United States National Hydrogen Fuel Cell Vehicle and Infrastructure Learning Demonstration – Status and Results

2009 JHFC Conference

Keith Wipke, Sam Sprik, Jennifer Kurtz, Todd Ramsden[1],
John Garbak[2]

March 6, 2009
Tokyo, Japan

[1]NREL, [2]US Dept. of Energy

NREL/PR-560-45464

Outline

- Project Objectives and Partners
- NREL's Role in the Project and Methodology
- How to Access Complete Results
- Vehicle Analysis Results
- Infrastructure Analysis Results
- Summary

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

Photo: NREL

Industry Partners:
4 Automaker/Energy-Supplier Teams

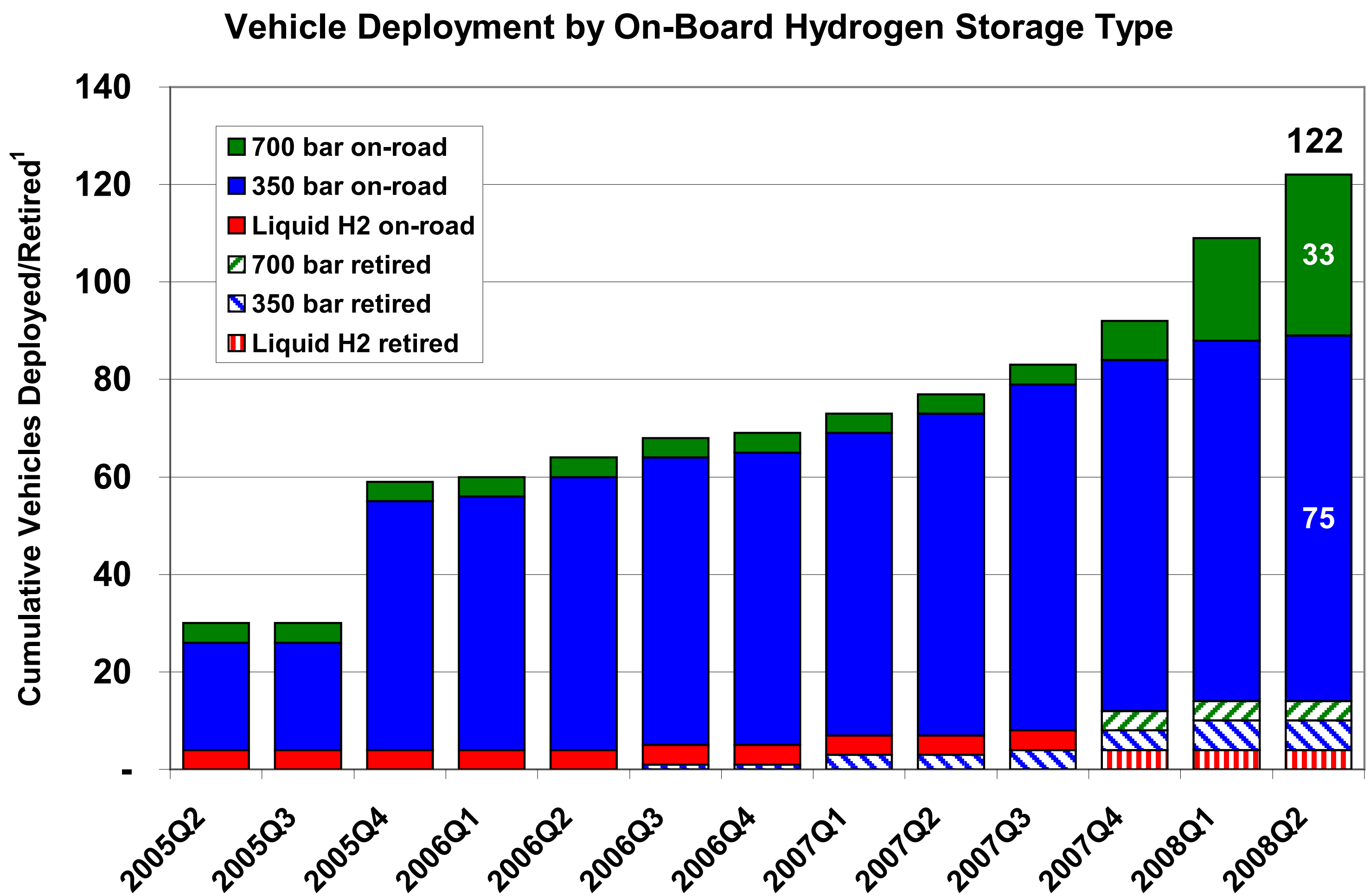
CHRYSLER
bp

Ford
bp

GM

Chevron
HYUNDAI
KIA
UTC Power
A United Technologies Company

Significant Number of Gen 2 Vehicles Now Deployed, Some Early Vehicles Retired

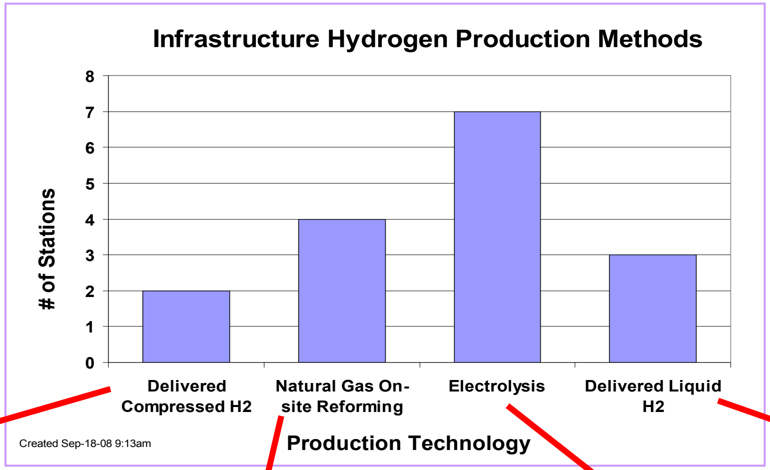


Created Sep-18-2008 8:20 AM

(1) Retired vehicles have left DOE fleet and are no longer providing data to NREL

Additional vehicles were added in 2008 Q3-Q4

Majority of Project's Fixed Infrastructure to Refuel Vehicles Has Been Installed – Examples of 4 Types



Mobile Refueler
Sacramento, CA

Delivered Liquid, 700 bar
Irvine, CA

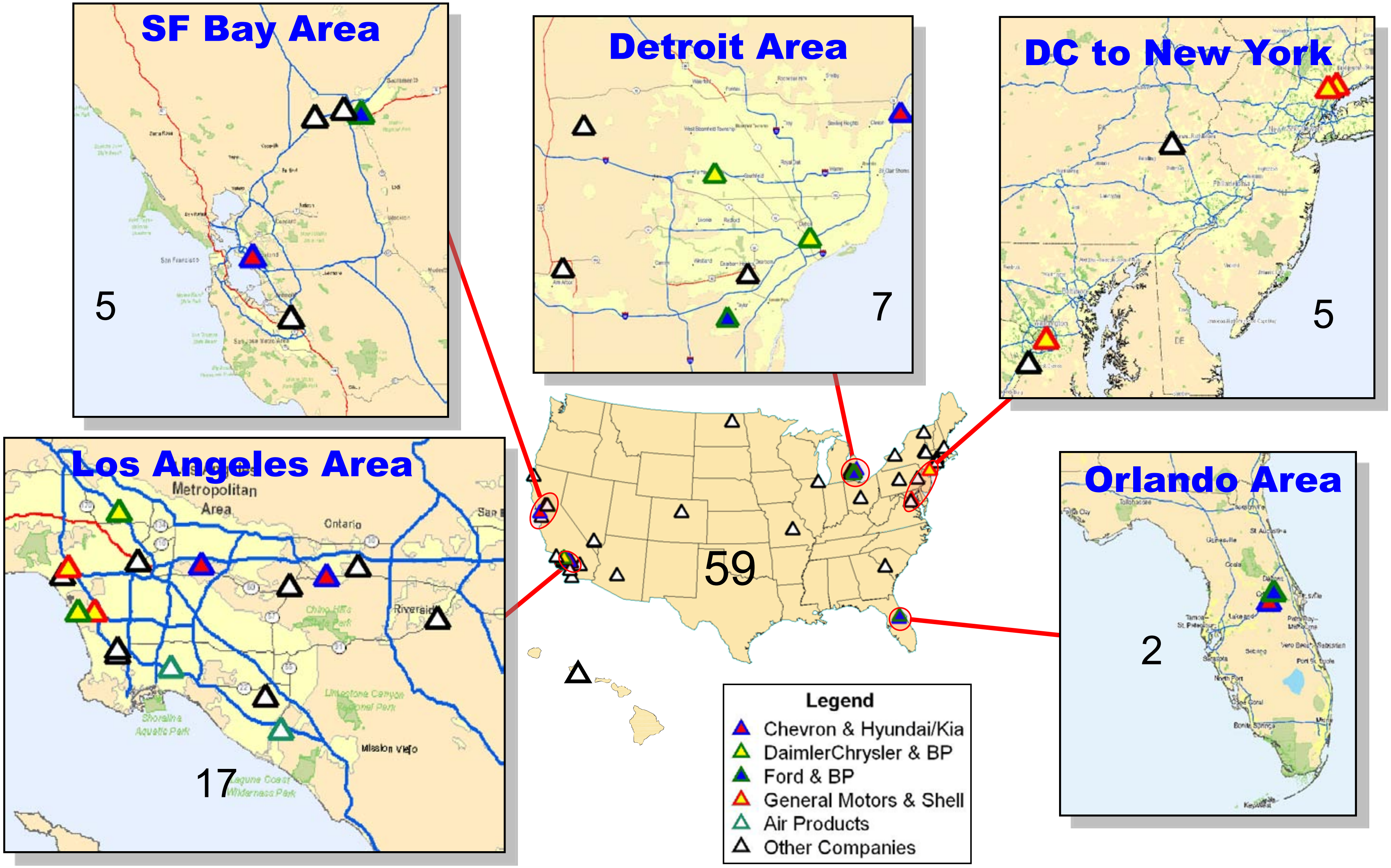

Steam Methane Reforming
Oakland, CA


Water Electrolysis
Santa Monica, CA

Total of >60,000 kg H2 produced or dispensed

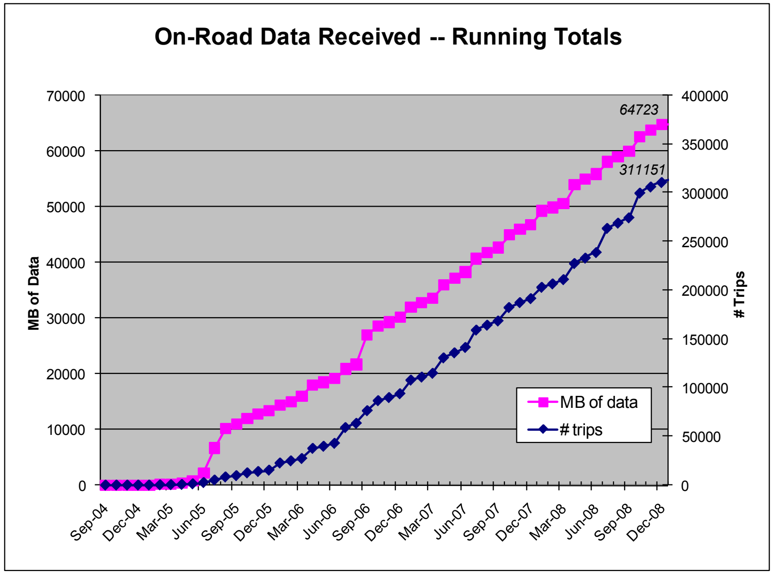
Stations added since June 2008:
Burbank, Long Beach, Ardsley, LAX-east
20 stations now deployed through Dec.

