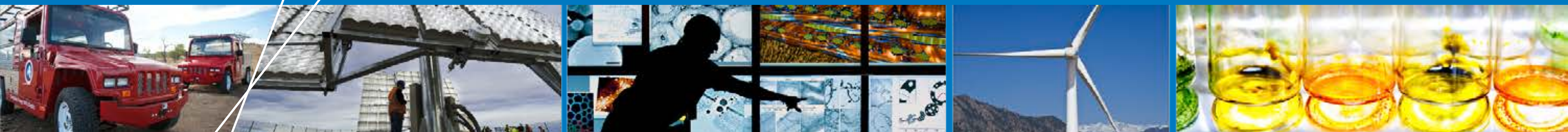
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Fuel Cell Electric Vehicle (FCEV) Evaluation



Jennifer Kurtz (PI), **Sam Sprik, Chris Ainscough, and Genevieve Saur**

December 15, 2015
Interagency Working Group Meeting
Washington, D.C.
Webinar

NREL/PR-5400-66609

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Sustainable Transportation Vision

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

- Reduction of greenhouse gas 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

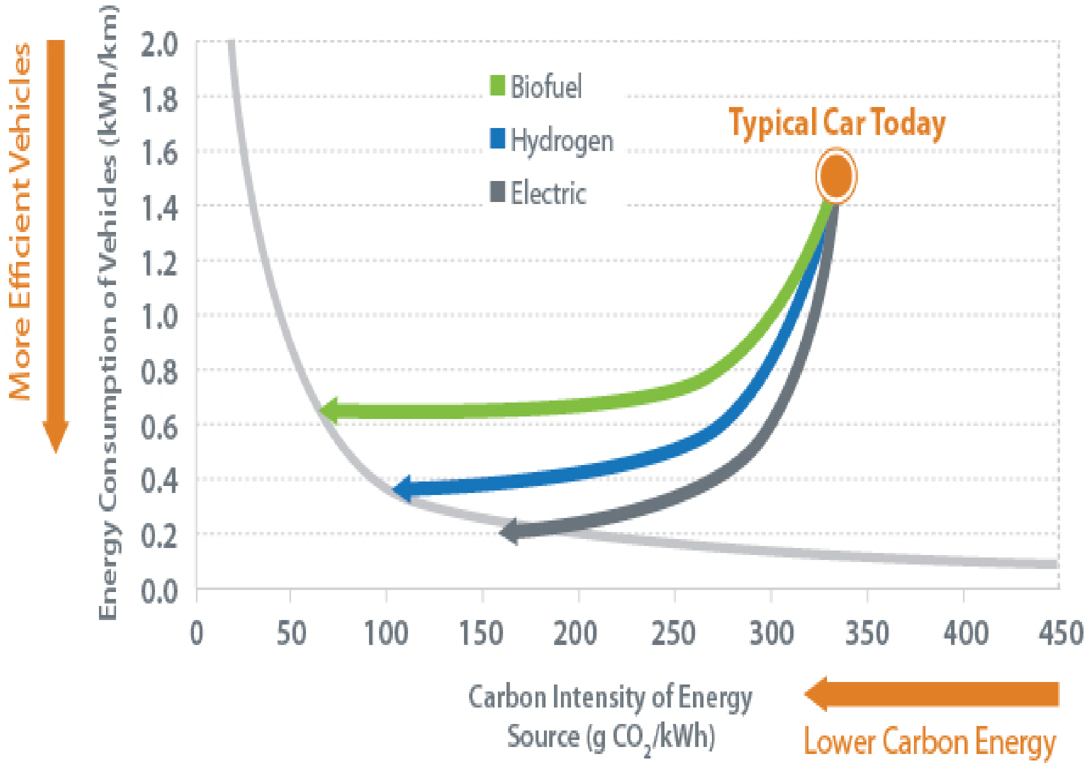


Figure by NREL

Why Hydrogen Fuel Cell Electric Vehicles

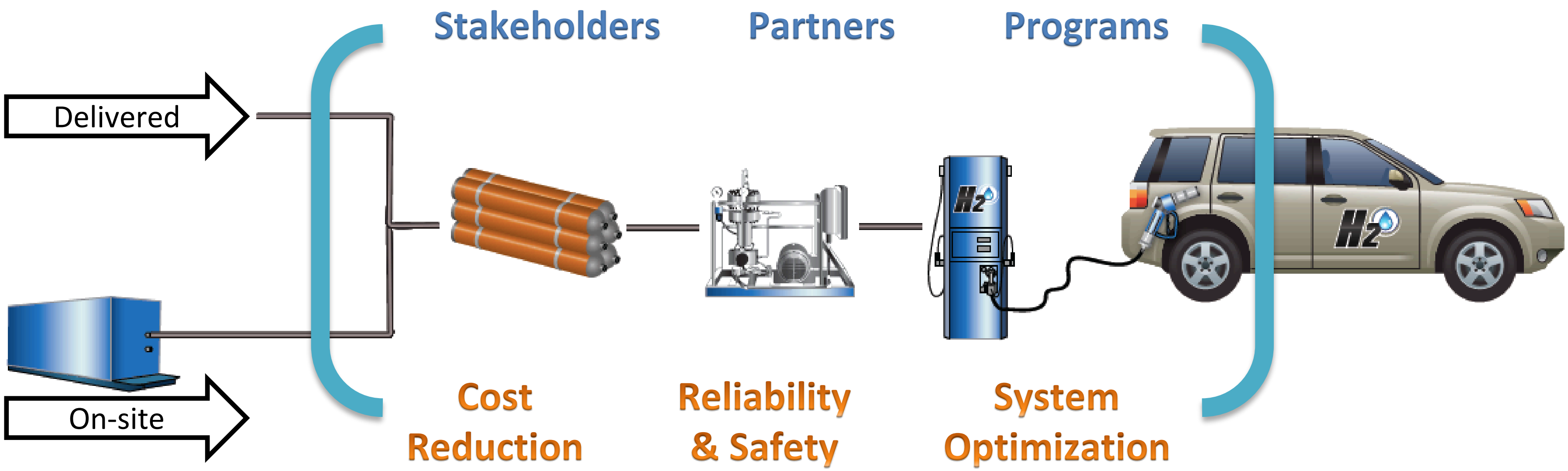
Hydrogen FCEVs are clean, efficient, refuel quickly, and provide long driving range

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

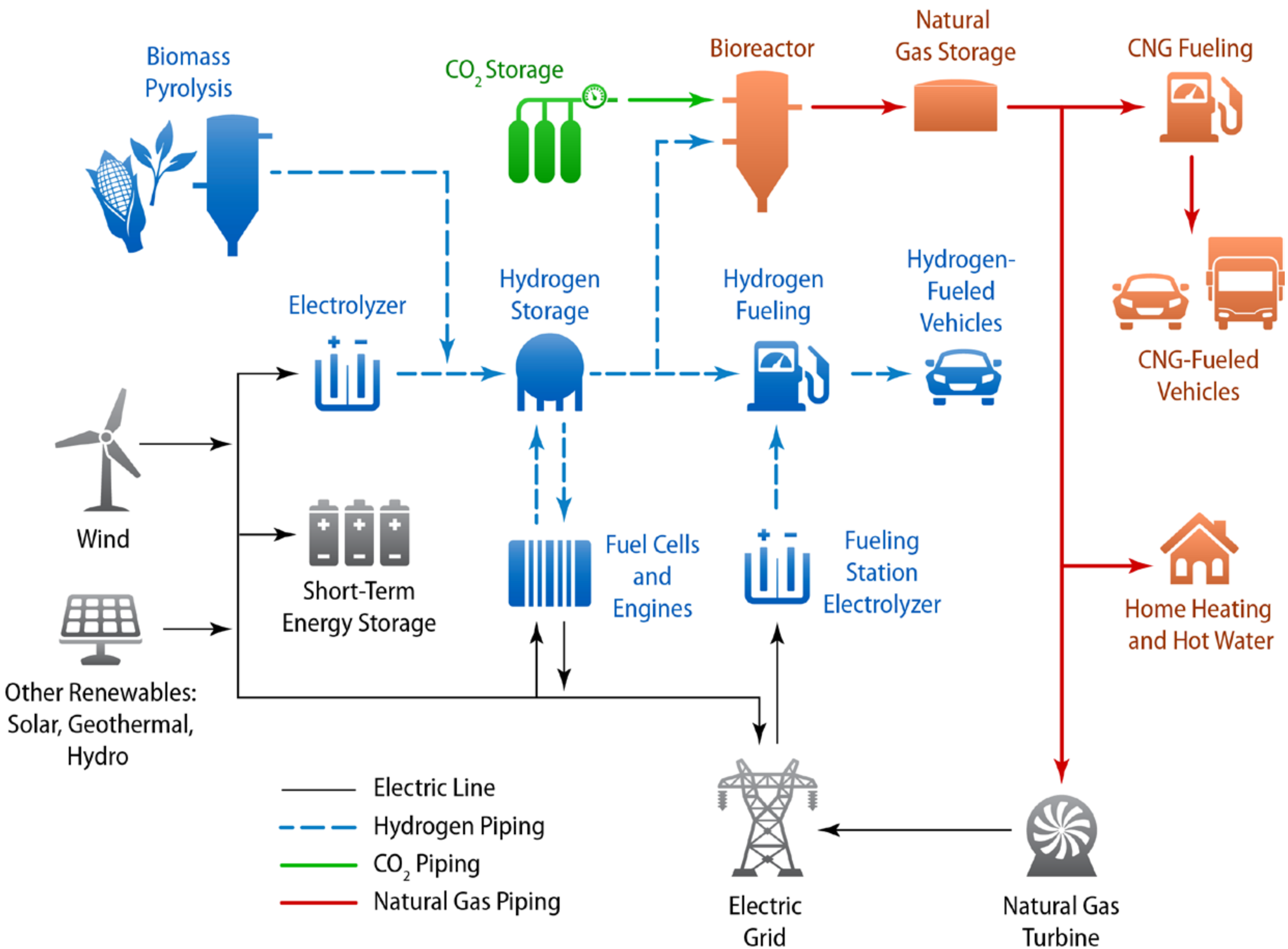
The Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) Project

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.



