

# EVS 23

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SUSTAINABILITY:  
THE FUTURE OF TRANSPORTATION

ANAHEIM, CALIFORNIA USA

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## FCV Learning Demonstration: Project Midpoint Status and Fall 2007 Results

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**EDTA**  
Electric Drive Transportation Association

In partnership with the World Electric  
Vehicle Association (WEVA)

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# Outline

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- 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 H<sub>2</sub> FC Vehicles and Infrastructure in Parallel
- Identify Current Status and Evolution of the Technology
  - Assess Progress Toward Technology Readiness
  - Provide Feedback to H<sub>2</sub> Research and Development

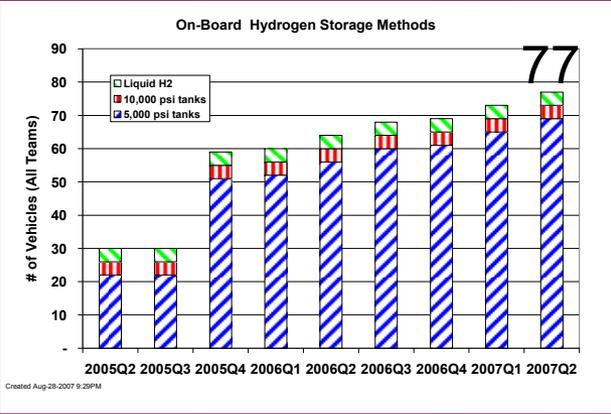
### Key Targets

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

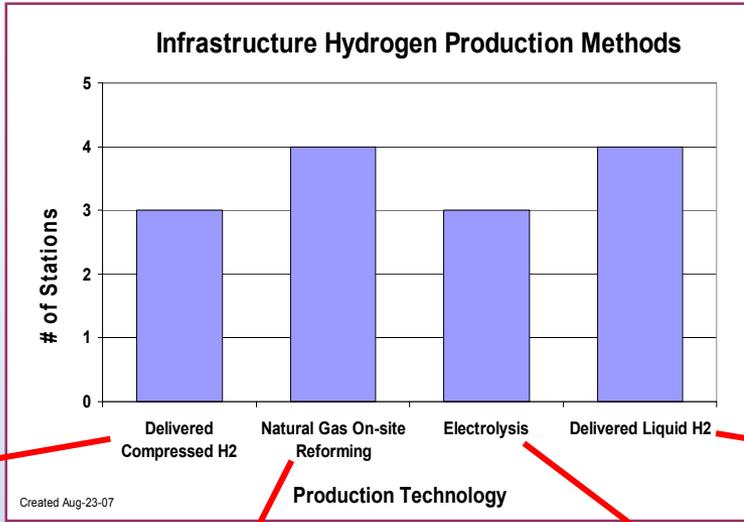


# Vehicle Status: All of First Generation Vehicles Deployed, 2<sup>nd</sup> Generation Initial Introduction in Fall 2007

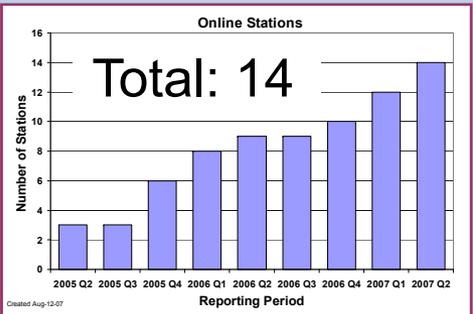


# ~2/3 of the Project's Infrastructure to Refuel Vehicles Has Been Installed – 4 Types (examples)

Mobile Refueler Sacramento, CA

