FCV Learning Demonstration: First-Generation Vehicle Results and Factors Affecting Fuel Cell Degradation

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This presentation does not contain any proprietary or confidential information

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

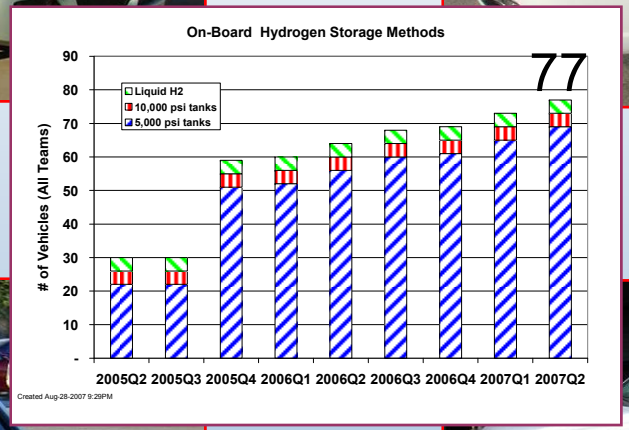
Key Targets

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

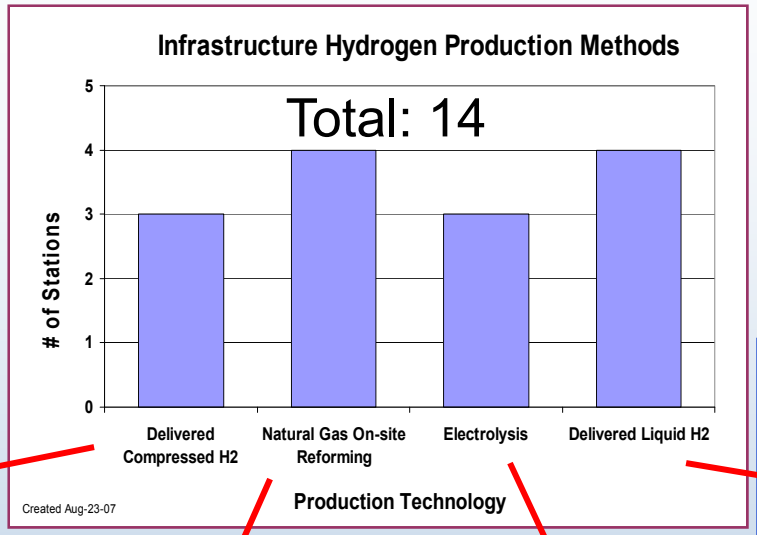
* To verify progress toward 2015 targets
** Subsequent projects to validate 2015 targets

Hydrogen refueling station, Chino, CA Photo: NREL

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

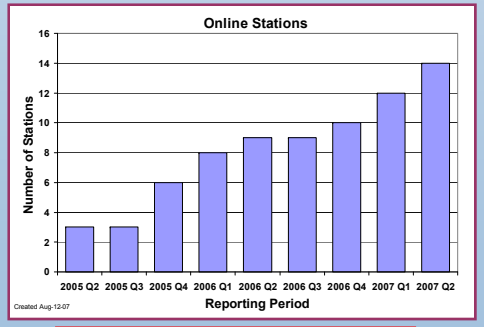


~2/3 of the Project's Infrastructure to Refuel Vehicles Has Been Installed – 4 Types (examples)



