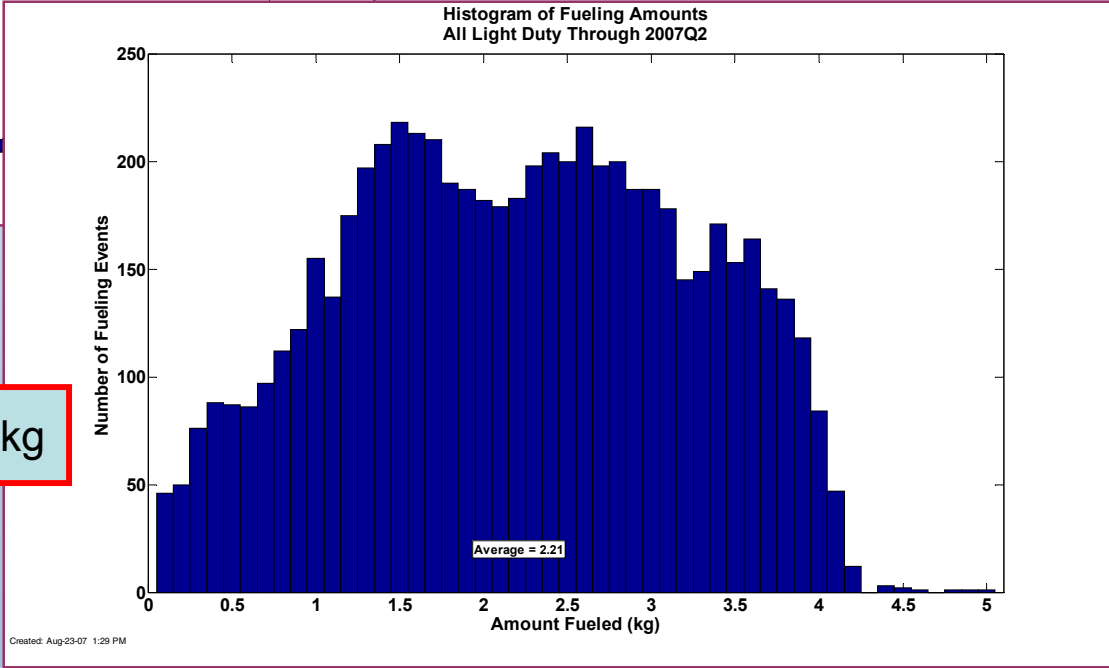


1. Results are from partial least squares (PLS) regression analysis of each team's fleet of vehicles individually
2. First two collections of factors cover ~61%-76% of decay rate variance

Actual Vehicle Refueling Times and Amounts from >6,300 Events: Measured by Stations or by Vehicles