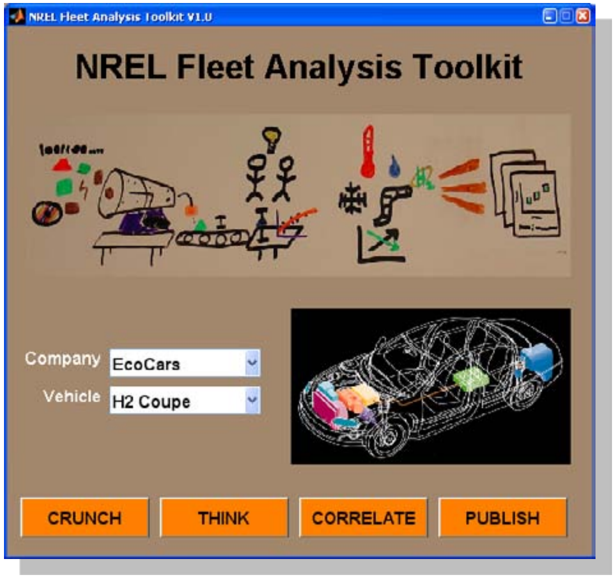
Refueling Stations Test Performance in Various Climates; Learning Demo Comprises ~1/4 of all US Stations



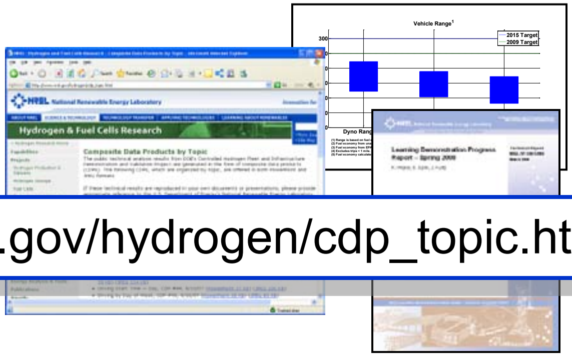
Feb-18-2009

Large Data Sets Processed with NREL Tools; Two Types of Results Serve a Diverse Audience





Through December 2008:
311,000 individual vehicle trips
64 GB of on-road data

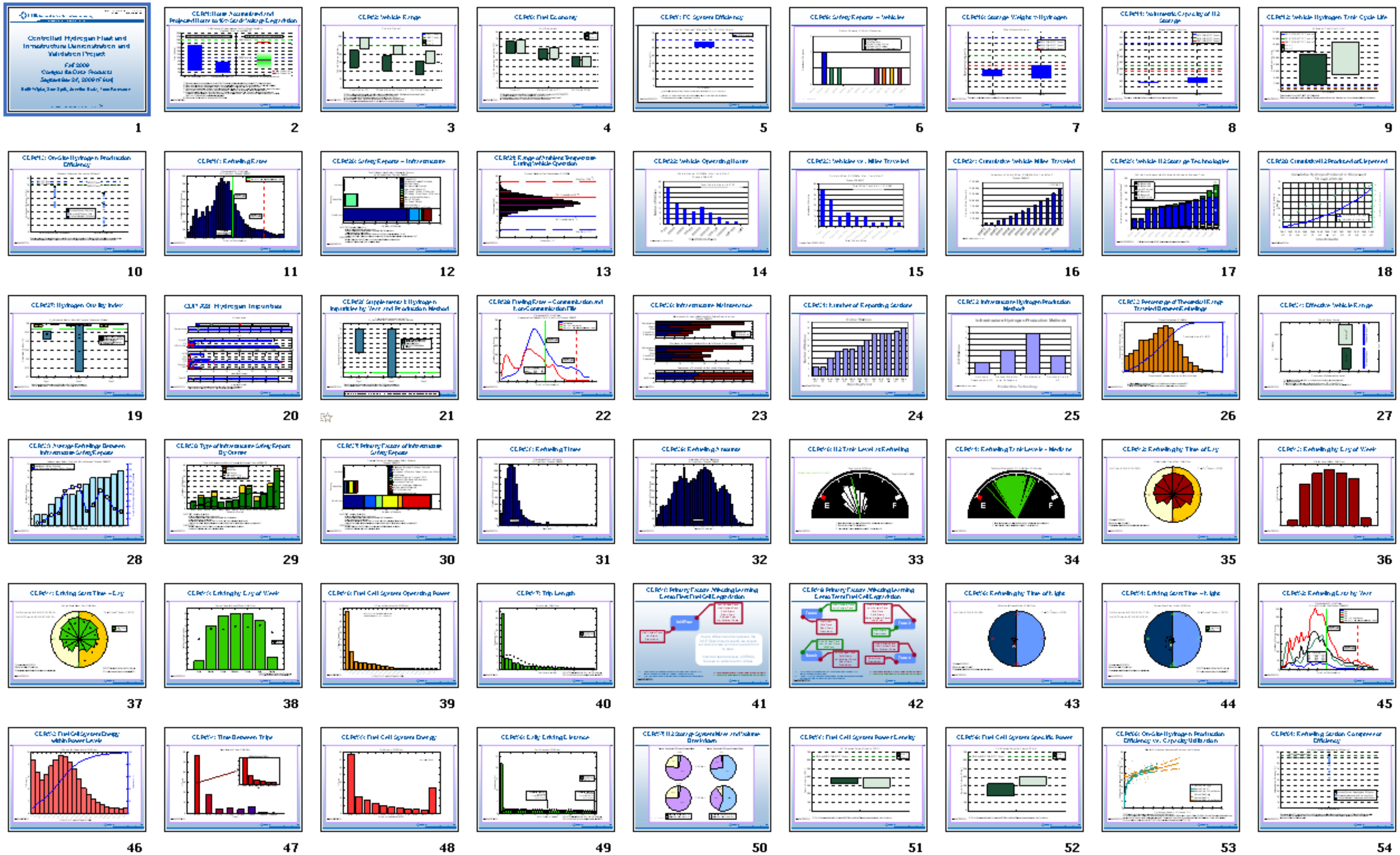


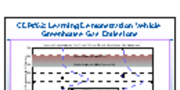
NREL HSDC → Composite Data Products → http://www.nrel.gov/hydrogen/cdp_topic.html

NREL HSDC → Detailed Data Products → Individual Team Discussions

Data Flow

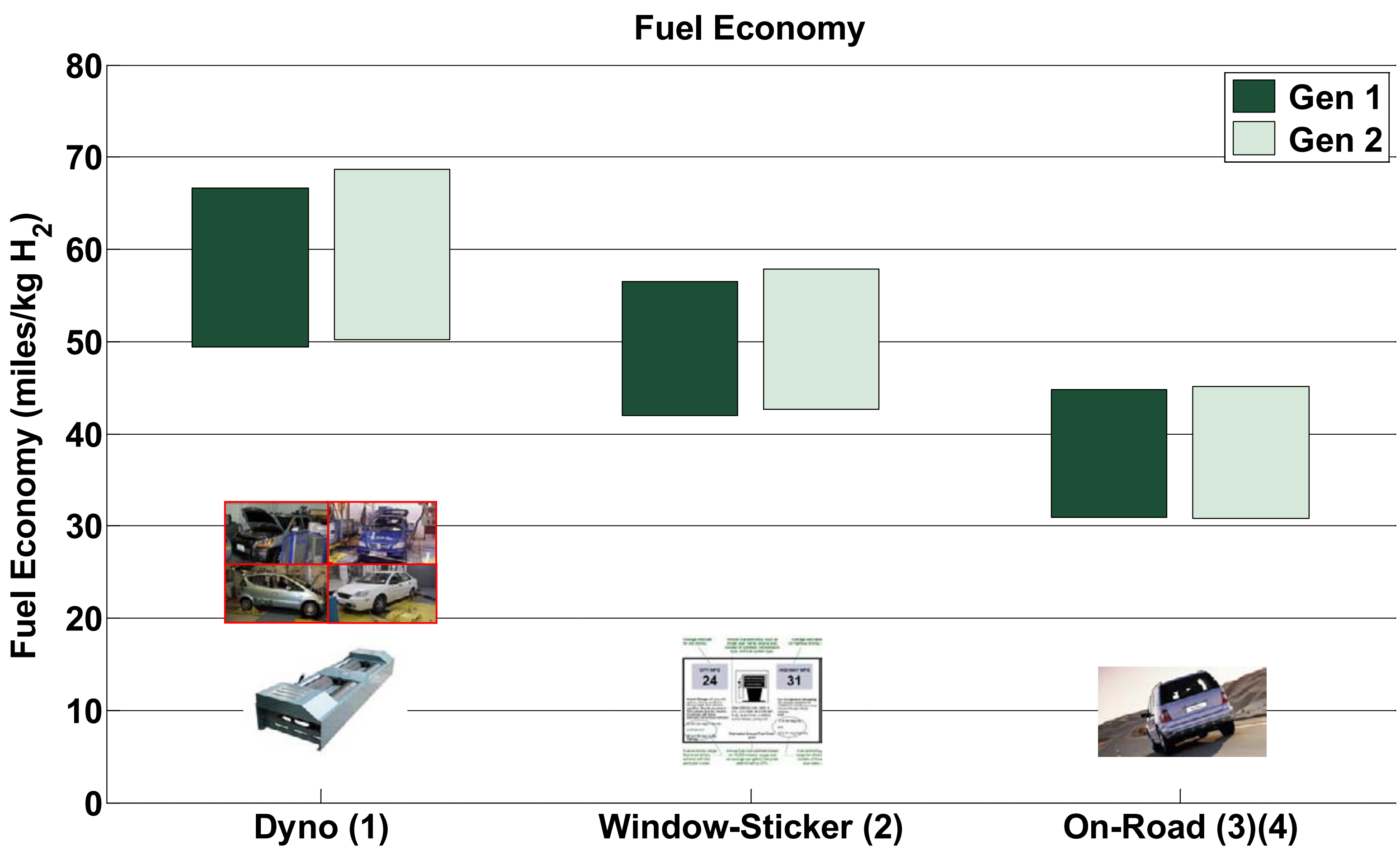
53 Public Composite Data Products Have Been Published; New Results and Updates Every 6 Months





Only a subset of these results is presented today

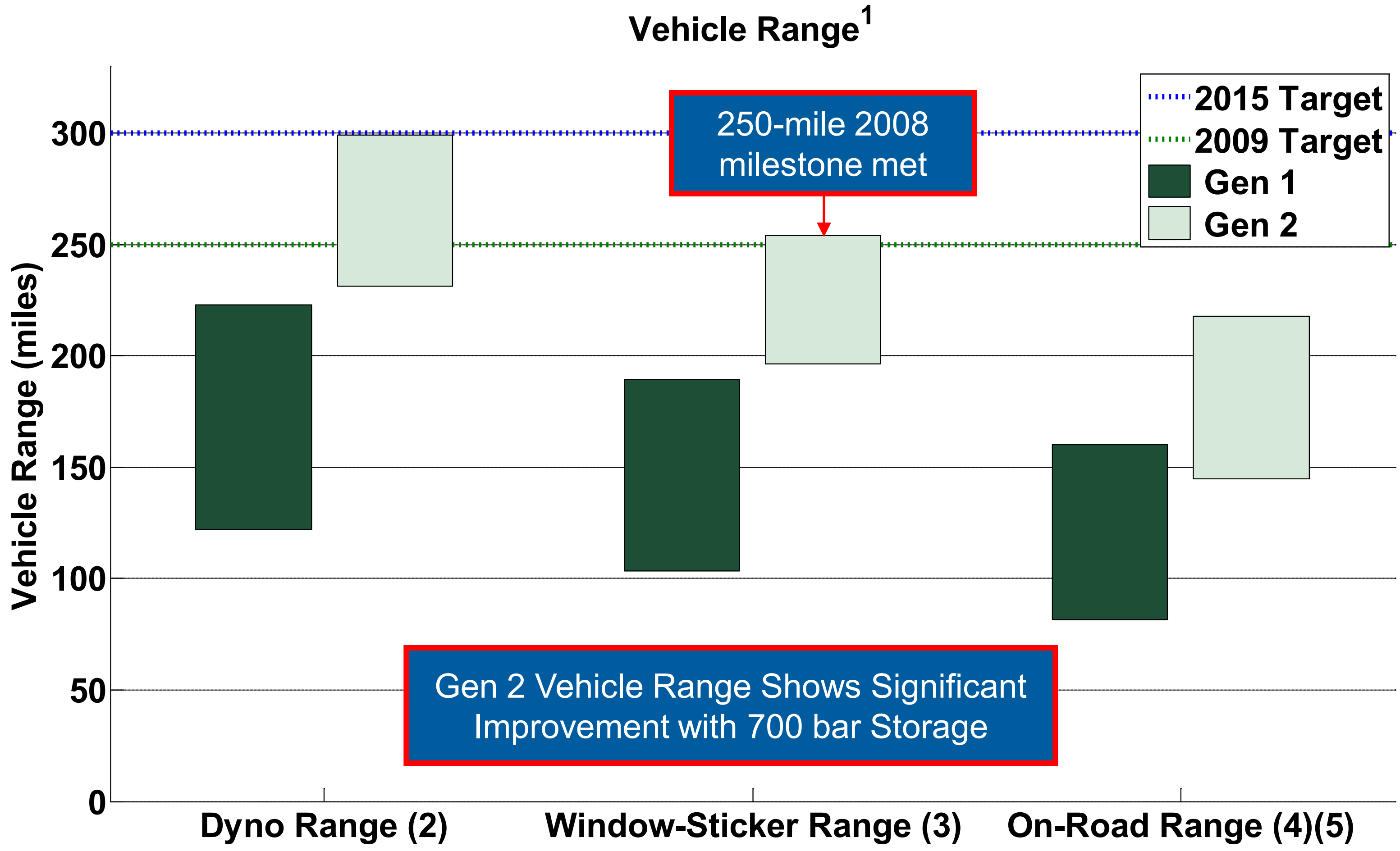
Ranges of Fuel Economy from Dynamometer and On-Road Data Similar for Gen 1 & 2



(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.