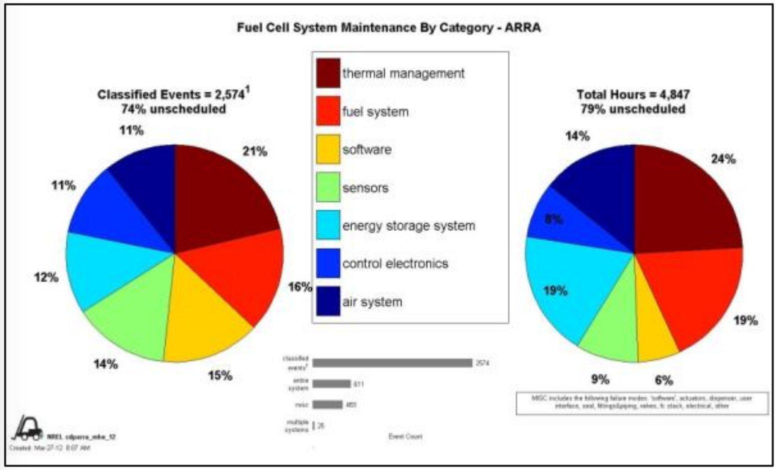
Renewable Hydrogen

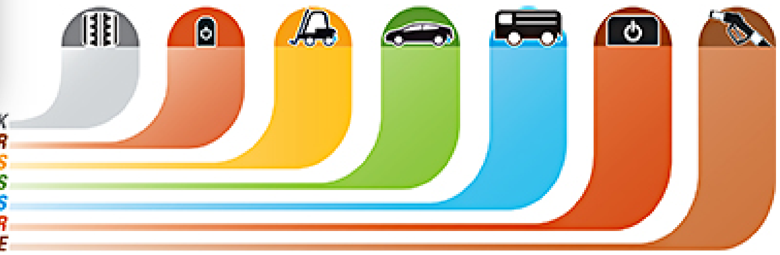


Hydrogen and Fuel Cell Technology Validation at NREL

Confirmation of component and system technical targets in real-world settings

Evaluation, optimization, and demonstration in integrated energy systems



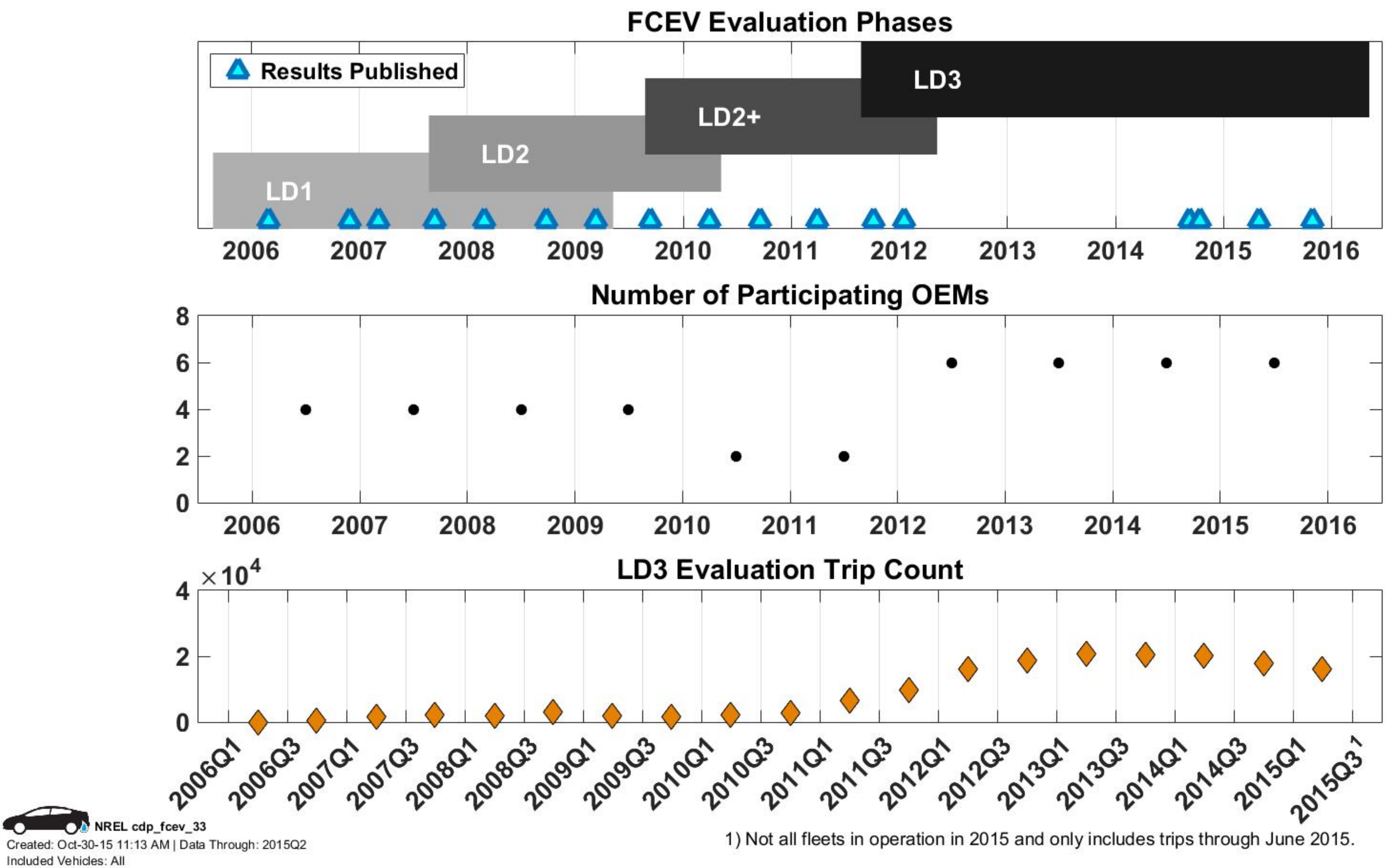


Key Analysis Topics

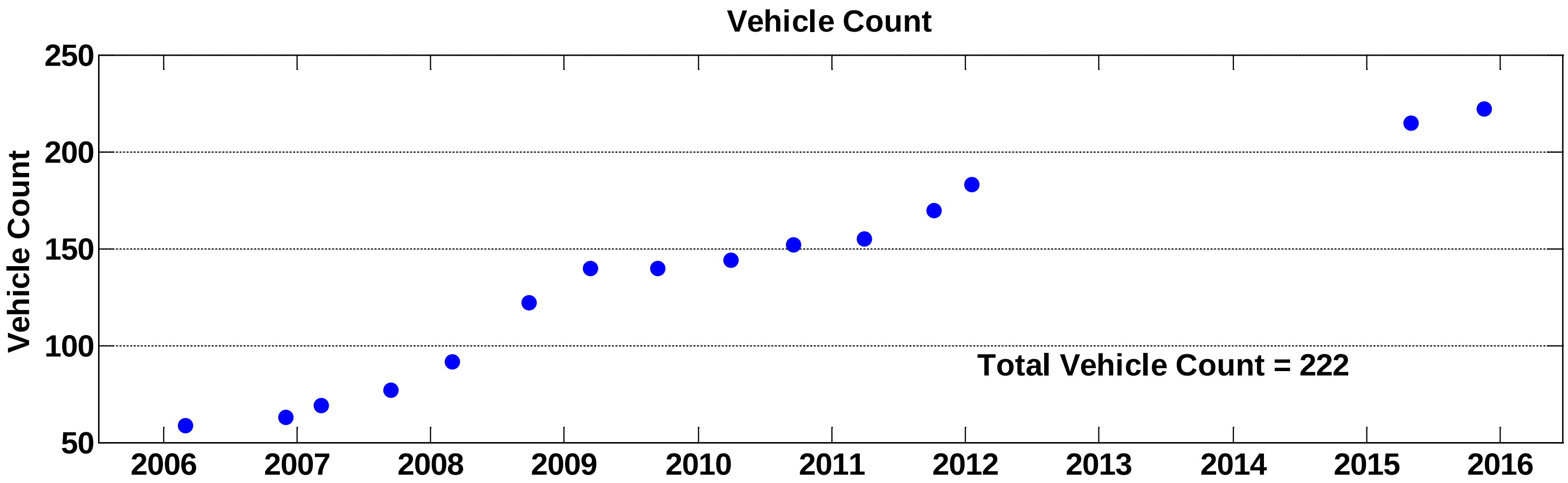
Critical	*Important*
• Fuel cell durability • Vehicle operation (hours, miles) • Specs (power density, specific power) • Range, fuel economy, and efficiency • Fill performance • Reliability	• Drive behaviors • Fill behaviors • Power management • Energy • Transients • Comparisons to conventional vehicles

