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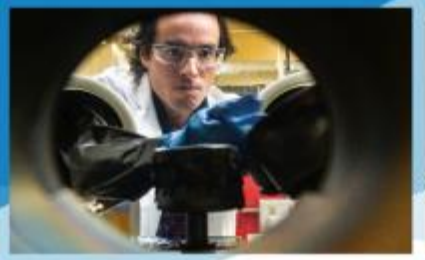



Fuel Cell Electric Vehicle Evaluation

Jennifer Kurtz (PI), Sam Sprik, Chris Ainscough, Genevieve Saur, Matt Jeffers

June 17, 2016
Advanced Automotive Battery Conference
Detroit, MI

NREL/PR-5400-66760

Content

- Why FCEVs
- Overview of FCEV evaluation
- Results

Sustainable Transportation Vision

NREL RD&D accelerates the process of bringing sustainable transportation technologies to the market with the ultimate goals of:

- Reduction of GHG emissions in the transportation sector to meet a 2050 goal of 80% below 2005 levels
- Diversification of transportation energy sources to reduce petroleum consumption and promote U.S. energy security

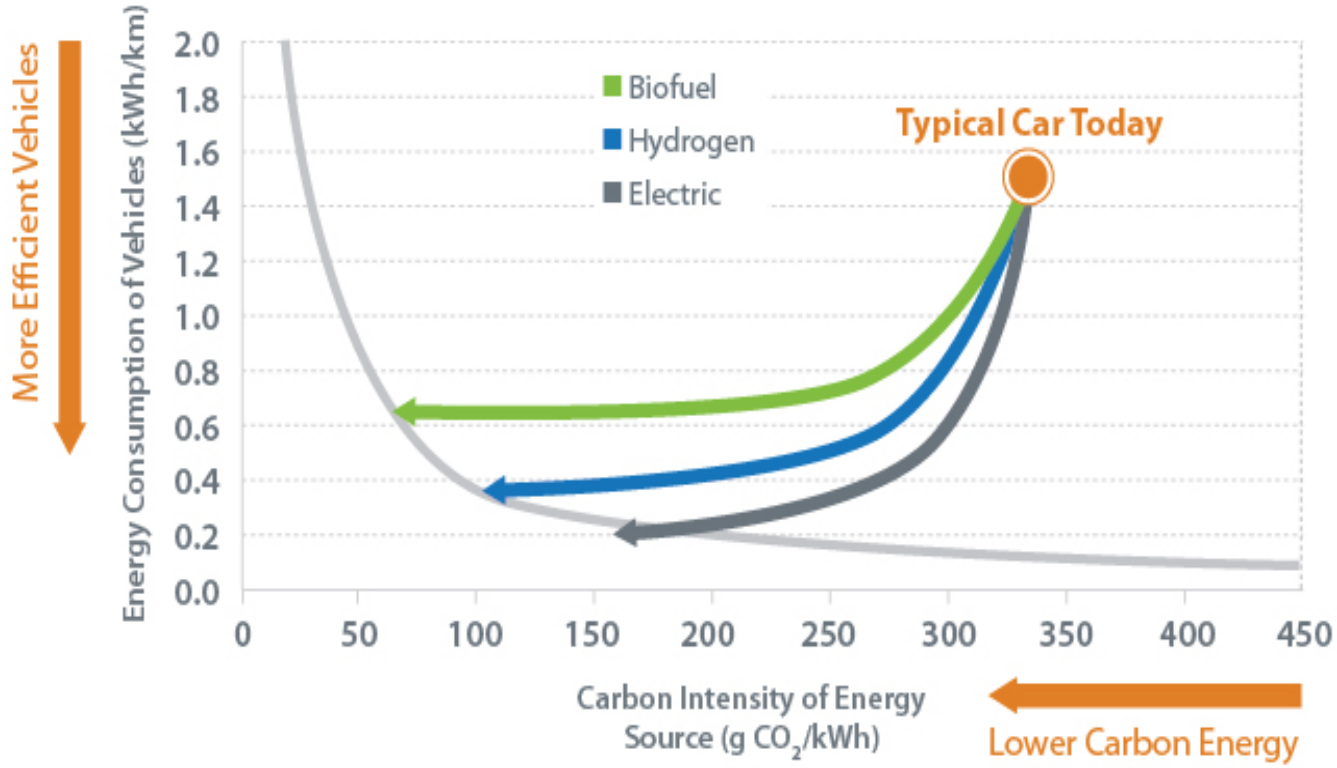


Figure by NREL

Why Hydrogen Fuel Cell Electric Vehicles

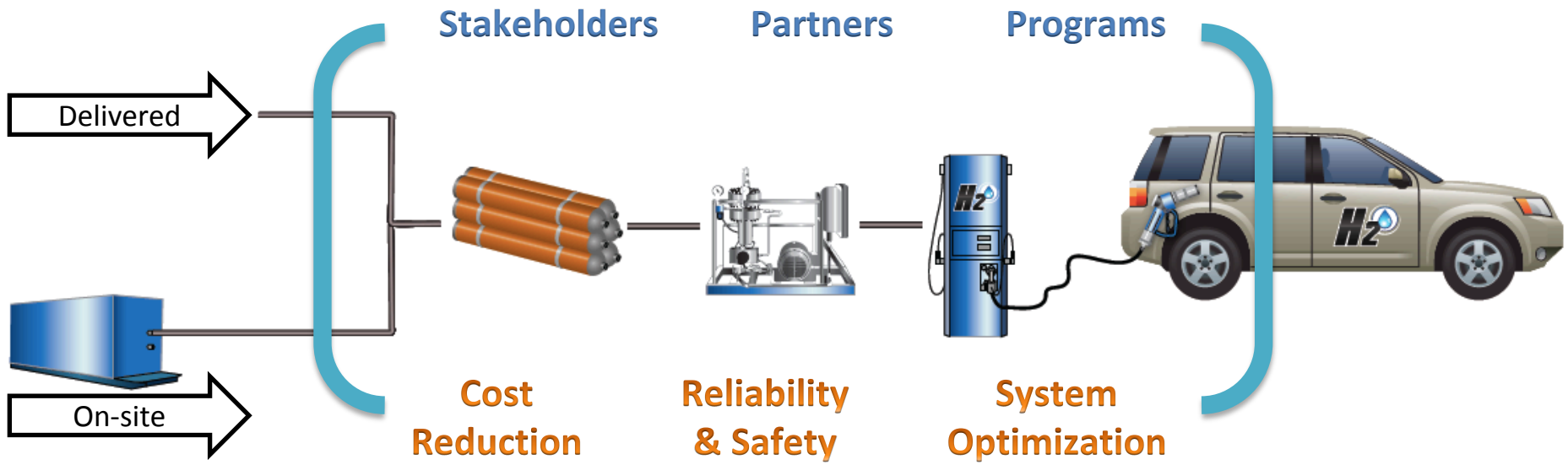
Hydrogen FCEVs are clean, efficient, refuel quickly, and provide long driving range

Challenges include hydrogen infrastructure cost & reliability, fuel cell durability & reliability

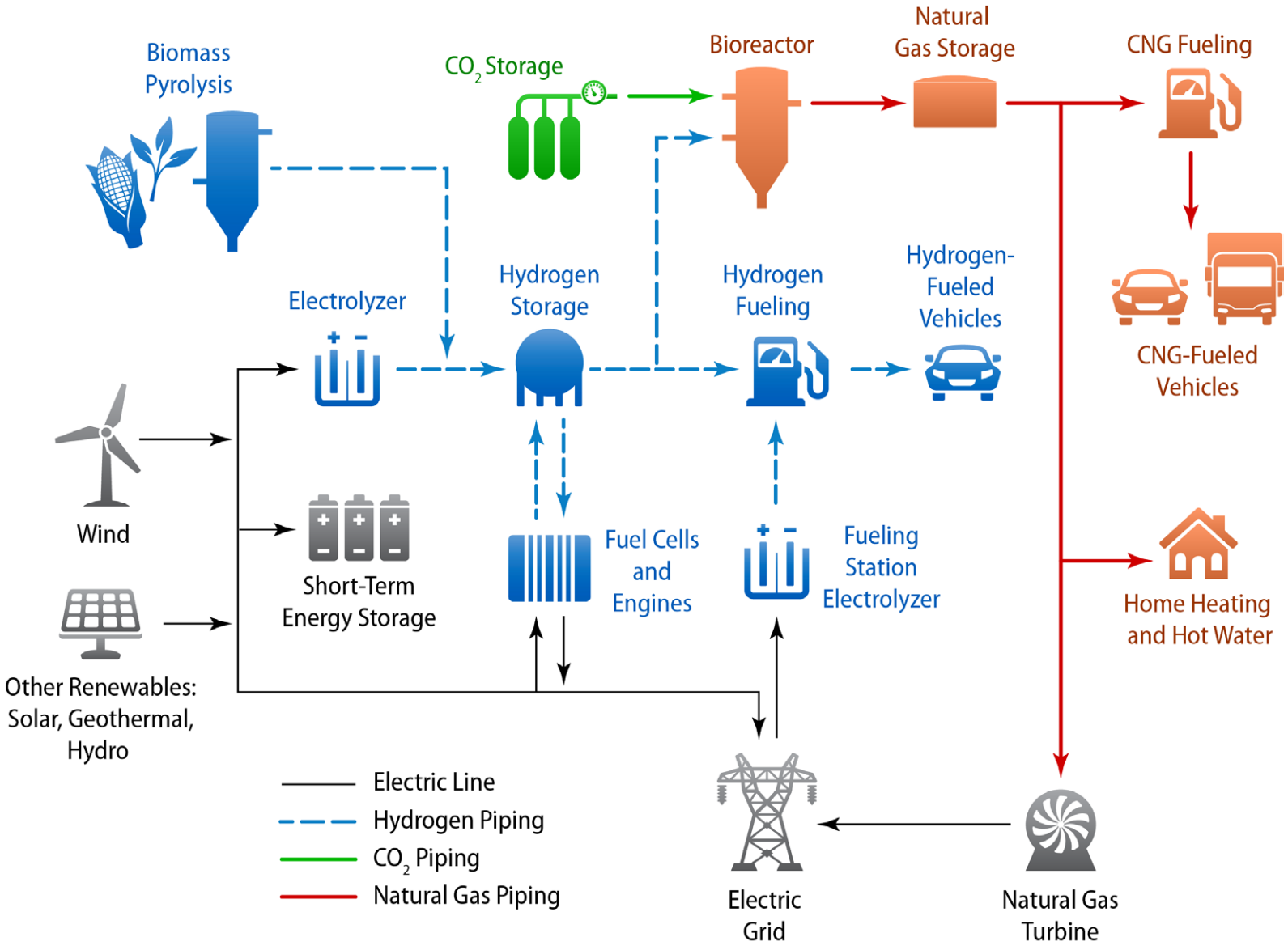
The Hydrogen Fueling Research & Station Technology