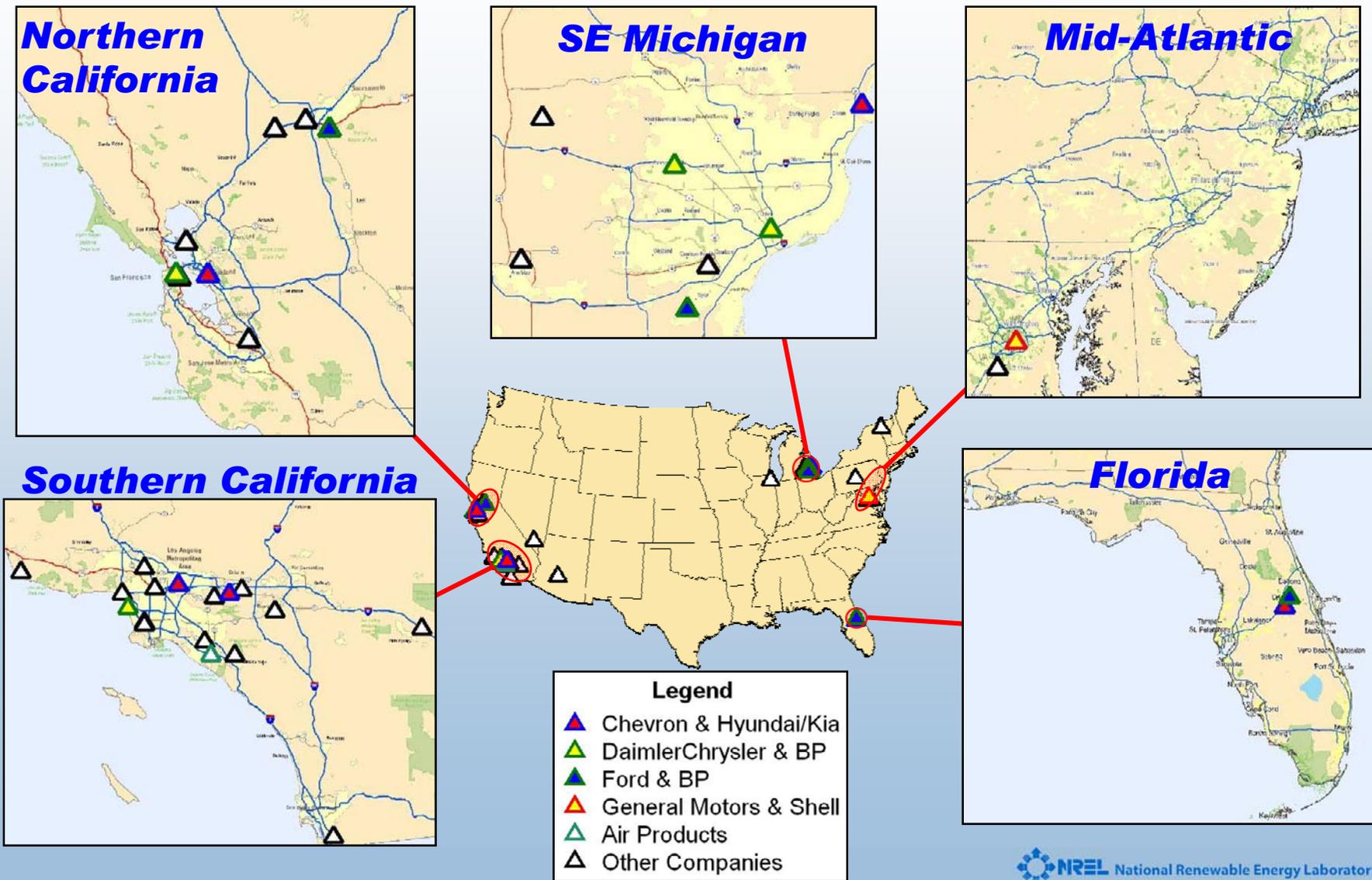


Hydrogen and Gasoline Station Washington, DC

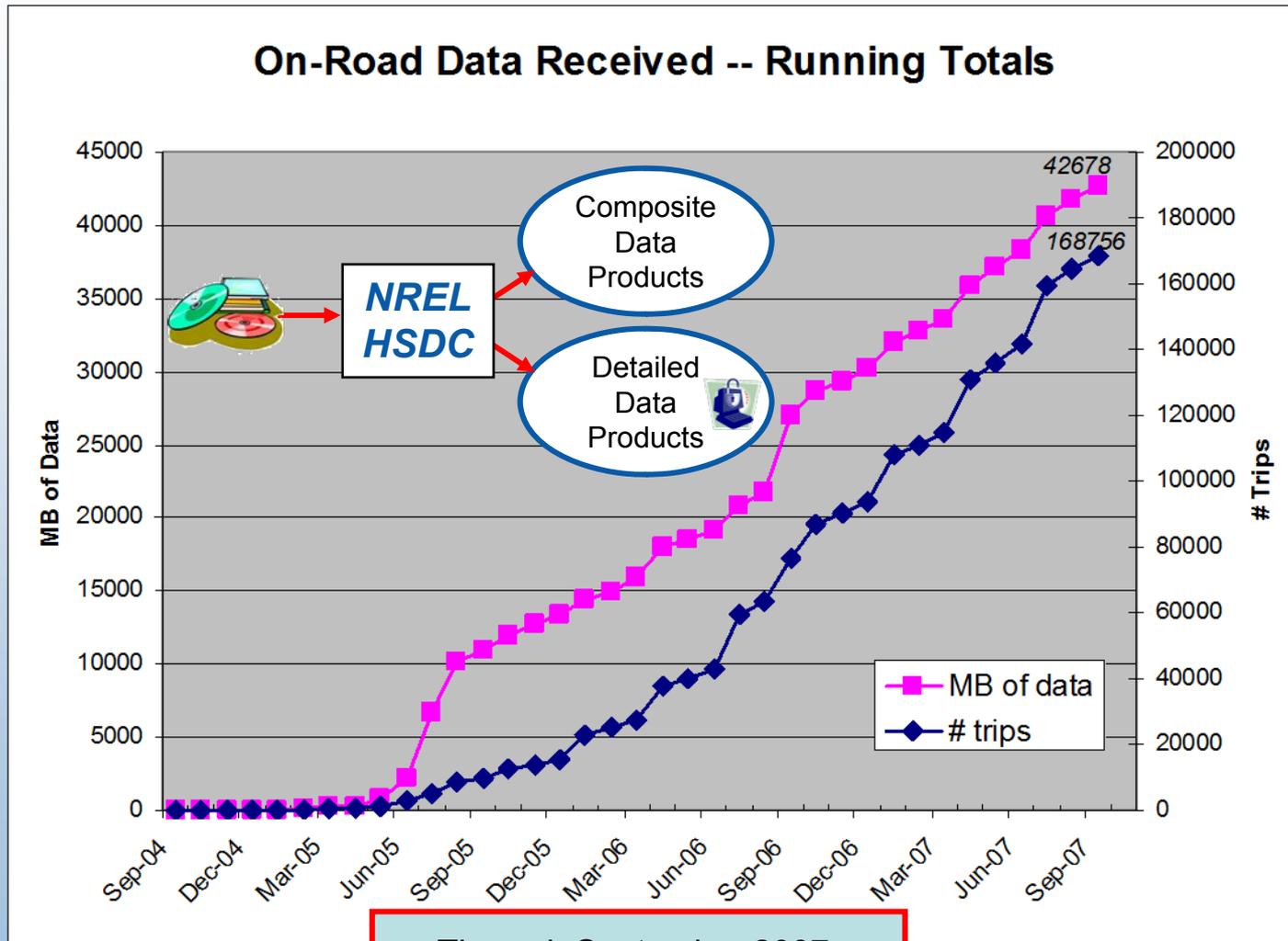


4 stations added in last six months

# 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

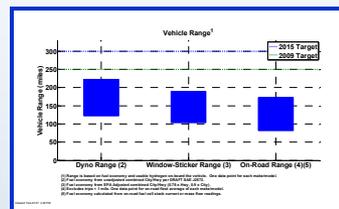


Through September 2007:  
>168,000 individual vehicle trips  
42 GB of on-road data

# 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 lists various categories such as 'Fuel Cell Stack Durability' and 'Fuel Cell Vehicle Range and Driving Behavior'. A red arrow points from the 'Fuel Cell Vehicle Range and Driving Behavior' section to a chart on the right.

[http://www.nrel.gov/hydrogen/cdp\\_topic.html](http://www.nrel.gov/hydrogen/cdp_topic.html)



Technical Report  
NREL/TP-560-41848  
July 2007  
K. Wipke, S. Sprik, H. Thomas, C. Welch, and J. Kurtz

[http://www.nrel.gov/hydrogen/proj\\_learning\\_demo.html](http://www.nrel.gov/hydrogen/proj_learning_demo.html)

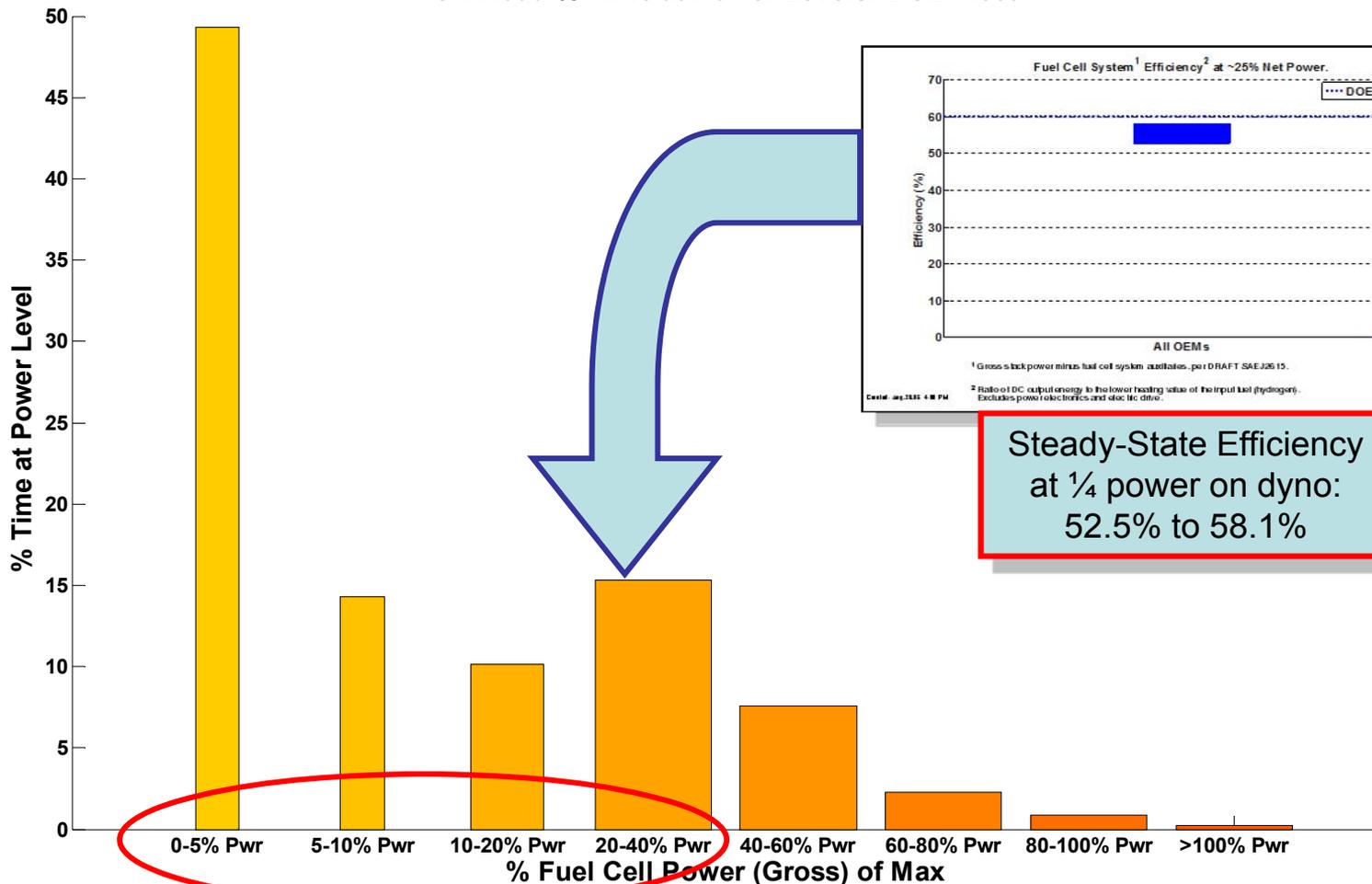
The screenshot shows the 'Presentations and Publications' section of the NREL website. It lists documents available as Adobe Acrobat PDFs. A red arrow points from the 'FCV Learning Demonstration: First-Generation Vehicle Results and Factors Affecting Fuel Cell Degradation' entry to a report cover on the right.