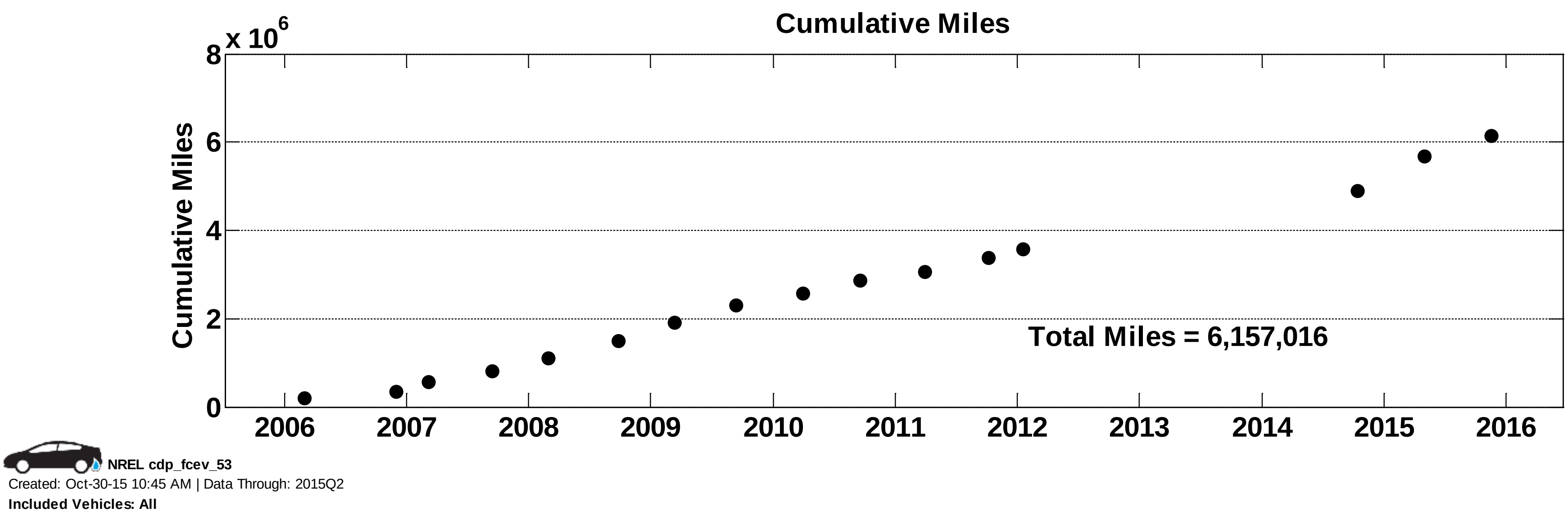
These key topics were selected based on review of past composite data products, targets, most commonly referenced topics, and DOE feedback.

FCEV Technology Validation Phases



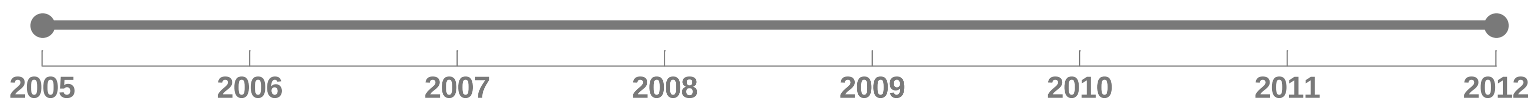
FCEV Technology Validation Phases





FCEV Data Partners and Vehicles

Range of FCEV Model Years

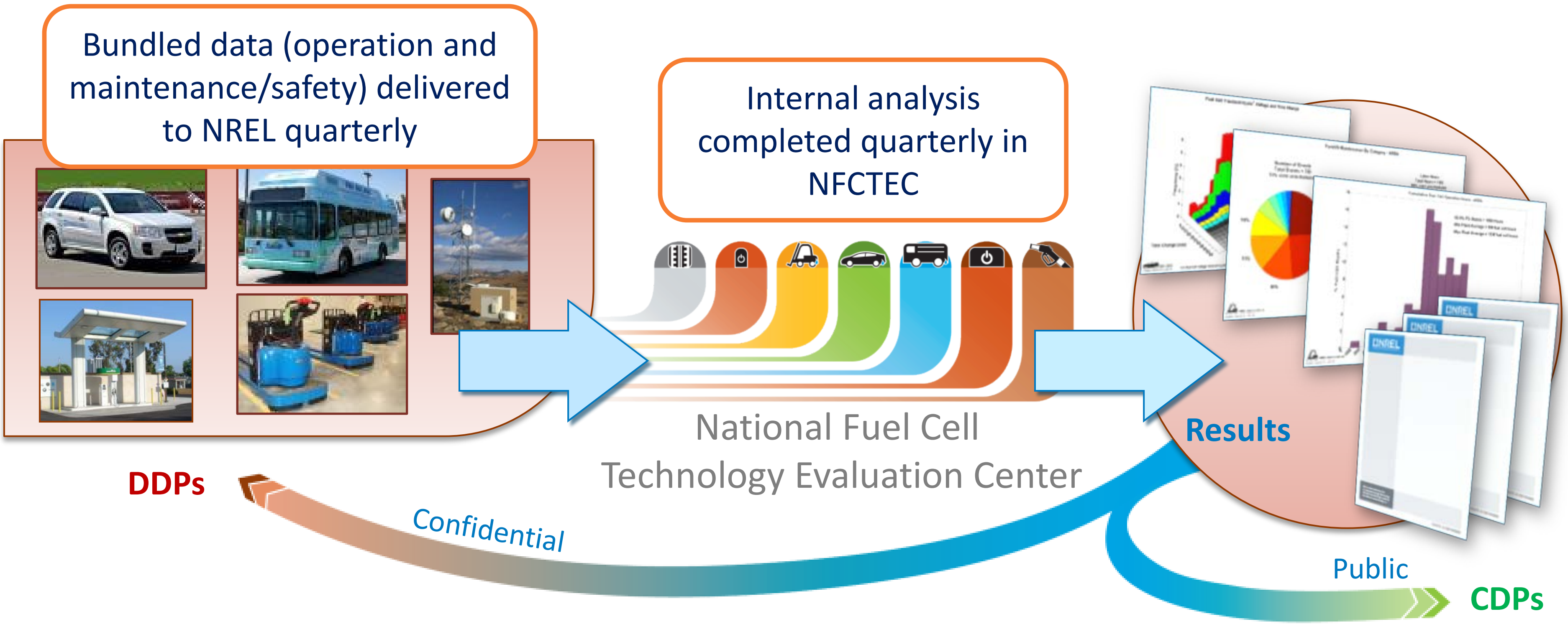


[1]DOE project overview:

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

[2]Project managed by Electricore
Award completed

NFCTEC Analysis and Reporting of Real-World Operation Data



Detailed Data Products (DDPs)

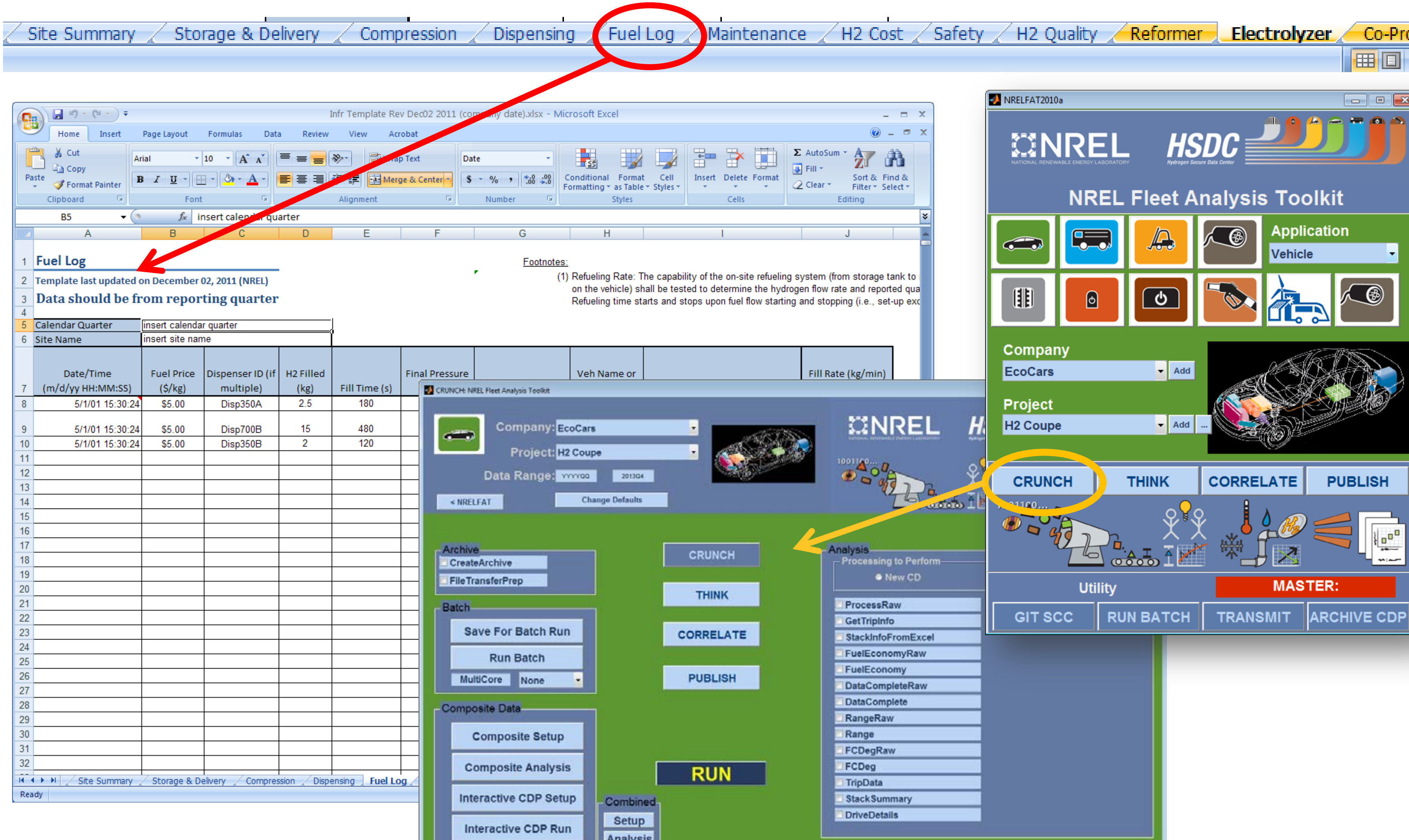
- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data

Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publish analysis results every six months without revealing proprietary data

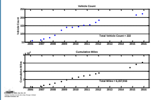
www.nrel.gov/hydrogen/proj_tech_validation.html

Data Templates and Tools



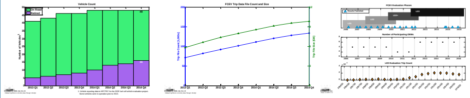
Templates enable collection of similar data from all the projects

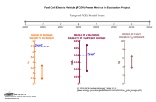
53 FCEV CDPs—Count and Category (Data through 6/2015)