Ensure that FCEV customers have a positive fueling experience relative to conventional gasoline/diesel stations as vehicles are introduced (2015-2017), and transition to advanced refueling technology beyond 2017.

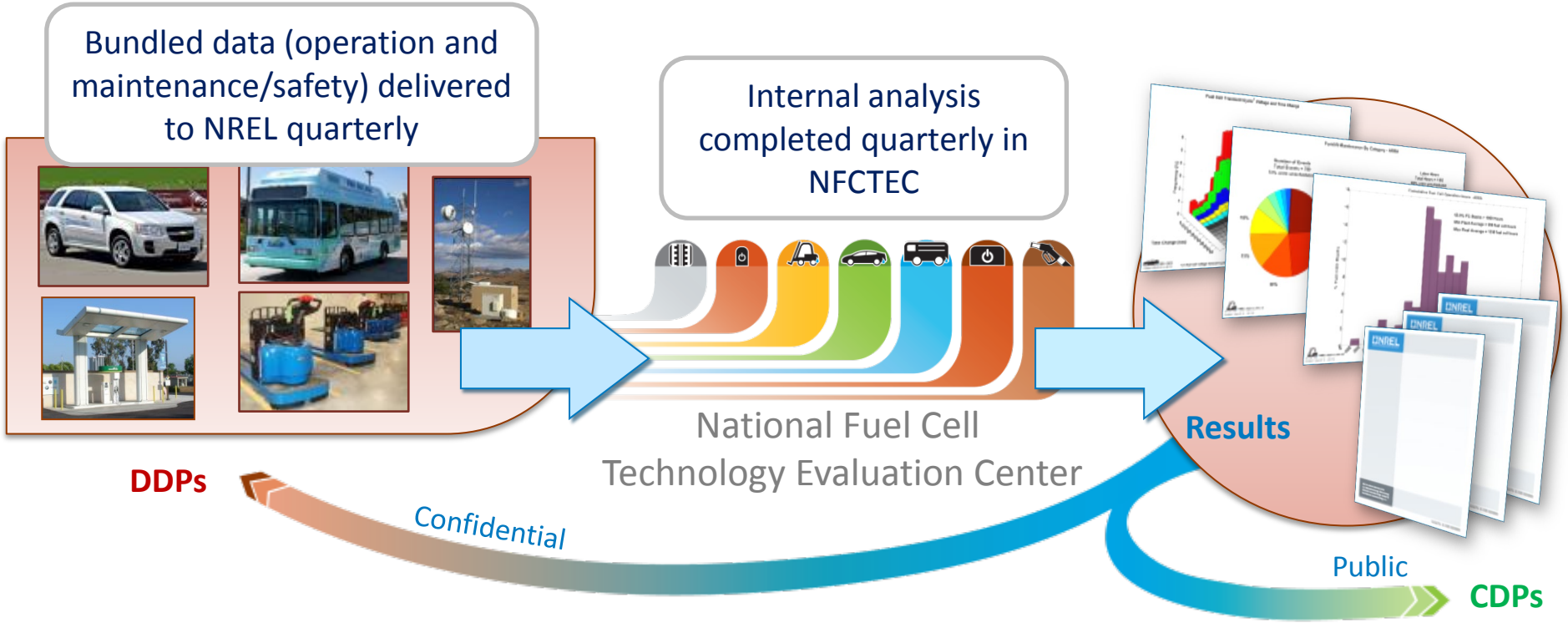
1. Reduce the installation cost of a hydrogen fueling station to be competitive with conventional liquid fuel.
2. Improve the availability, reliability, and cost while ensuring the safety of high-pressure components.
3. Focus a flexible and responsive set of technical experts and facilities to help solve today's urgent challenges and the future unpredicted needs.
4. Enable distributed generation of renewable hydrogen in a broader energy ecosystem.



Renewable Hydrogen Options



NFCTEC Analysis and Reporting of Real-World Operation Data



Detailed Data Products (DDPs)
- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data

Composite Data Products (CDPs)
- Aggregated data across multiple systems, sites, and teams
- Publish analysis results every six months without revealing proprietary data

www.nrel.gov/hydrogen/proj_tech_validation.html

On-road FCEVs & Partners

Objectives

- Data analysis and reporting of hydrogen fuel cell electric vehicles (FCEV) operating in real-world setting
- Identify current status and evolution of the technology
- Publish performance status and progress from multiple FCEV models

Six Data Providers[1]

Range of FCEV Model Years

[1]DOE project overview:

- $5.5 million DOE funding
- Data to be collected from up to ~90 vehicles

[2]Project managed by Electricore
Award completed

FCEV Deployment and Operation Through 12/2015

55
FCEVs total

51
Average on-road
fuel economy miles/kg

4,100
Max fleet voltage durability
(Hours to 10% degradation metric)