Created: Sep-22-08 11:51 AM

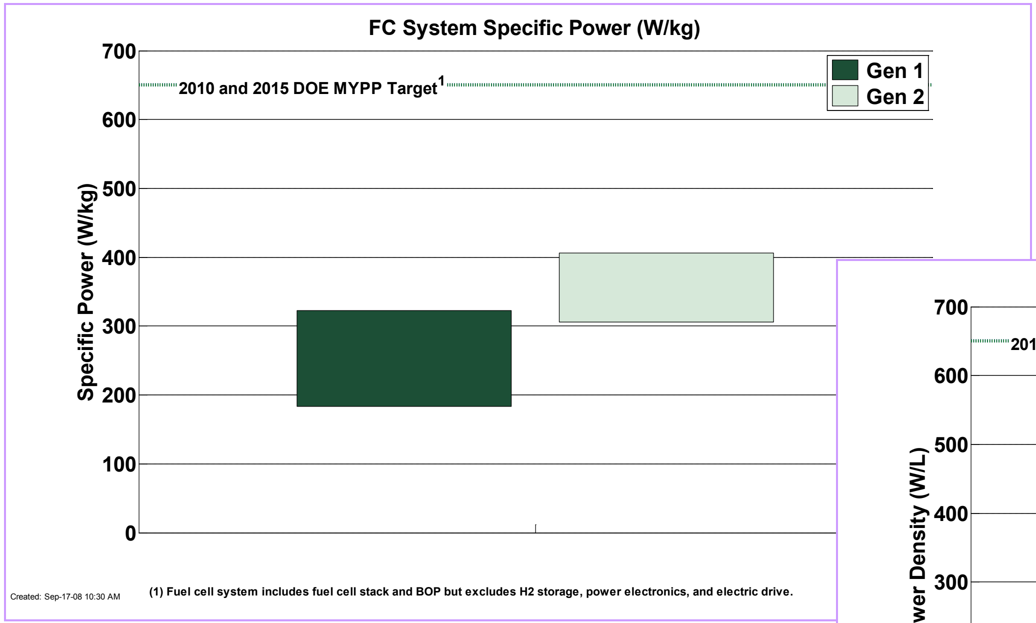
Vehicle Range Based on Dyno Results and Usable H2 Fuel Stored On-Board



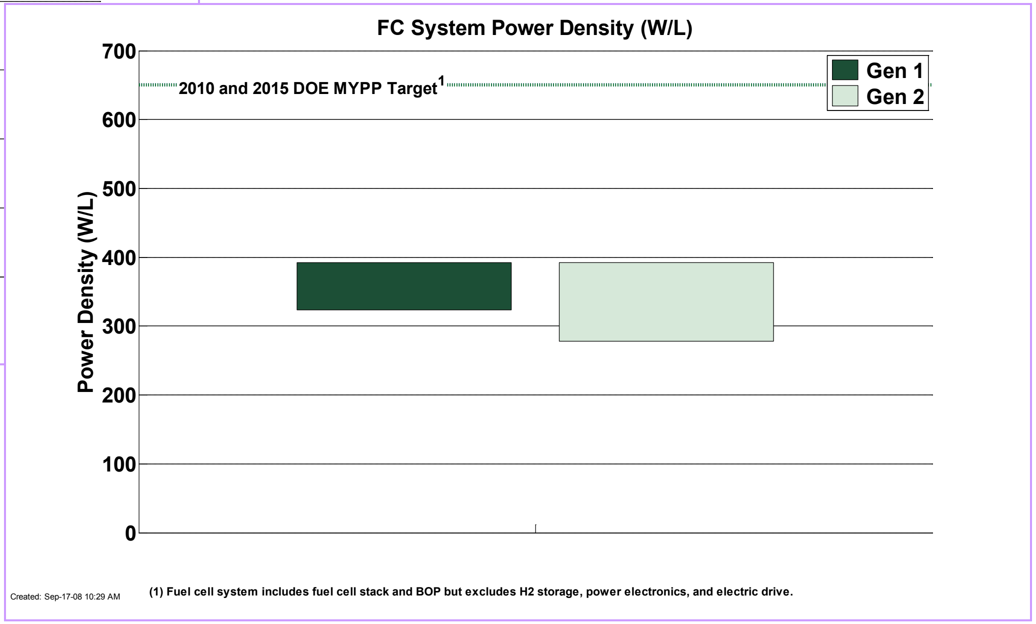
(1) Range is based on fuel economy and usable hydrogen on-board the vehicle. One data point for each make/model.
(2) Fuel economy from unadjusted combined City/Hwy per DRAFT SAE J2572.
(3) Fuel economy from EPA Adjusted combined City/Hwy (0.78 x Hwy, 0.9 x City).
(4) Excludes trips < 1 mile. One data point for on-road fleet average of each make/model.
(5) Fuel economy calculated from on-road fuel cell stack current or mass flow readings.

Created: Sep-22-08 11:51 AM

Comparison of FC System Specific Power and Power Density Between Gen 1 to Gen 2

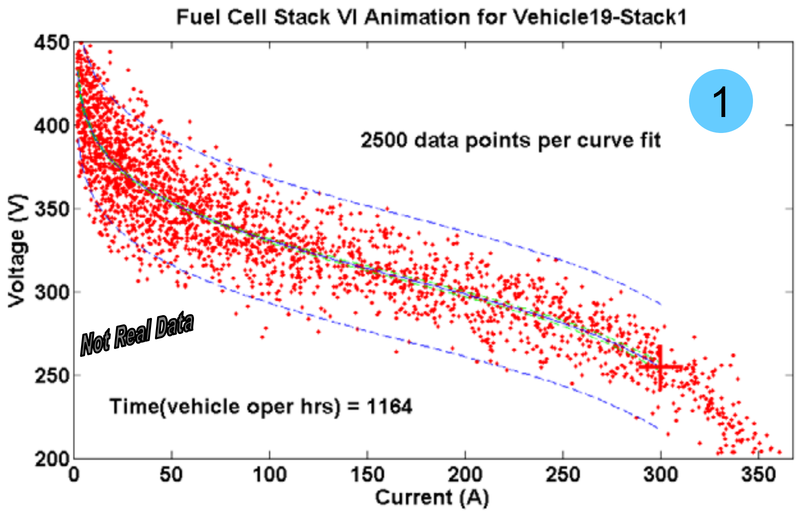


Significant Improvements Seen in Specific Power (…systems getting lighter)



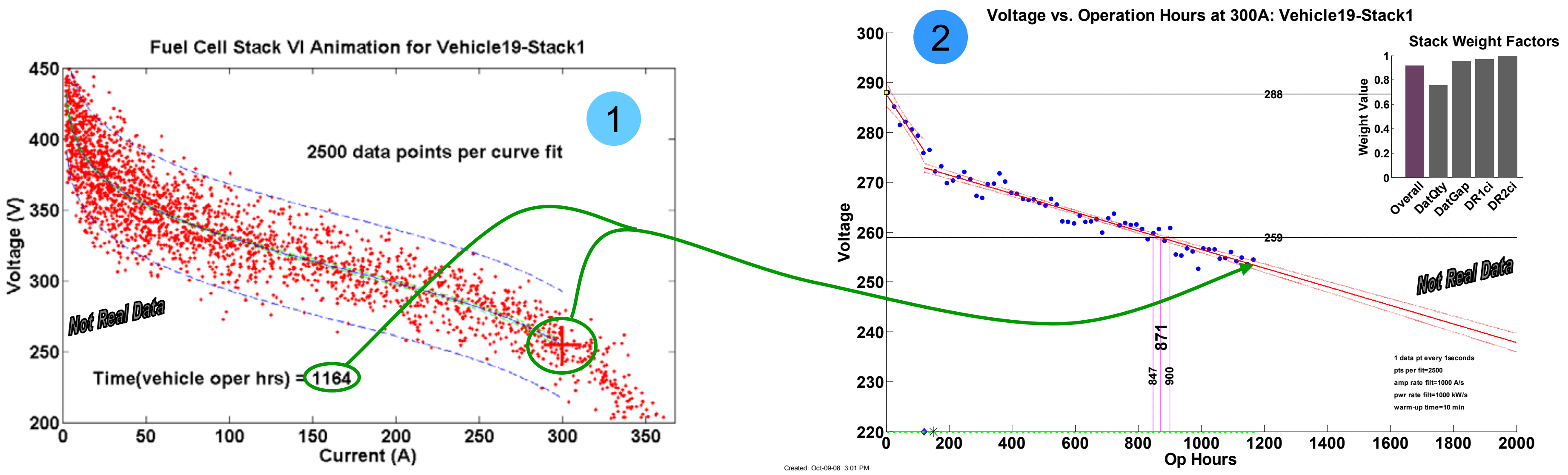
Power Density Did Not Improve Between Gen 1 and Gen 2 (…same size or larger)

Improved Method for Calculating Projected Time to 10% Voltage Drop for Stack and Fleet



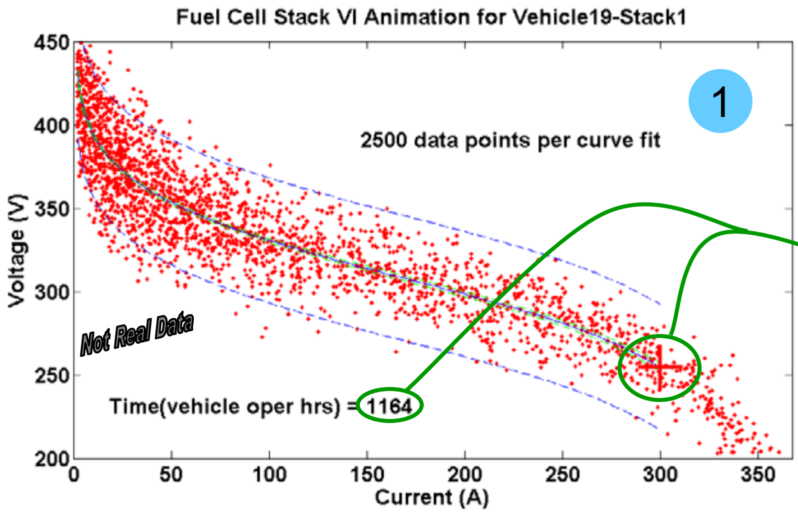
1. ***FC Stack*** voltage & current polarization fit

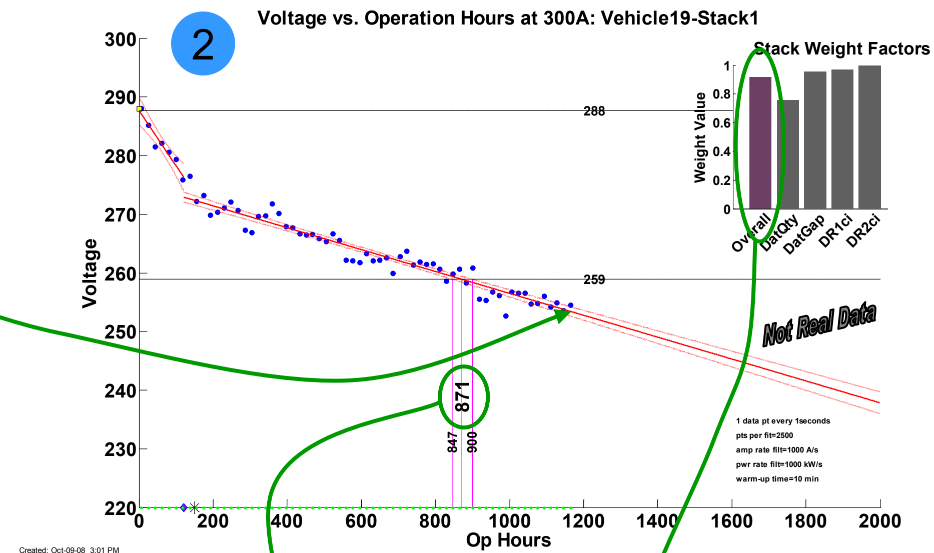
Improved Method for Calculating Projected Time to 10% Voltage Drop for Stack and Fleet