Mobile Refueler
San Francisco, CA

Hydrogen and gasoline station
Washington, DC

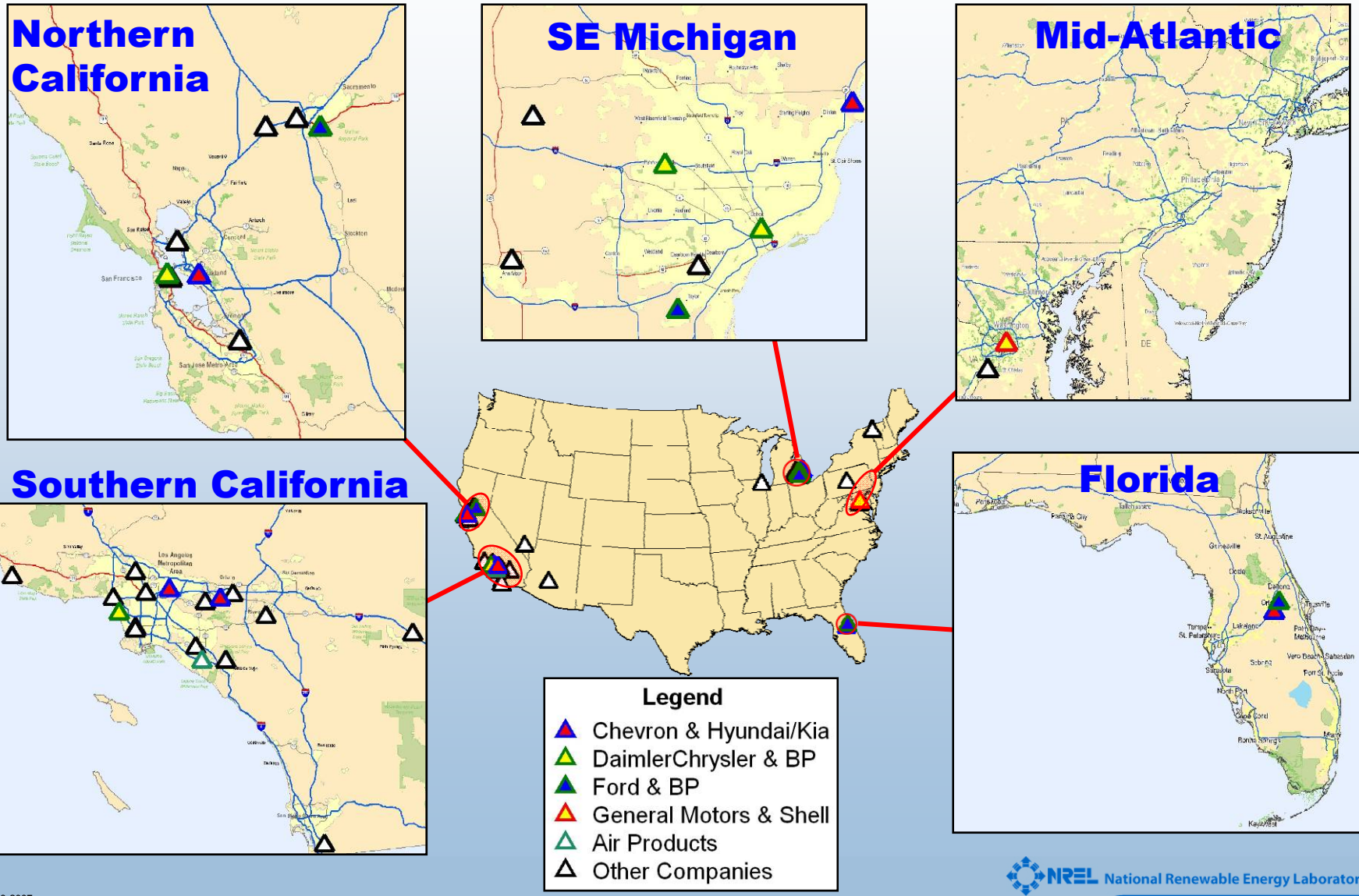


4 stations added in last six months

Autothermal Reformer
Chino, CA

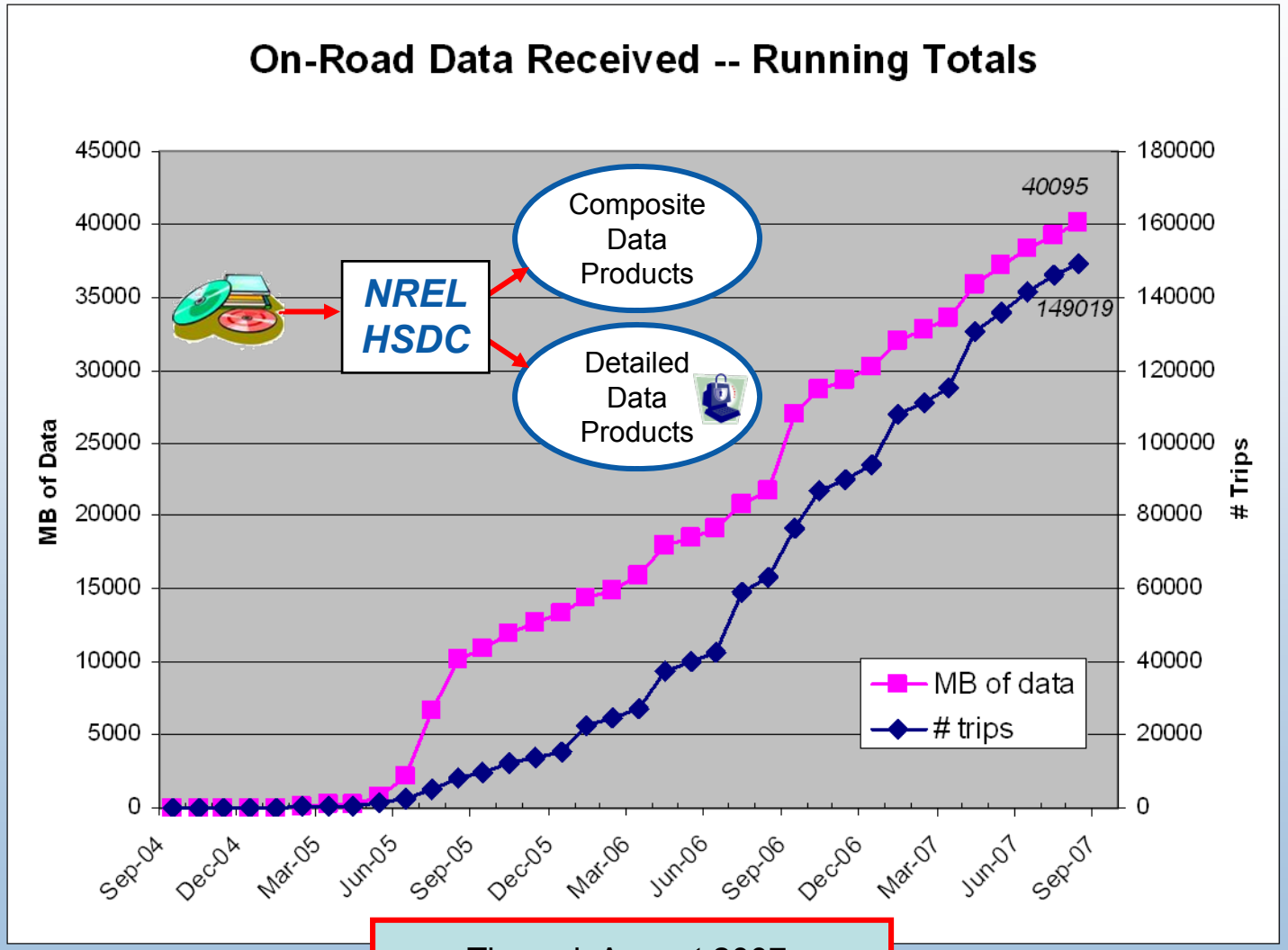
DTE/BP Power Park
Southfield, MI

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



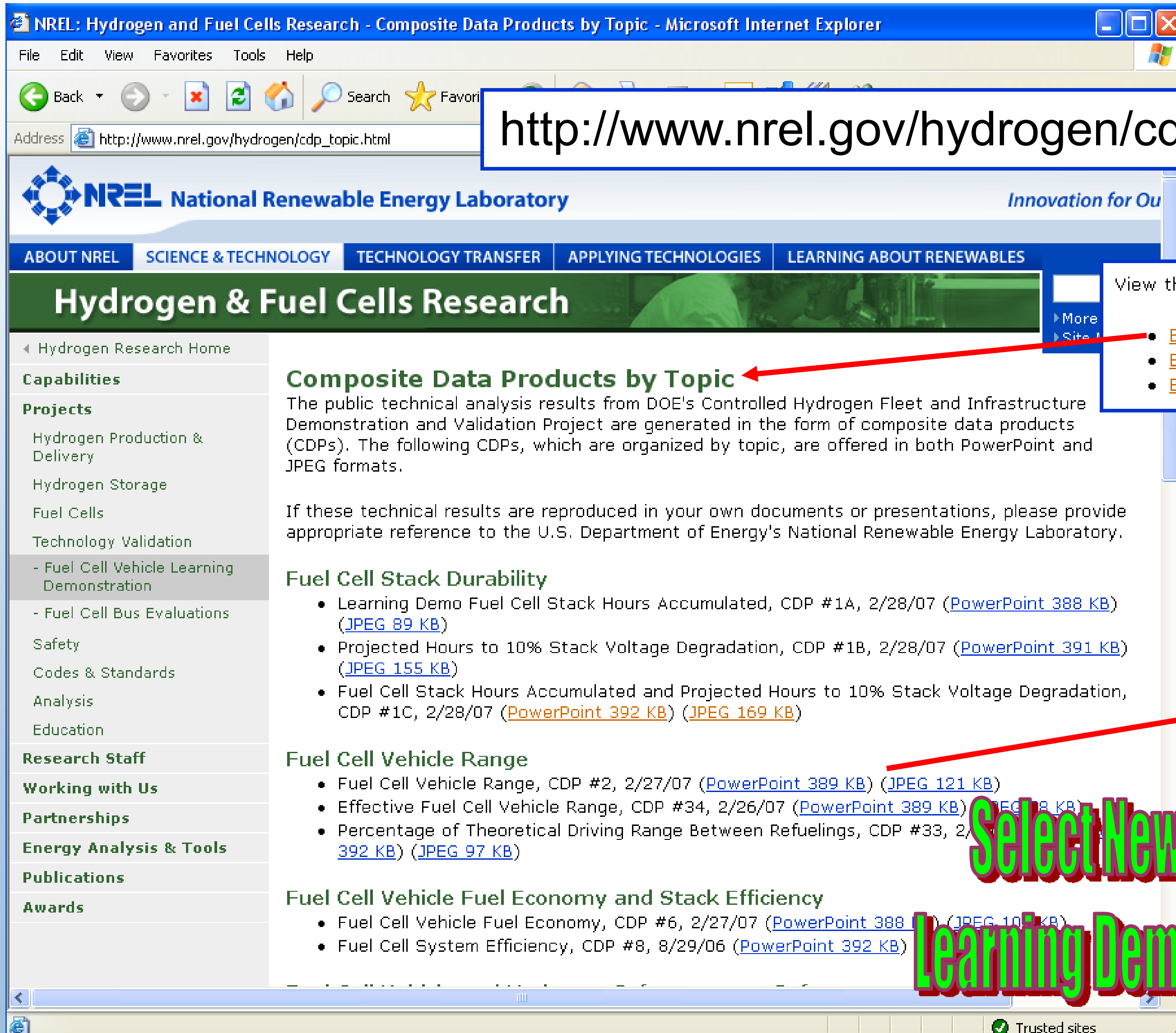
>2 Years of Data Analyzed To-Date

Current Status of Data Reporting to the Hydrogen Secure Data Center at NREL



Through August 2007:
>149,000 individual vehicle trips
40 GB of on-road data

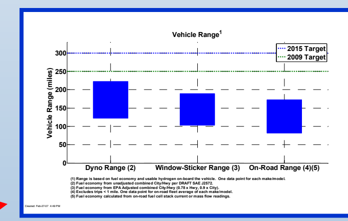
NREL Web Page Provides Direct Access to All Composite Data Products



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

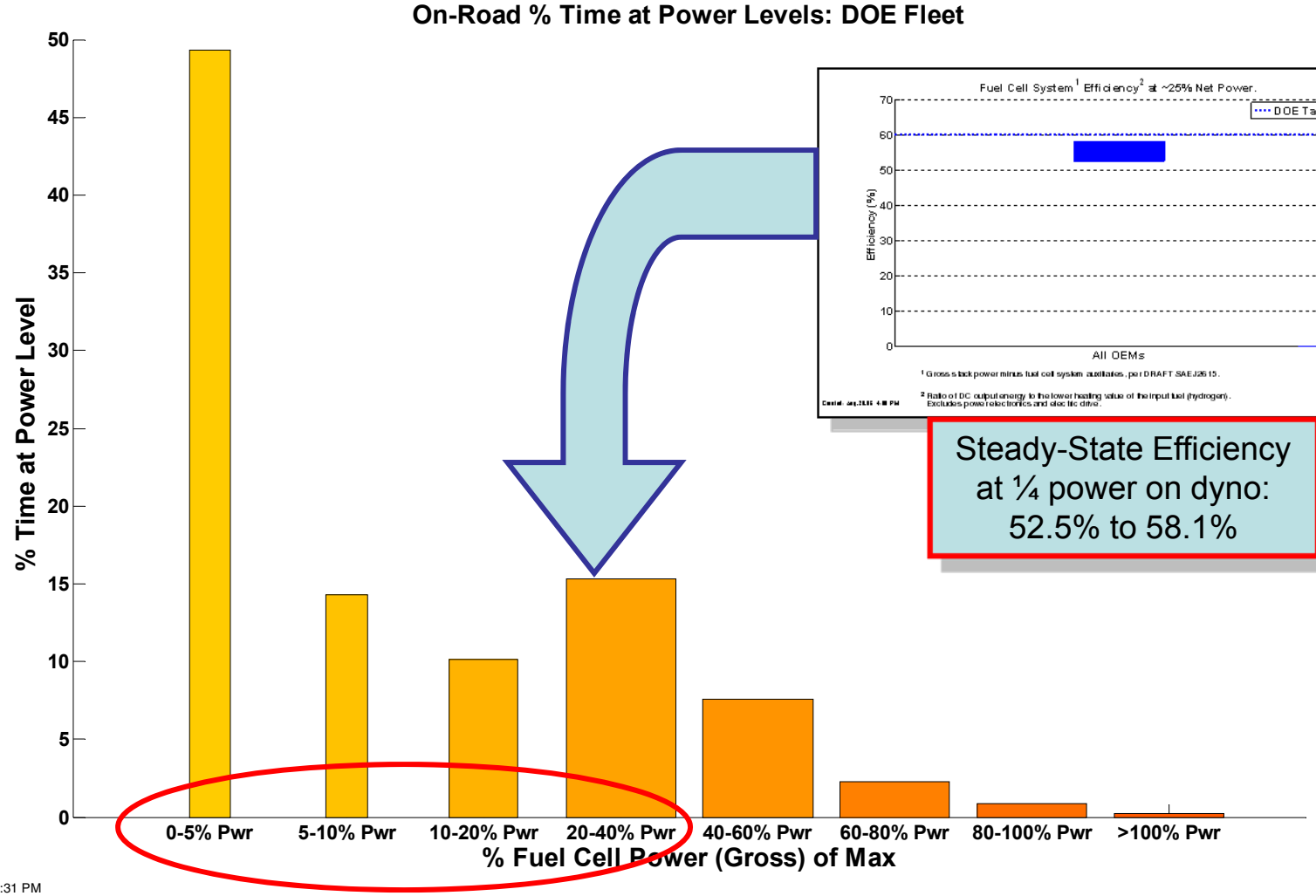
View the Learning Demonstration CDPs:

