

Measuring CO₂ Emissions from LDVs: A View from the U.S.

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Historical Evolution of U.S. CO₂ Program

- EPA has measured CO₂ emissions since the early 1970s for determining fuel economy via “carbon balance”
- EPA has continually improved CO₂/fuel economy test cycles and methodology for projecting real world values
 - Biggest change was adoption of “5-cycle” approach in 2006
- EPA set US GHG emissions standards for light-duty vehicles in 2010 and 2012 for MY 2012-2025
 - Now undergoing Midterm Evaluation for MY 2022-2025
- EPA will periodically review and improve test cycles and methodology

Why Does U.S. Use Laboratory Tests?



U.S. Vehicle Testing Overview

EPA Grouping

10,000 vehicle “sub-configurations”
1000+ Model Type groupings
1000+ Test Vehicles

Automaker Prototype Testing

1000+ Test Vehicles (selected by EPA)
Coastdown inputs for chassis testing
1000+ laboratory chassis tests

Multi-faceted EPA Oversight

200+ confirmatory chassis tests at EPA lab
Audit coastdowns for production vehicles
Can test vehicles directly from assembly line
Data from manufacturer in-use program
Random on-road tests
Can order vehicle recalls

Five U.S. Chassis Dynamometer Test Cycles

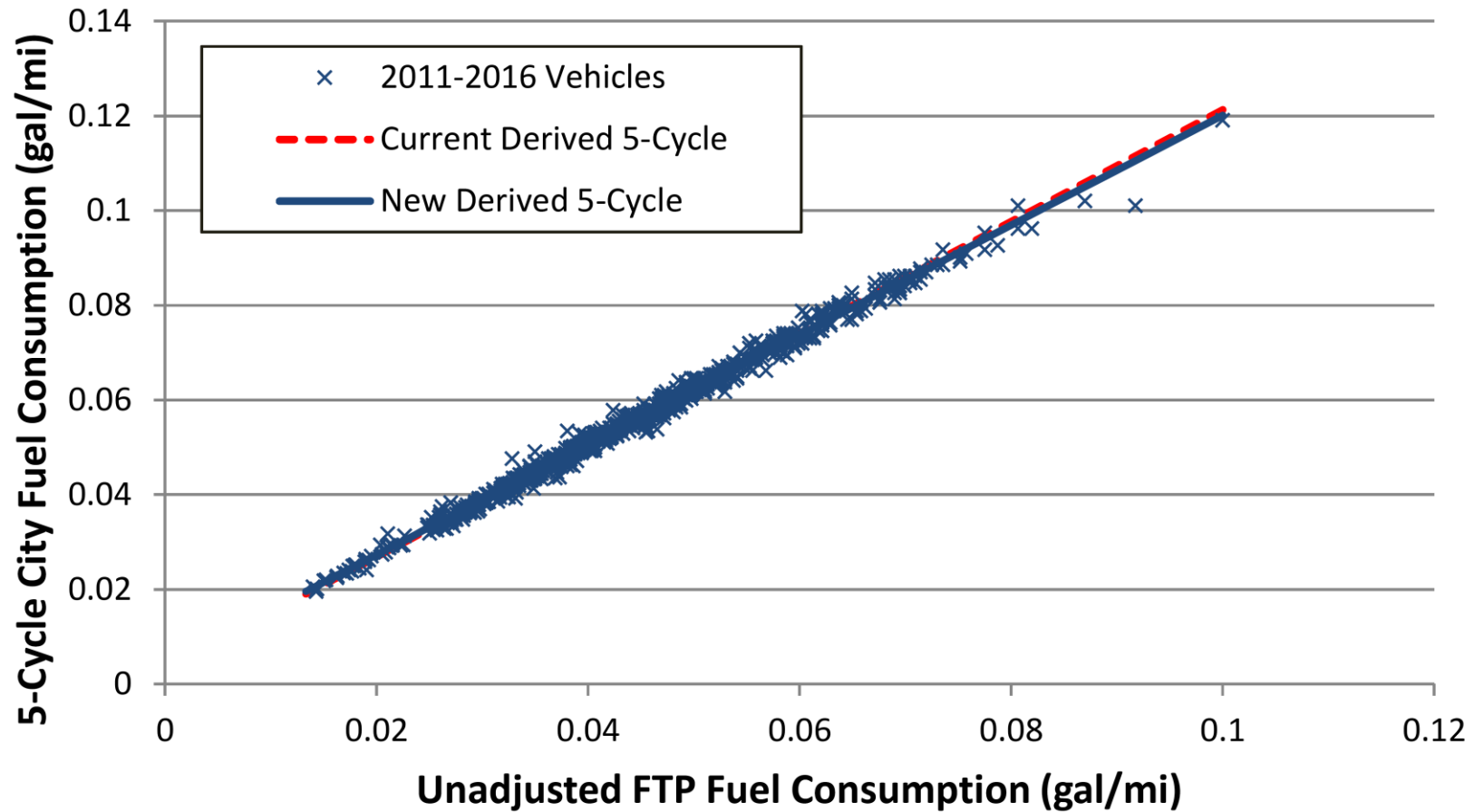
| | City (1970s) | Highway (1970s) | | High Speed Aggressive (2008) | Hot, Max A/C (2008) | Cold City (2008) |
|-------------------------|-----------------|--------------------|--|------------------------------------|---------------------------|------------------------|
| Maximum Speed | 57 mpg | 60 mph | | 80 mph | 55 mph | 57 mph |
| Maximum Acceleration | 3.3 mph/sec | 3.3 mph/sec | | 8.5 mph/sec | 5.1 mph/sec | 3.3 mph/sec |
| Temperature | 72 F | 72 F | | 72 F | 95 F | 20 F |
| A/C Use | Off | Off | | Off | On | Off |