24
FCEVs retired

> 3,052,000
miles traveled

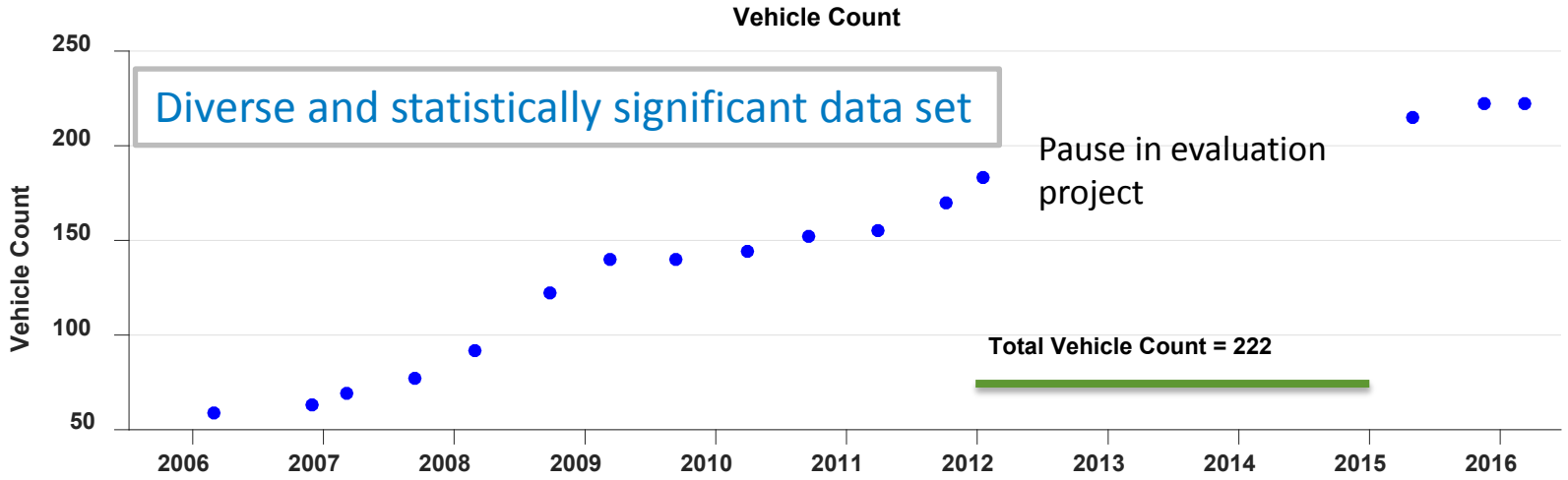
> 190,300
Max FCEV odometer miles

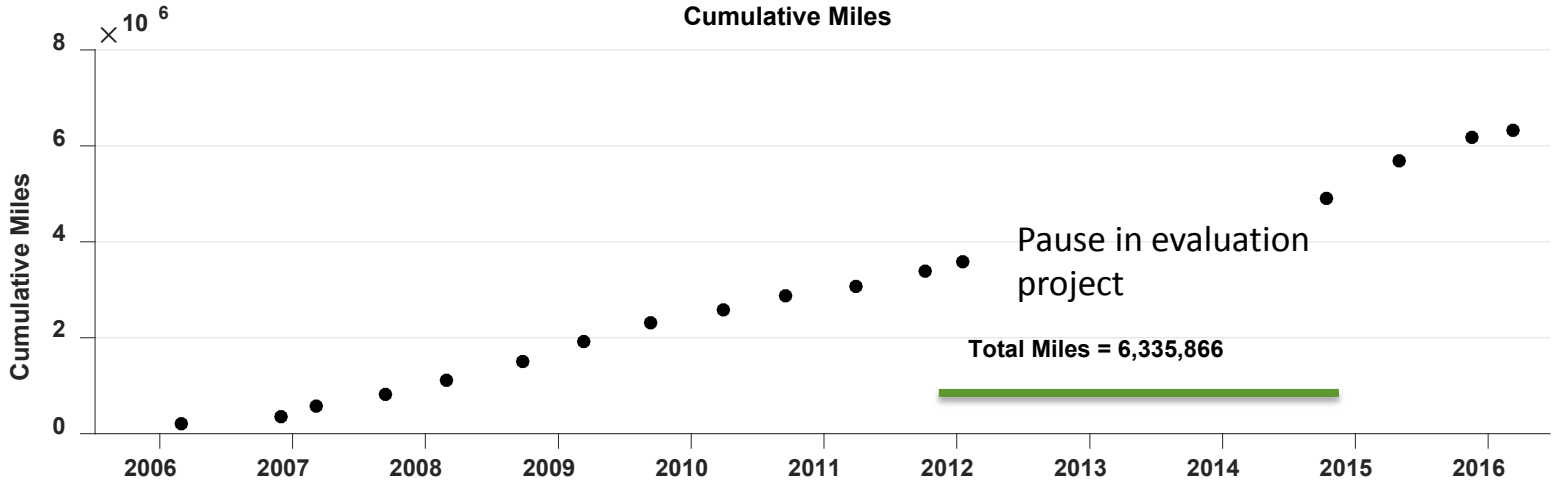
NREL Hydrogen Station Dedication 10/2015