- By topic
- By date
- By CDP#

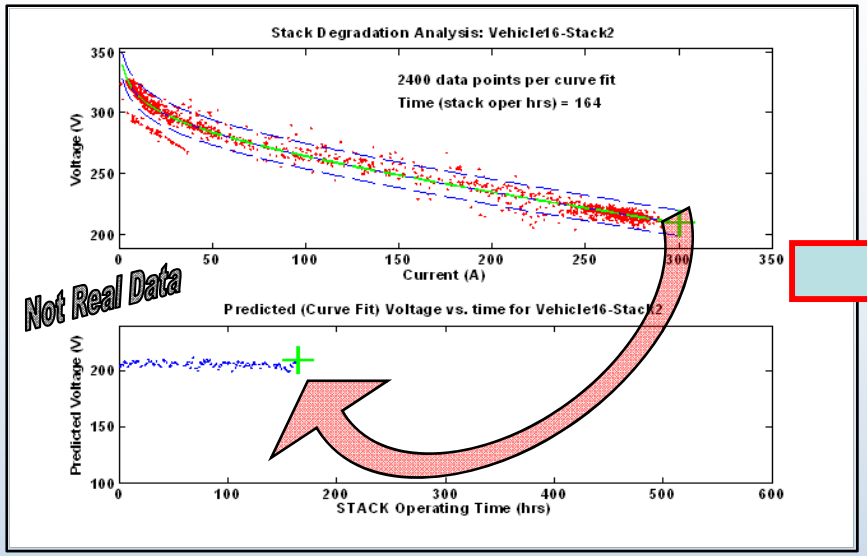


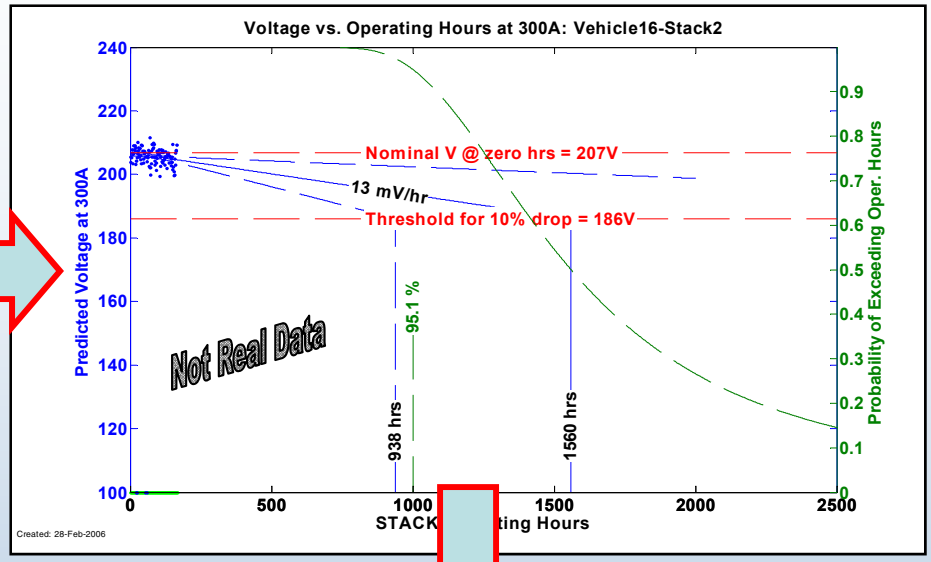
Select New and Updated Learning Demo Results Follow

On-Road FC Operating Power Points: Dyno Tests Validated High Efficiency at ¼ Power Point – Key to Overall Efficiency



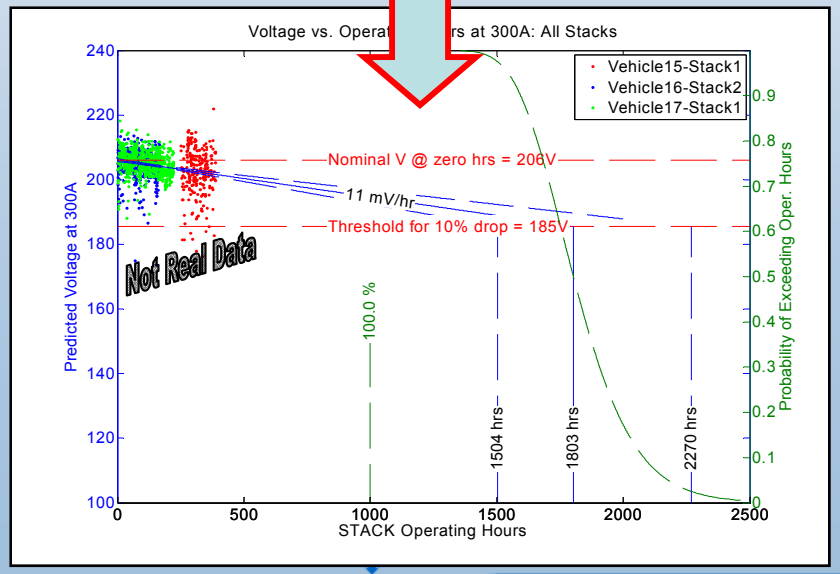
Method for Projecting Time to 10% Fuel Cell Stack Voltage Degradation