Deployment

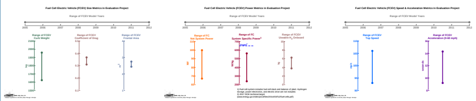
(# 01, 10, 33, 53)





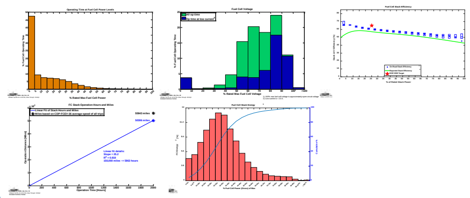
Specifications

(#11, 12, 13, 48)



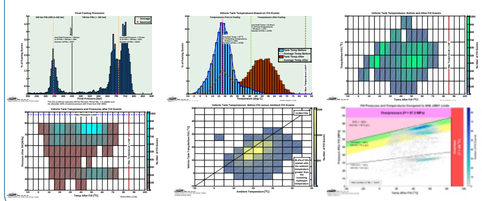
Fuel Cell Operation

(# 24, 40, 45, 51, 52)



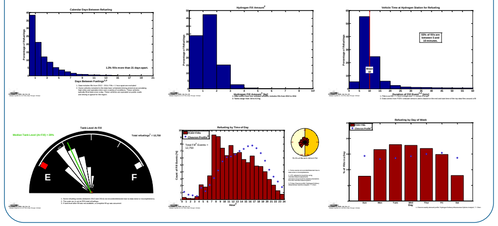
H2 Performance

(# 25, 28, 29, 30, 46, 49)



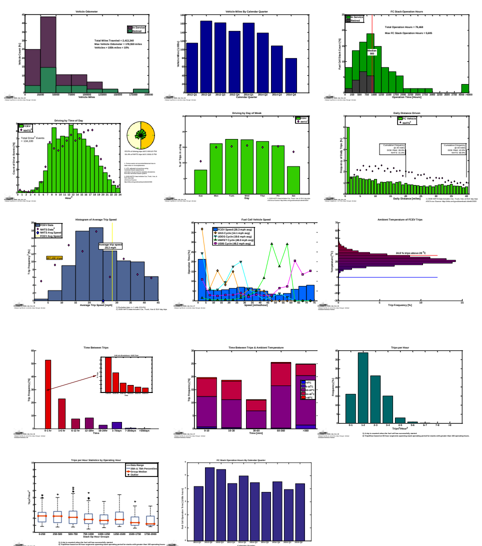
Fueling

(# 6, 8, 9, 15, 16, 17)



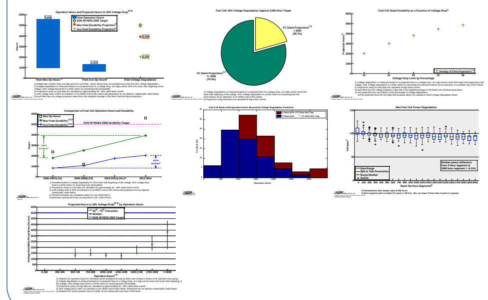
Driving

(# 2, 3, 4, 5, 18, 19, 20, 26, 27, 35, 36, 37, 38, 39)



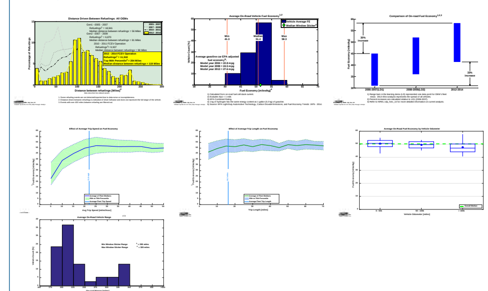
Fuel Cell Durability

(# 21, 22, 23, 31, 34, 43, 50)



Fuel Economy and Range

(# 7, 14, 32, 41, 42, 44, 47)



Results are not all presented here but are available online at www.nrel.gov/hydrogen/proj_tech_validation.html

FCEV Deployment and Operation
Summary in Evaluation Project through 2015CYQ2

55
FCEVs

50
Average on-road
fuel economy miles/kg

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

22
FCEVs retired

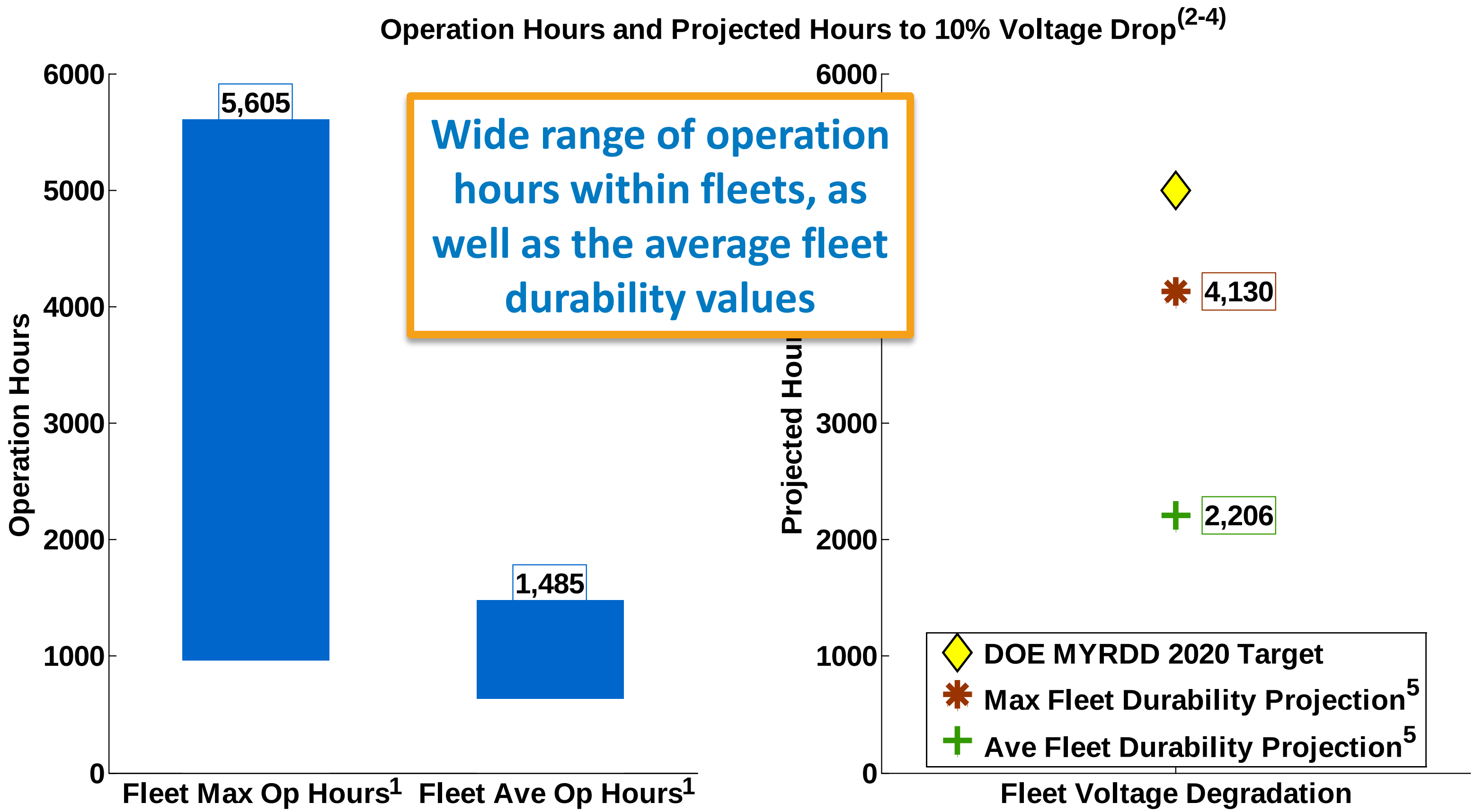
> 2,890,000
miles traveled

> 178,000
Max FCEV odometer miles

> 95,700
Fuel cell
operation hours

5,600
Max fuel cell
operation hours

FCEV Operation Hours and Durability



1) Range bars created using one data point for each fleet. Some stacks have accumulated hours beyond 10% voltage degradation.
2) Voltage degradation is measured based on a projected time to a voltage drop, at a high current, level 10% lower than beginning of life voltage. 10% voltage drop level is a DOE metric for assessing fuel cell durability.
3) Projections using on-road data are calculated at approximately 55 - 65% rated stack current.
4) 10% voltage drop is NOT an indication of an OEM's end-of-life criteria and projections do not address catastrophic stack failure.
5) Each fleet has one voltage projection value that is the weighted average of the fleet's fuel cell stack projections.