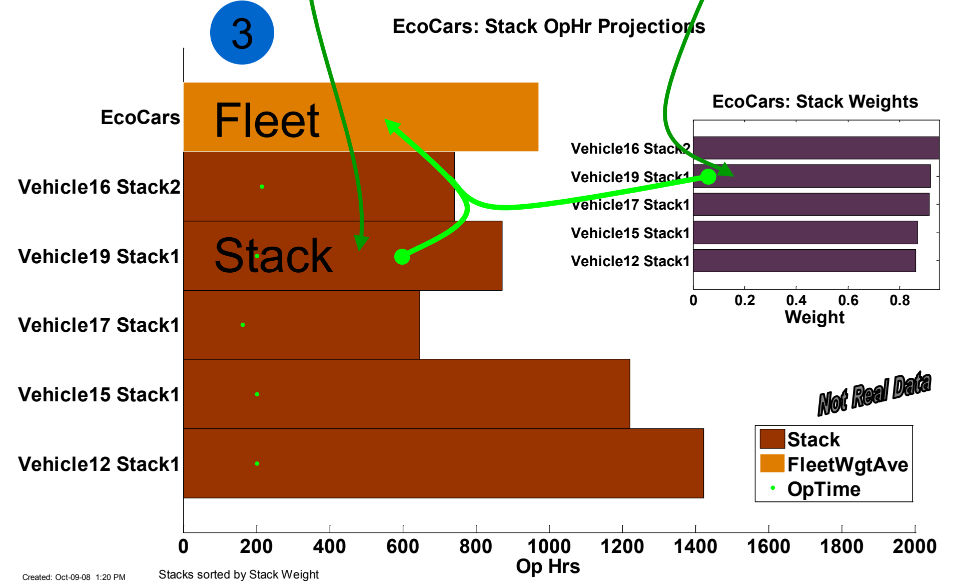


1. ***FC Stack*** voltage & current polarization fit
2. ***FC Stack*** voltage decay estimate using robust, improved **segmented linear fit** instead of linear fit (follows non-linear decay trends & early voltage decay)

Improved Method for Calculating Projected Time to 10% Voltage Drop for Stack and Fleet



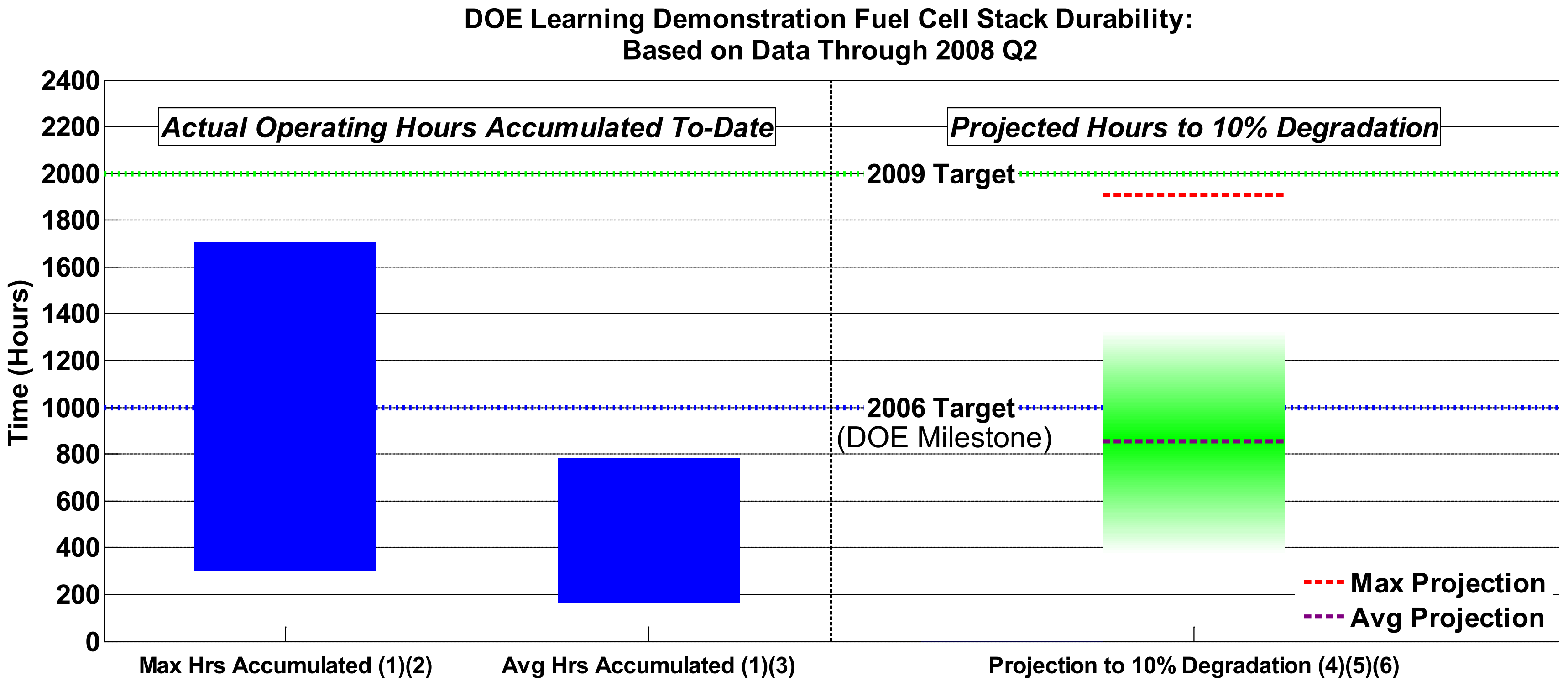




1. ***FC Stack*** voltage & current polarization fit
2. ***FC Stack*** voltage decay estimate using robust, improved **segmented linear fit** instead of linear fit (follows non-linear decay trends & early voltage decay)
3. ***Fleet*** weighted average using FC Stack operating hour projections and weights (based on data and confidence in fit)

Note, 10% voltage drop is a DOE target/metric, not an indicator of end-of-life

Some Gen 1 FC Stacks Have Now Accumulated a Significant Number of Hours Without Repair

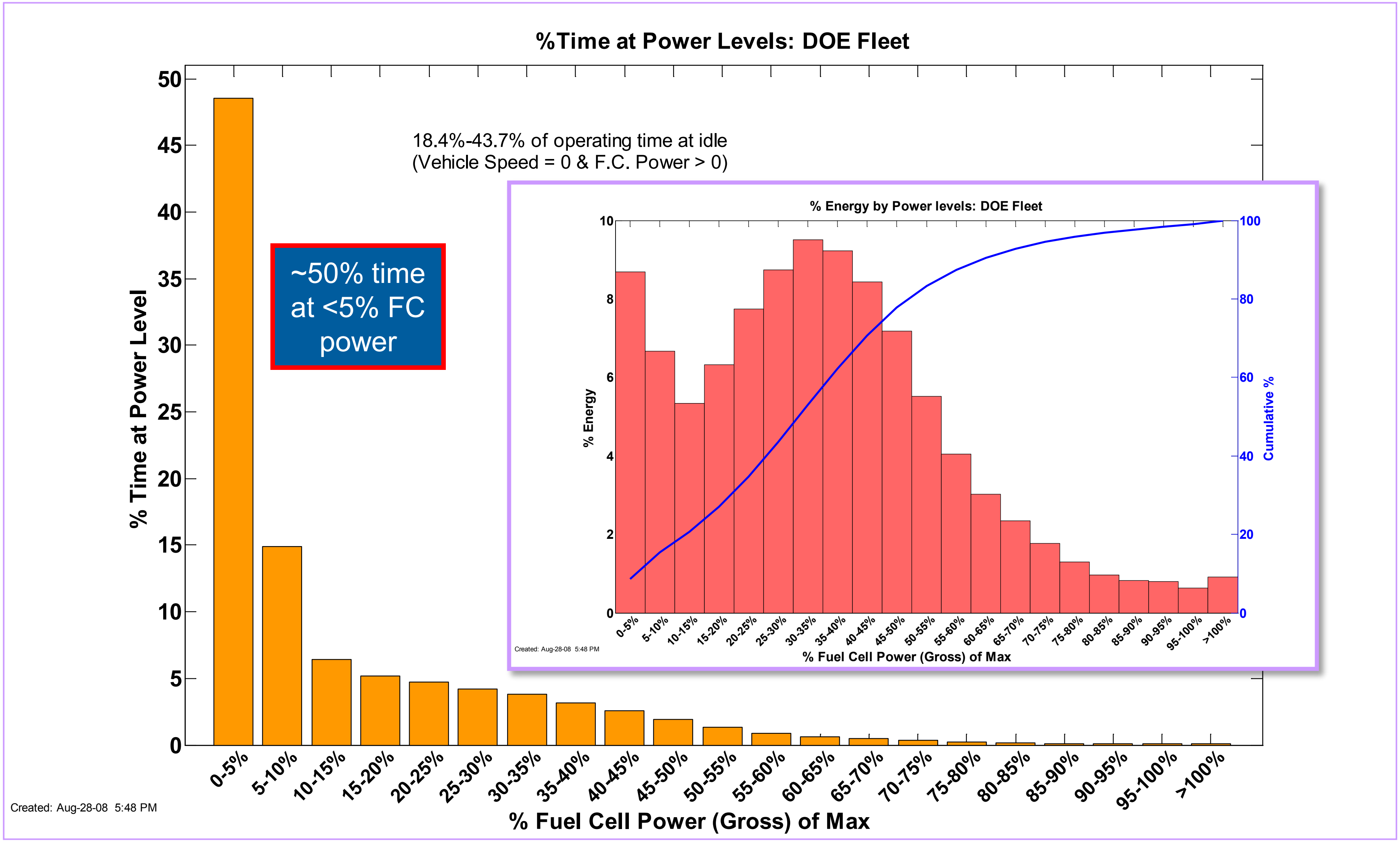


(1) Range bars created using one data point for each OEM. Some stacks have accumulated hours beyond 10% voltage degradation.
(2) Range (highest and lowest) of the maximum operating hours accumulated to-date of any OEM's individual stack in "real-world" operation.
(3) Range (highest and lowest) of the 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 green bar 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 2008 Q2 data.

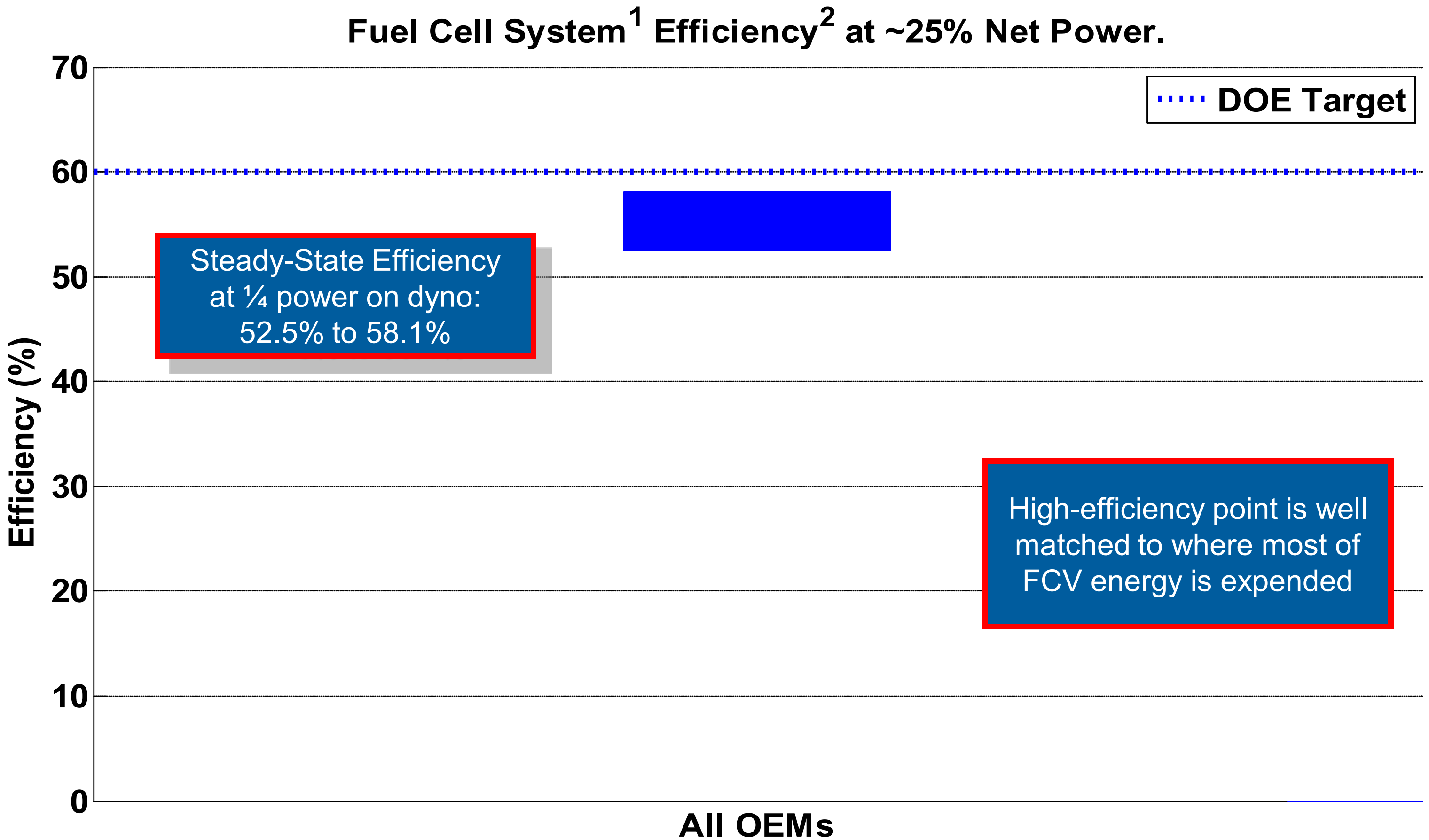
Created: Sep-03-08 10:36 AM

More data required to make Gen 2 projections (late 2009)