Technical Report  
NREL/TP-560-42264  
October 2007  
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

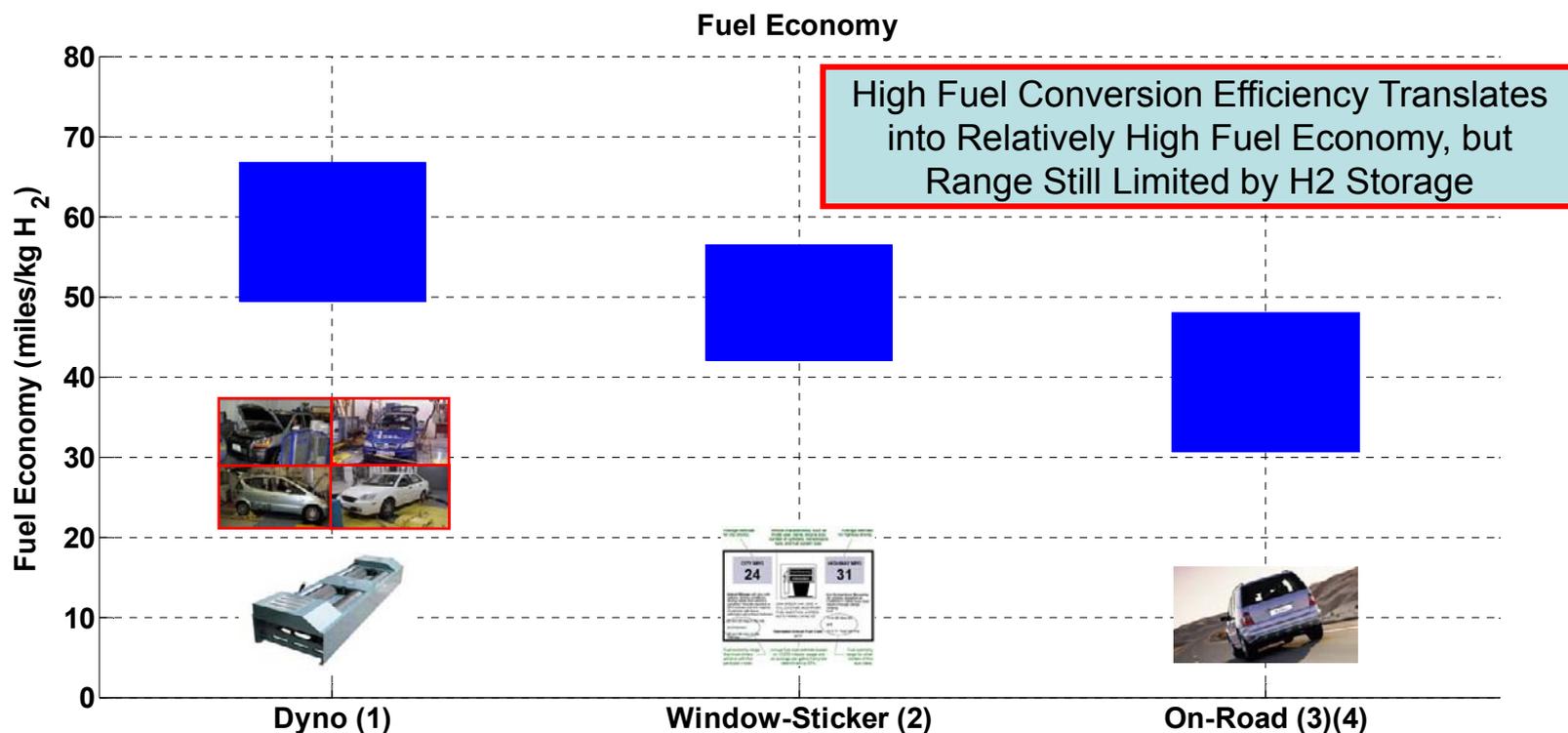


Steady-State Efficiency at 1/4 power on dyno: 52.5% to 58.1%

~85% time spent at <40% power

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# 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 x Hwy, 0.9 x City).

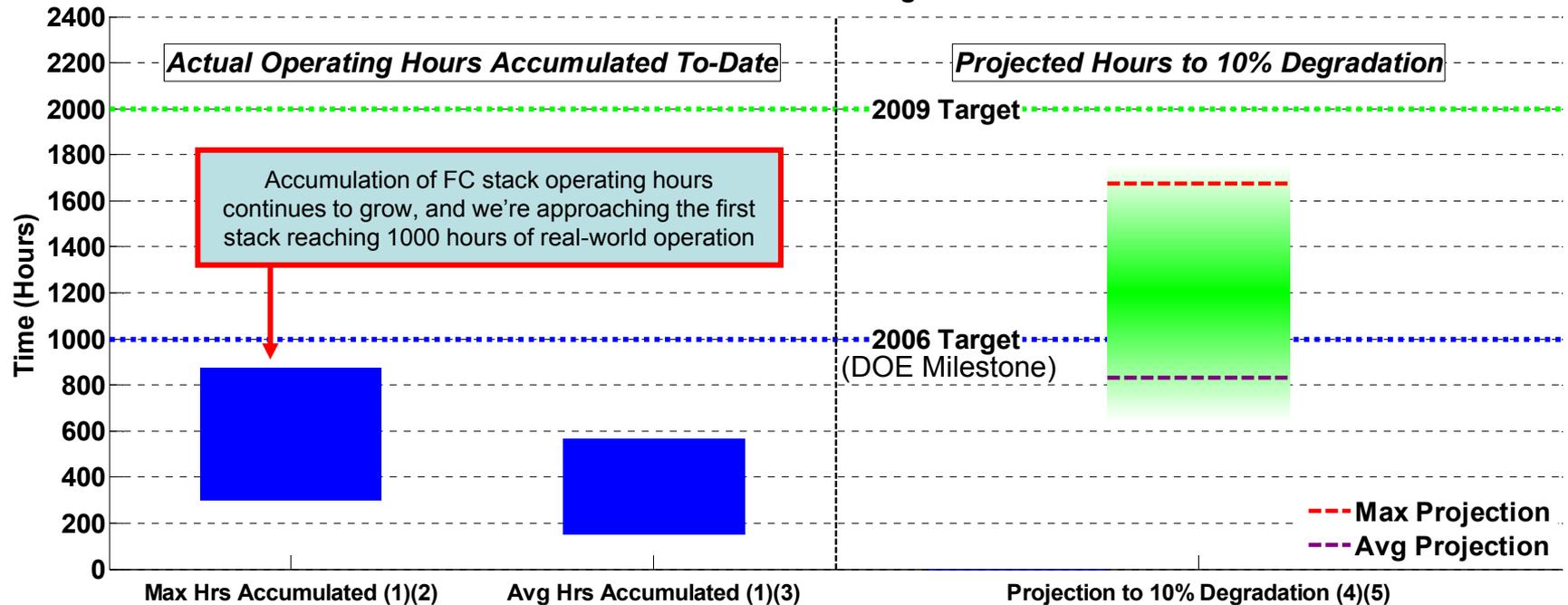
(3) Excludes trips < 1 mile. One data point for on-road fleet average of each make/model.

(4) Calculated from on-road fuel cell stack current or mass flow readings.