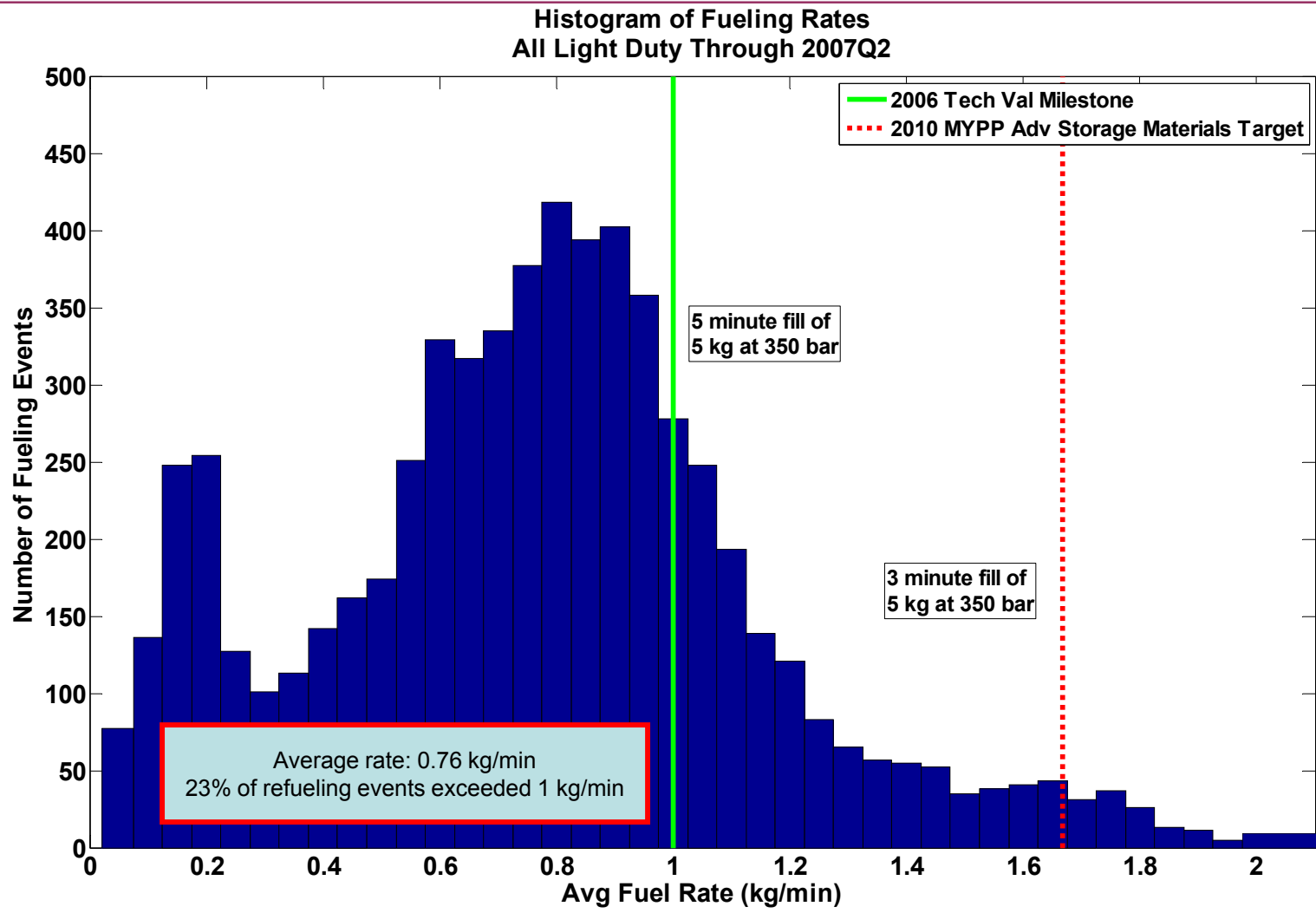
Average time: 3.66 min
85% of refueling events took <5 min



Average fill amount: 2.21 kg

Includes Comm. and Non-Comm. Fills

Actual Vehicle Refueling Rates from >6,300 Events: Measured by Stations or by Vehicles