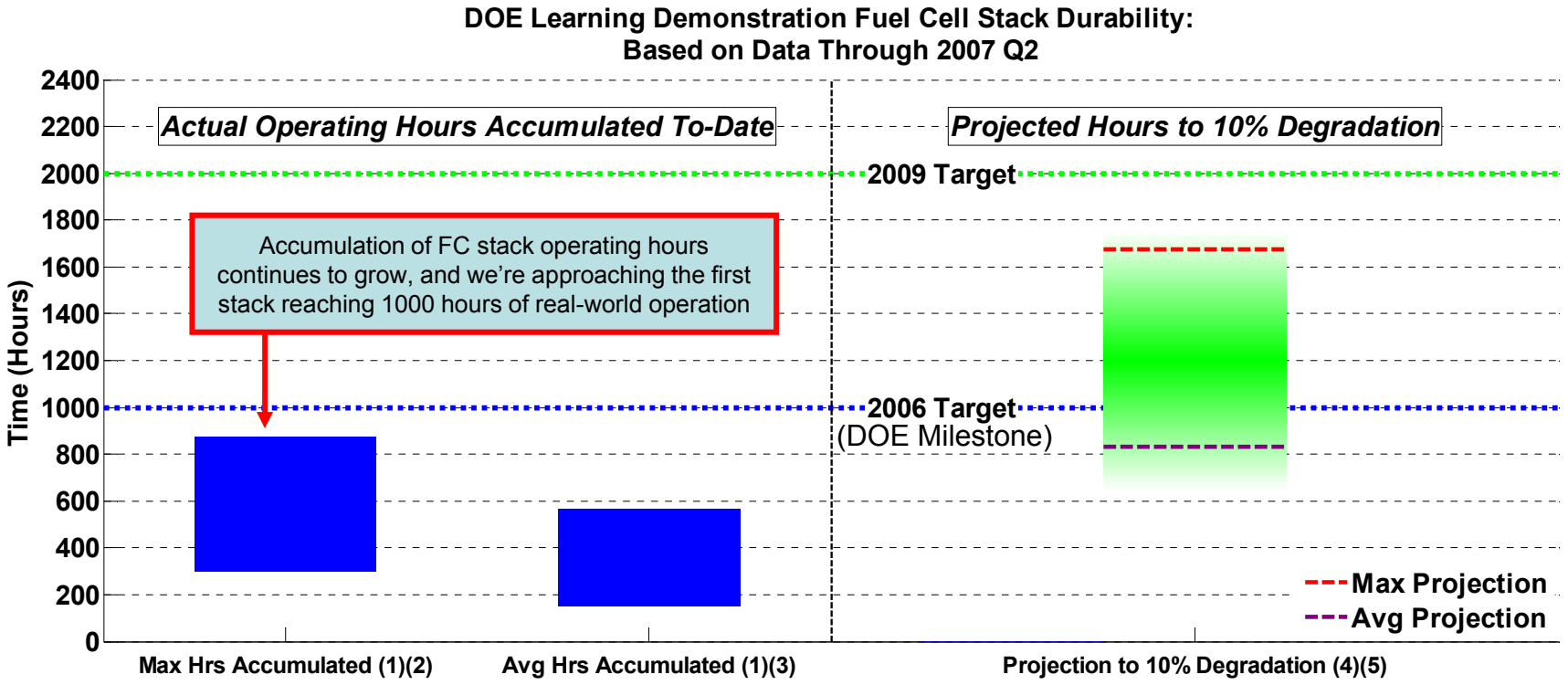


Note: 10% is an R&D metric for FC stack degradation. It does not necessarily indicate an end-of-life condition. OEMs may use other values or indicators.

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



(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.

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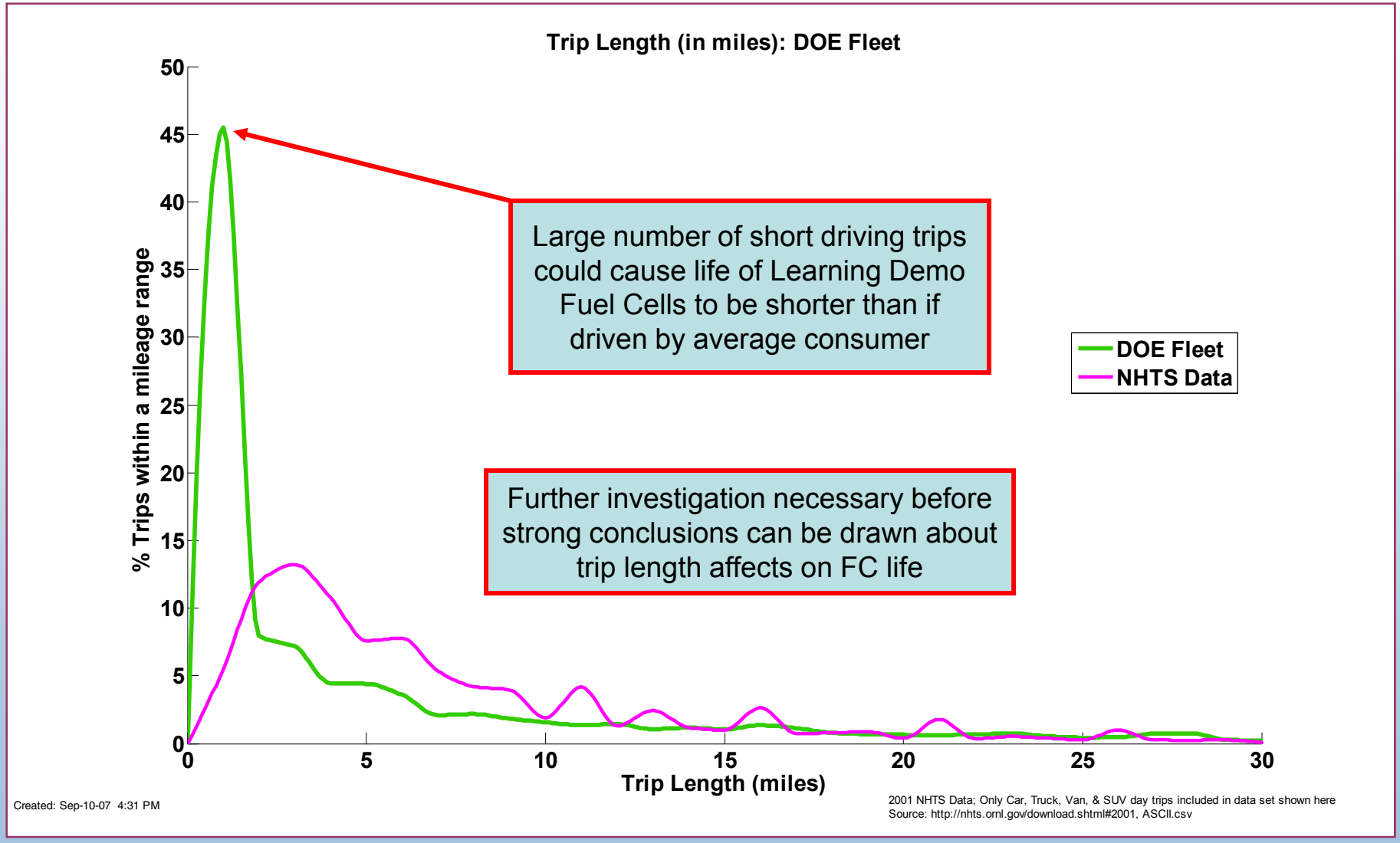
Primary Factors Affecting Learning Demo Fleet Fuel Cell Degradation: FC Diversity (Among Teams) Limits Drawing Strong Conclusions

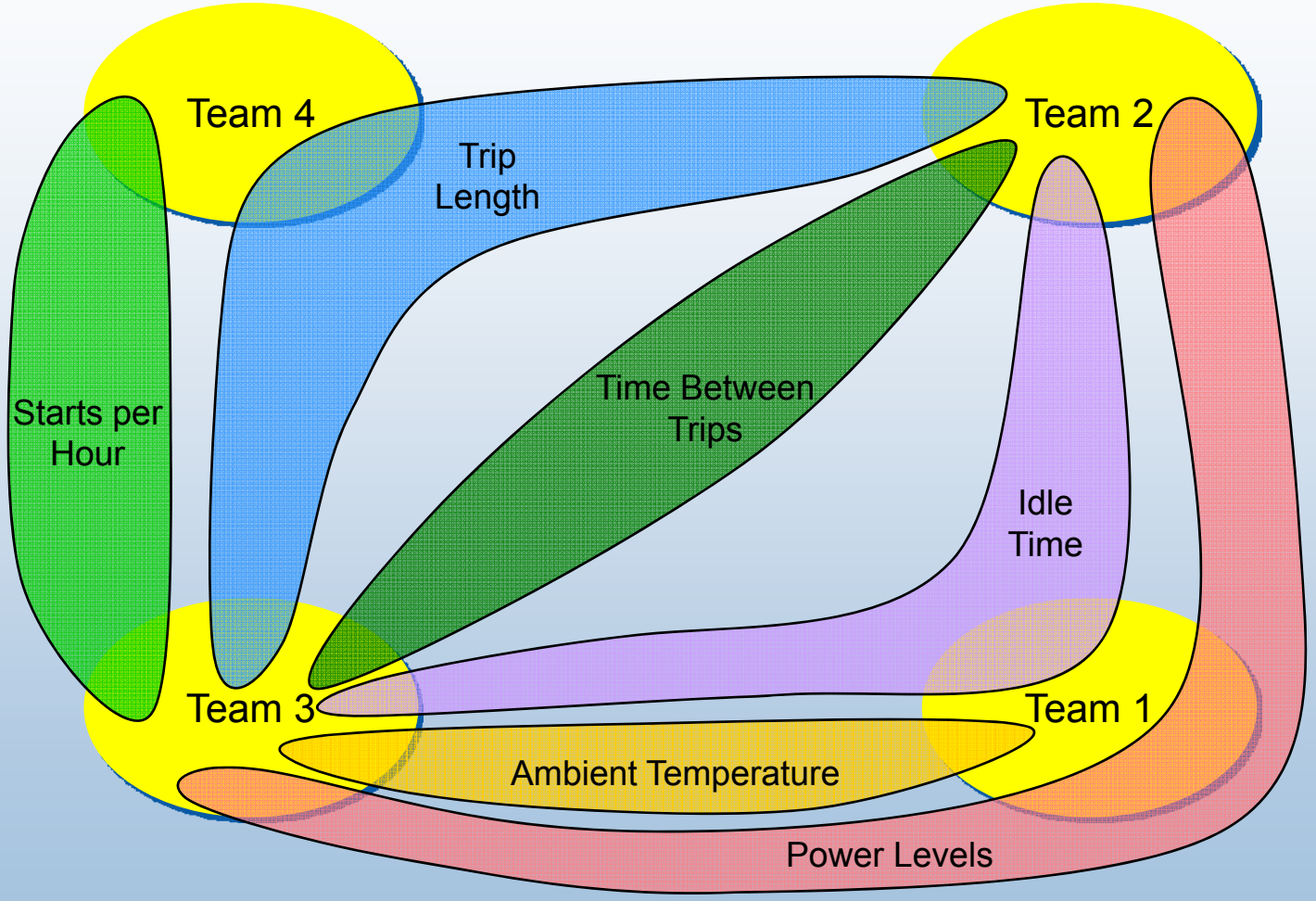
~29% Decay rate variance explained by a combination of the data variables below[1]	***Correlation to Decay Rate Data***
Starts per hour (+)	High decay rate[2]
Power levels (high & average) (+)	
Trip length (-)	
Time between trips (+)	
~10% Decay rate variance explained by a combination of the data variables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