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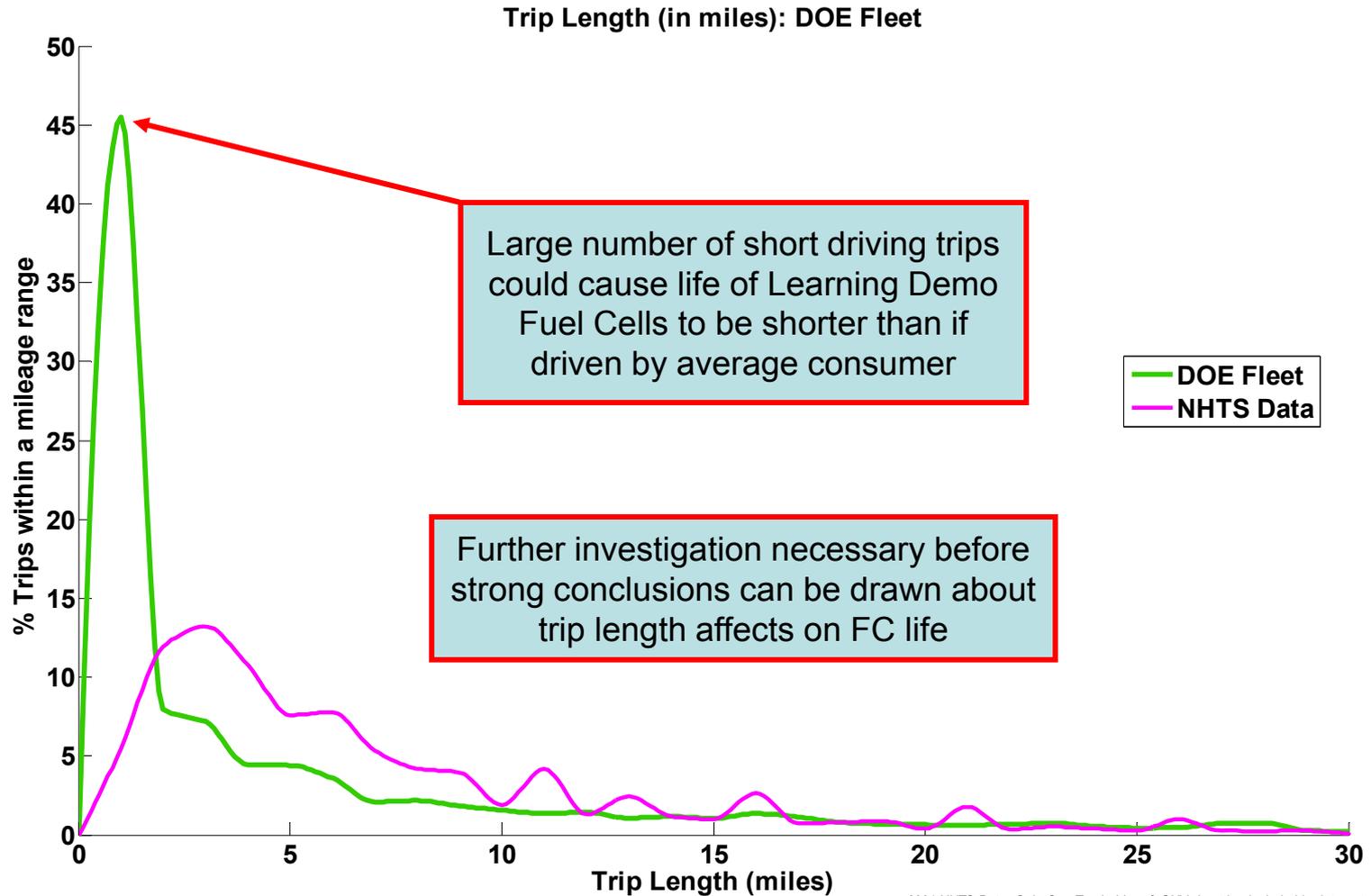
# As More Gen 1 Data Is Accumulated, Some Teams Are Demonstrating Long FC Durability

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



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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

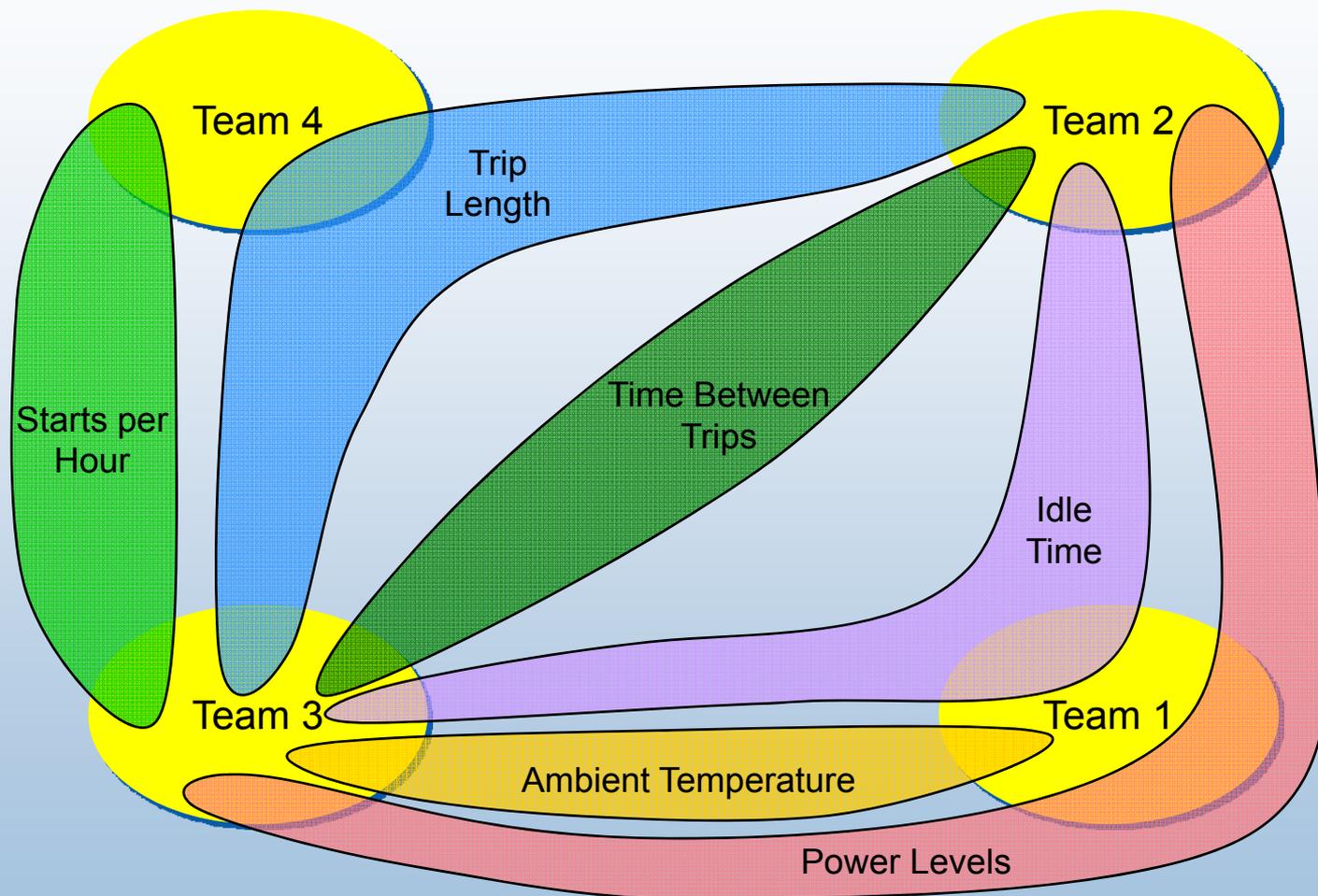
# Primary Factors Affecting Learning Demo Fleet Fuel Cell Degradation: FC Diversity (Among Teams) Limits Drawing Strong Conclusions

<b>~29% Decay rate variance explained by a combination of the data variables below<sup>1</sup></b>	<b>Correlation to Decay Rate Data</b>
Starts per hour (+)	High decay rate <sup>2</sup>
Power levels (high & average) (+)	
Trip length (-)	
Time between trips (+)	
<b>~10% Decay rate variance explained by a combination of the data variables below<sup>1</sup></b>	<b>Correlation to Decay Rate Data</b>
Idle time (+)	High decay rate <sup>2</sup>
Power levels (low) (+)	

1. Findings based on a Learning Demonstration Fleet, Partial Least Squares (PLS) regression model. Approximately 39% decay rate variance explained by the model.