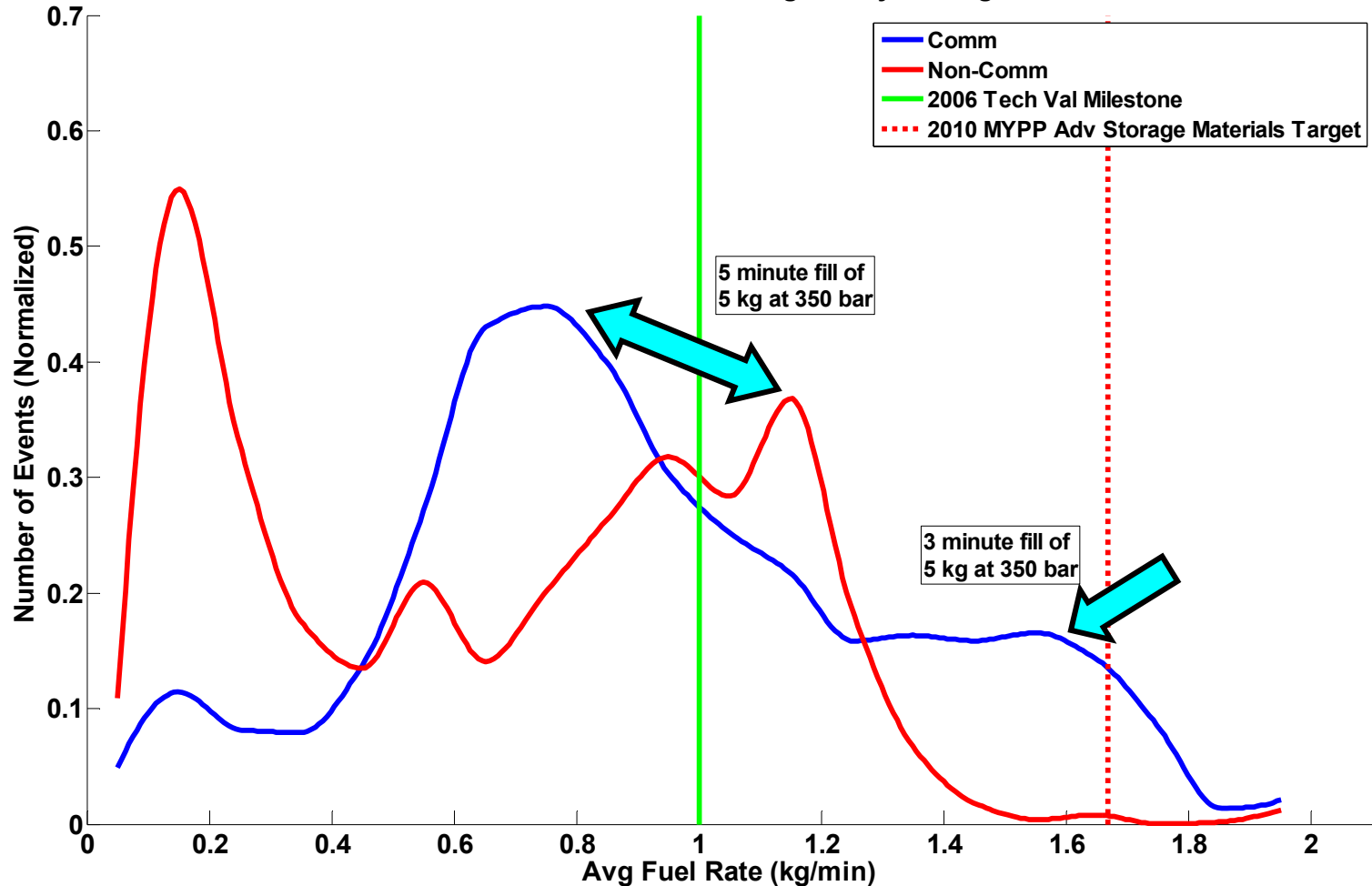


Created: Aug-23-07 1:29 PM

Includes Comm. and Non-Comm. Fills

Communication H2 Fills Achieving Higher Fill Rate than Non-Communication, But Not Uniformly

Histogram of Fueling Rates
Comm vs Non-Comm Fills - All Light Duty Through 2007Q2