While Most of FC *Time* is Spent at Idle, Bulk of *Energy* is at 20-50% Power



Gen 1 Baseline Dyno Tests Validated High Efficiency at ¼ Power Point – *Gen 2 Efficiency Results Public in 2009*

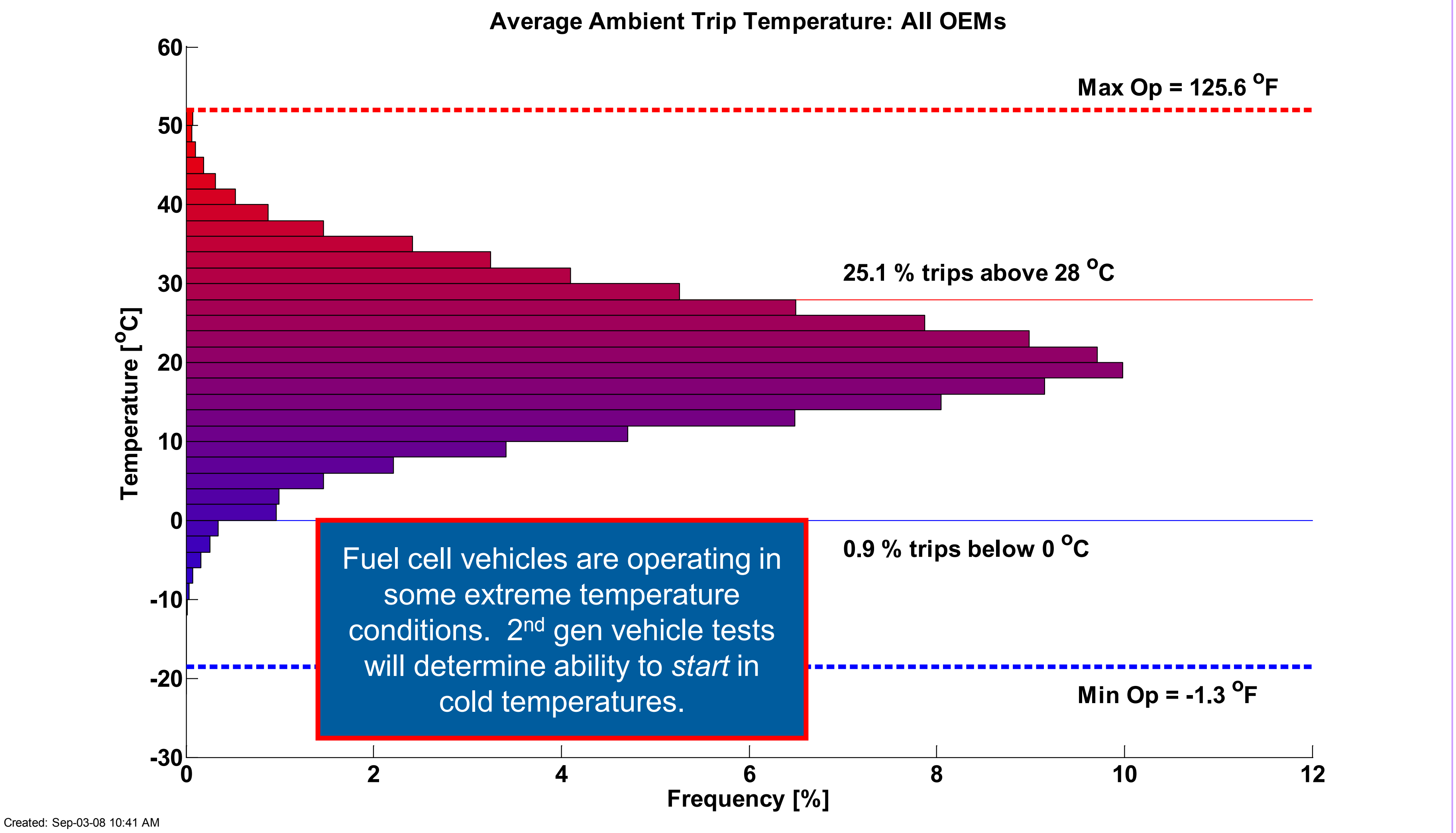


[1] Gross stack power minus fuel cell system auxiliaries, per DRAFT SAEJ2615.

[2] Ratio of DC output energy to the lower heating value of the input fuel (hydrogen). Excludes power electronics and electric drive.

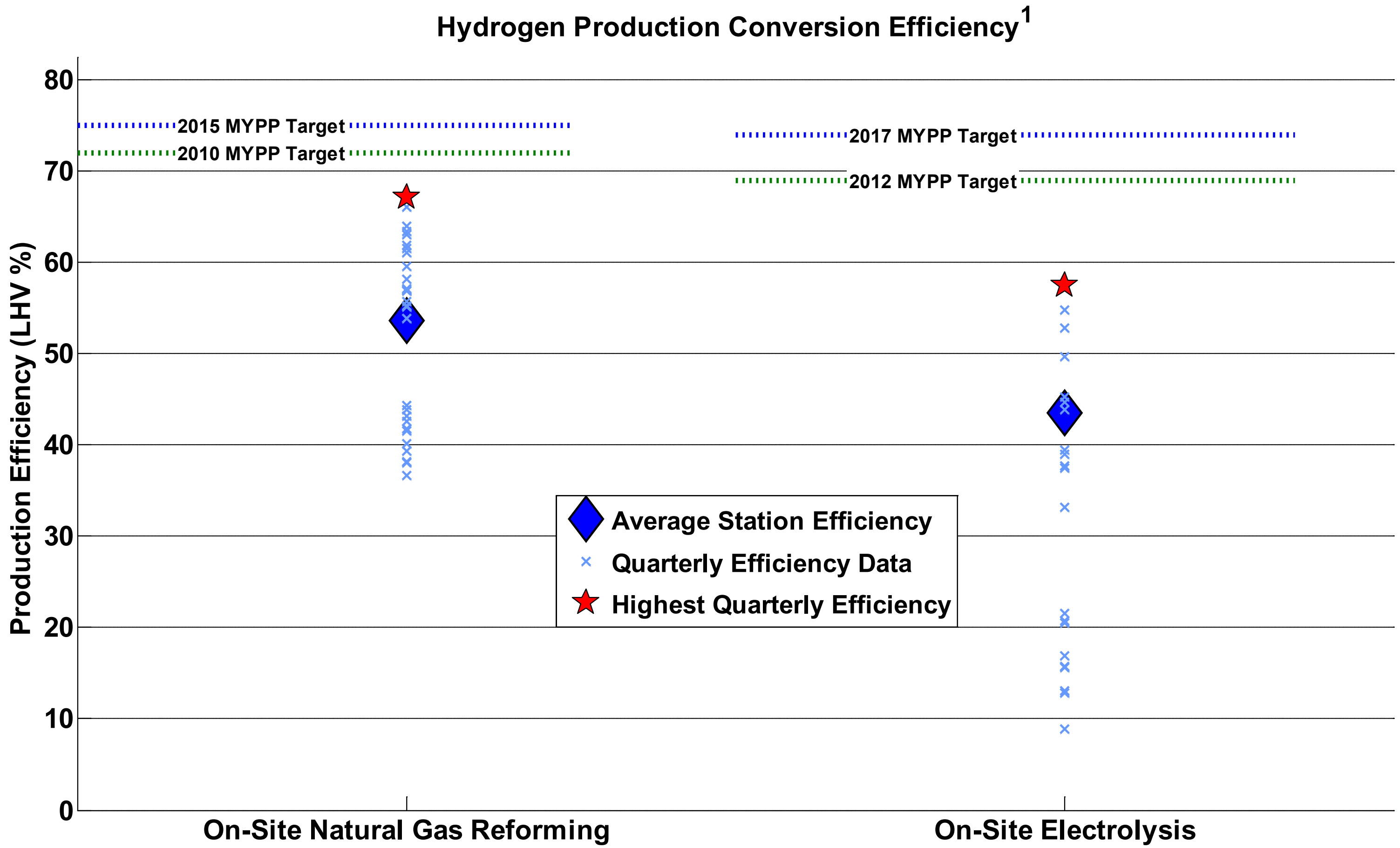
Created: Aug-29-06 4:09 PM

Range of Average Ambient Temperatures During Vehicle Operation



Fuel cell vehicles are operating in some extreme temperature conditions. 2nd gen vehicle tests will determine ability to *start* in cold temperatures.

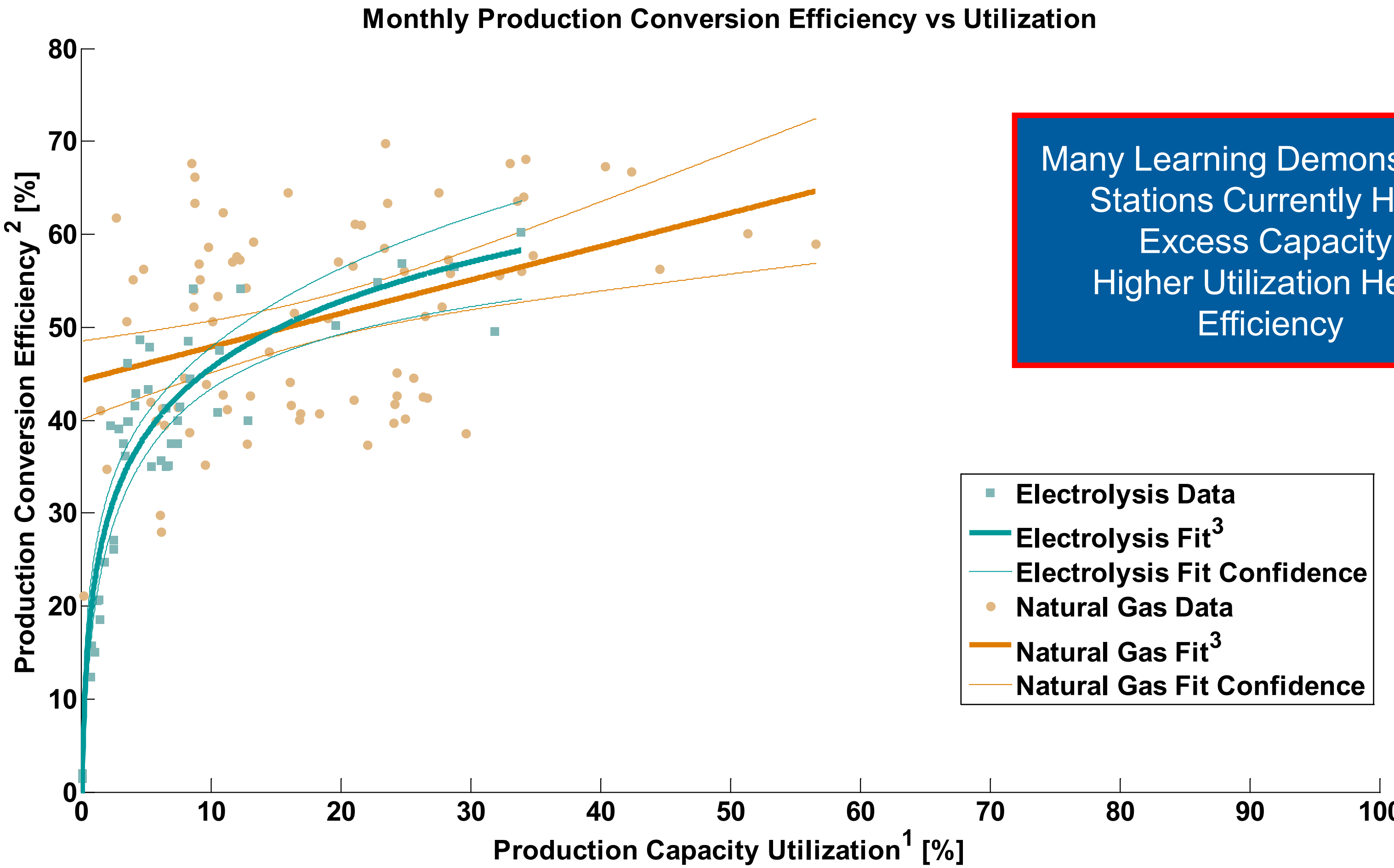
On-Site Production Efficiency from Natural Gas Reformation and Electrolysis Compared to Targets



[1]Production conversion efficiency is defined as the energy of the hydrogen out of the process (on an LHV basis) divided by the sum of the energy into the production process from the feedstock and all other energy as needed. Conversion efficiency does not include energy used for compression, storage, and dispensing.