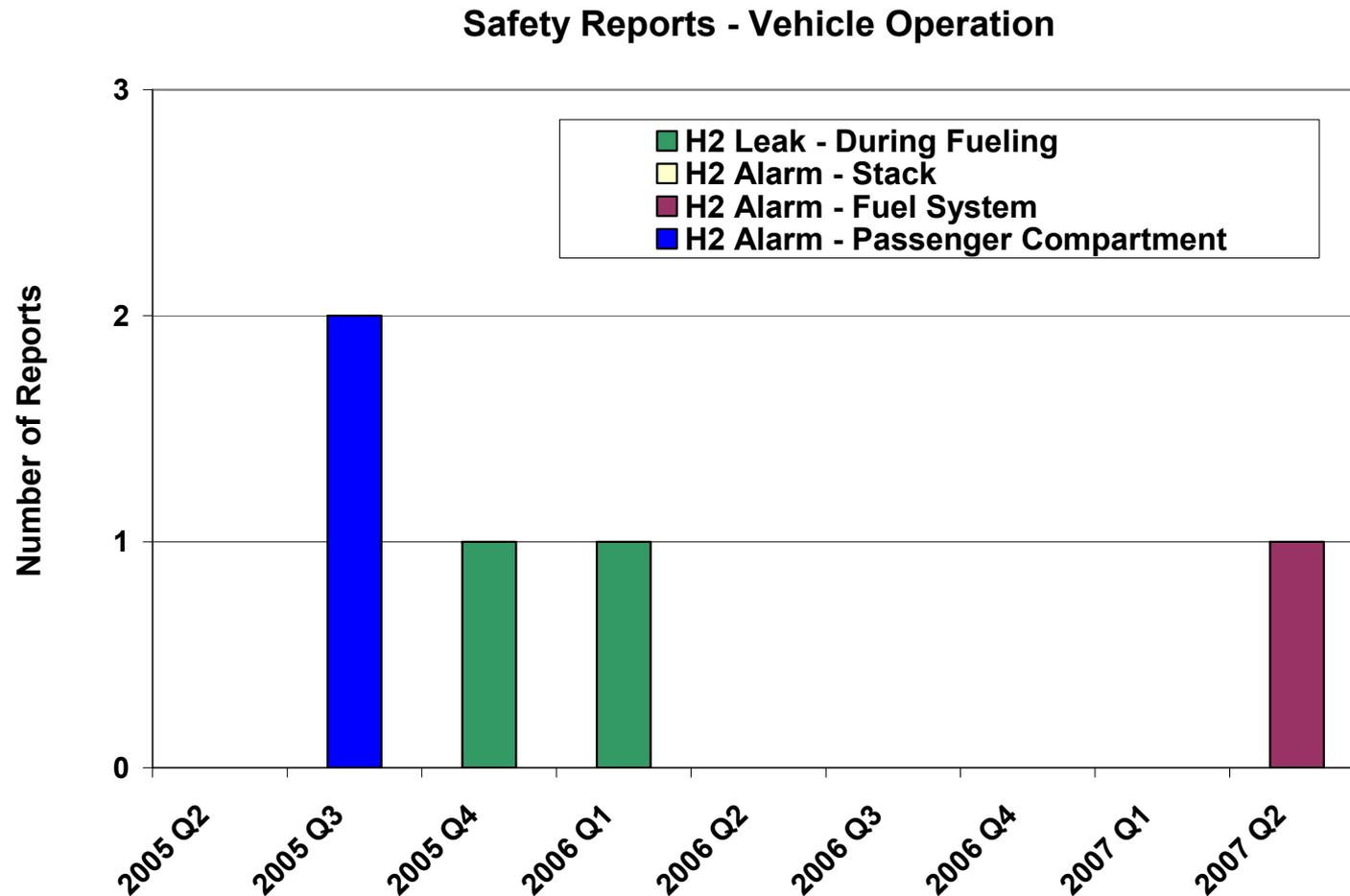
2. As part of the variable combination, a (+) indicates a directional relation to high decay rate and a (-) indicates an inverse relation.

# Easier (but Still Difficult!) to Pull Out Dominant Degradation Factors When Looking at One Team's Stacks at a Time



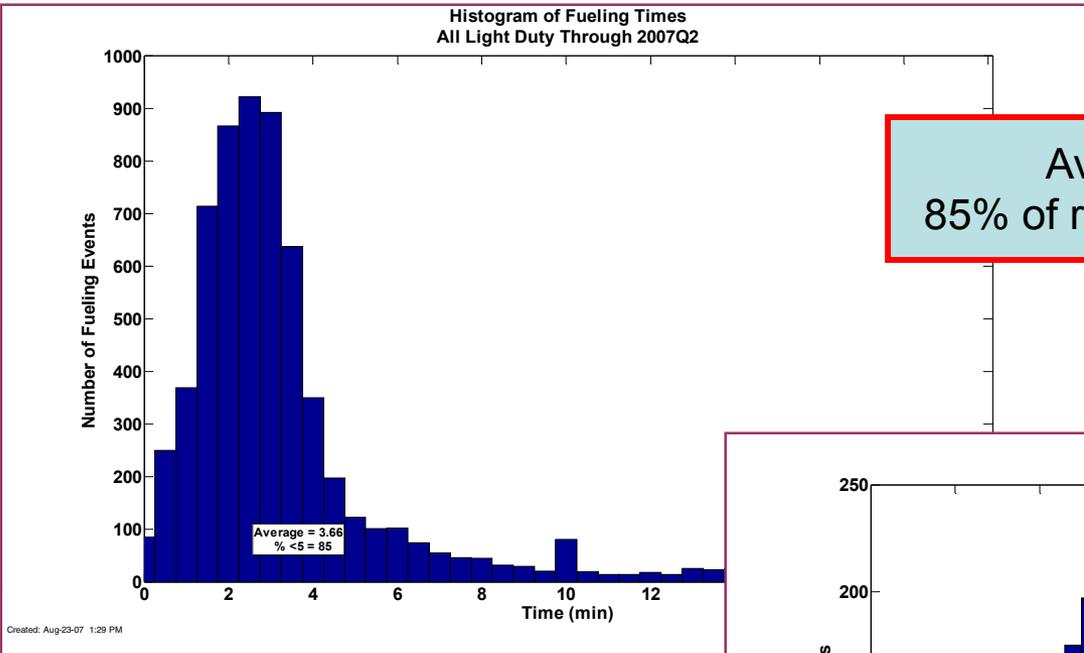
1. Results are from partial least squares (PLS) regression analysis of each team's fleet of vehicles individually
2. First two collections of factors cover ~61%-76% of decay rate variance

# Vehicle Reports Indicate Strong Safety Record; Issue Relative to H2 Sensor Alarms Resolved

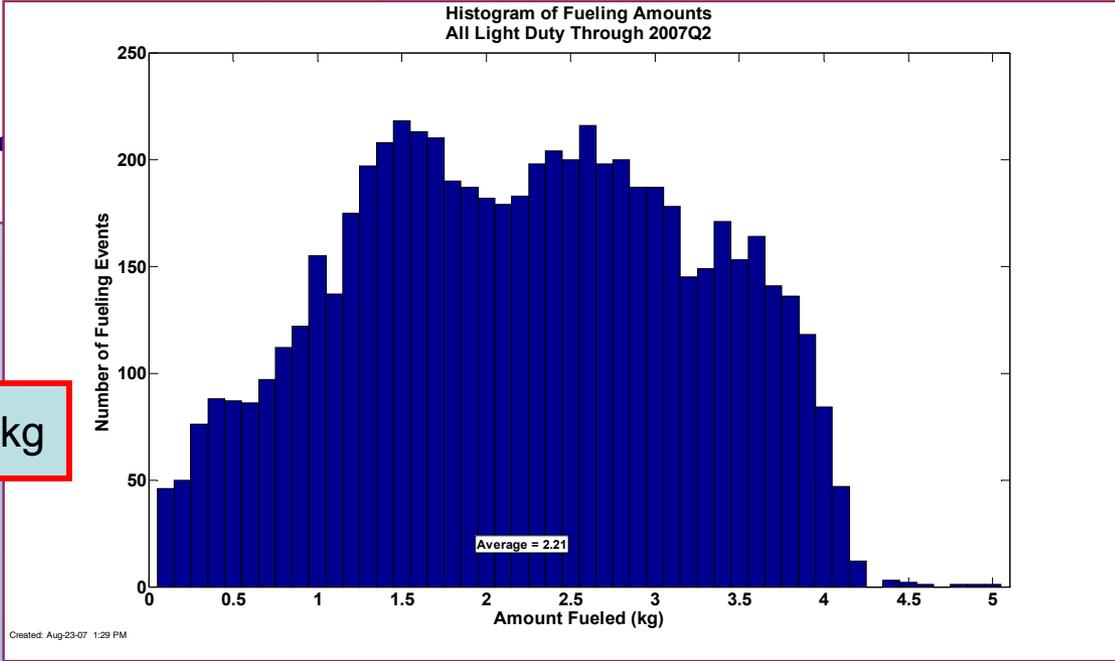


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# Actual Vehicle Refueling Times and Amounts from >6,300 Events: Measured by Stations or by Vehicles