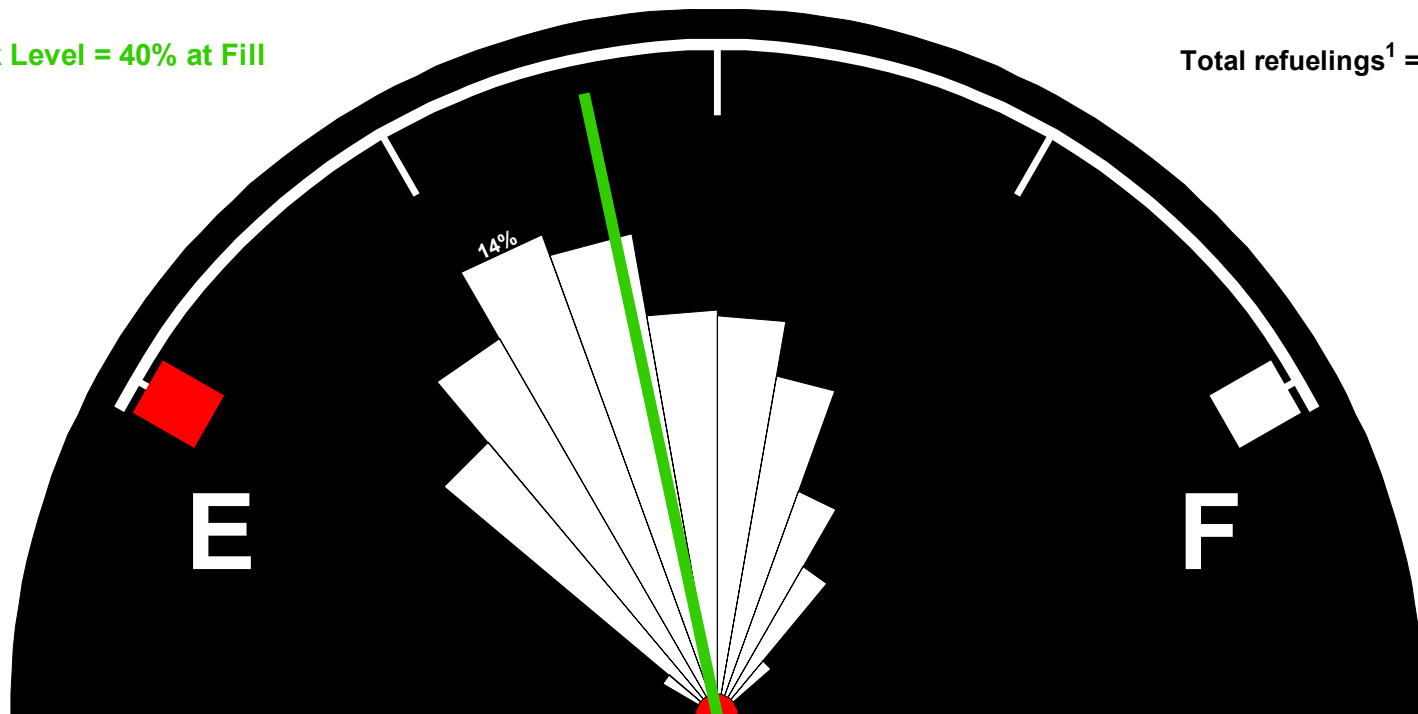
Created: Aug-22-07 5:46 PM

Large Spread in H2 Tank Level at Refueling Peak at ~1/4 Full, Median at ~3/8 Full

Tank Levels: DOE Fleet

Median Tank Level = 40% at Fill

Total refuelings¹ = 10303



1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. The outer arc is set at 20% total refuelings.
3. If tank level at fill was not available, a complete fill up was assumed.

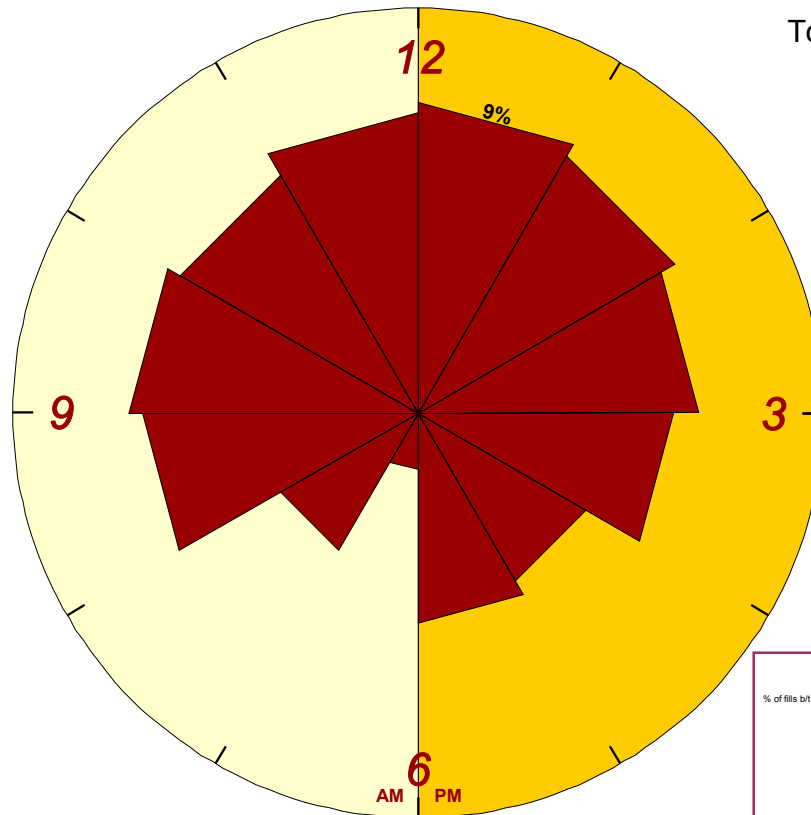
Created: Sep-10-07 3:14 PM

Refueling by Time of Day; Relative Uniform Refueling Infrastructure Demand Between 8-4

Refueling by Time of Day: DOE Fleet

% of fills b/t 6 AM & 6 PM: 86.0%

Total Fill³ Events = 9070



1. Fills between 6 AM & 6 PM
2. The outer arc is set at 12 % total Fill.
3. Some events not recorded/detected due to data noise or incompleteness.