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



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

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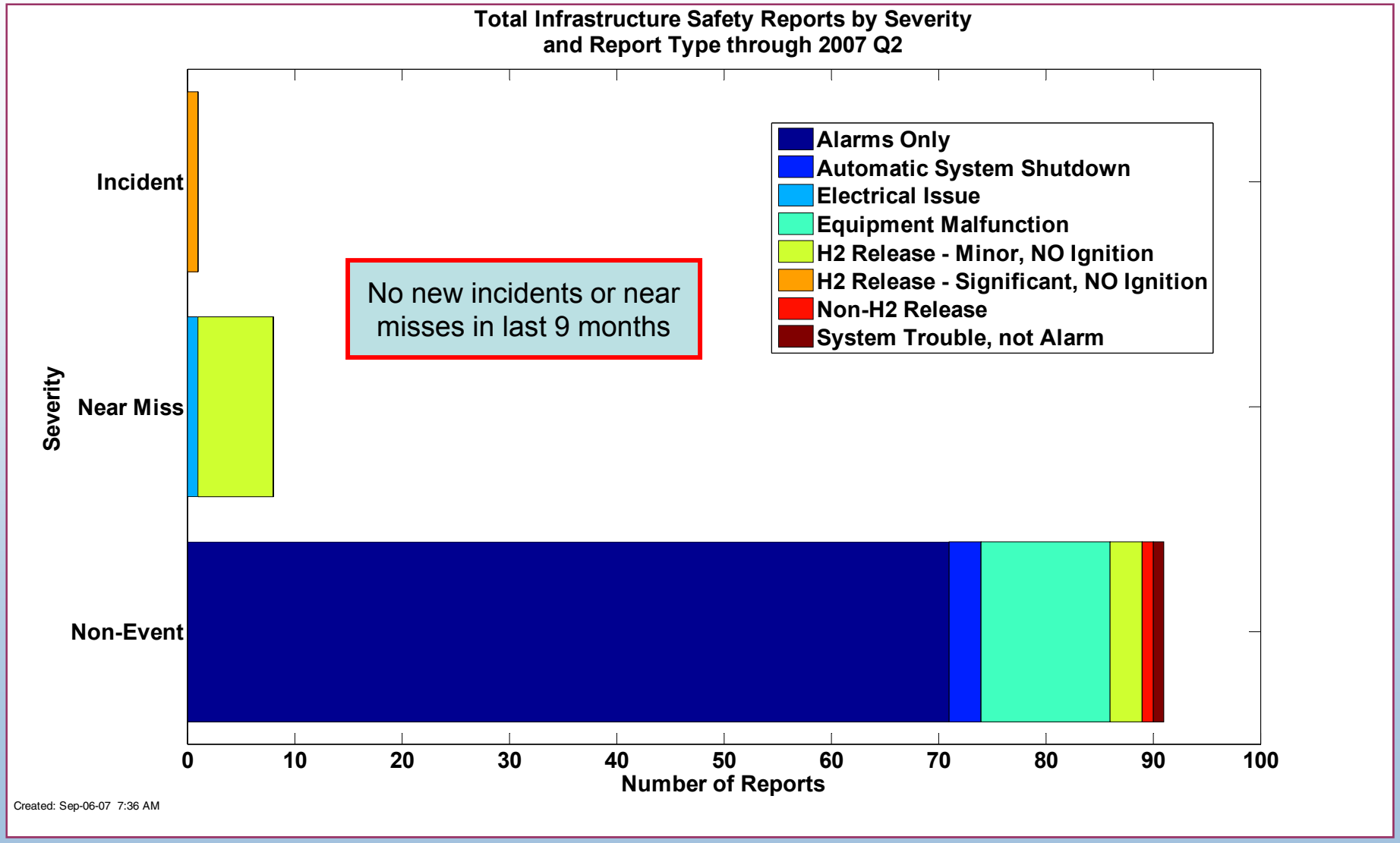
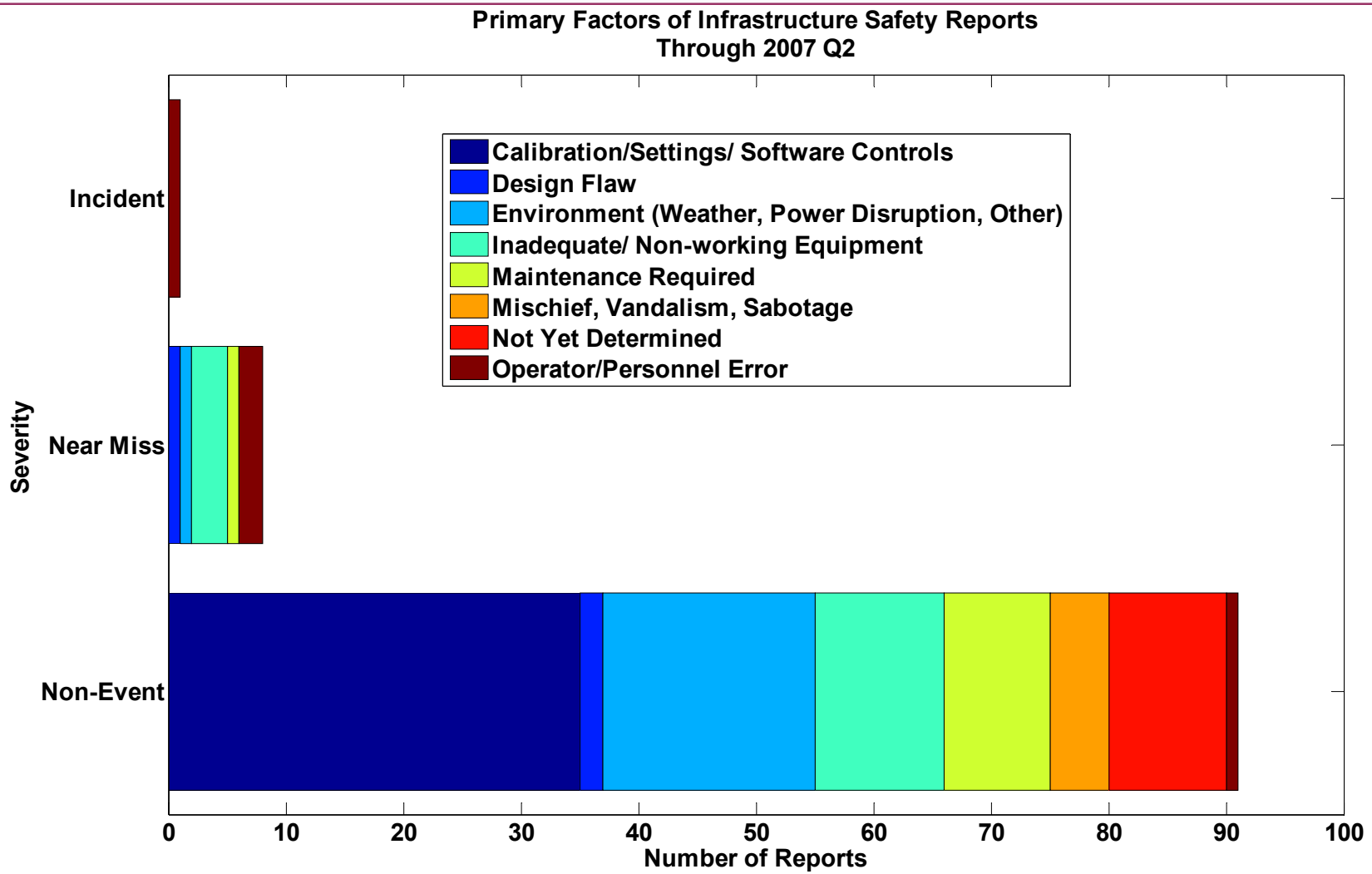
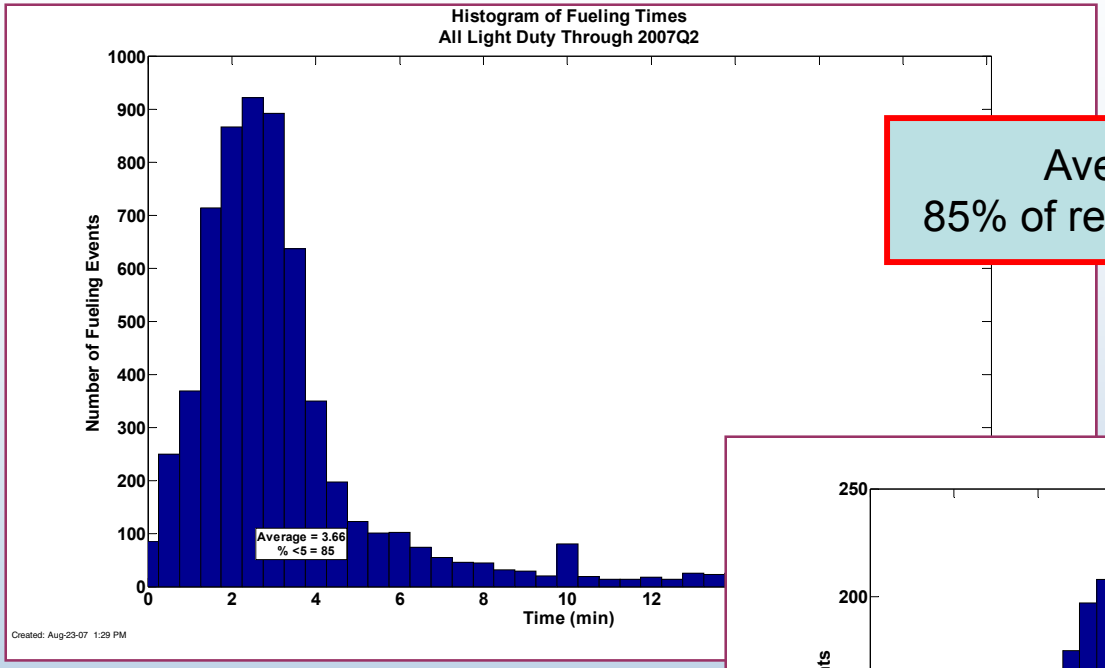
Most of Infrastructure Safety Reports are Non-Events (and Most of Those, Alarms Only)