> 101,400
Fuel cell
operation hours

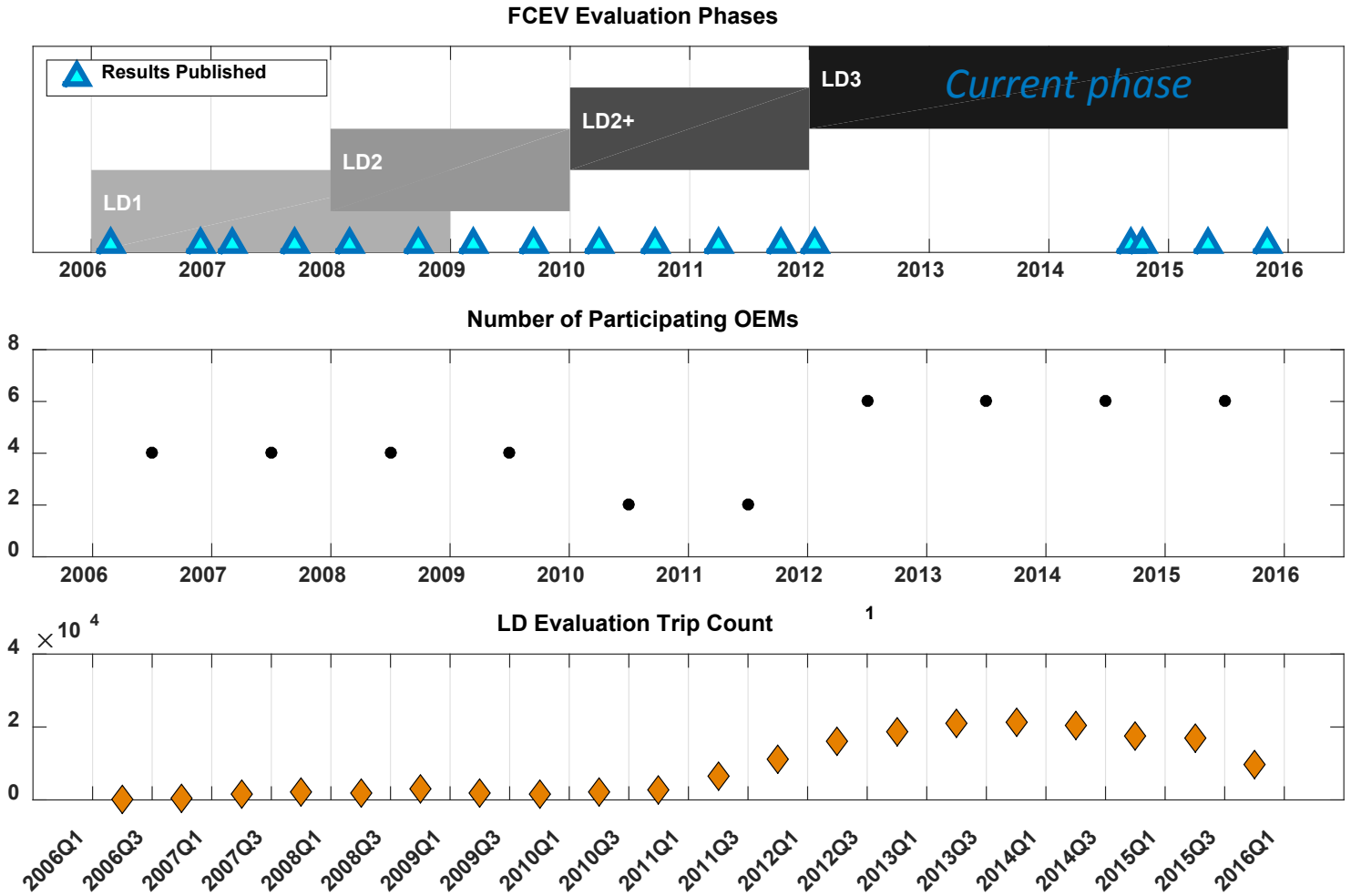
5,600
Max fuel cell
operation hours

Vehicle Count & Miles Since 2006





Participants and Trips Since 2006



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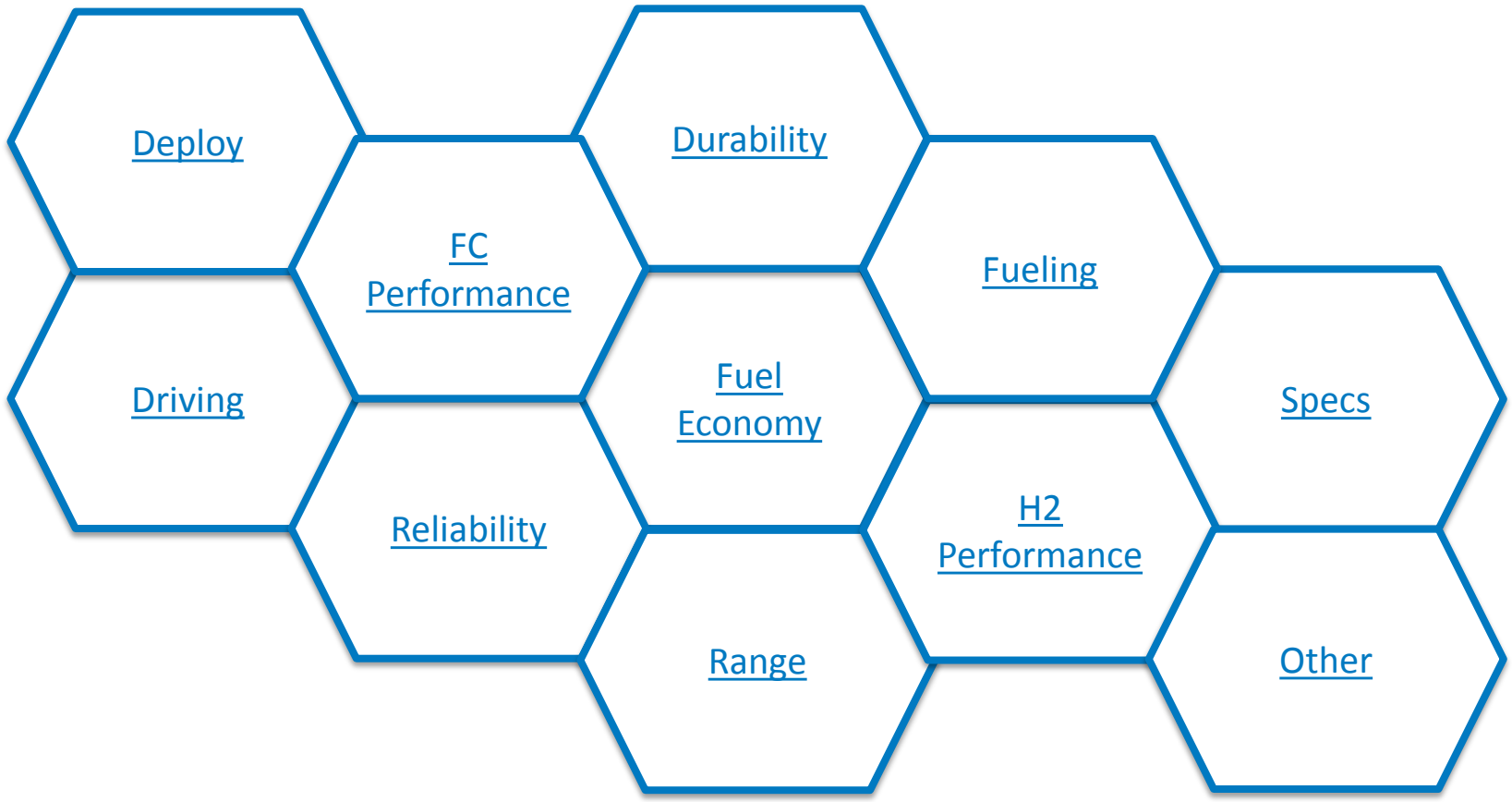
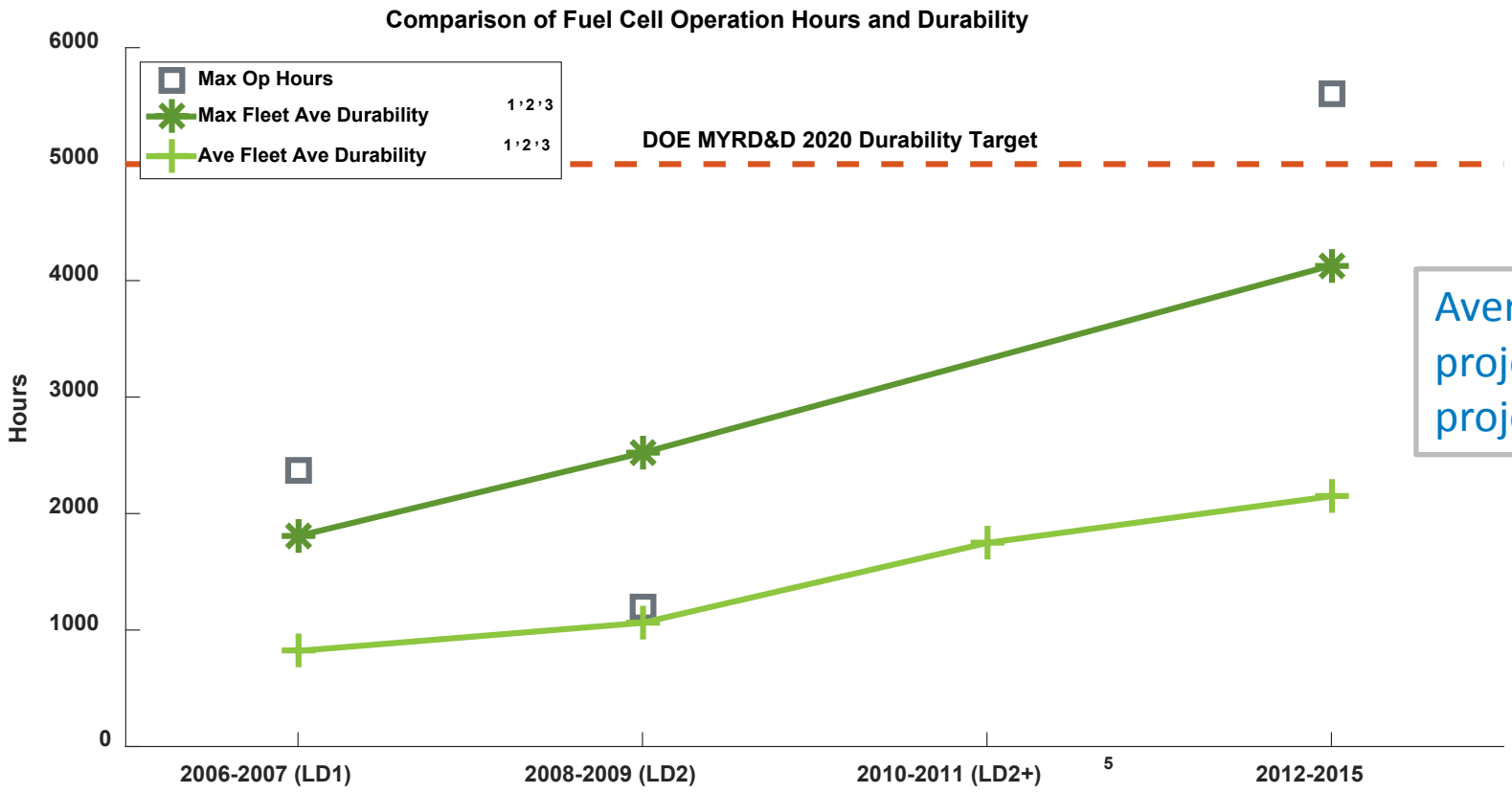
NREL analyzed trips decreasing due to planned vehicle decommissioning of older generation vehicles.

FCEV Analysis Categories



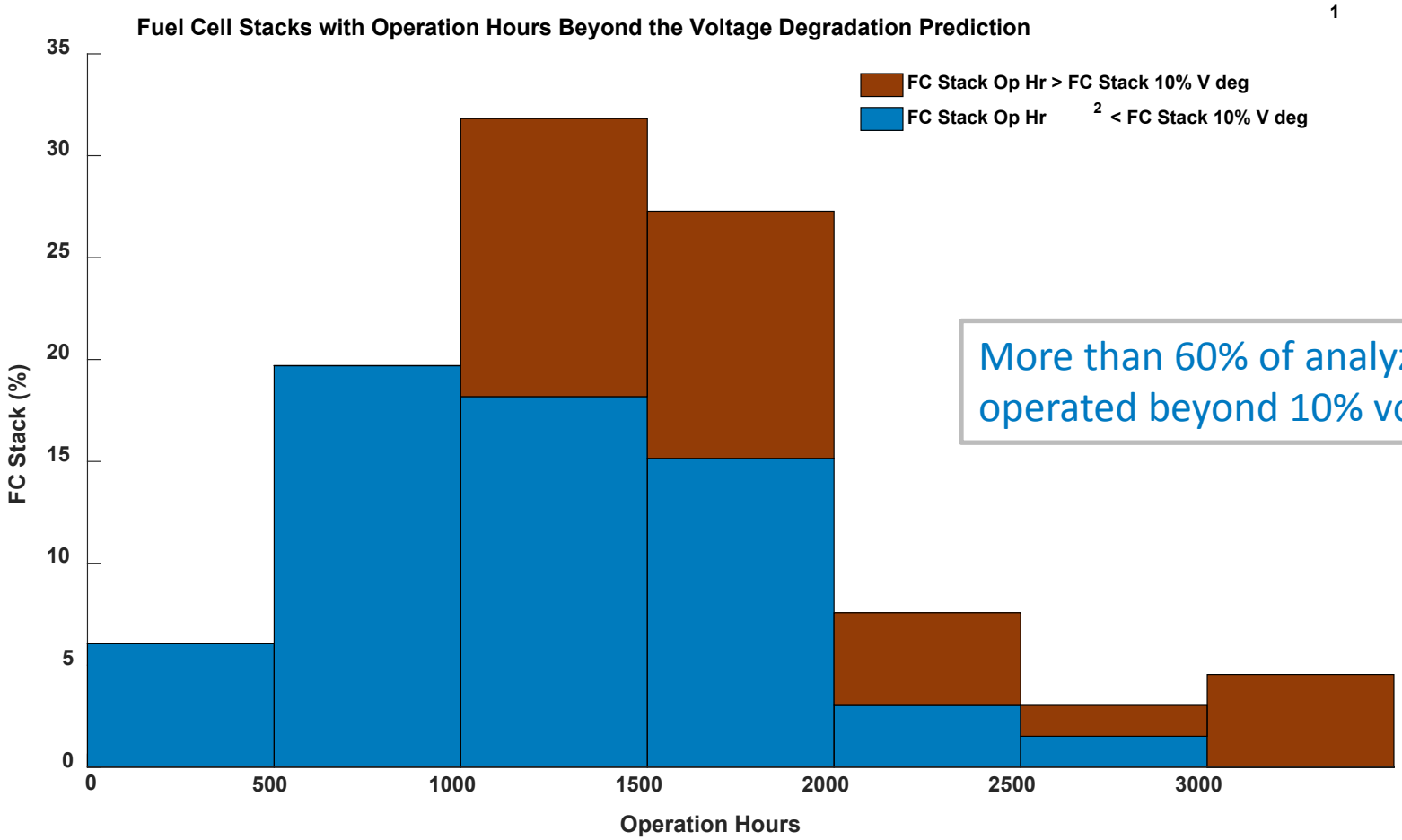
Analyzed data through 12/2015
All results not included here. All results available online at www.nrel.gov/hydrogen/proj_tech_validation.html