Created: Sep-24-08 4:17 PM

On-Site Hydrogen Production Efficiency vs. Capacity Utilization

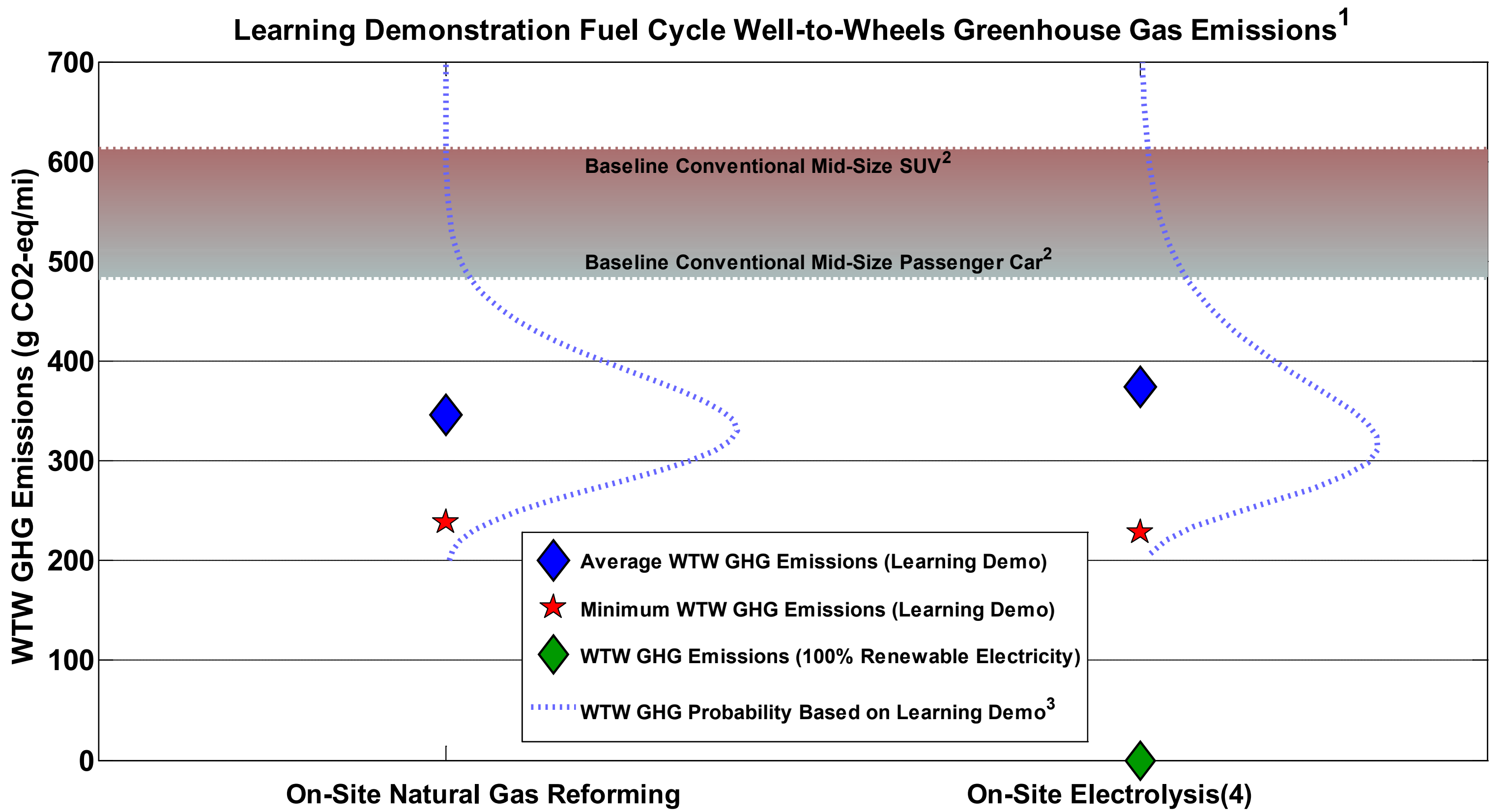


Many Learning Demonstration Stations Currently Have Excess Capacity; Higher Utilization Helps Efficiency

1) 100% production utilization assumes operation 24 hrs a day, 7 days a week
2) Production conversion efficiency is defined as the energy of the hydrogen out of the process (on a LHV basis) divided by the sum of the energy into the production process from the feedstock and all other energy as needed. Conversion efficiency does not include energy used for compression, storage, and dispensing.
3) High correlation with electrolysis data (R^2 = 0.81) & low correlation with natural gas data (R^2 = 0.058)

Created: Sep-24-08 4:15 PM

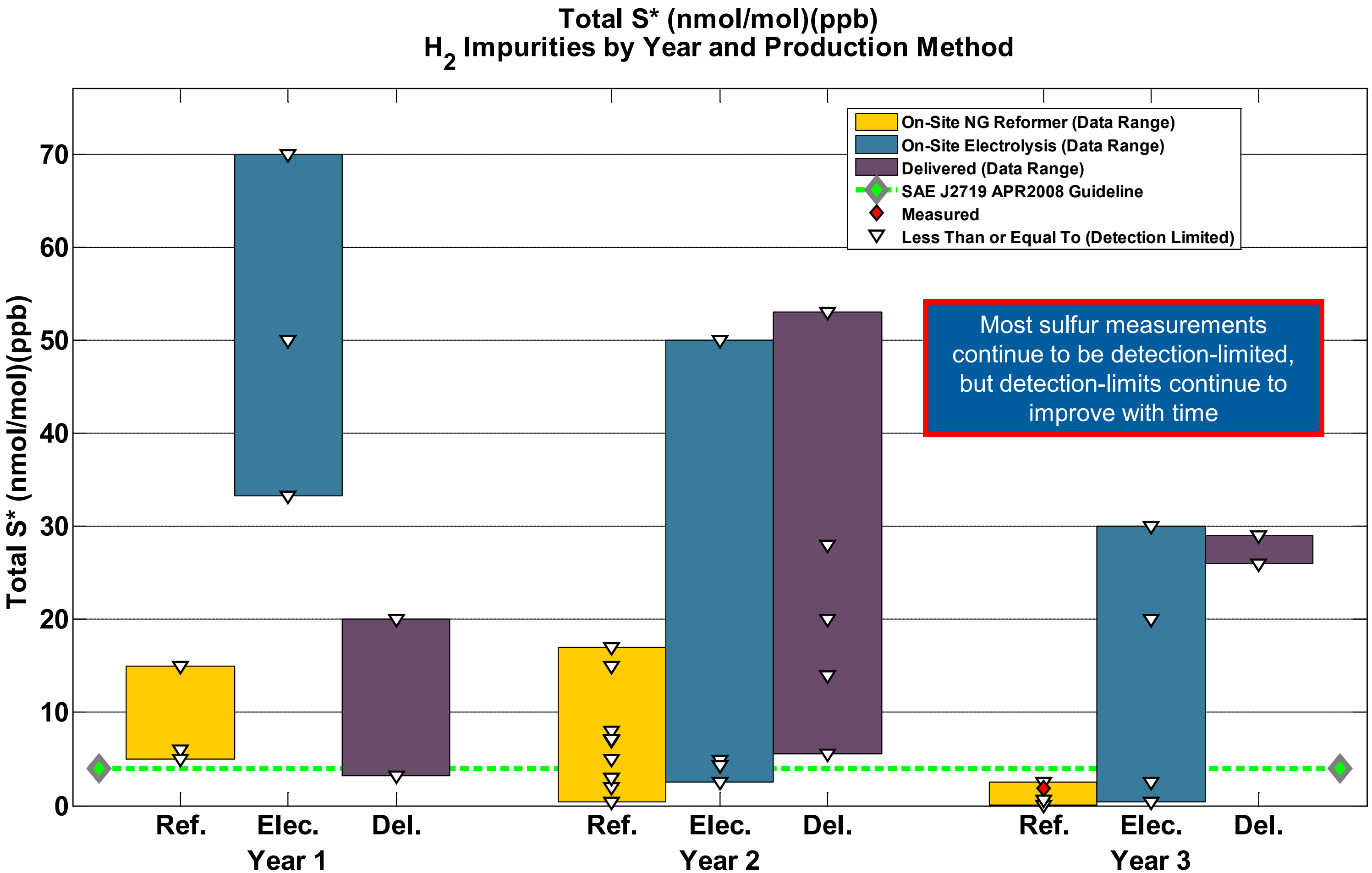
Learning Demonstration Vehicle Greenhouse Gas Emissions Using Actual Production Efficiencies and Fuel Economies



1. Well-to-Wheels greenhouse gas emissions based on DOE's GREET model, version 1.8b. Analysis uses default GREET values except for FCV fuel economy, hydrogen production conversion efficiency, and electricity grid mix. Fuel economy values are the Gen 1 and Gen 2 window-sticker fuel economy data for all teams (as used in CDP #6); conversion efficiency values are the production efficiency data used in CDP #13.
2. Baseline conventional passenger car and light duty truck GHG emissions are determined by GREET 1.8b, based on the EPA window-sticker fuel economy of a conventional gasoline mid-size passenger car and mid-size SUV, respectively. The Learning Demonstration fleet includes both passenger cars and SUVs.
3. The Well-to-Wheels GHG probability distribution represents the range and likelihood of GHG emissions resulting from the hydrogen FCV fleet based on window-sticker fuel economy data and monthly conversion efficiency data from the Learning Demonstration.
4. On-site electrolysis GHG emissions are based on the average mix of electricity production used by the Learning Demonstration production sites, which includes both grid-based electricity and renewable on-site solar electricity. GHG emissions associated with on-site production of hydrogen from electrolysis are highly dependent on electricity source. GHG emissions from a 100% renewable electricity mix would be zero, as shown. If electricity were supplied from the U.S. average grid mix, average GHG emissions would be 1296 g/mile.