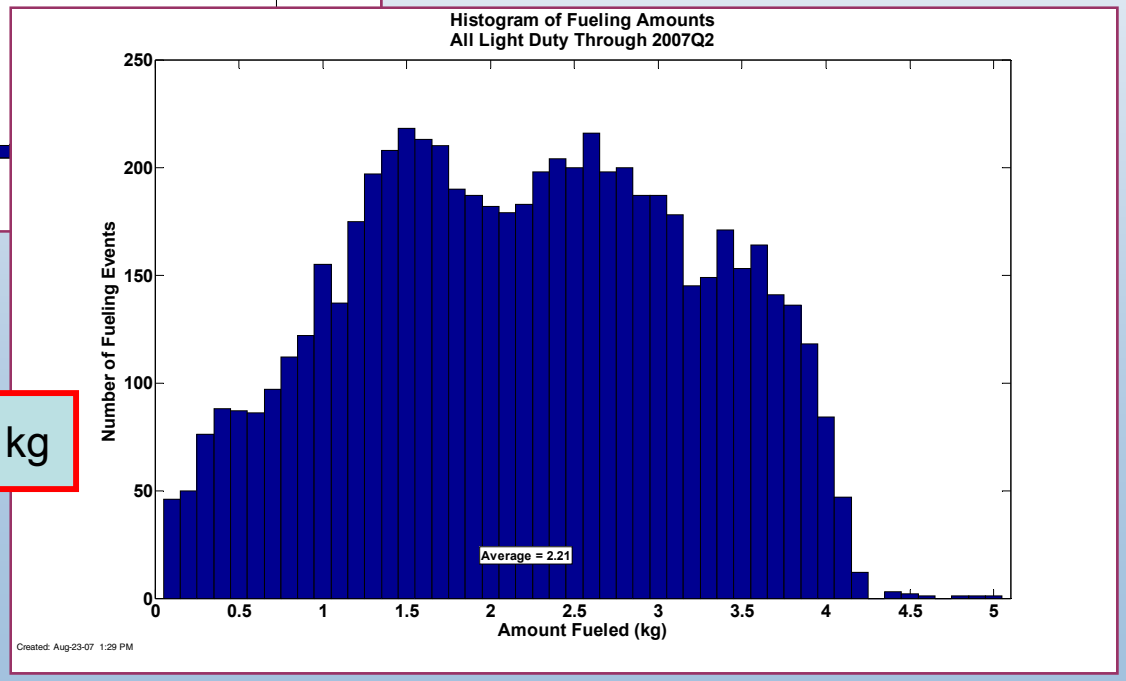
No Single Dominant Factor Triggering H2 Refueling Station Safety Reports



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



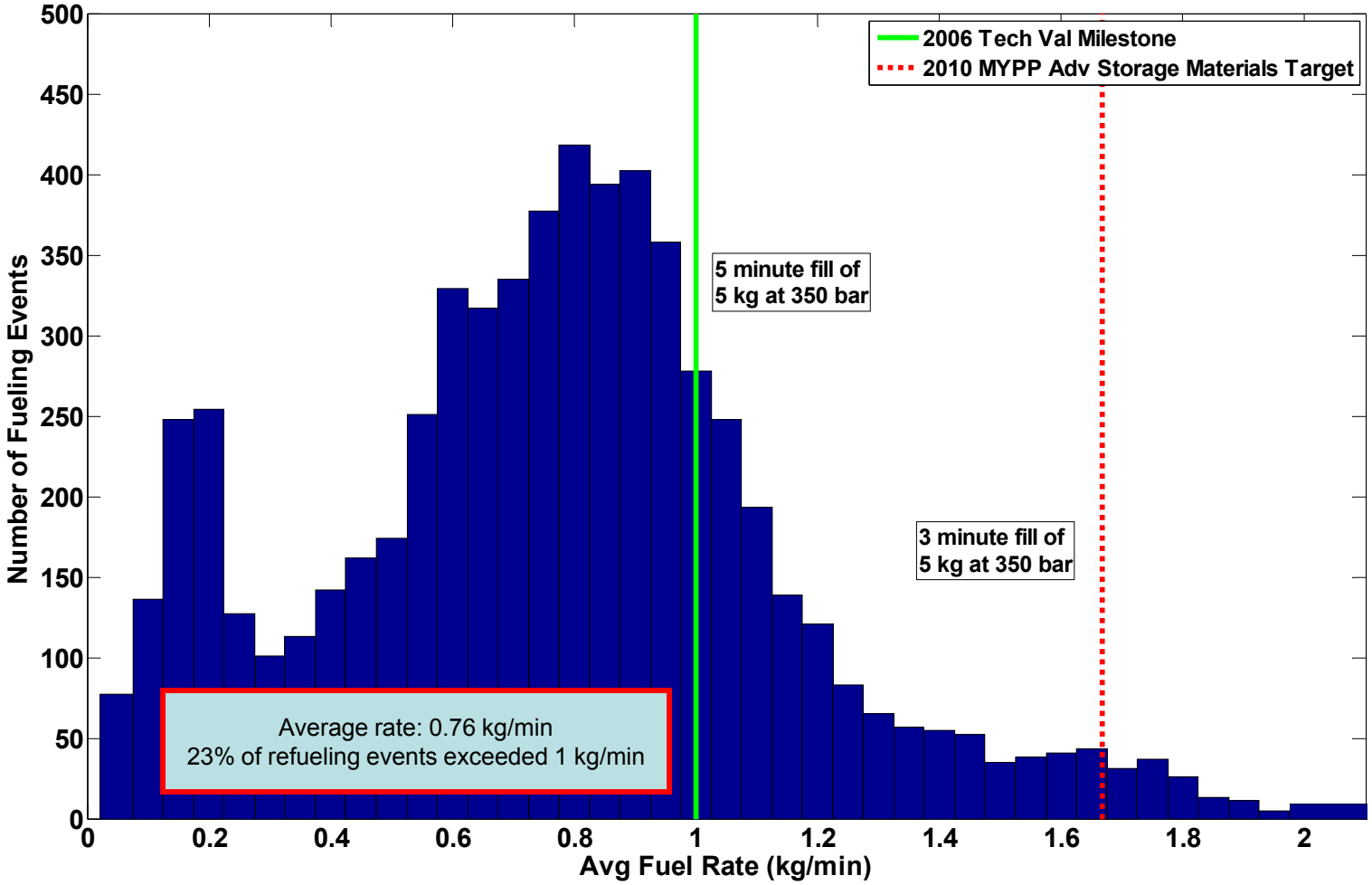
Average time: 3.66 min
85% of refueling events took <5 min