FCEV Voltage Durability



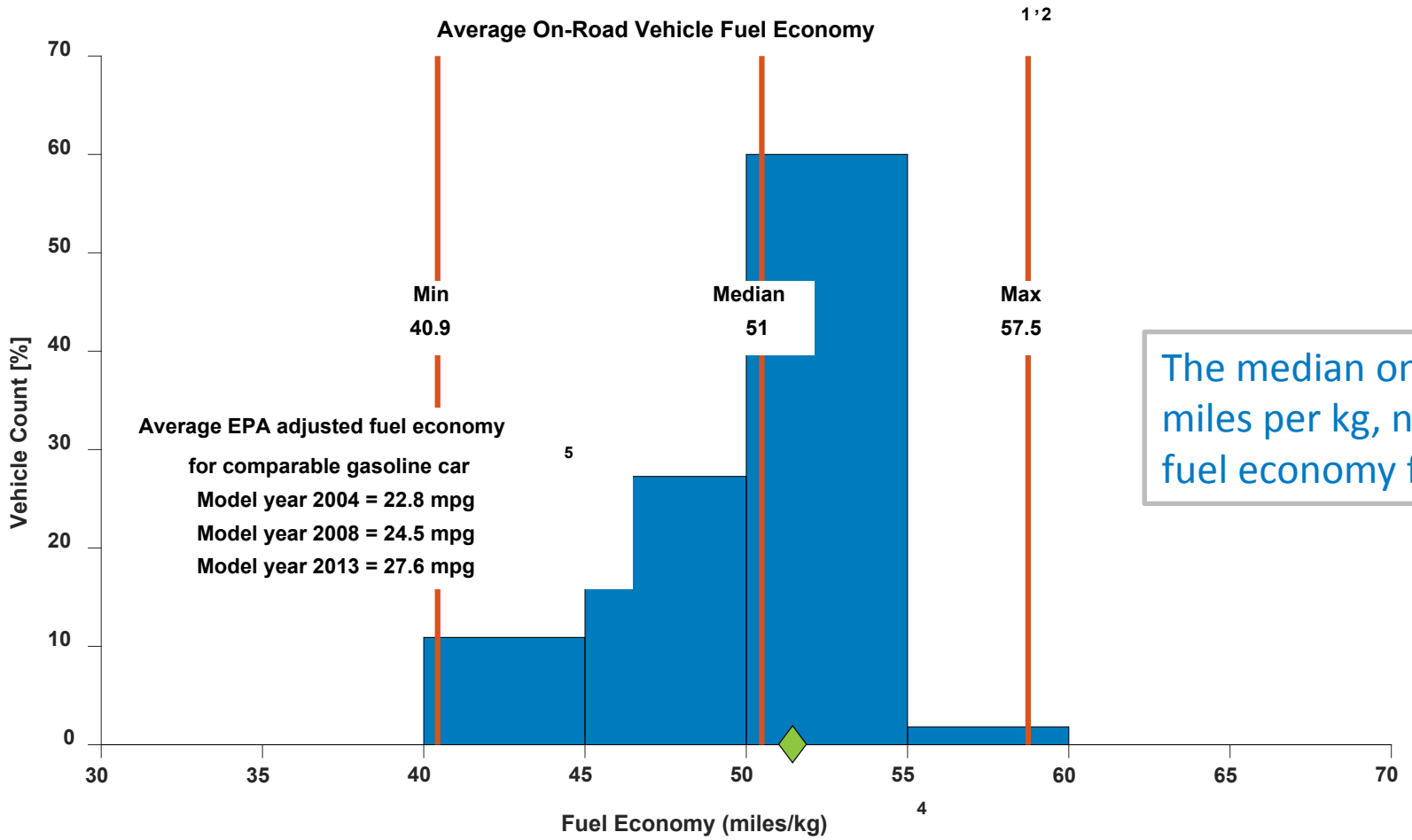
Average fleet voltage durability projection increased > 160% from initial projections in 2006 (CDP-FCEV-31)

Comparison of FC Stacks Operated Beyond 10% Voltage Degradation



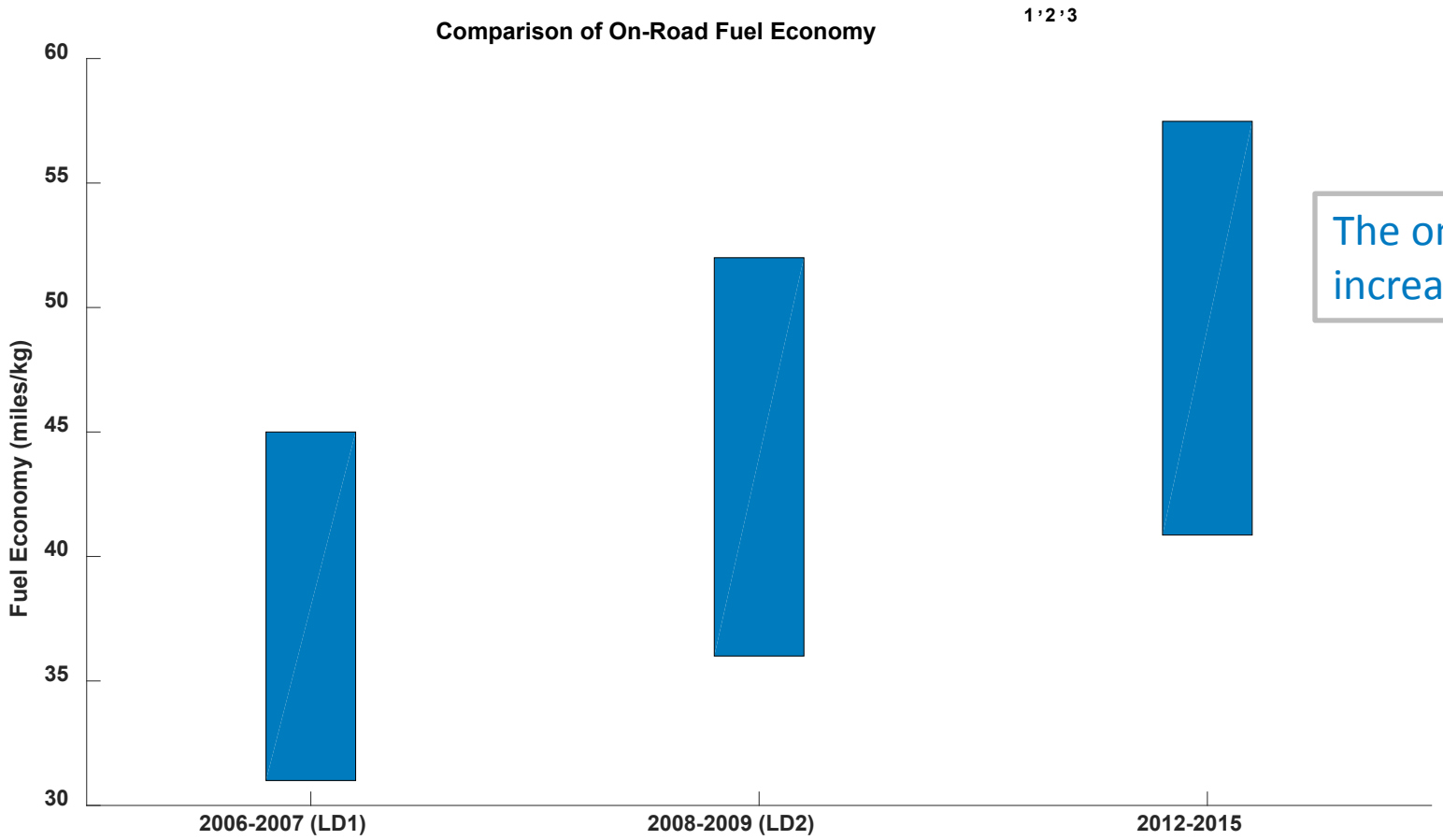
More than 60% of analyzed stacks have not operated beyond 10% voltage degradation.

On-Road Fuel Economy



The median on-road vehicle fuel economy is 51 miles per kg, nearly twice the 2013 EPA adjusted fuel economy for gasoline.

Comparison of On-Road Fuel Economy



The on-road fuel economy has consistently increased over the last 10 years.

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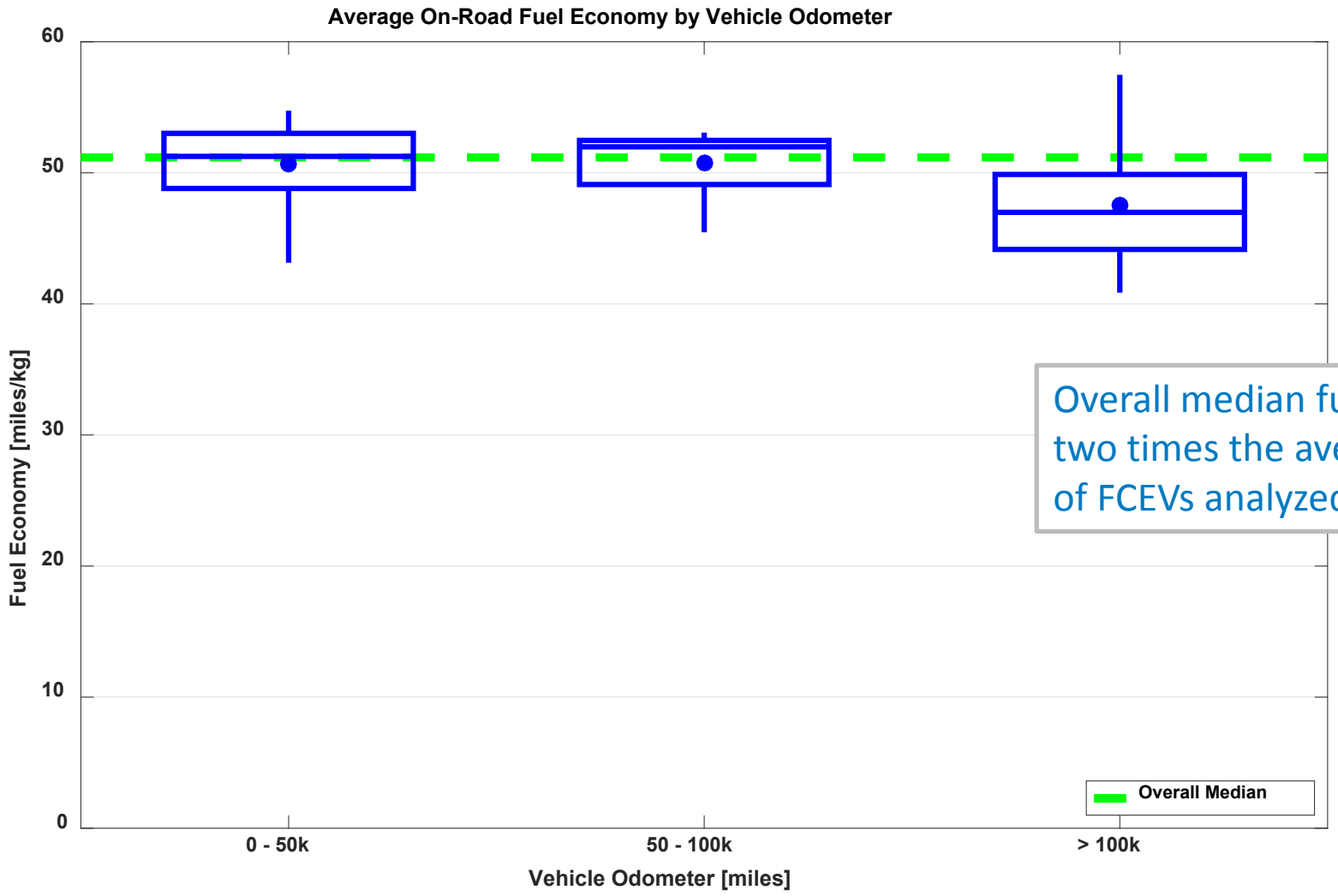
Average On-Road Fuel Economy by Vehicle Odometer



Overall median fuel economy = 51 m/kg, more than two times the average 2008 (comparable model year of FCEVs analyzed) EPA car fuel economy.