2-Cycle vs 5-Cycle

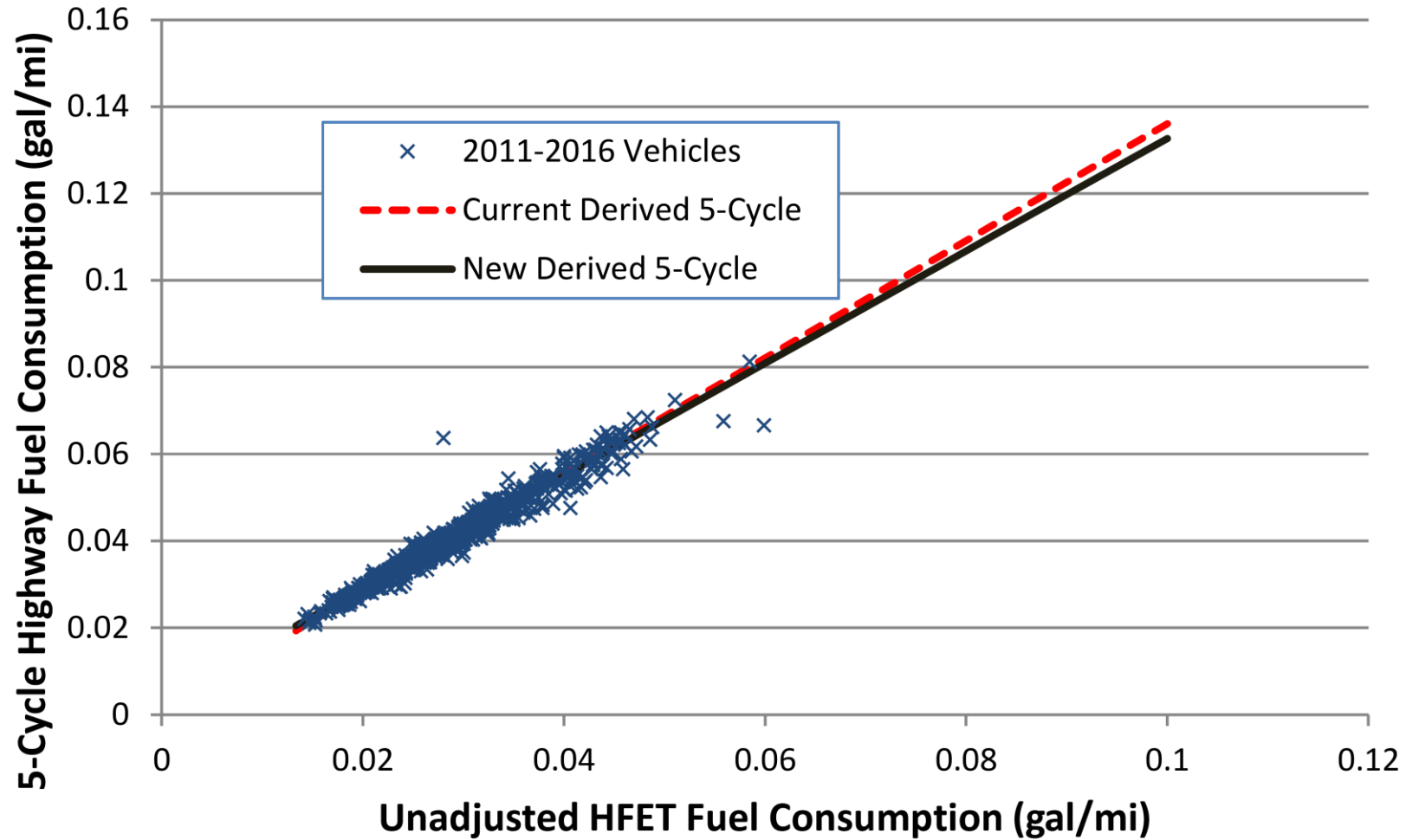
| | 2-Cycle Test Data | 5-Cycle Test Data |
|------------------------|---|---|
| Era | 1970s | 2000s |
| Original Purpose | HC/CO/NOx compliance CAFE compliance Fuel economy label | HC/CO/NOx compliance Fuel economy label Real world CO ₂ and fuel economy |
| Current Use | CO ₂ compliance CAFE compliance (by law) | Same as above |
| City/Highway Weighting | 55% city/45% highway | 43% city/57% highway |
| MY 2016 Fleetwide | About 278 g/mi About 32 mpg | About 355 g/mi About 25 mpg |
| MY 2025 Fleetwide* | About 163 g/mi About 54.5 mpg-e | About 222 g/mi About 40 mpg |