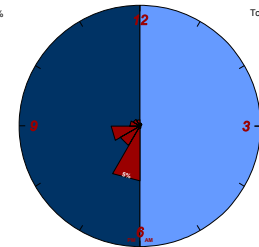
Created: Sep-10-07 3:14 PM

(Night)

Refueling by Time of Night: DOE Fleet

% of fills b/t 6 PM & 6 AM: 14.0%

Total Fill³ Events = 9070



1. Fills between 6 PM & 6 AM
2. The outer arc is set at 12 % total Fill.
3. Some events not recorded/detected due to data noise or incompleteness.

Created by user: 2:02 PM

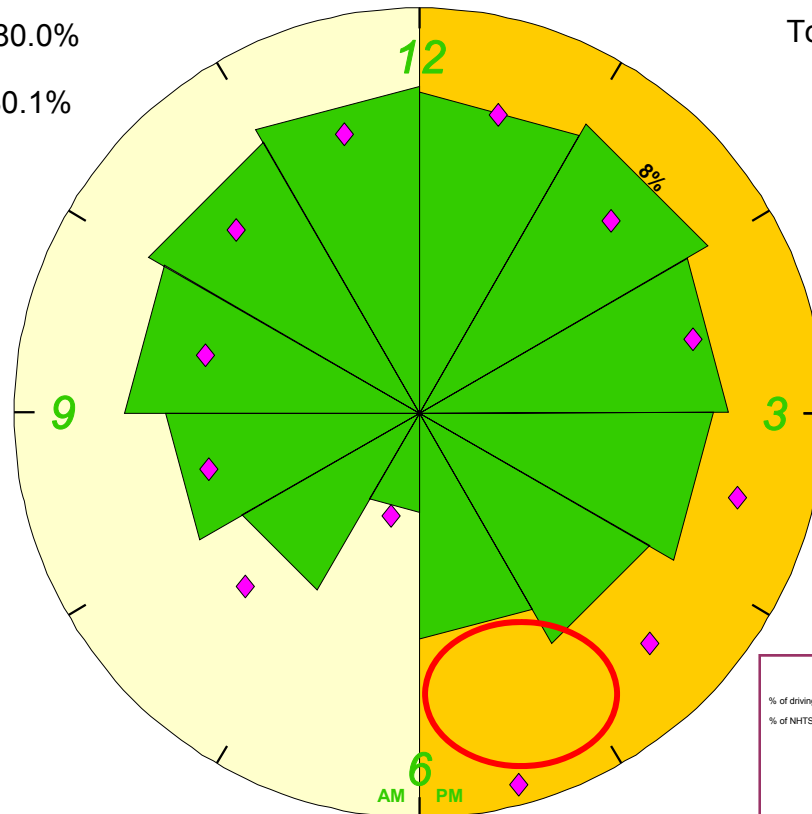
Driving Trip Start Time – Day; Roughly Matches National Statistics Except for 5-6 PM

Driving Start Time - Day: DOE Fleet

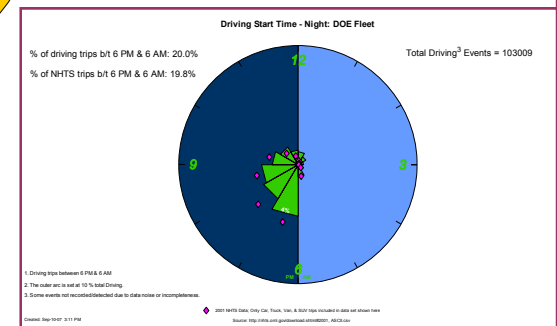
% of driving trips b/t 6 AM & 6 PM: 80.0%

% of NHTS trips b/t 6 AM & 6 PM: 80.1%

Total Driving³ Events = 103009



(Night)