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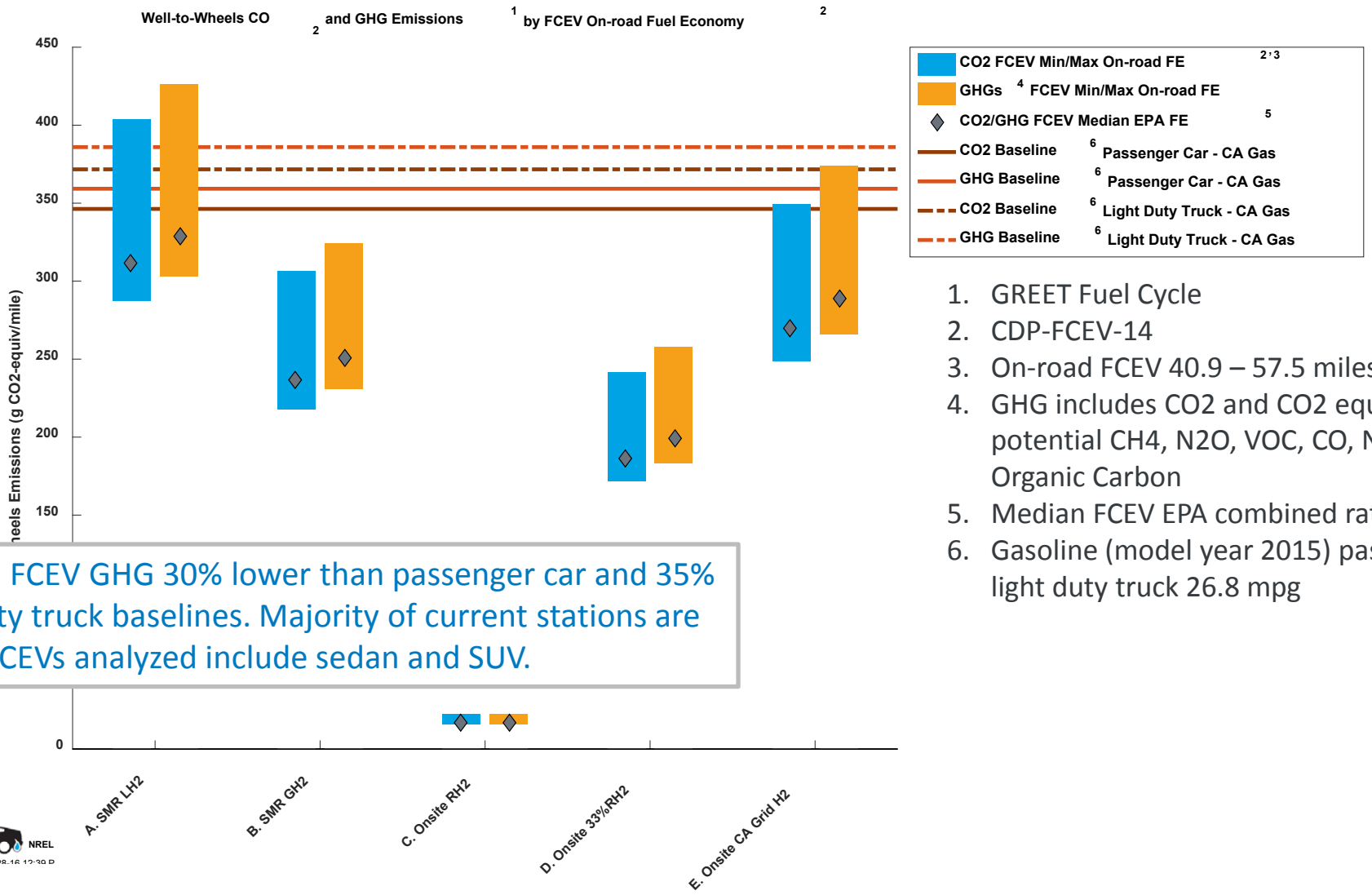
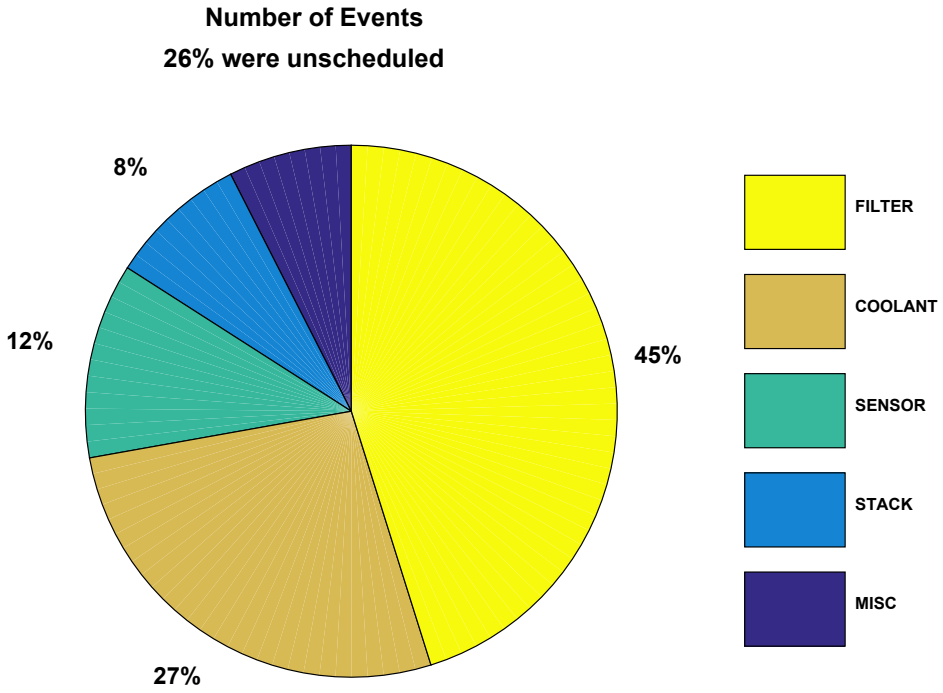
GHG Emissions Comparisons

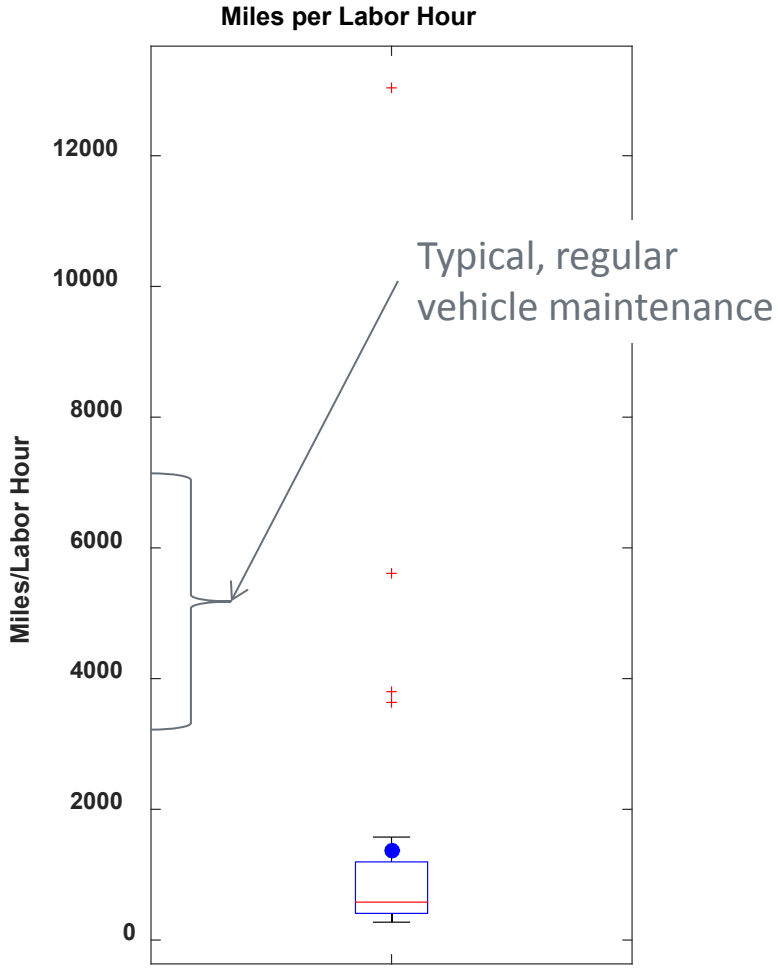


Scenario B: Median FCEV GHG 30% lower than passenger car and 35% lower than light duty truck baselines. Majority of current stations are delivered gas and FCEVs analyzed include sedan and SUV.