Average 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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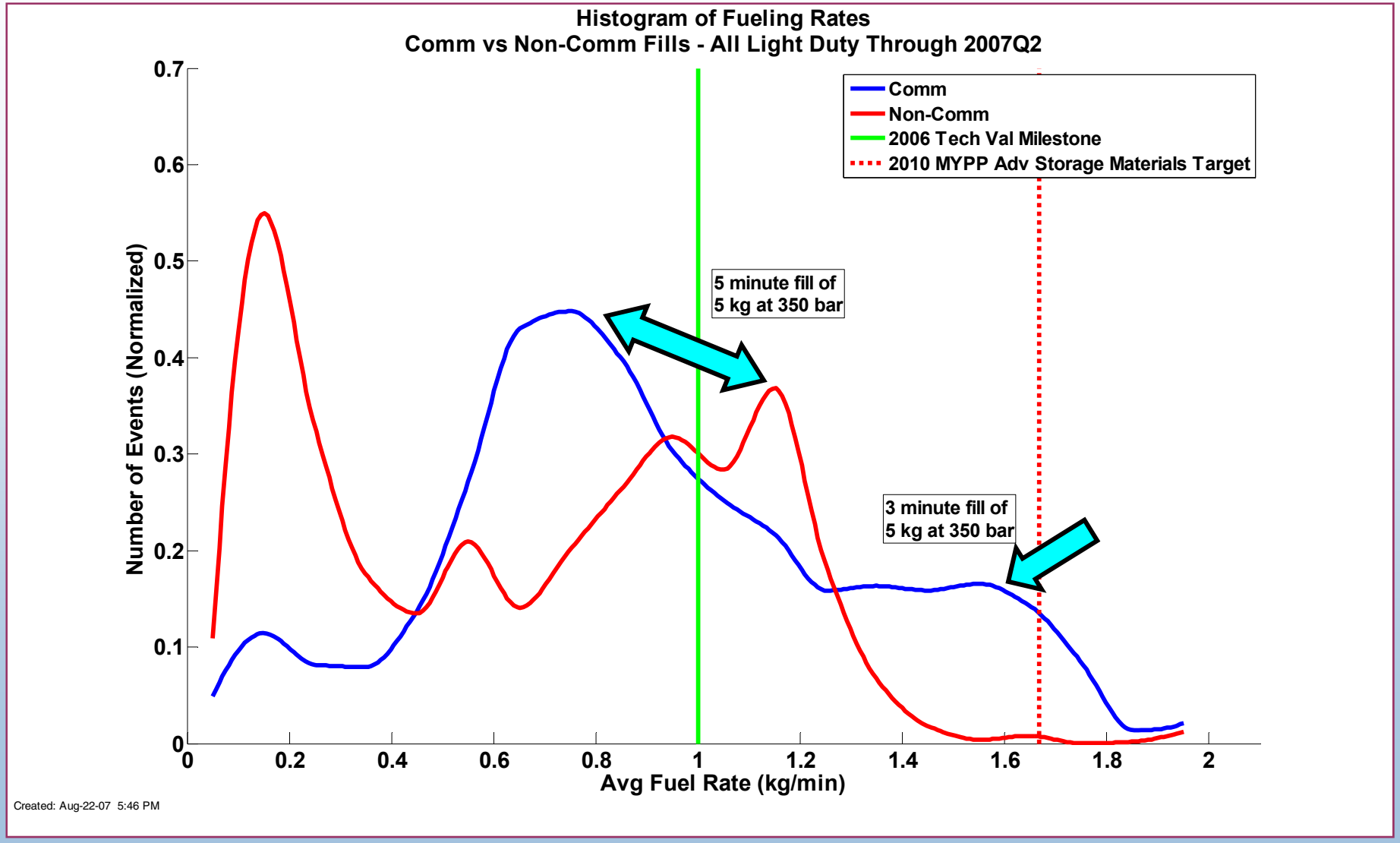
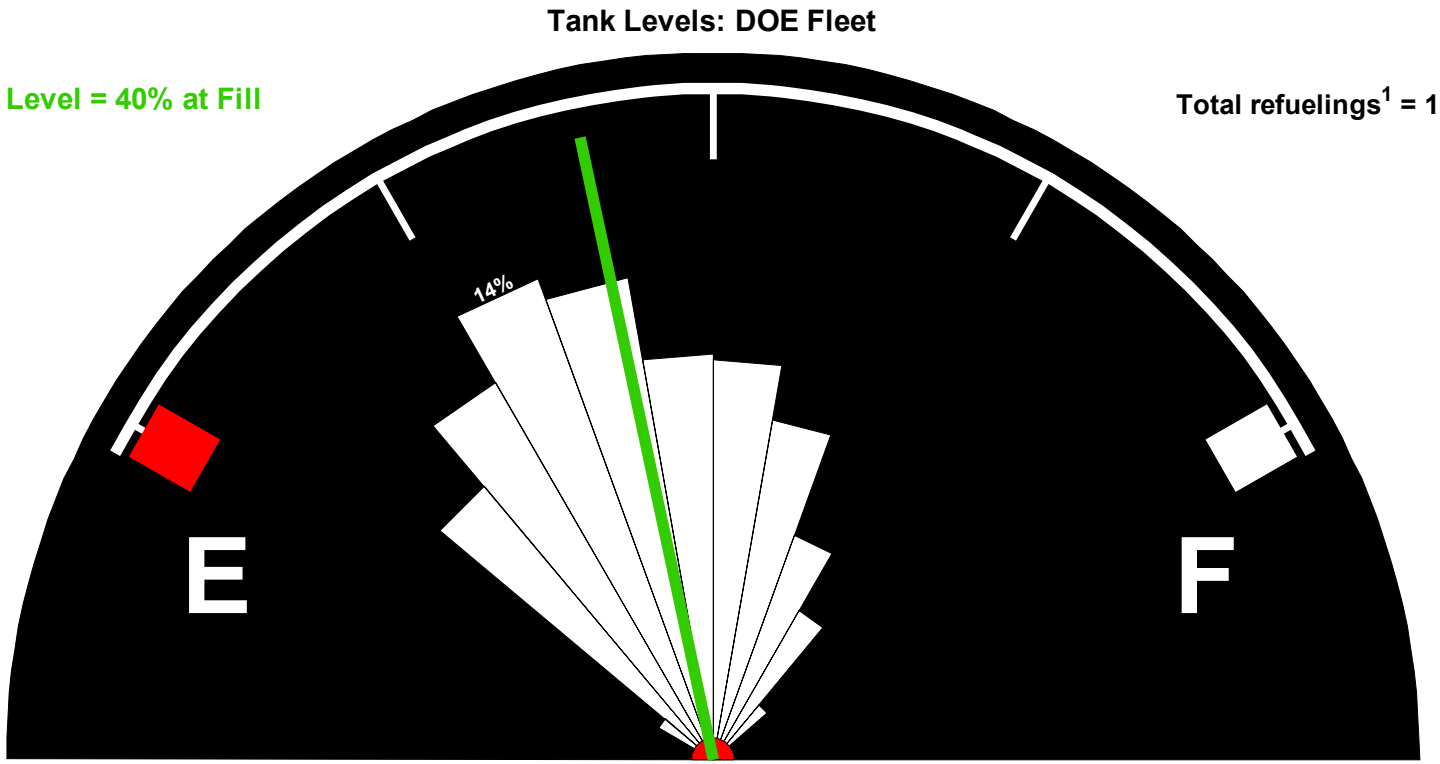
Includes Comm. and Non-Comm. Fills