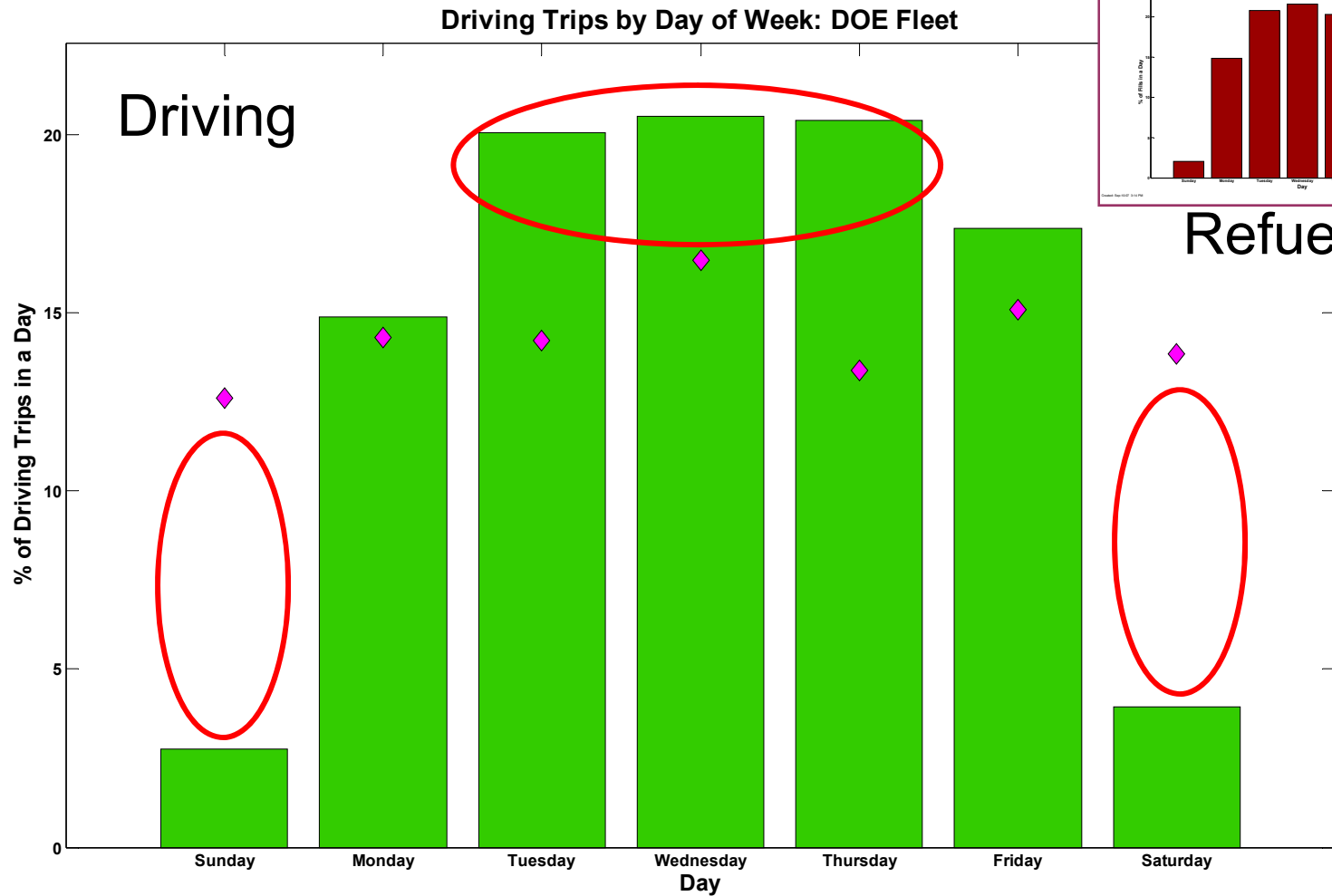
1. Driving trips between 6 AM & 6 PM
2. The outer arc is set at 10 % total Driving.
3. Some events not recorded/detected due to data noise or incompleteness.