1. GREET Fuel Cycle
2. CDP-FCEV-14
3. On-road FCEV 40.9 – 57.5 miles/kg
4. GHG includes CO2 and CO2 equivalent global warming potential CH4, N2O, VOC, CO, NOx, Black Carbon, and Organic Carbon
5. Median FCEV EPA combined rating
6. Gasoline (model year 2015) passenger car 28.8 mpg, light duty truck 26.8 mpg

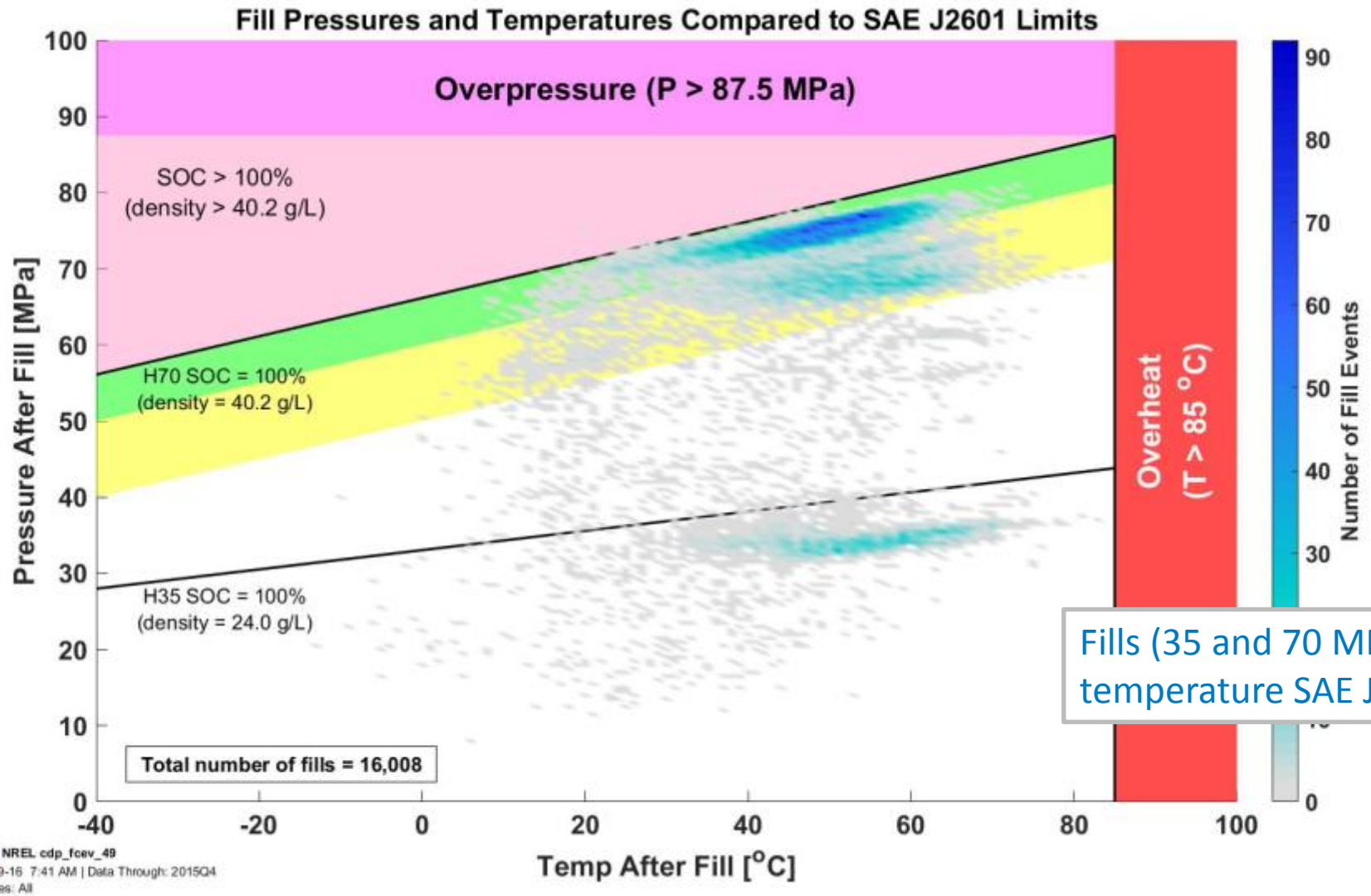
FCEV Maintenance and Reliability





Majority of FCEVs are older generation without commercial grade maintenance expectations. Simple unscheduled maintenance (72%) filters and coolant fills. Only 3.5% of failures occurred on-road (CDP-FCEV-73). Average maintenance per vehicle decreasing since 2012 (CDP-FCEV-68).

Comparison of Fills to SAE J2601 Temperature and Pressure Limits



Fills (35 and 70 MPa) following pressure and temperature SAE J2601 limits

Summary of Key Metrics

	Vehicle Performance Metrics	DOE Target (Year 2020)[a]	LD3[b]	LD2+[c]	LD2[c]	LD1[c]
Durability	Max Fuel Cell Durability Projection (hours)	5,000	4,130	--	2,521	1,807
	Average Fuel Cell Durability Projection (hours)		2,149	1,748	1,062	821
	Max Fuel Cell Operation (hours)		5,605	1,582	1,261	2,375
Efficiency	Adjusted Dyno (Window Sticker) Range		200 - 320 miles	--	196-254 miles	103-190 miles
	Median On-Road Distance Between Fuelings		123	98 miles	81 miles	56 miles
	Fuel Economy (Window Sticker)		51 mi/kg (median)	--	43 – 58 mi/kg	42 – 57 mi/kg
	Fuel Cell Efficiency at ¼ Power	60%	57% (average)	--	53% – 59%	51% – 58%
	Fuel Cell Efficiency at Full Power		43% (average)	--	42% – 53%	30% – 54%
Specs	Specific Power (W/kg)	650	240 - 563		306-406	183-323
	Power Density (W/L)	850	278 - 619		300-400	300-400
Storage	System Gravimetric Capacity (kg H2/kg system)	5.5%	2.5% - 3.7%			
	System Volumetric Capacity (kg H2/L system)	0.04	0.018 - 0.054			

a) Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan (http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22)

b) Current results are available at http://www.nrel.gov/hydrogen/proj_fc_vehicle_evaluation.html (Updated 11/2015)

c) National Fuel Cell Vehicle Learning Demonstration Final Report (http://www.nrel.gov/hydrogen/pdfs/54860.pdf)

Updated values since 6/2015 report and continued progress demonstrated over the four evaluation periods with FCEV technology improvements especially in key technical areas like fuel cell durability, range, and fuel economy.

Learn more at
www.nrel.gov/transportation
and
www.nrel.gov/hydrogen/proj_tech_validation

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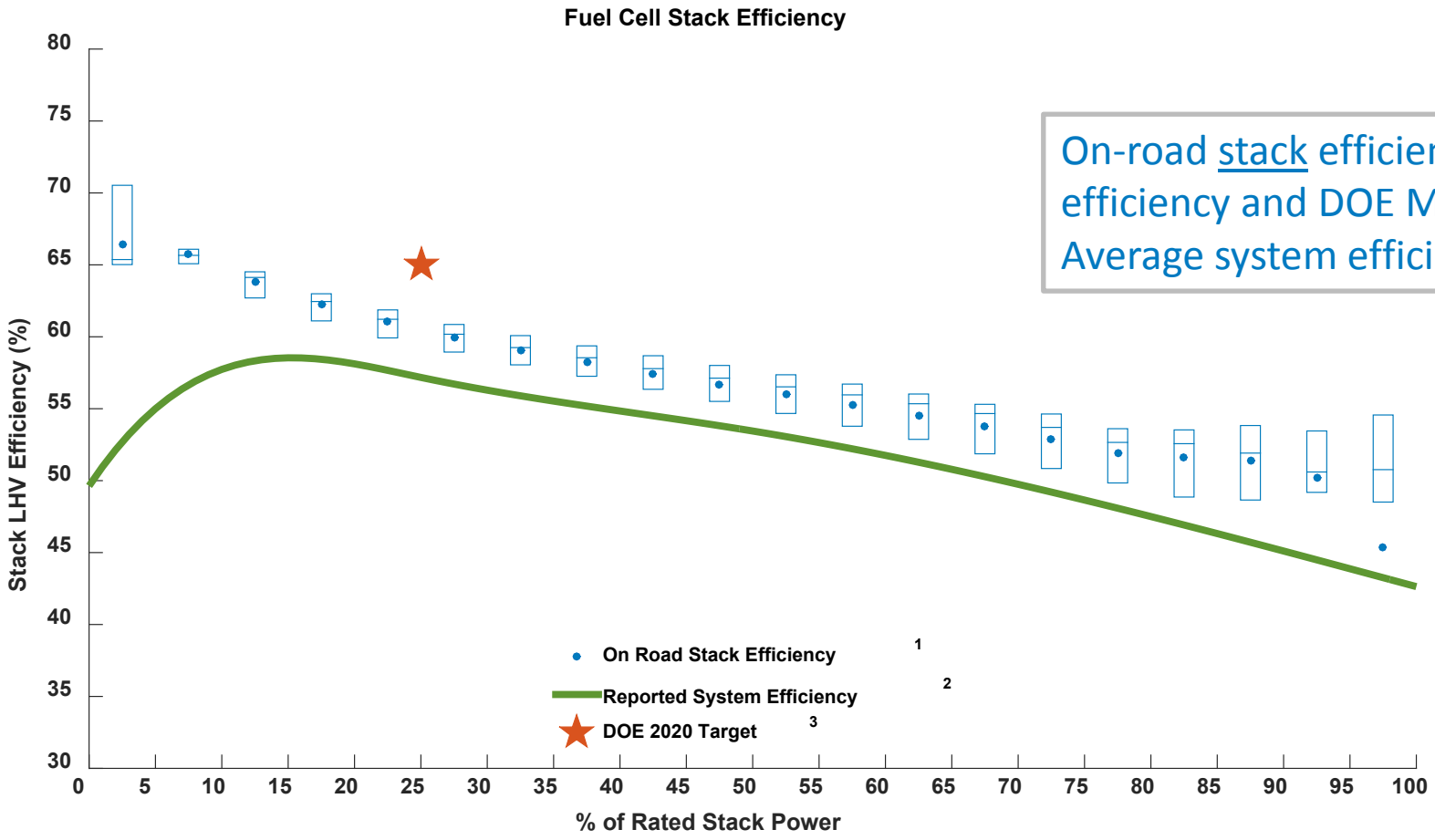
Technical Back-Up Slides