Created: Sep-24-08 4:19 PM

Hydrogen Impurities by Year and Production Method – Total Sulfur



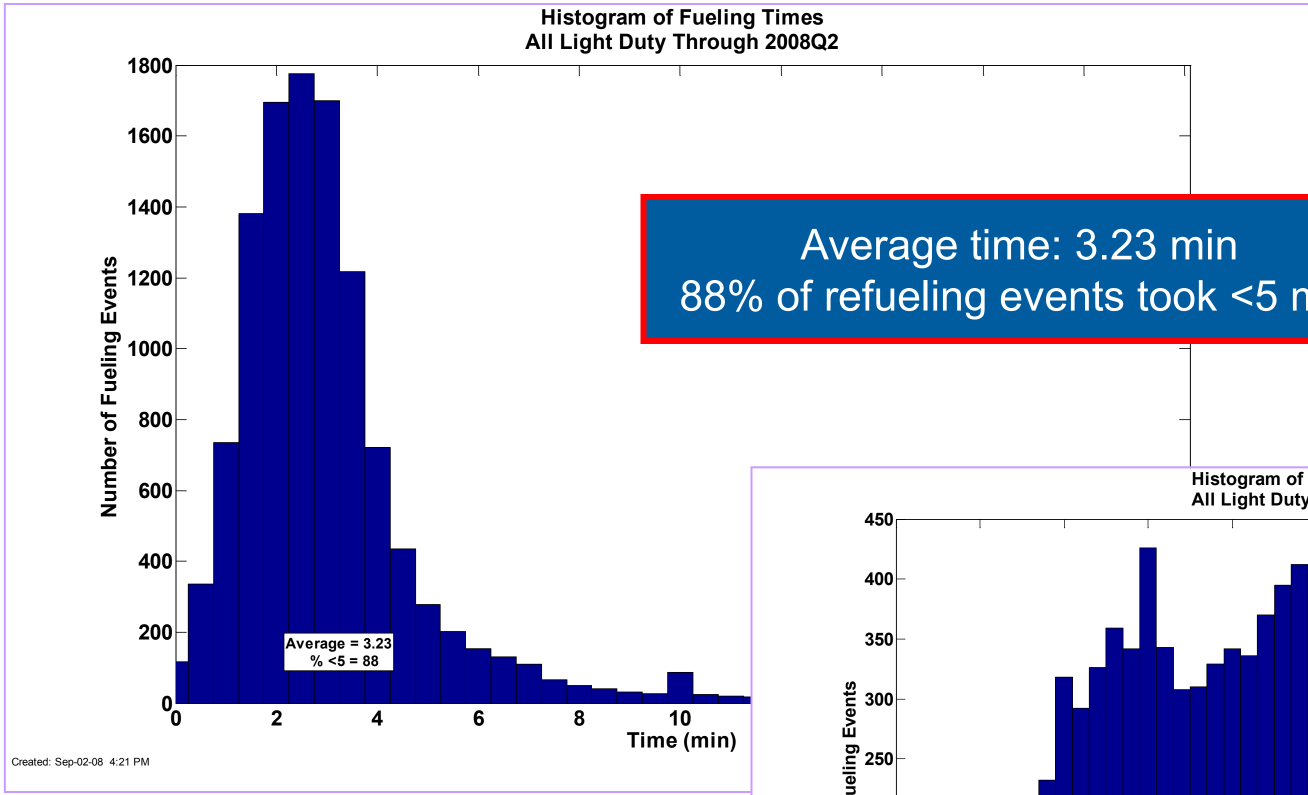
Most sulfur measurements continue to be detection-limited, but detection-limits continue to improve with time

Data is from Learning Demonstration and California Fuel Cell Partnership testing
Year 1 is 2005Q3-2006Q2, Year 2 is 2006Q3-2007Q2, and Year 3 is 2007Q3-2008Q2
*Total S calculated from SO2, COS, H2S, CS2, and Methyl Mercaptan (CH3SH).

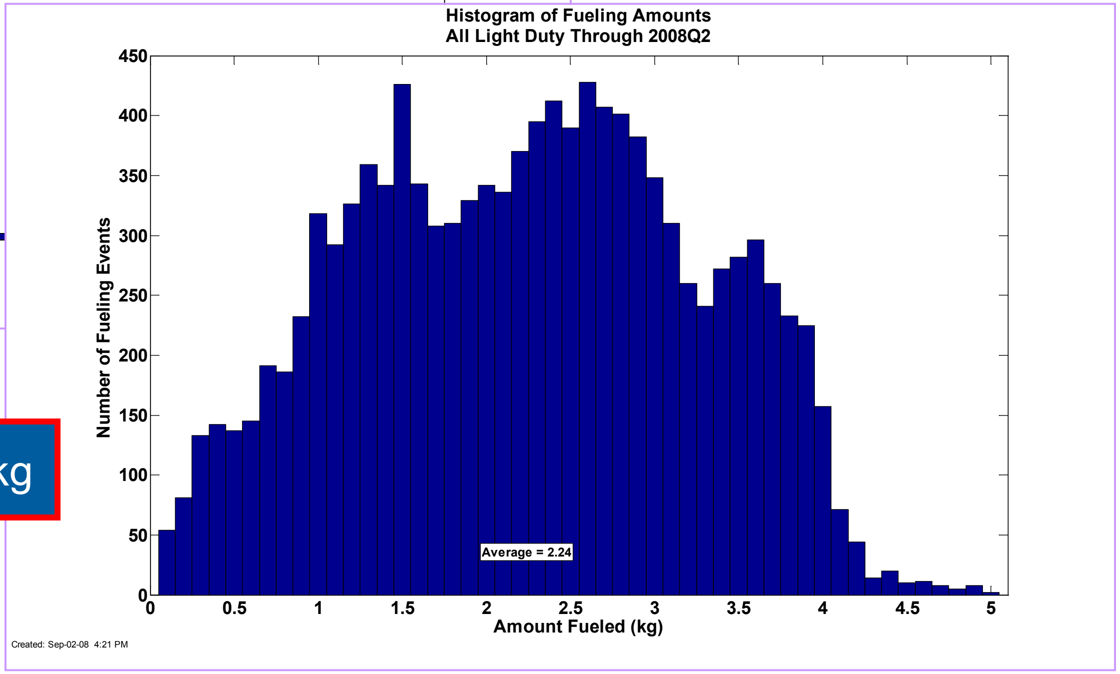
Created: Sep-22-08 1:42 PM

This is 1 of over a dozen impurities now reported by time and production technology

Actual Vehicle Refueling *Times* and *Amounts* from 11,500 Events: Measured by Stations or by Vehicles



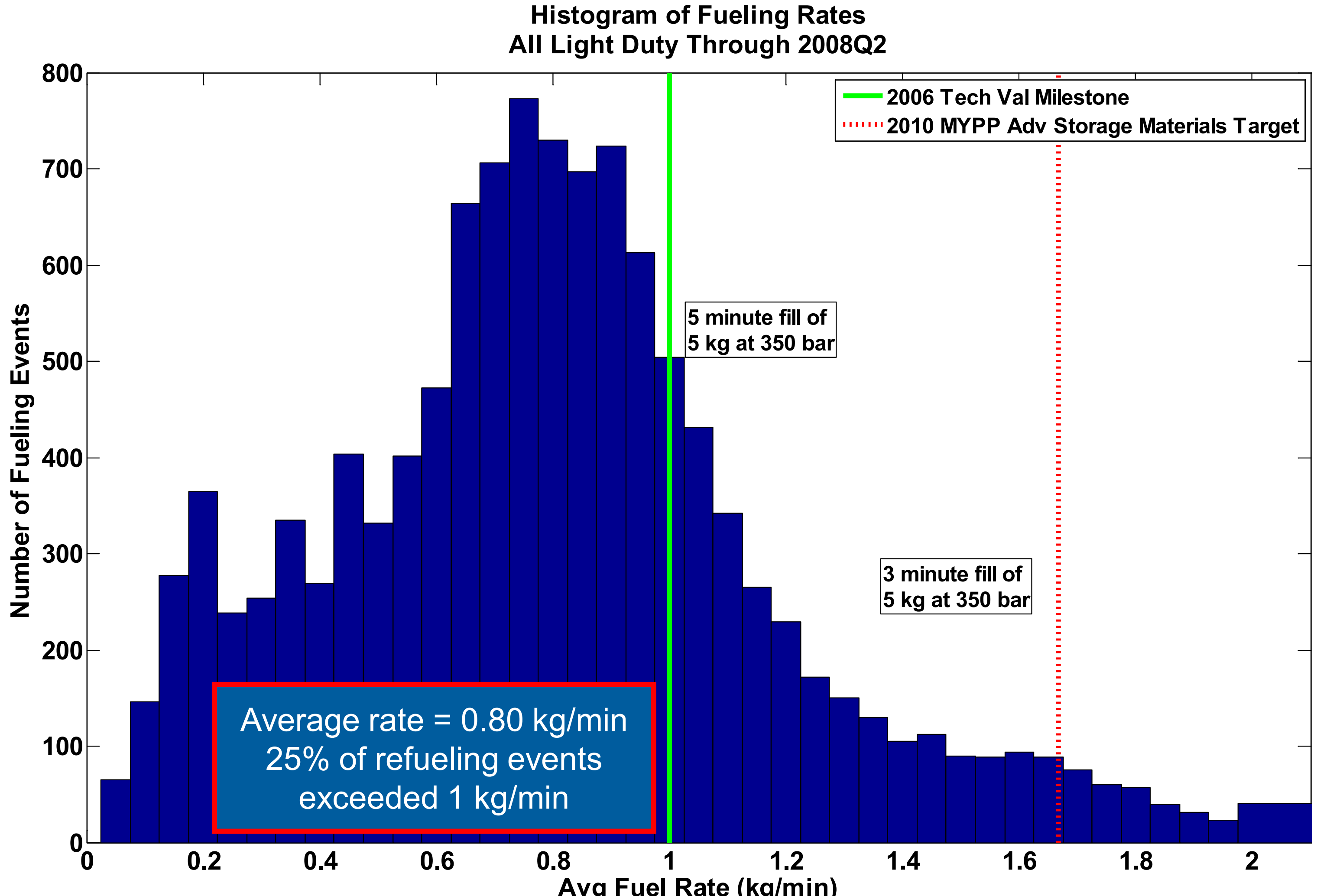
Average time: 3.23 min
88% of refueling events took <5 min



Average fill amount: 2.24 kg

Includes Communication and Non-Communication Fills

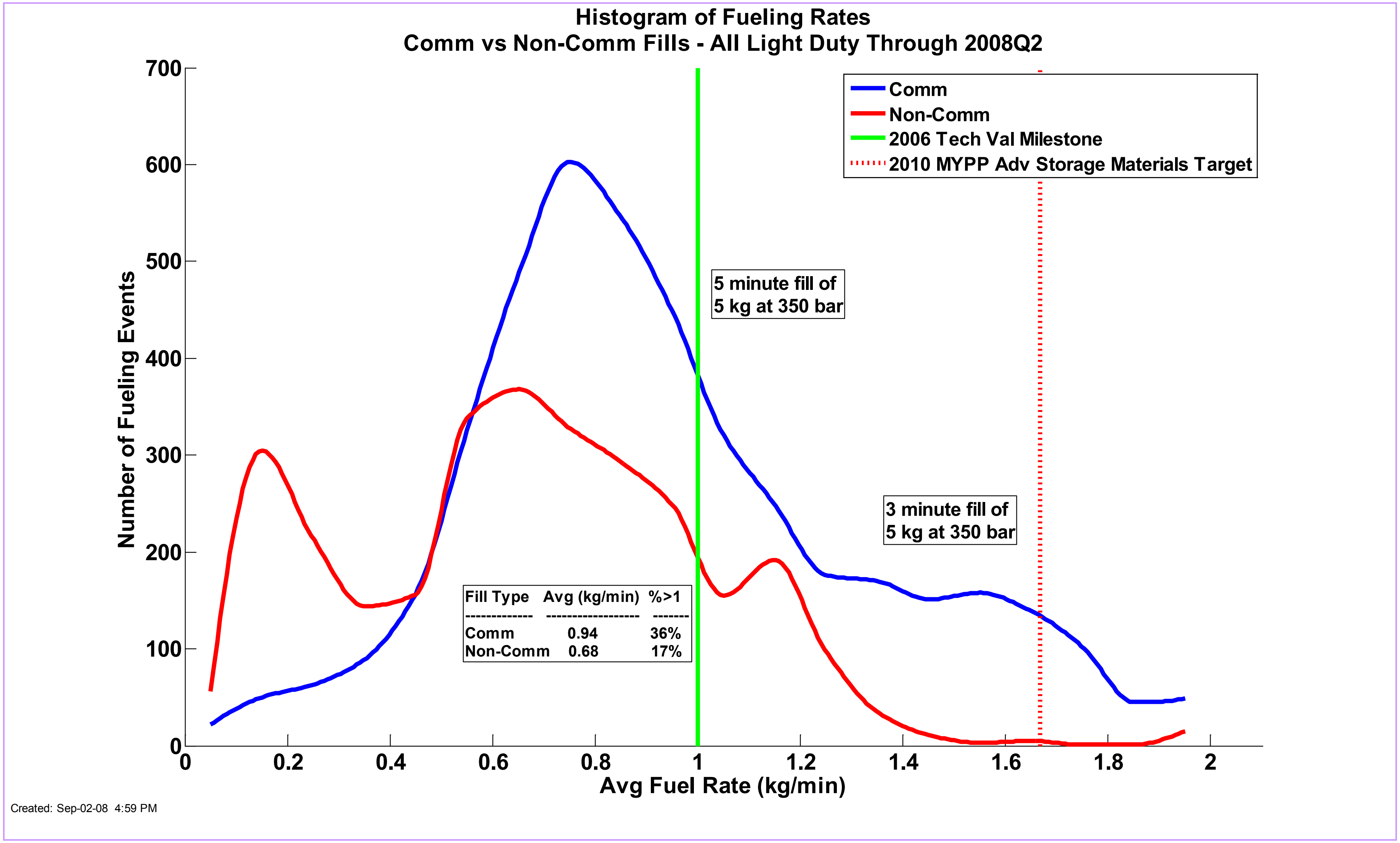
Actual Vehicle Refueling *Rates* from 11,500 Events: Measured by Stations or by Vehicles