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



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



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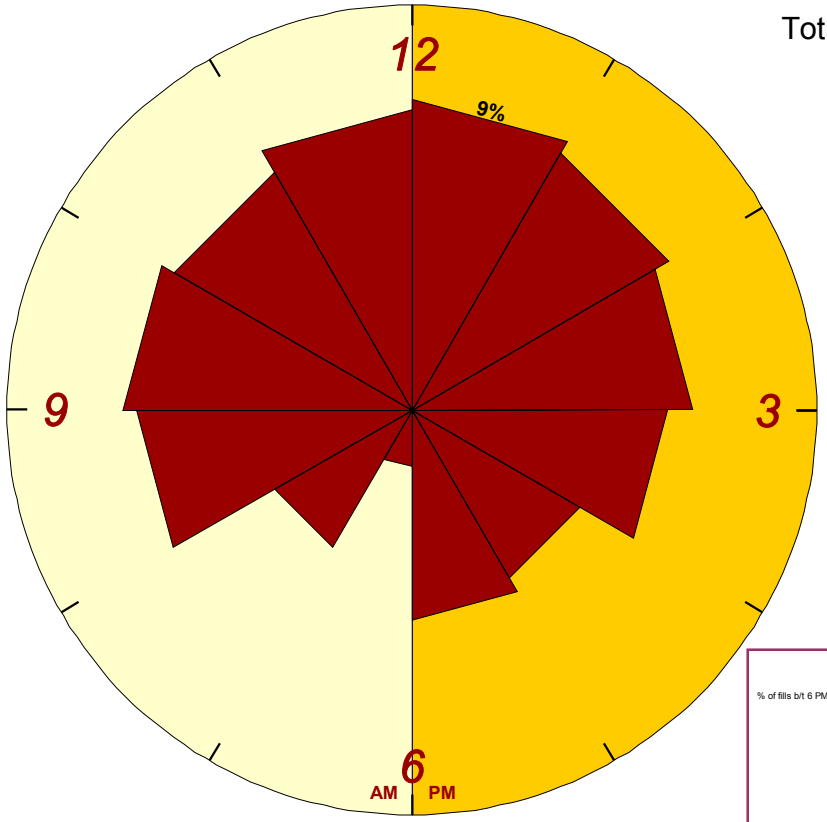
Refueling by Time of Day; Relatively Uniform Refueling Infrastructure Demand Between 8-4

Refueling by Time of Day: DOE Fleet

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

Total Fill^3 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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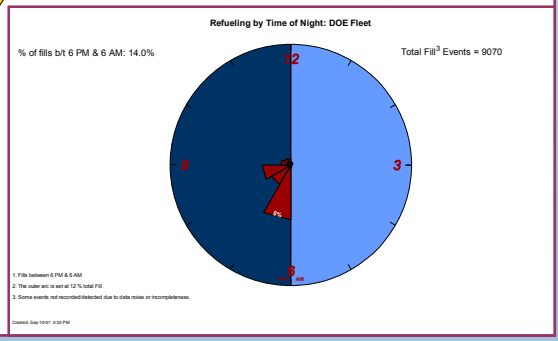
(Night)



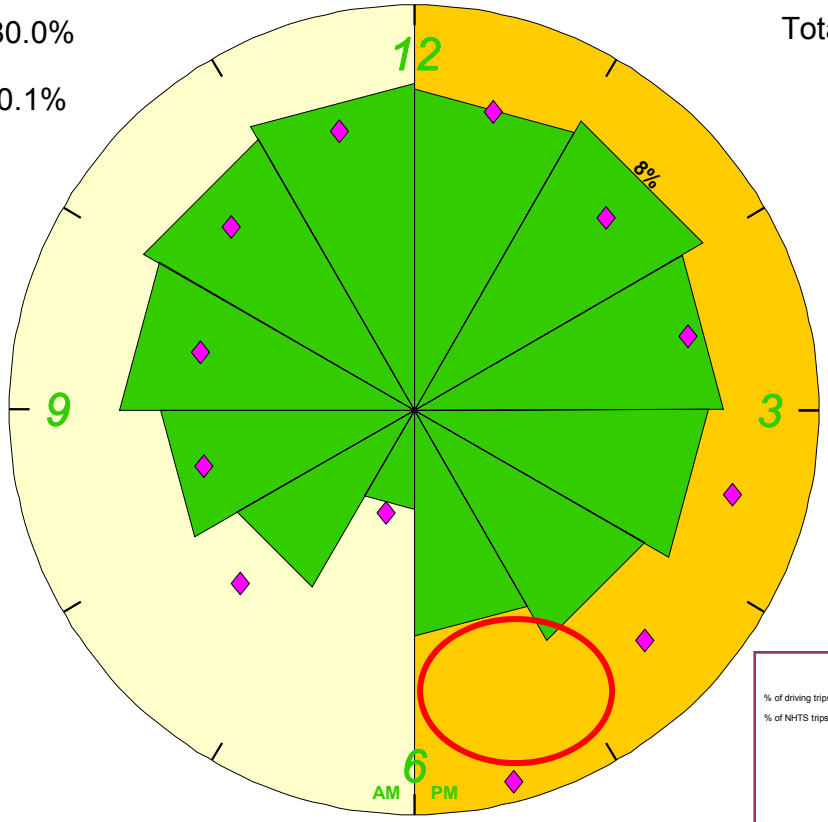
Driving Trip Start Time – Day; Roughly Matches National Statistics Except for 5-6 PM

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[3] Events = 103009



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

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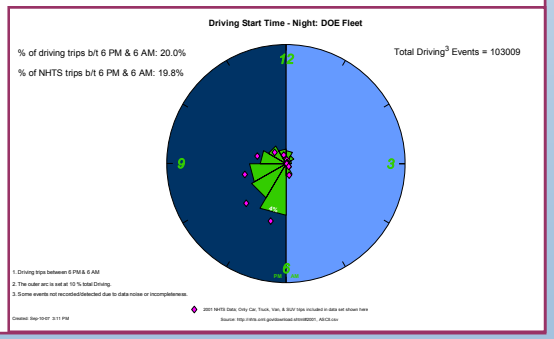
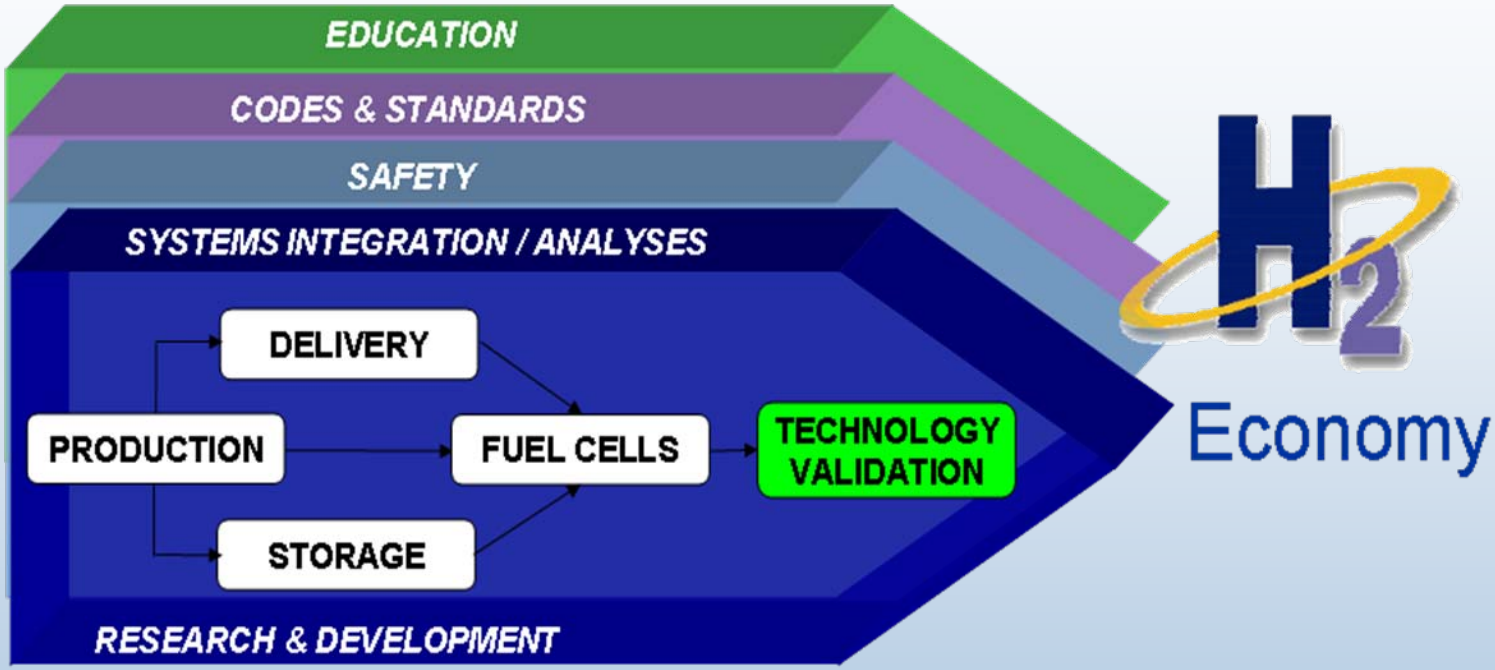


Summary

- More than half of project completed
  - 77 vehicles and 14 stations deployed
  - 800,000 miles traveled, 30,000 kg H_2 produced or dispensed
  - 114,000 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
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All public Learning Demo papers and presentations are available online at http://www.nrel.gov/hydrogen/proj_tech_validation.html