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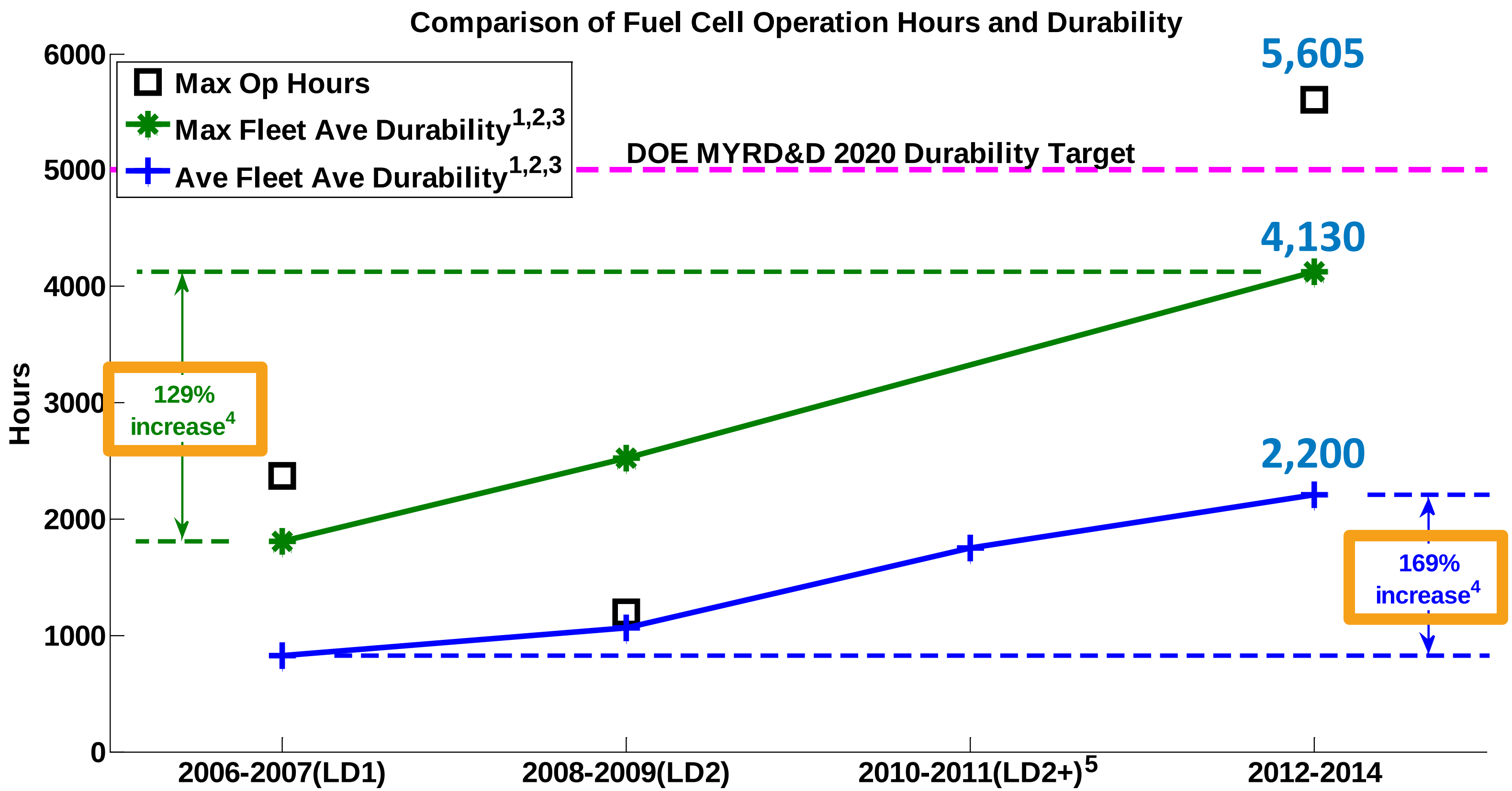
FCEV operation hours and durability projections to 10% voltage degradation. Each fleet has a max and average fuel cell operation hours value and a weighted average hours to 10% voltage degradation.

FCEV Durability Trend



1) Durability based on voltage degradation to 10% lower than beginning of life voltage. 10% voltage drop level is a DOE metric for assessing fuel cell durability.
2) Projections using on-road data are calculated at approximately 55 - 65% rated stack current.
3) 10% voltage drop is NOT an indication of an OEM's end-of-life criteria and projections do not address catastrophic stack failure.
4) Percent increases are calculated relative to LD1 (2006-2007).
5) Maximum operational hours not reported in LD2+ (2010-2011).

NREL cdp_fcev_31
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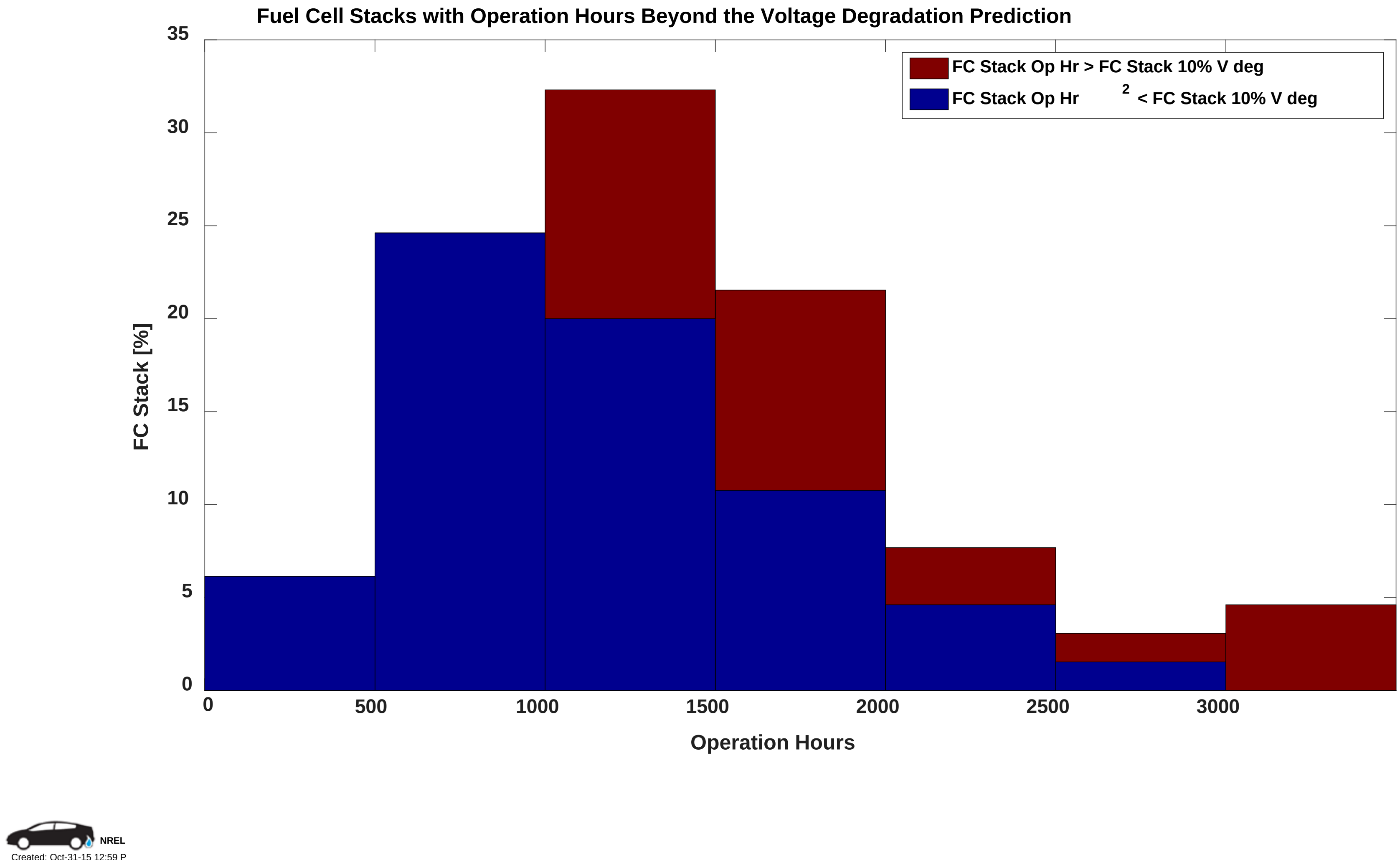
Included Vehicles: Partial

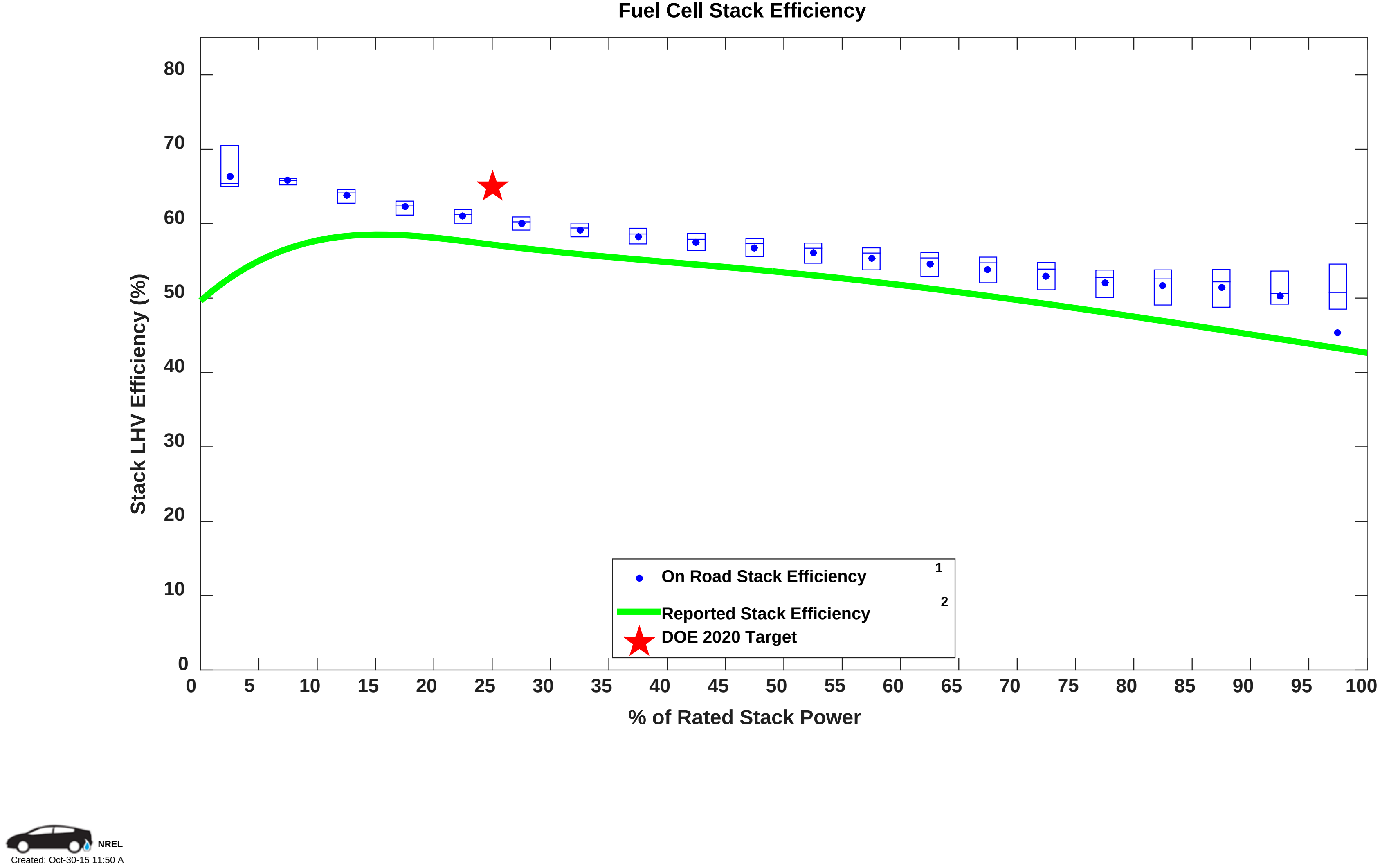
FCEV voltage durability has continually improved over time.