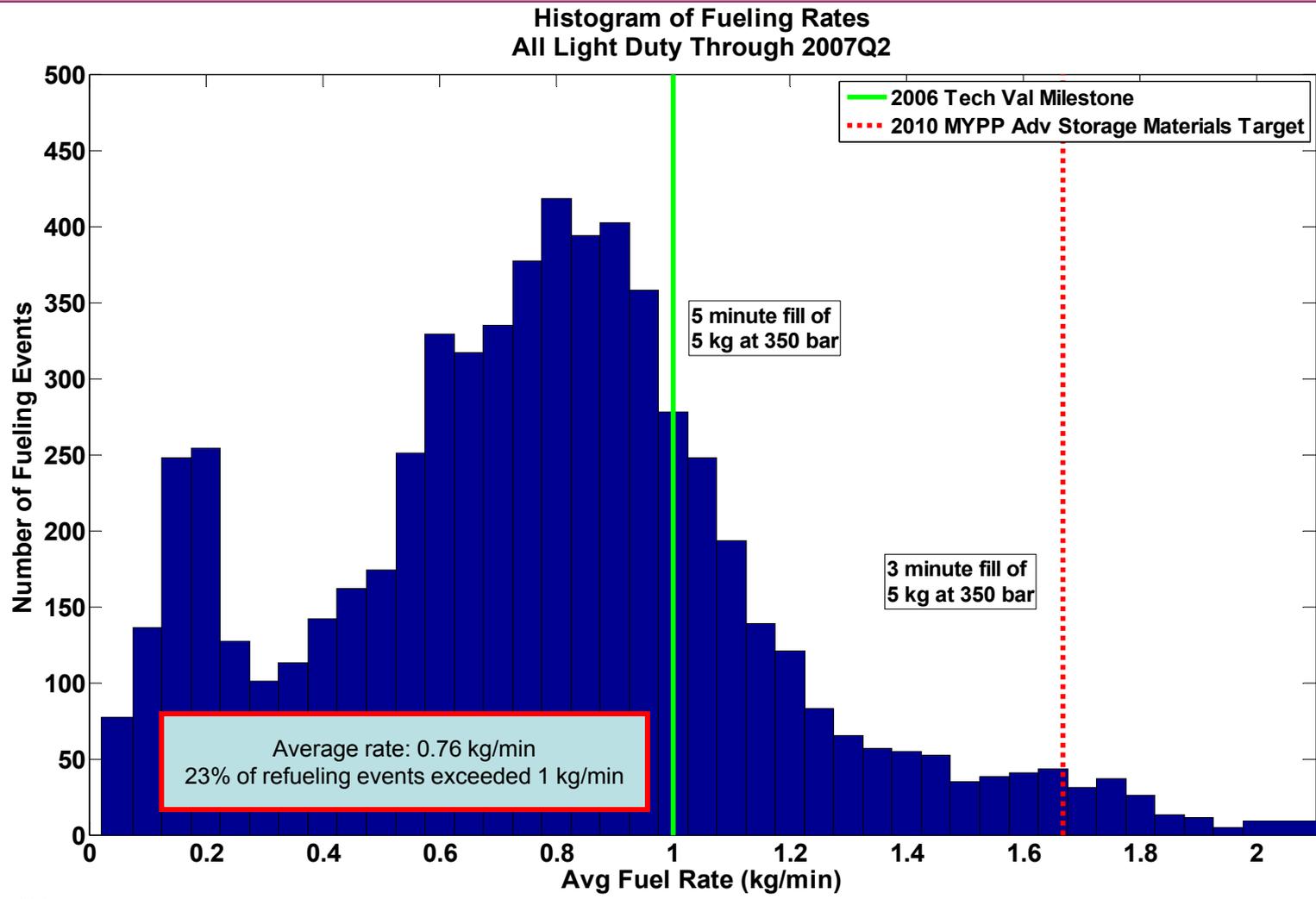
Average time: 3.66 min  
85% of refueling events took <5 min



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

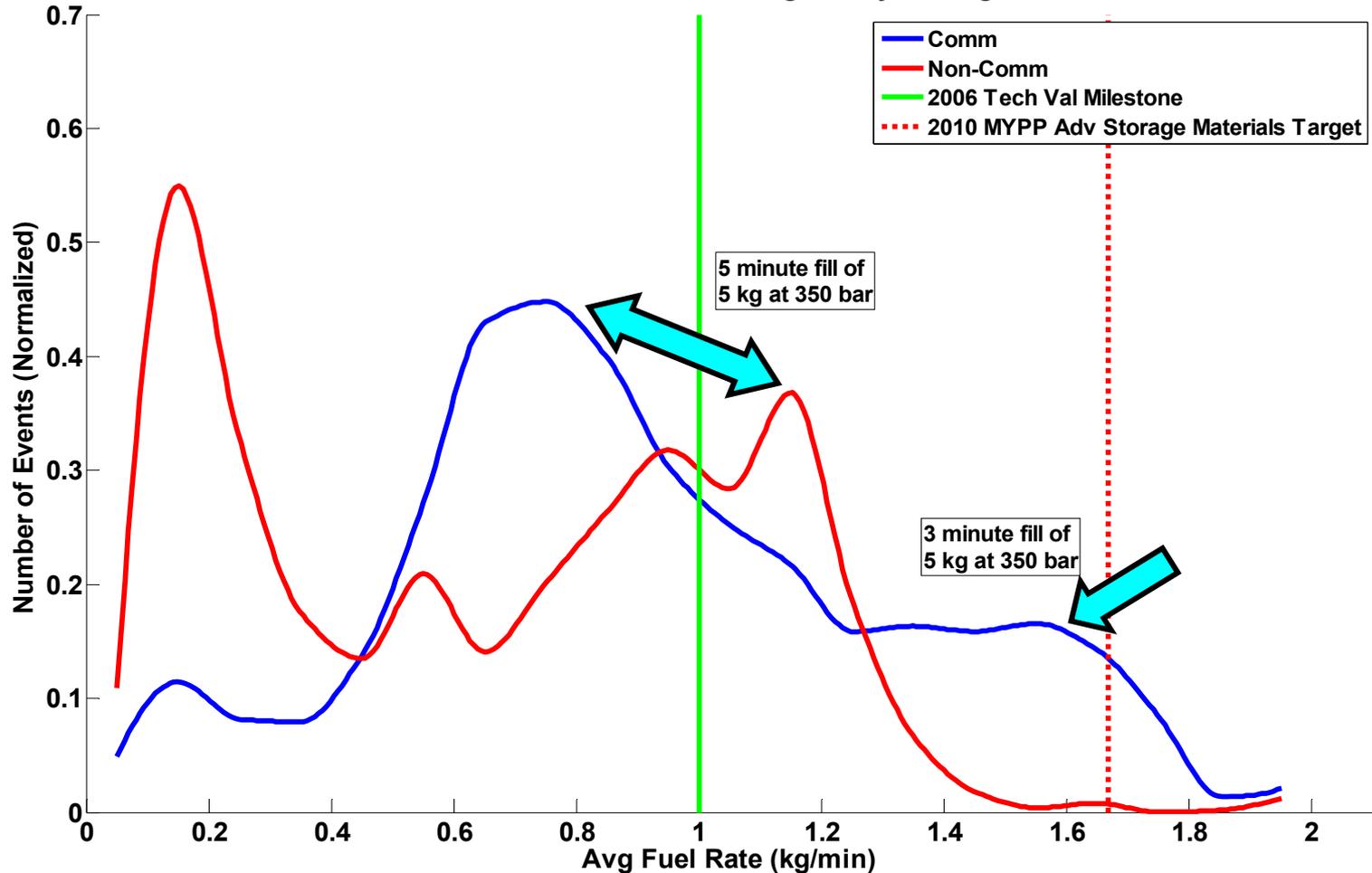


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Includes Comm. and Non-Comm. Fills