On-Road Fuel Cell Stack Efficiency

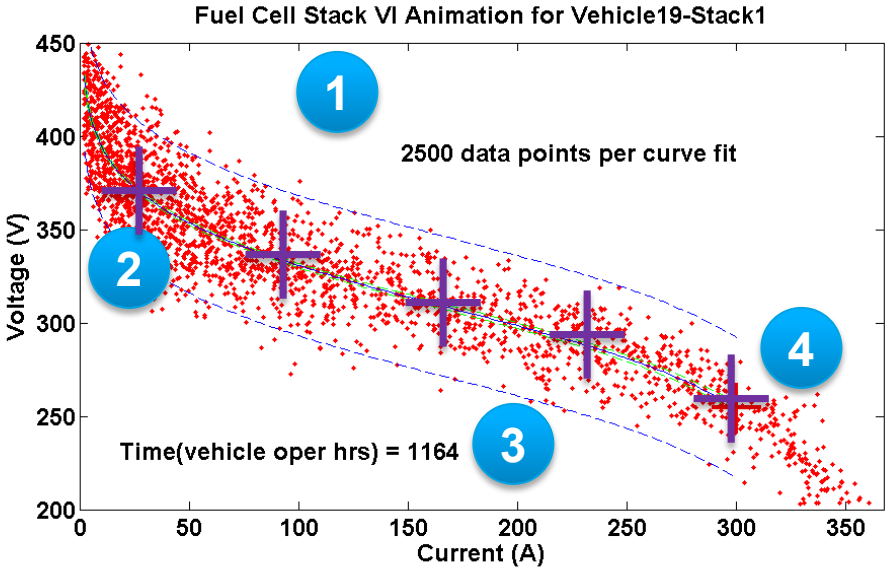


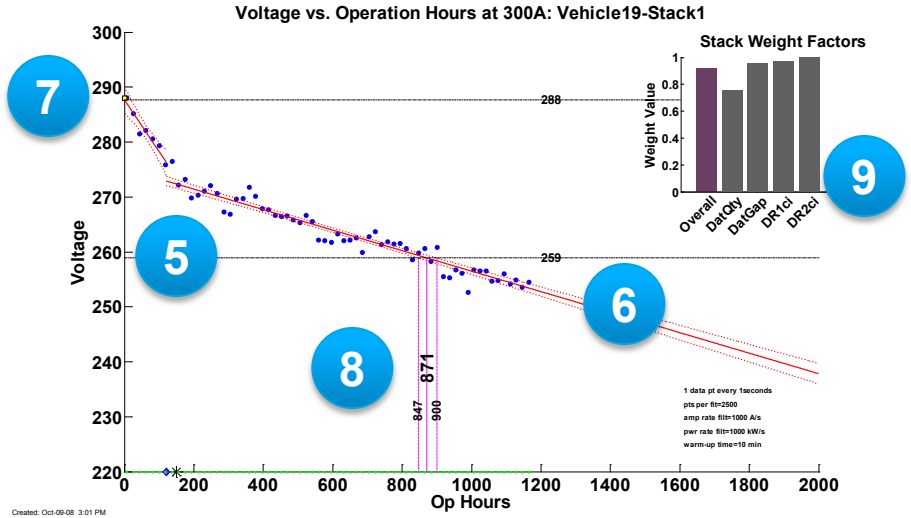
On-road stack efficiency compared with dyno system efficiency and DOE MYRDD 2020 Stack Target (65%). Average system efficiency at 25% power is 57%.

Voltage Degradation Analysis Approach

Analysis – EXAMPLE DATA

1. Voltage and current data
2. Apply polarization fit
3. Corresponding operation hour
4. Voltages from polarization fit at set currents
5. Fit voltage and operation data
6. Degradation linear fit
7. Y-intercept beginning of life voltage
8. Record operation hour when fit crosses 10% nominal voltage drop
9. Investigate fit quality





Key Analysis Topics

Critical

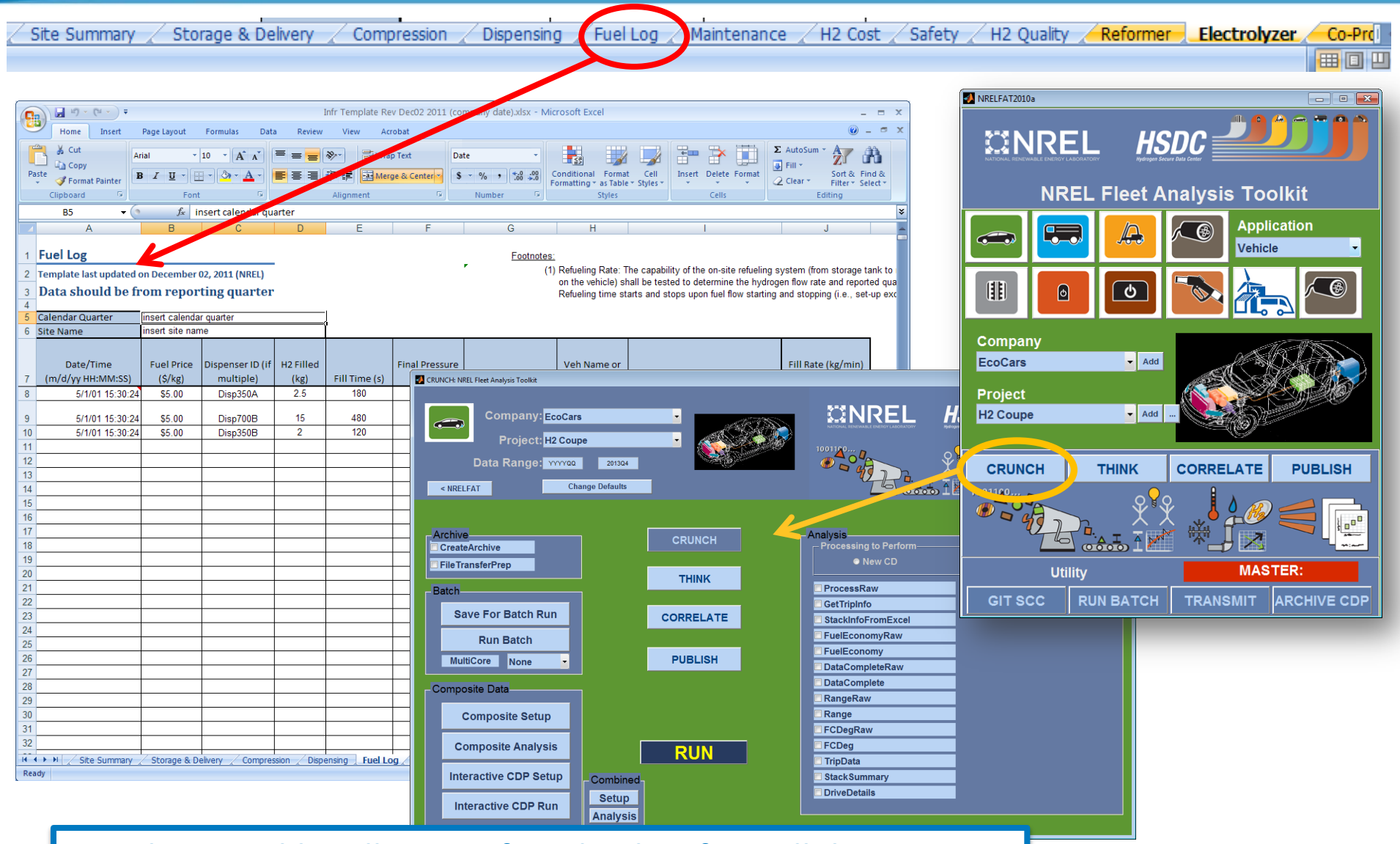
- Fuel cell durability
- Vehicle operation (hours, miles)
- Specs (power density, specific power)
- Range, fuel economy, and efficiency
- Fill performance
- Reliability

Important

- Drive behaviors
- Fill behaviors
- Power management
- Energy
- Transients
- Comparisons to conventional vehicles

These key topics were selected based on review of past CDPs, targets, most commonly referenced topics, and DOE feedback.

Data Templates and Tools



Templates enable collection of similar data from all the projects

Thank you!

www.nrel.gov