Fuel Cell Operation Hours with 10% Voltage Degradation Metric



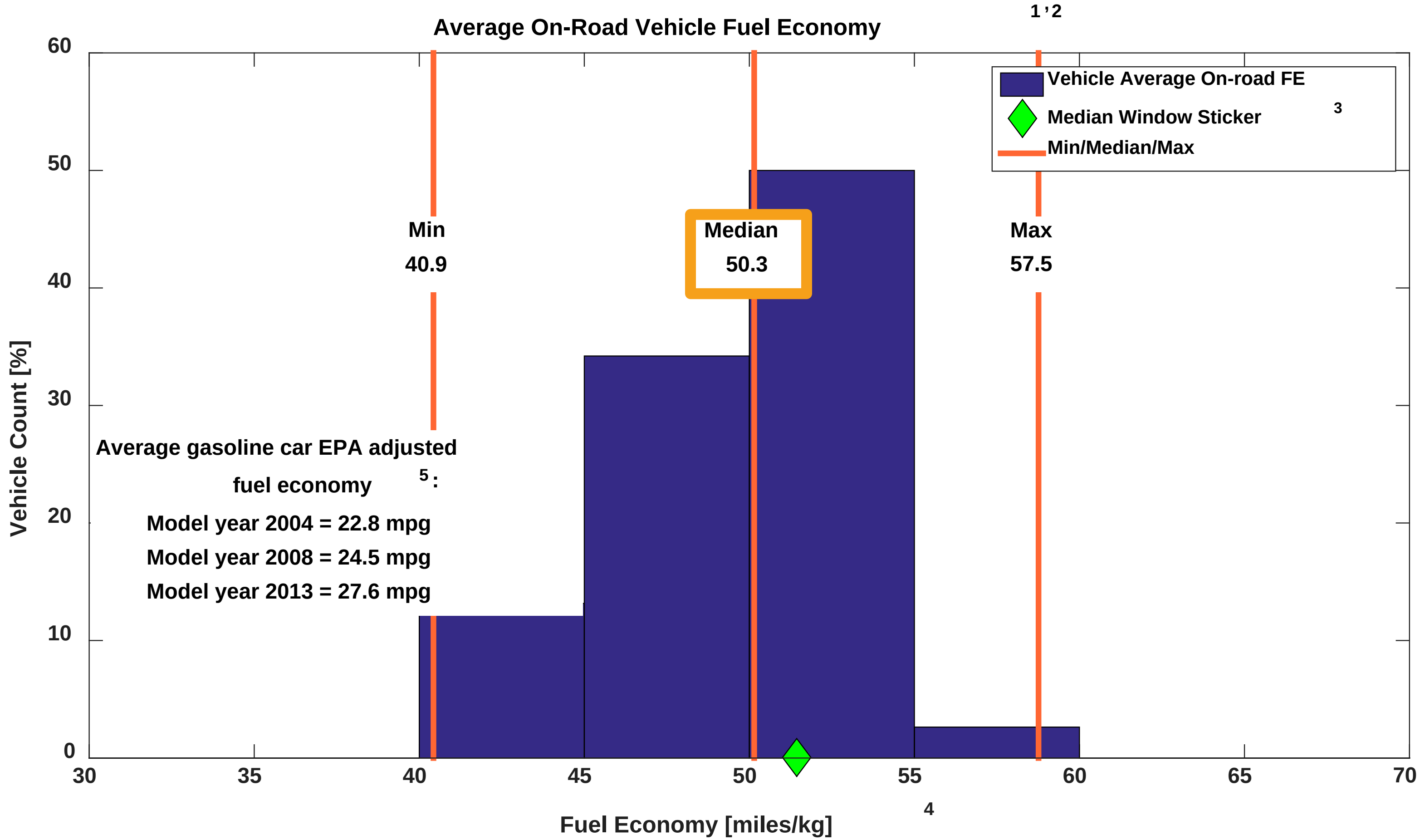
All fuel cell stacks with operation hours greater than 3,000 have more than 10% voltage degradation.

Fuel Cell Stack Efficiency at Power



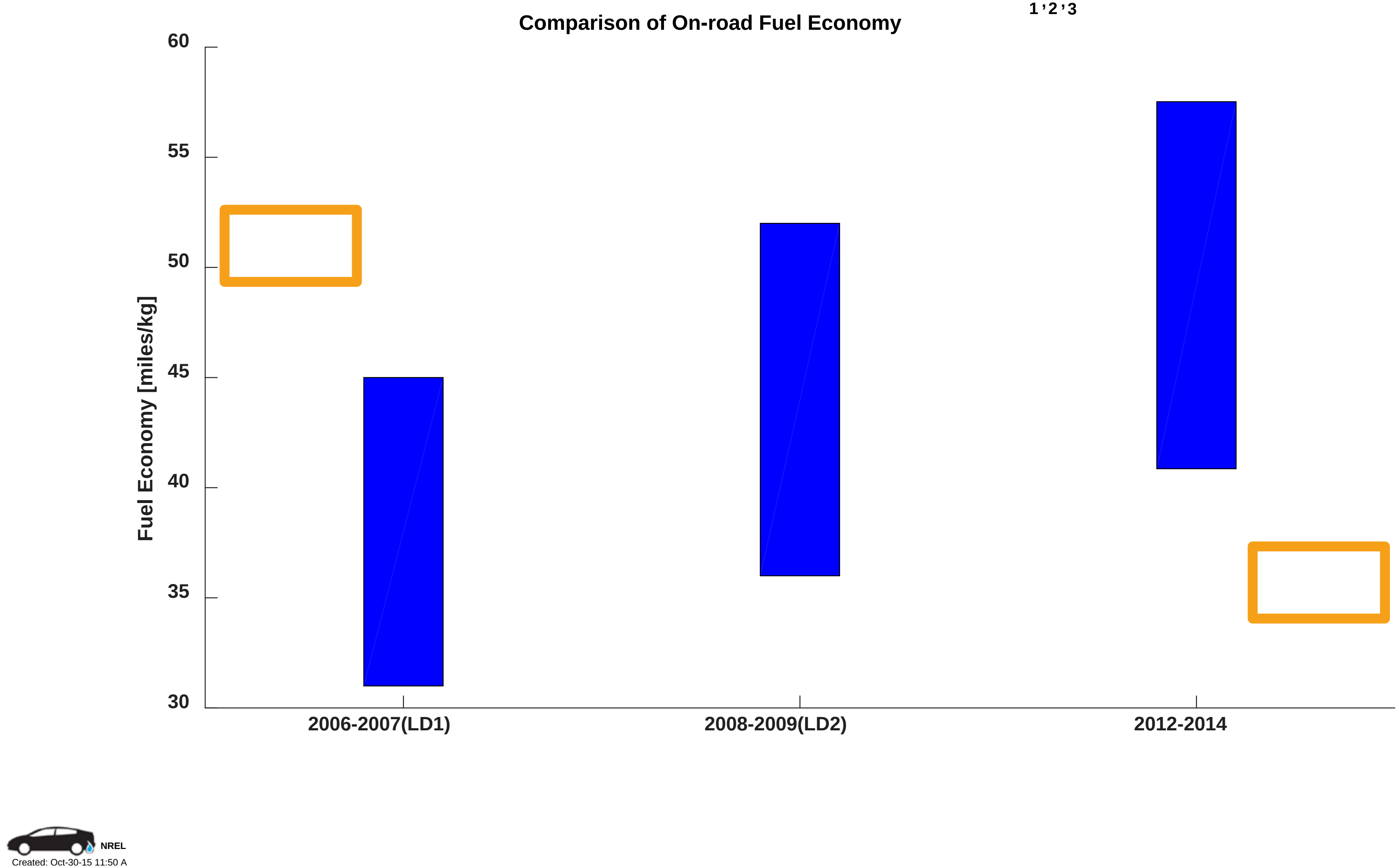
Fuel cell efficiency shown for stack and average (stack and balance of plant) of the fleets. Efficiency close to DOE 2020 target at 25% rated power.