Relationship Between 2-Cycle and 5-Cycle

5-Cycle City vs. FTP Fuel Consumption



5-Cycle Highway vs. HFET Fuel Consumption

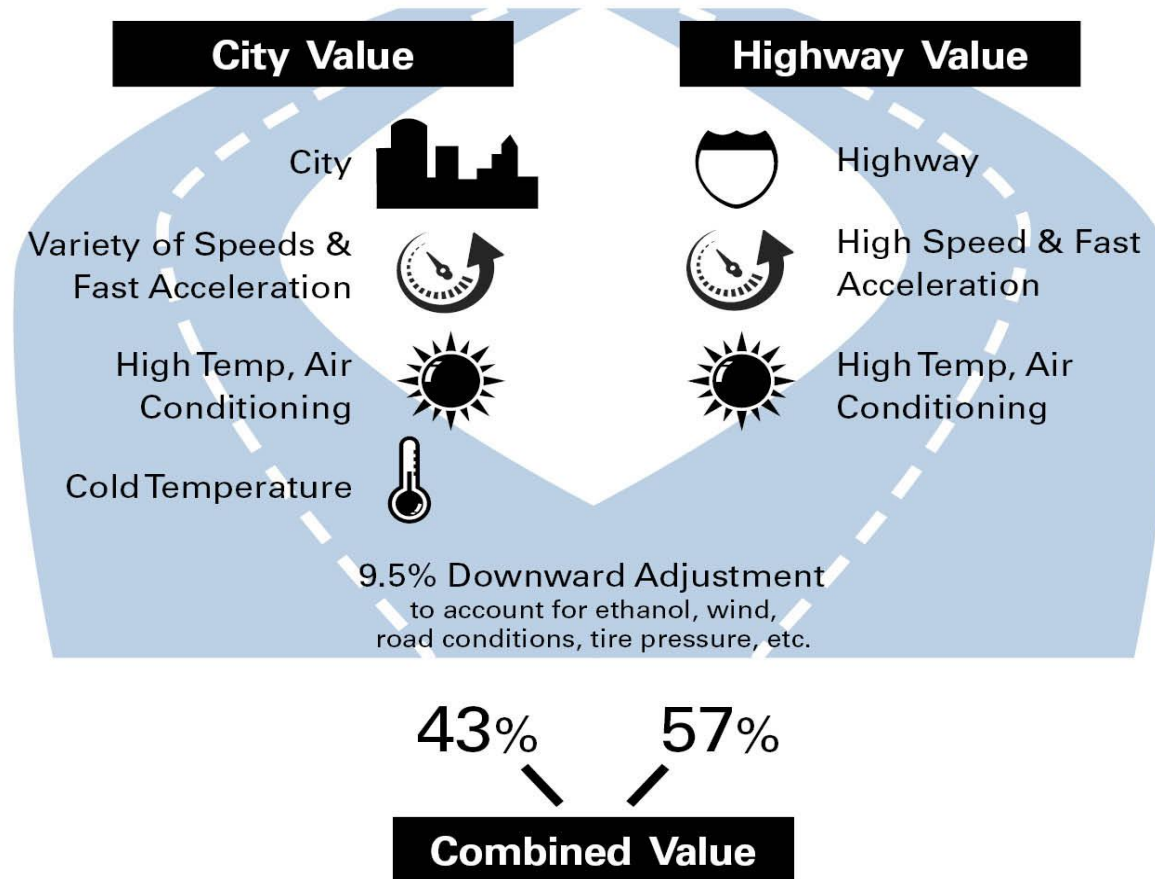


Relationship Between 5-Cycle and Real World

5-cycle Designed to Reflect Real World

- Added three new test cycles to capture the effect of much broader driver behavior and climatic conditions
- Analyzed real world driver activity data and ambient conditions to identify “national average”
- Equations use weighted data from the five test cycles so results are calibrated to the “national average”
- Also analyzed factors that are not reflected in our five cycles, and added a 9.5% downward adjustment factor to account for the “national average” impact