# 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



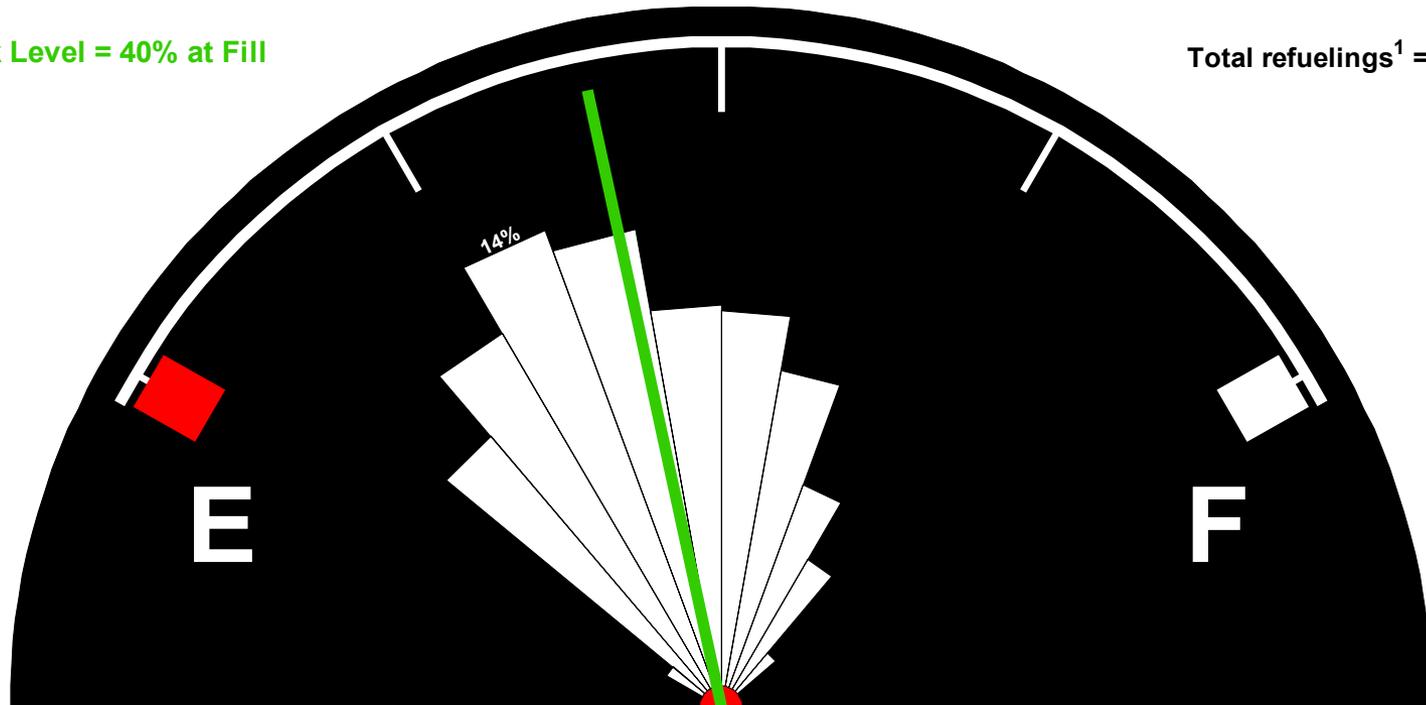
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# Large Spread in H2 Tank Level at Refueling Peak at ~1/4 Full, Median at ~3/8 Full

Tank Levels: DOE Fleet

Median Tank Level = 40% at Fill

Total refuelings<sup>1</sup> = 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.

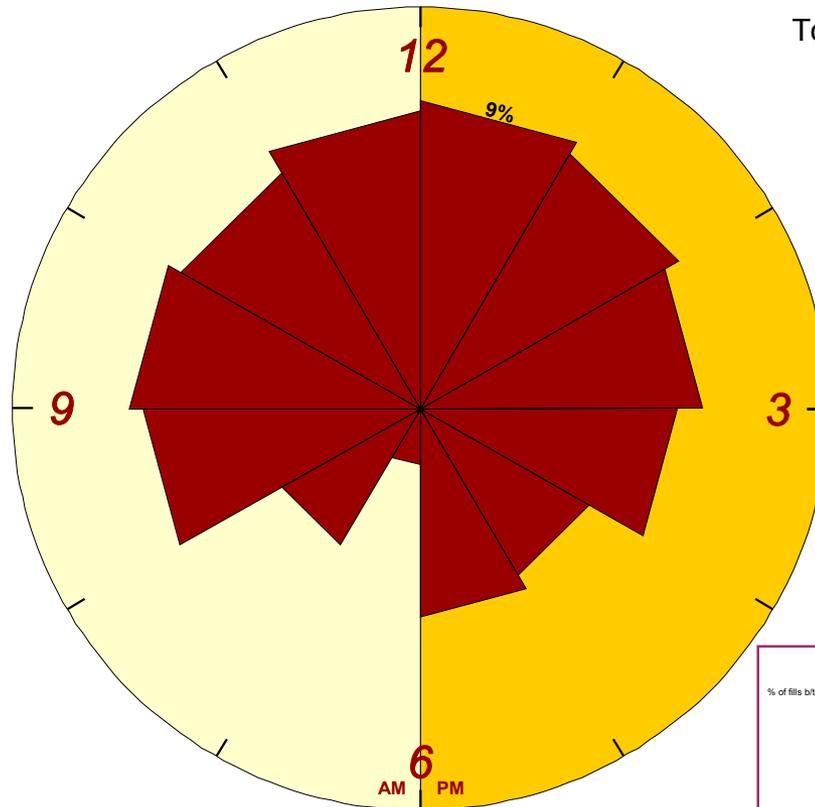
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# Refueling by Time of Day; Relative Uniform Refueling Infrastructure Demand Between 8-4

Refueling by Time of Day: DOE Fleet

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

Total Fill<sup>3</sup> 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.

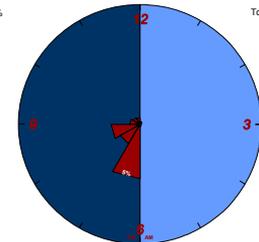
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(Night)

Refueling by Time of Night: DOE Fleet

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

Total Fill<sup>3</sup> 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.

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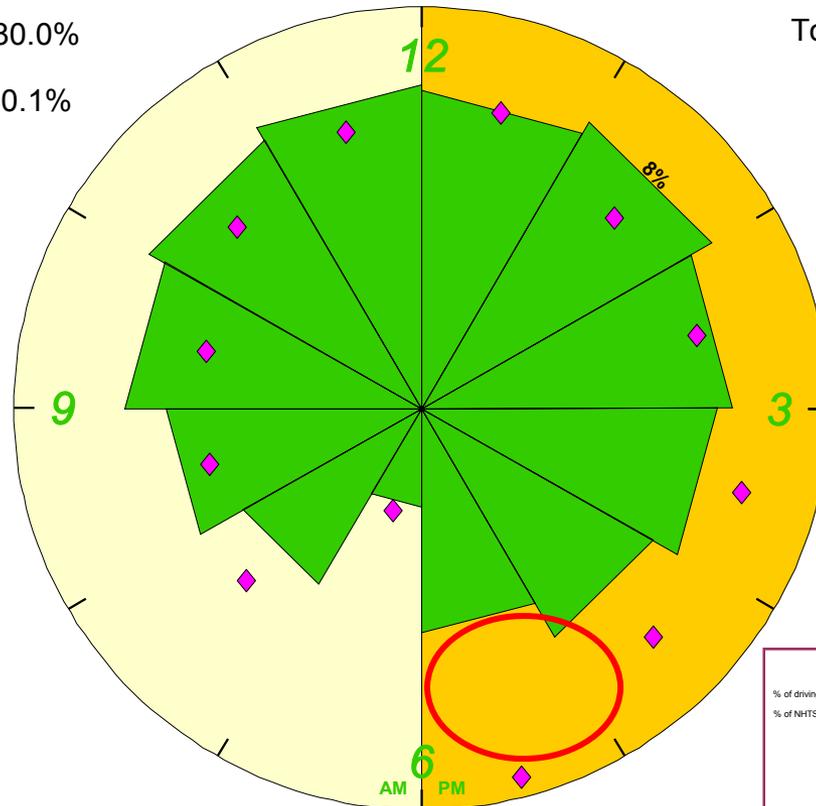
# Driving Trip Start Time – Day; Roughly Matches National Statistics Except for 5-6 PM