On-Road Fuel Economy



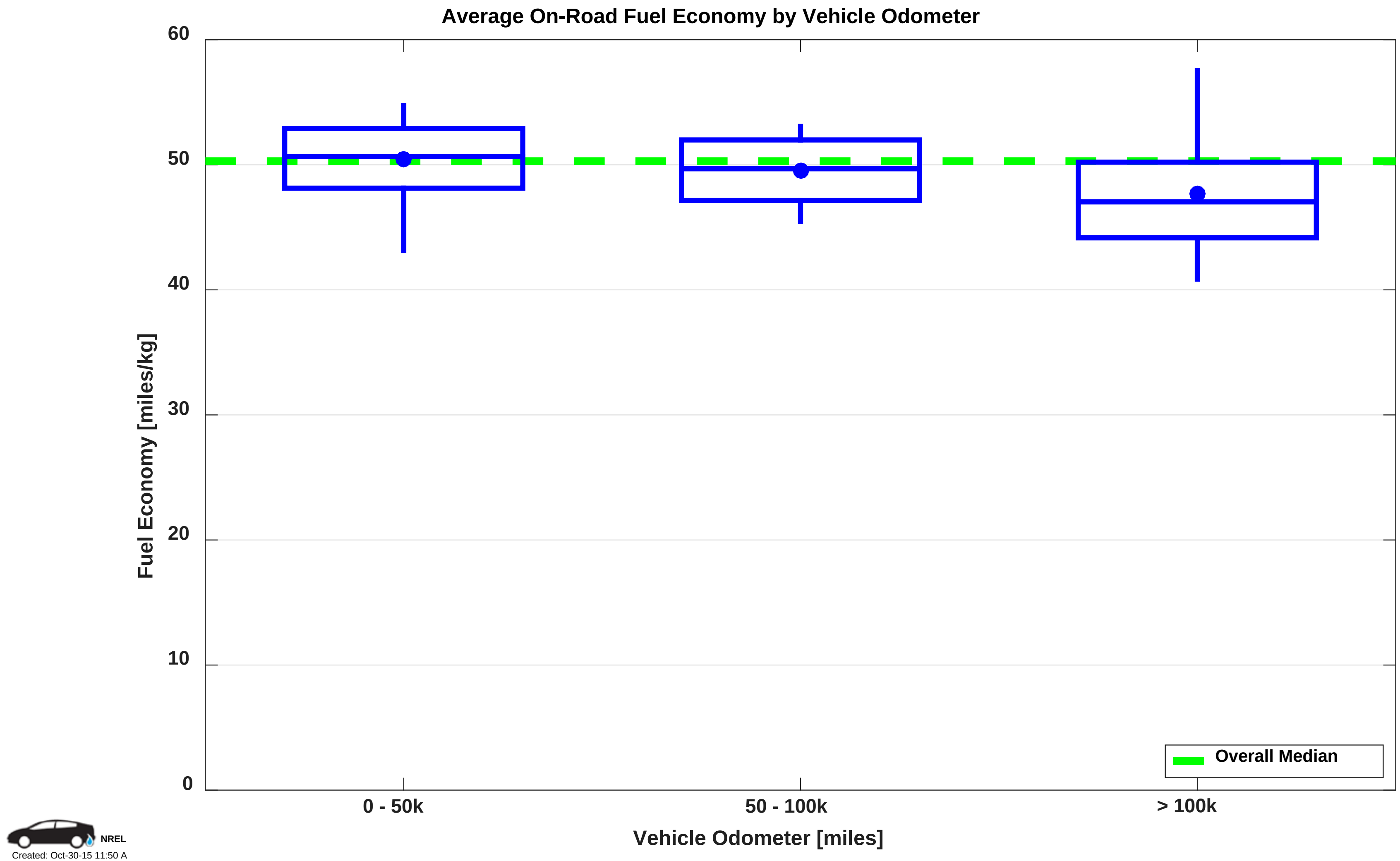
The median on-road vehicle fuel economy is ~50 miles per kg, nearly twice the 2013 EPA adjusted fuel economy for gasoline.

On-Road Fuel Economy Trends



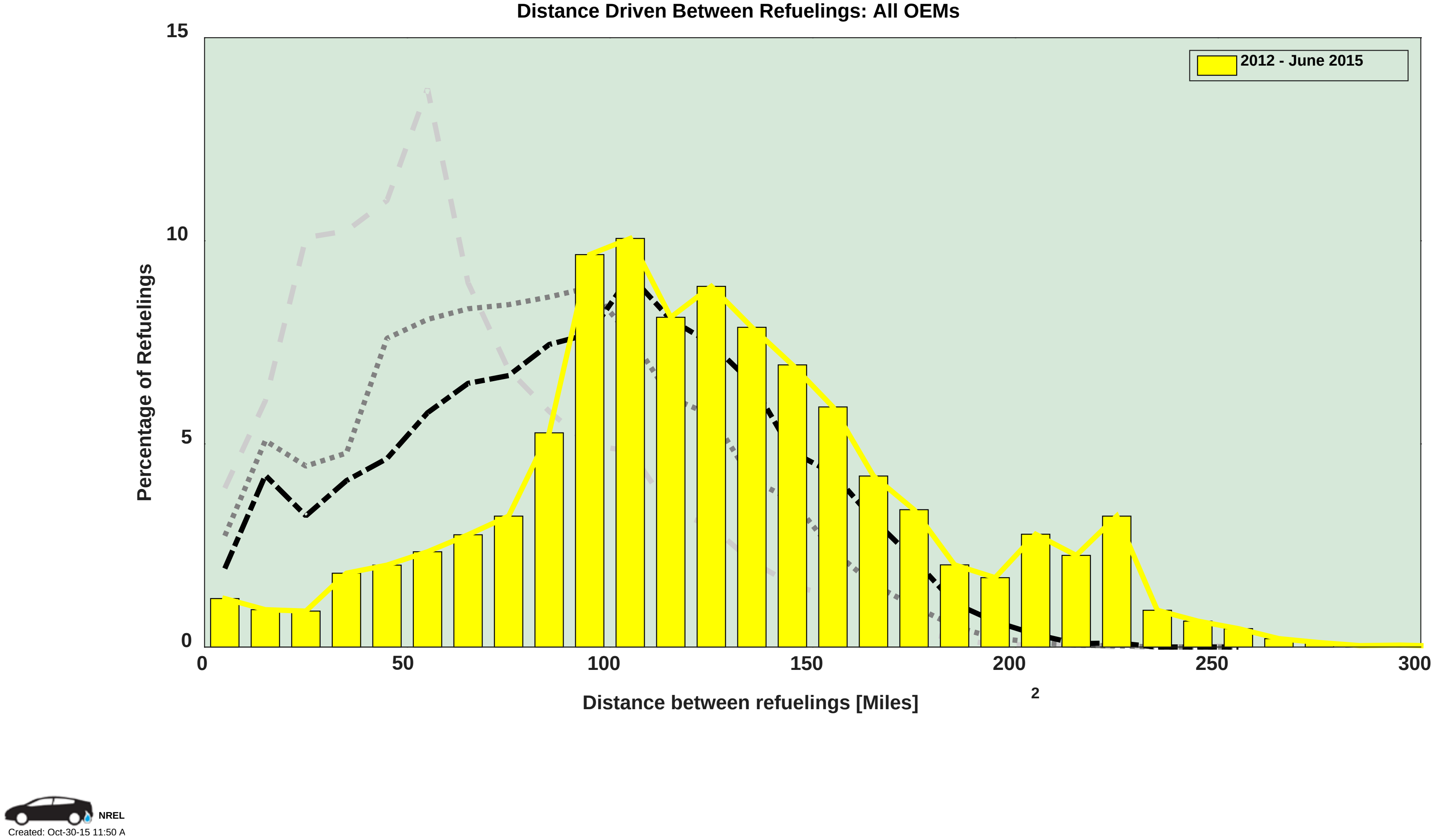
The on-road fuel economy has consistently increased over the last 10 years.

On-Road Fuel Economy By Vehicle Mileage



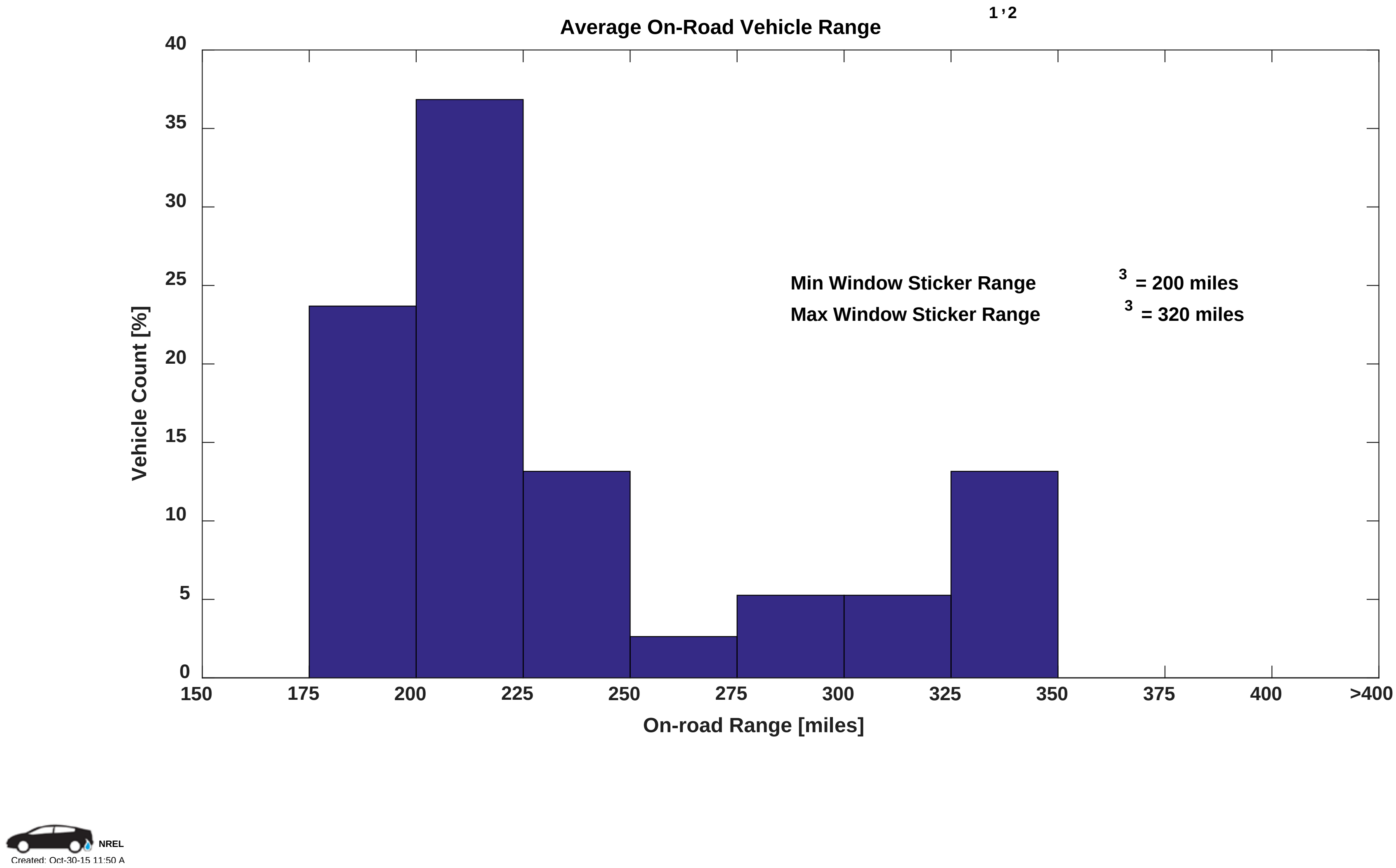
High mileage and low mileage vehicles have similar on-road fuel economy averages.