◆ 2001 NHTS Data: Only Car, Truck, Van, & SUV trips included in data set shown here

Source: <http://nhts.ornl.gov/download.shtml#2001>, ASCII.csv

Created: Sep-10-07 3:11 PM

Gen 1 Learning Demo FCV Travel Has Been Primarily Weekday Driving; Doesn't Match NHTS



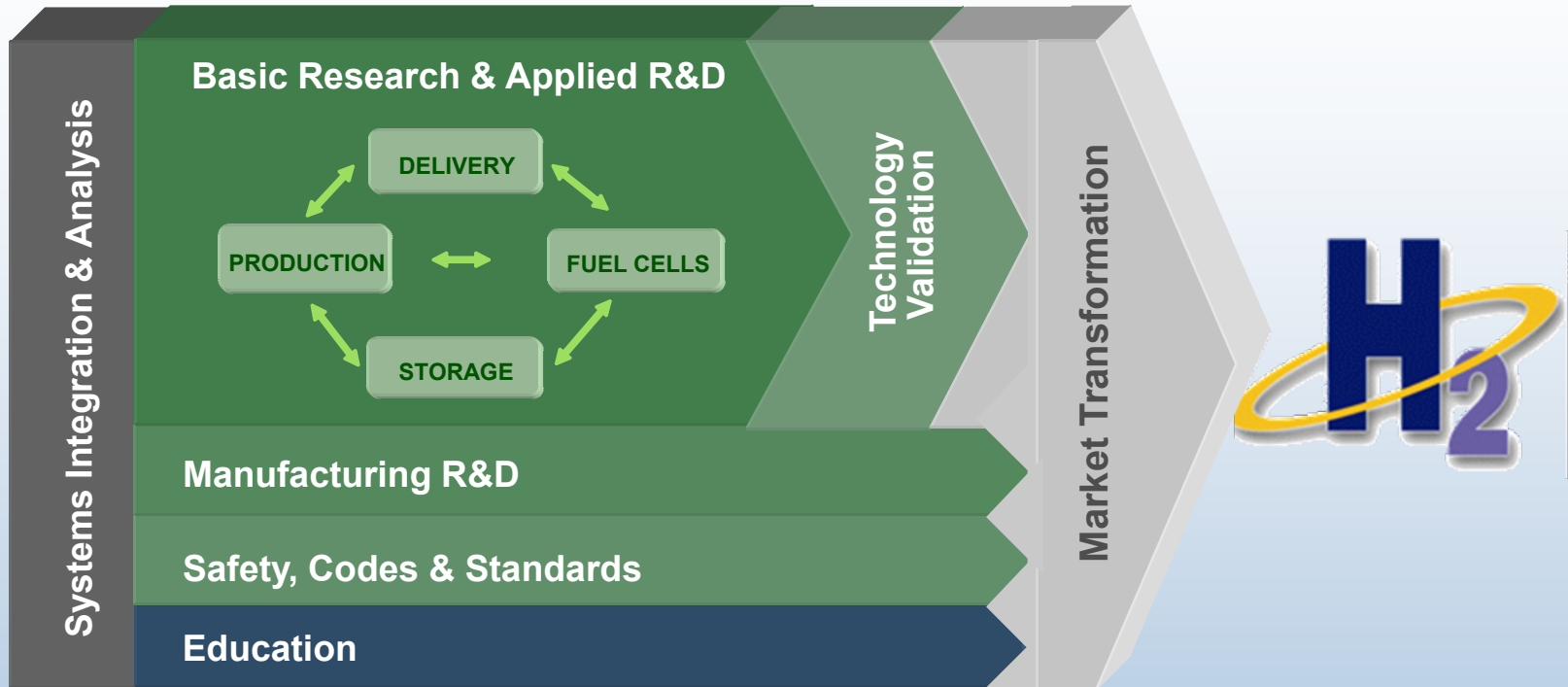
Created: Sep-10-07 3:11 PM

◆ 2001 NHTS Data: Only Car, Truck, Van, & SUV trips included in data set shown here
Source: <http://nhts.ornl.gov/download.shtml#2001>, ASCII.csv

Summary

- More than half of project completed
 - 77 vehicles and 14 stations deployed
 - 800,000 miles traveled, 30,000 kg H₂ produced or dispensed
 - 168,000 individual vehicle trips analyzed
 - Project to continue through 2009
- Examination of Factors Affecting FC Degradation Initiated
 - More difficult to identify trends across all 4 teams than for each team individually
 - NREL will collaborate with each team to investigate further
- Total of 41 composite data products published to date
 - This presentation only covered some of the new/updated results
 - Web site allows direct web access to all CDPs
- Roll-out of 2nd generation vehicles is beginning now
 - First public 700 bar station opened in U.S. – Irvine
 - Additional 700 bar refueling being installed in next year

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