Driving Start Time - Day: DOE Fleet

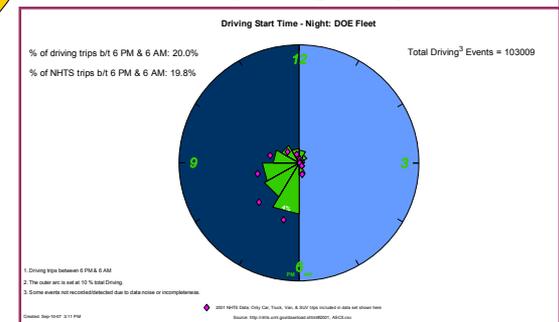
% of driving trips b/t 6 AM & 6 PM: 80.0%

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

Total Driving<sup>3</sup> Events = 103009



(Night)



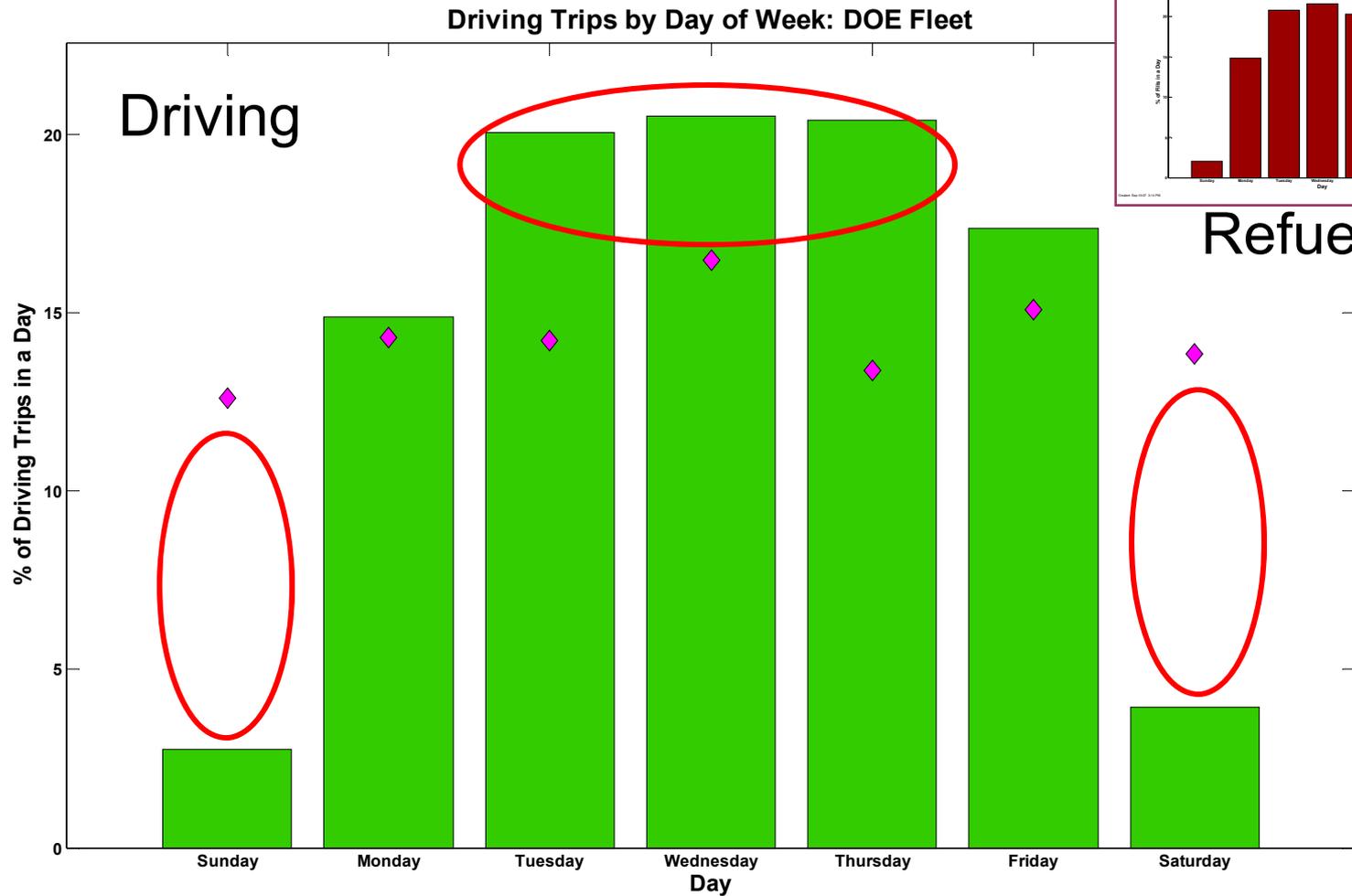
1. Driving trips between 6 AM & 6 PM
2. The outer arc is set at 10% total Driving.
3. Some events not recorded/detected due to data noise or incompleteness.

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

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

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



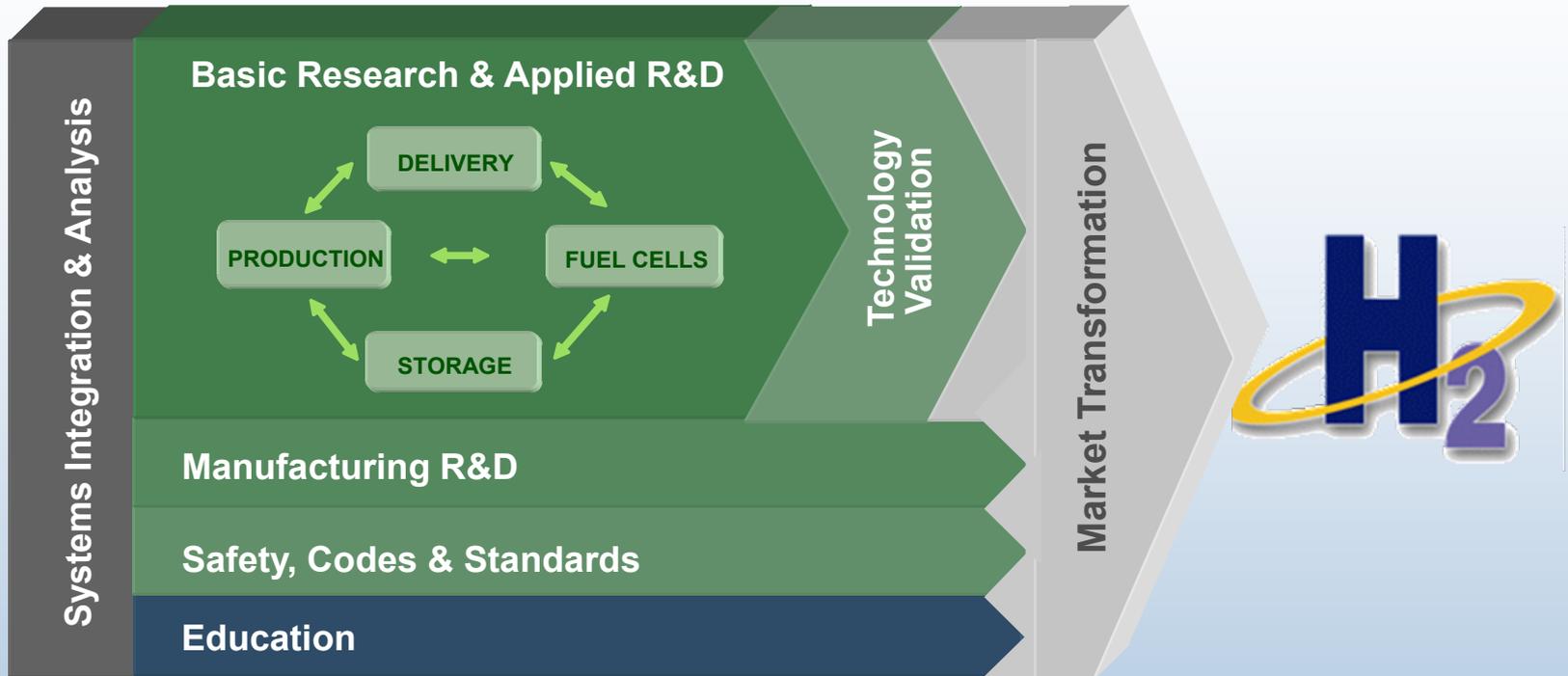
Created: Sep-10-07 3:11 PM

◆ 2001 NHTS Data: Only Car, Truck, Van, & SUV trips included in data set shown here  
Source: <http://nhts.oml.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 H<sub>2</sub> 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 2<sup>nd</sup> 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](http://www.nrel.gov/hydrogen/proj_tech_validation.html)