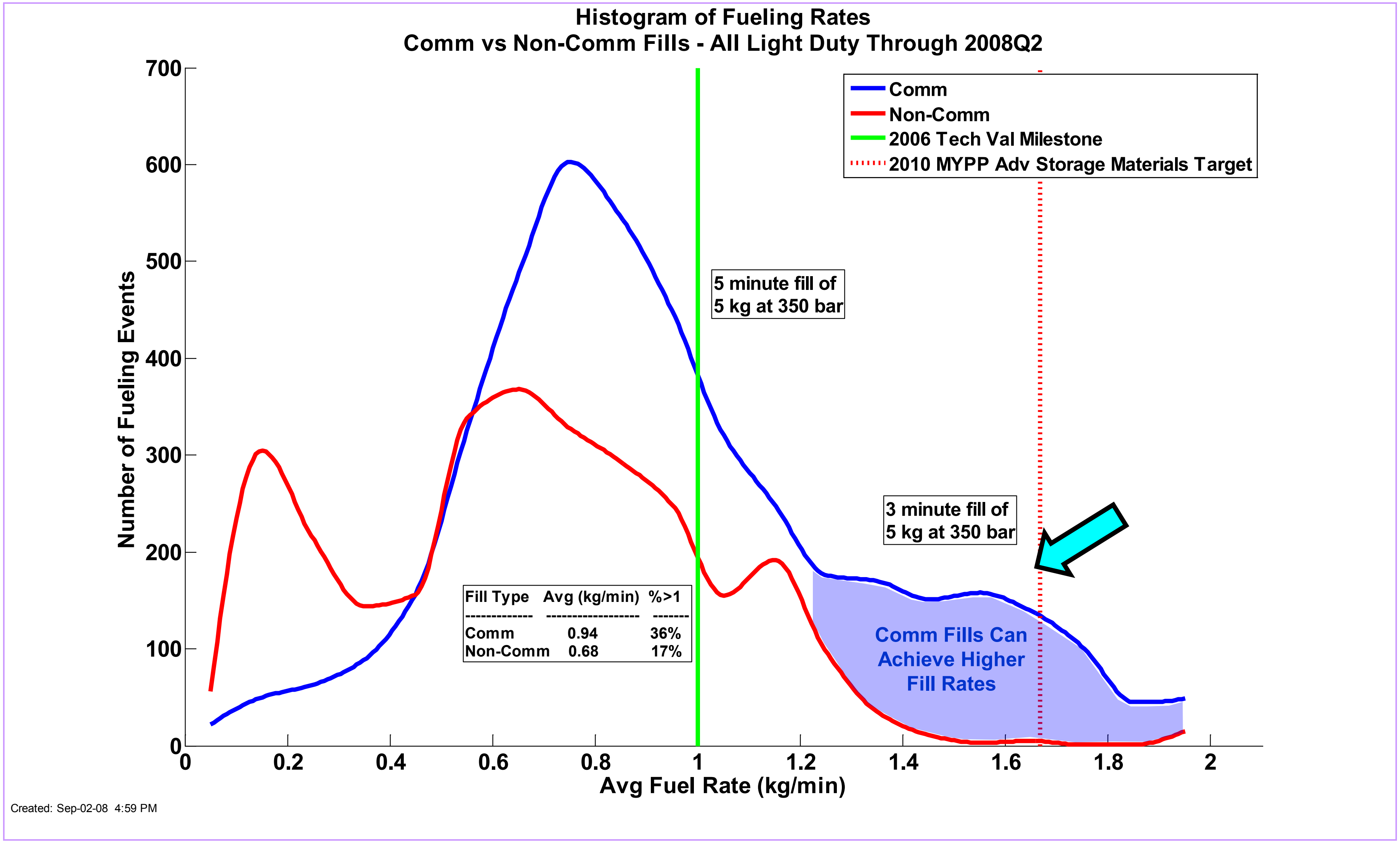
Average rate = 0.80 kg/min
25% of refueling events exceeded 1 kg/min

Includes Communication and Non-Communication Fills

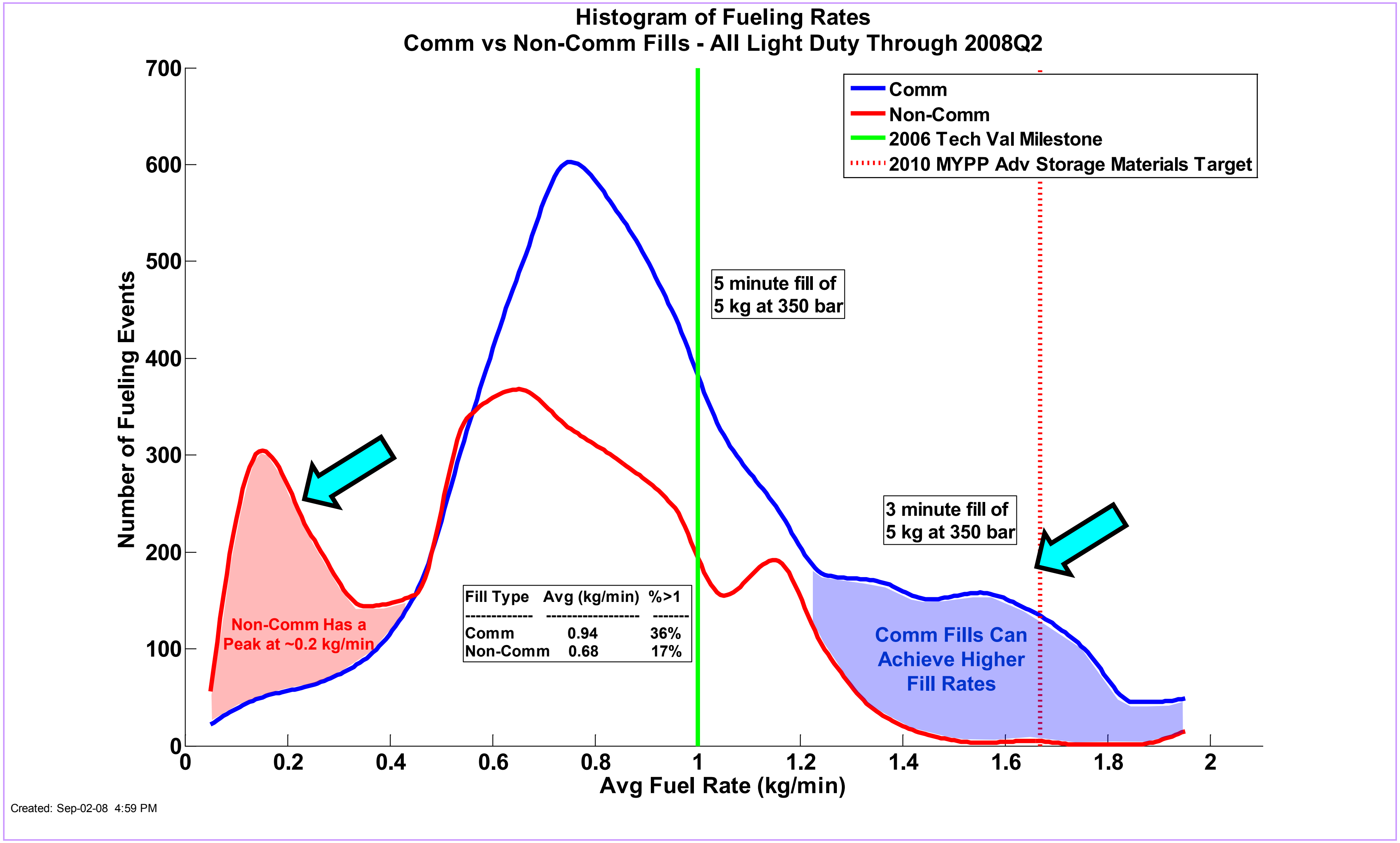
Communication H2 Fills Achieving Higher Fill Rate than Non-Communication



Communication H2 Fills Achieving Higher Fill Rate than Non-Communication



Communication H2 Fills Achieving Higher Fill Rate than Non-Communication

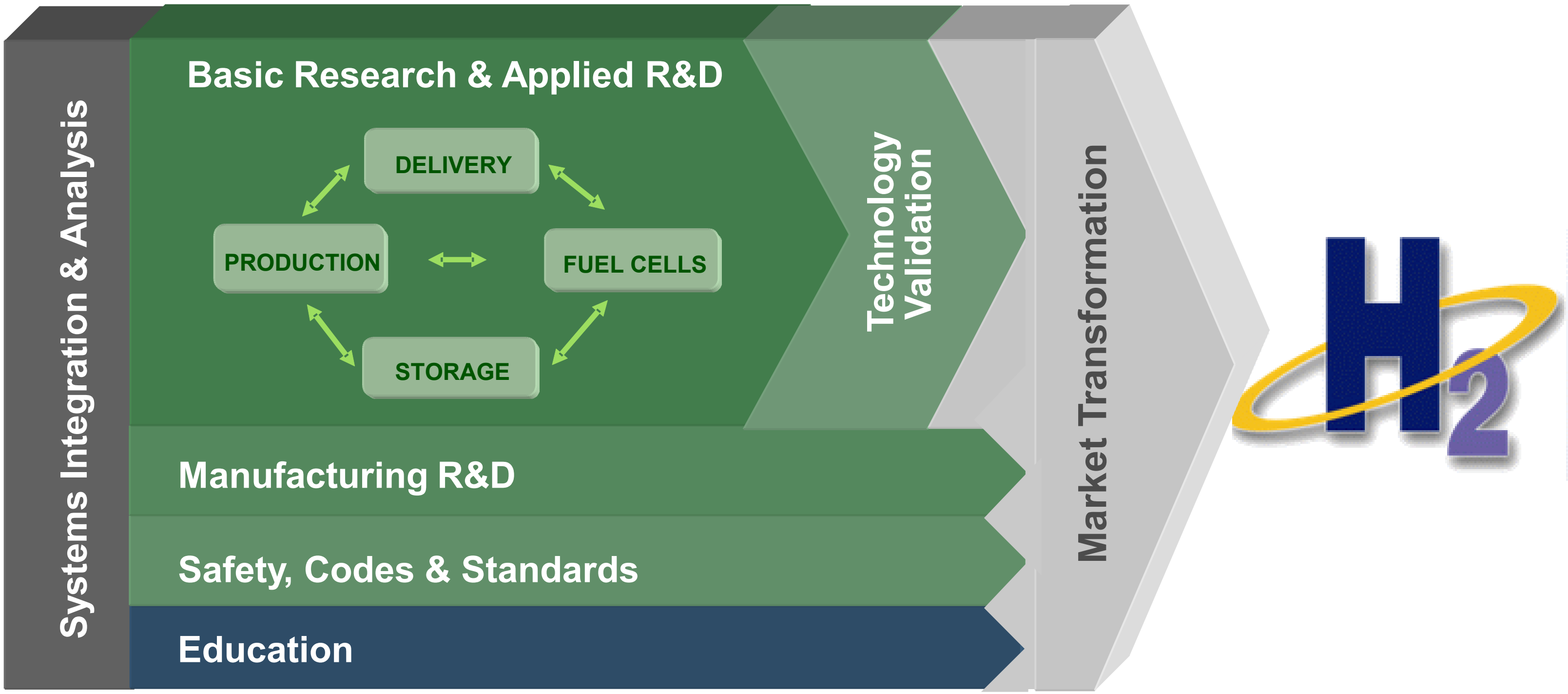


Fill Type	Avg (kg/min)	%>1
Comm	0.94	36%
Non-Comm	0.68	17%

Summary

- Learning Demo project is ~75% complete
  - >122 vehicles and 20 stations deployed
  - 1.5 million miles traveled, 60,000 kg H_2 produced or dispensed
  - 311,000 individual vehicle trips analyzed
  - Project to continue through 2010
- Many new results in the Fall 2008 composite data products
  - 50 new/updated results, 3 unchanged, for a total of 53
  - Several Gen 1 vs. Gen 2 vehicle comparisons
  - Hydrogen production efficiency related results
  - Vehicle greenhouse gas estimates using actual production efficiencies
  - Fuel cell system W/kg and W/L
  - Hydrogen impurity breakdown by year and production technology
  - All results available on web site
- Roll-out of 2^{nd} generation vehicles continues
  - All remaining vehicles to be deployed this year
  - Additional 700 bar stations coming online soon

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