Accomplishment: Driving Distance between Refuelings



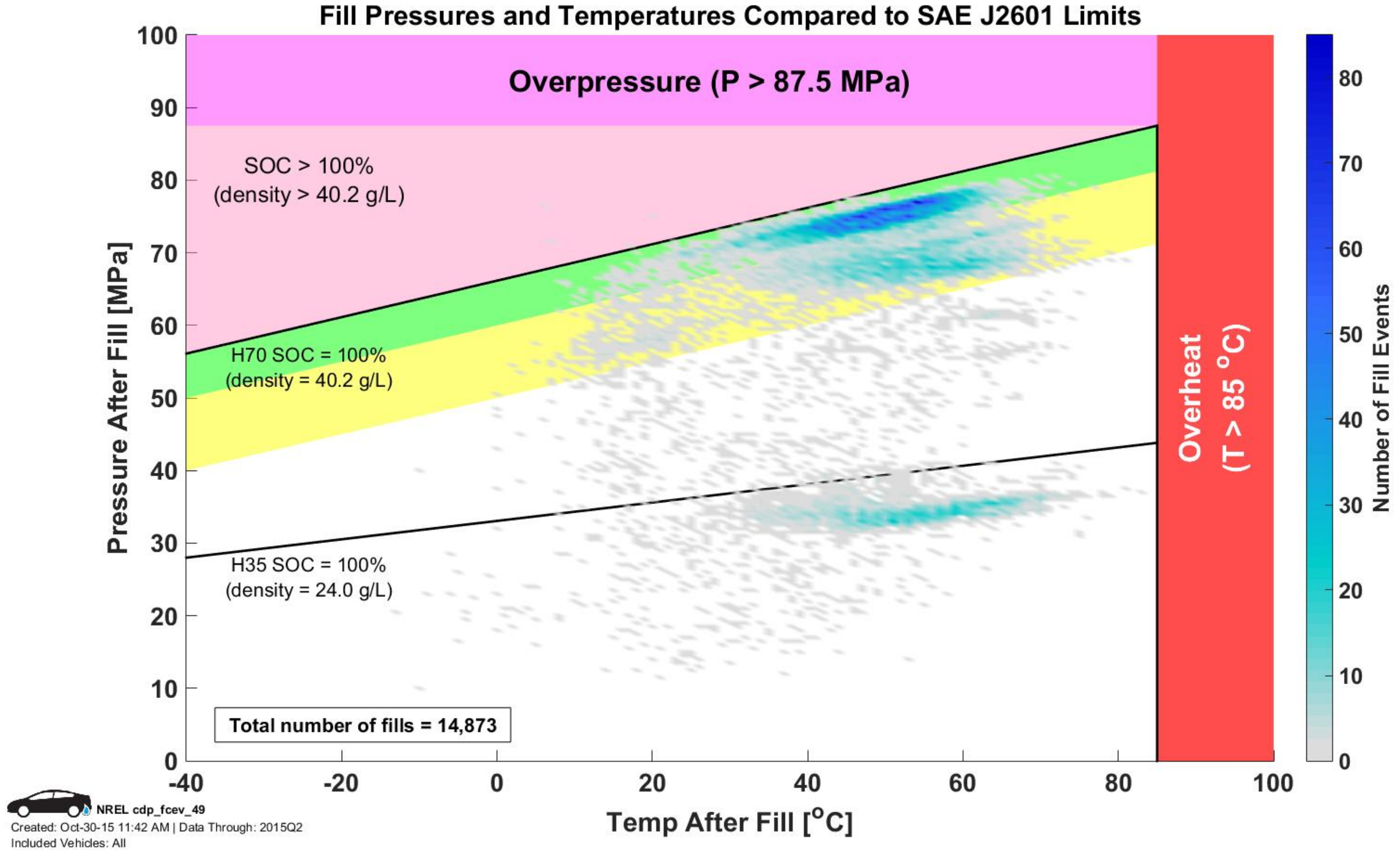
The median distance between refuelings is 122 miles. Distance is based on actual driving and not the full vehicle range.

Average On-Road Range per FCEV



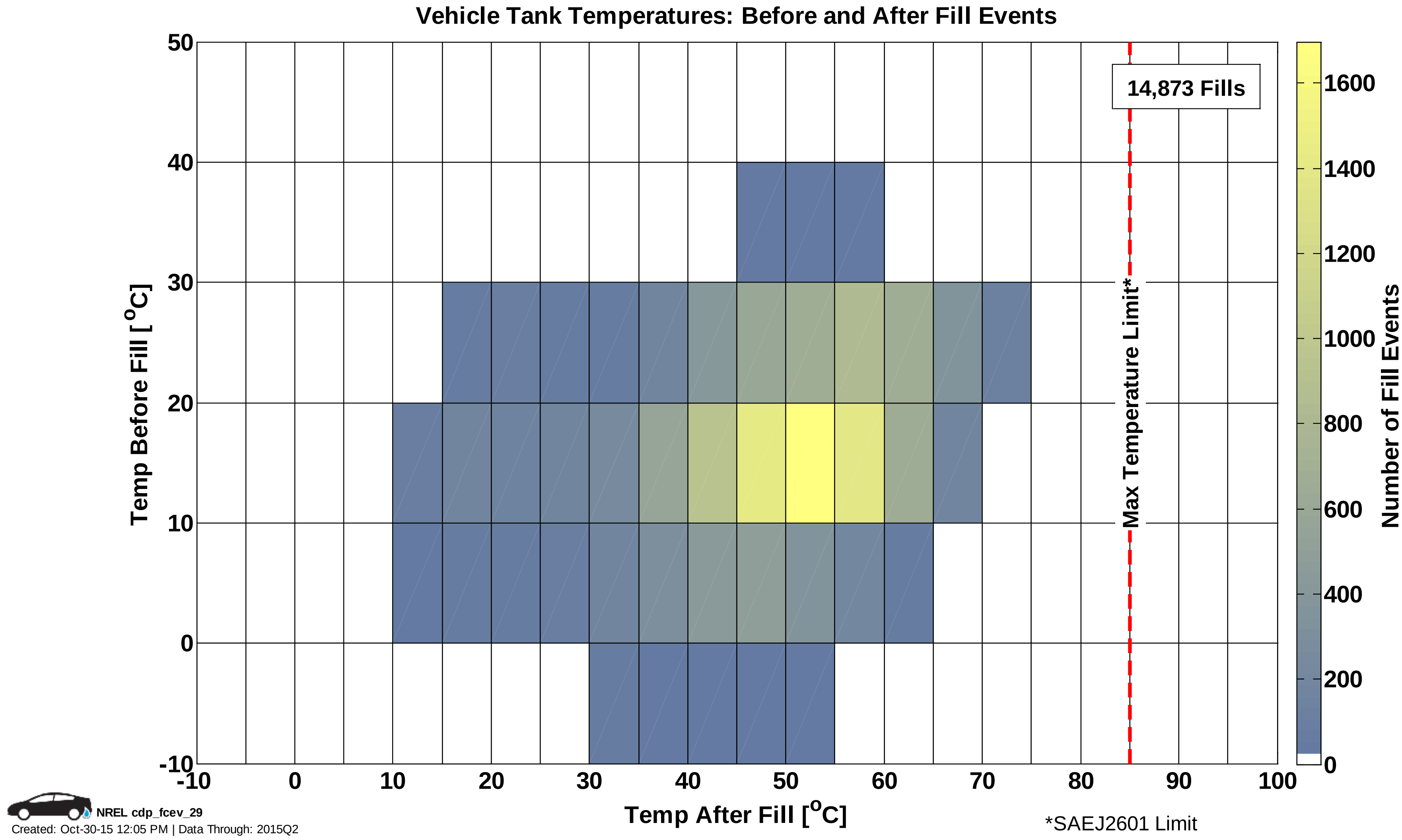
Wide range of min and max window sticker range 200–320 miles, includes different vehicle platforms and generations.

Fueling Pressures and Temperatures



All fills analyzed (>14,800) have followed the SAE J2601 guidelines for on-board tank pressure and temperature after fill.

On-Board Hydrogen Tank Temperatures



The tank temperature is typically 10°C to 20°C (approximately ambient) before a fill and 40°C to 65°C after a fill. The tank temperature after a fill has not exceeded 85°C.

Summary Status Against Technical Targets

	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	3,930	--	2,521	1,807
	Average Fuel Cell Durability Projection (hours)		2,032	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		122 miles	98 miles	81 miles	56 miles
	Fuel Economy (Window Sticker)		50 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)

Steady progress has been demonstrated over the four evaluation periods with FCEV technology improvements especially in key technical areas like fuel cell durability, range, and fuel economy.

Future Work

- **Regular analysis (once a quarter) and published results twice a year (as data is available)**
- **Future analysis topics include:**
    - Validation of technical targets for durability, fuel economy, range, reliability and safety, transient performance, power management and specifications, and refueling performance
    - Relationship between FCEVs and new stations coming online
    - Impacts of hydrogen demand increasing over time
    - Identify technology gaps and needs based on the on-road performance data
    - Define technology validation efforts as more and more FCEVs are commercial
- **Other research areas**
    - Infrastructure
    - Fleet operation, education, and outreach
    - Renewable hydrogen
    - Safety, codes, and standards

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