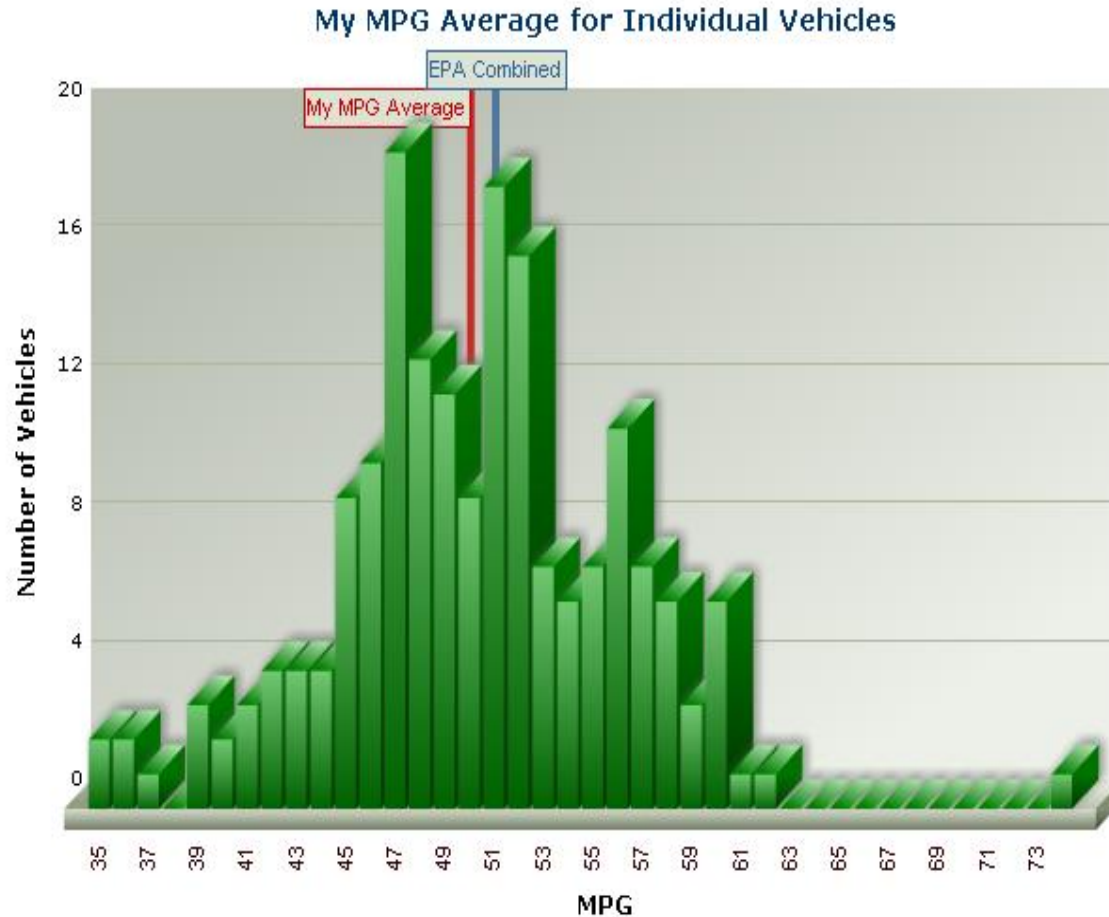
Calculating 5-cycle CO₂ Emissions Values



Challenges re Real World Emissions

- Every unique vehicle-driver-trip has its own real world emissions
 - Scores of factors can affect real world performance
- Unless we can access data from every driver, the best approach is to aim for the national average at a given point in time
- The real world is always changing
 - New powertrain technologies
 - More sophisticated electronic controls
 - Driver behavior
 - Fuel composition
 - Road conditions, traffic conditions...

U.S. Owner Data Variability for 2010 Prius



| | |
|----------------------------|--------------------|
| Number of Vehicles: | 187 |
| Range: | 35 - 74 MPG |
| Average User MPG: | 49.4 |
| Label MPG | 50 |

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CO₂ Data and U.S. GHG Standards

- 2-cycle data used for GHG standard-setting and compliance
 - Most engineering data on technology CO₂ effectiveness in 2010 and 2012 rulemakings were from 2-cycle tests (little 5-cycle data)
 - U.S. DOT, by law, must use 2-cycle for car CAFE standard
- But, all projected GHG emissions and fuel savings benefits are based on our 5-cycle methodology
 - We adjusted all 2-cycle CO₂ data by multiplying by 1.25, the average factor based on the 5-cycle methodology
 - Ethanol has slightly lower CO₂ per Joule, and this lowered the effective factor to about 1.24

Lessons Learned from the U.S. Experience

Critical Factors for Success

- Deep in-house technical expertise
- State-of-the-art laboratory
- Multi-faceted oversight and enforcement program
- Data transparency
- Willingness to assess large penalties, when necessary
- Commitment to continuous improvement