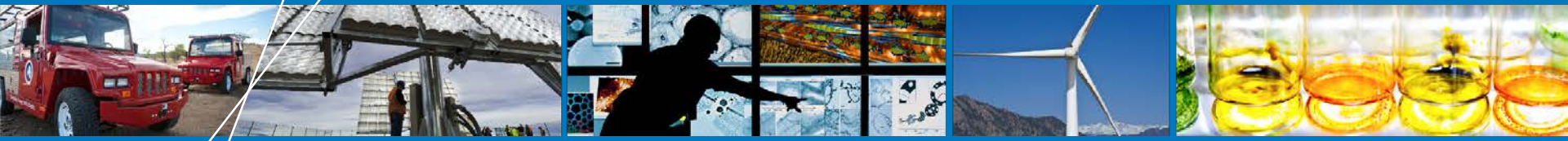
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The Increasing Importance of Vehicle Real-World Data

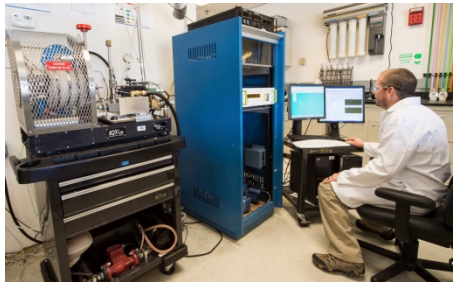


Matthew Thornton
National Renewable Energy Laboratory
March 17, 2016

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.

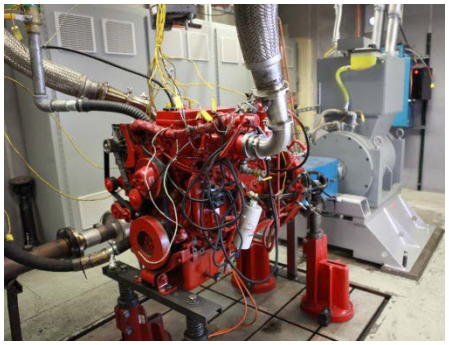
The Role of PEMS and Real-World Data

The Emissions Testing Continuum--Repeatability Versus Reality

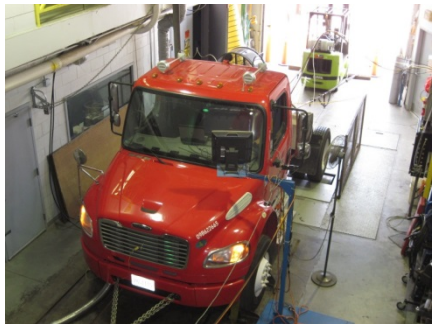


Combustions Device

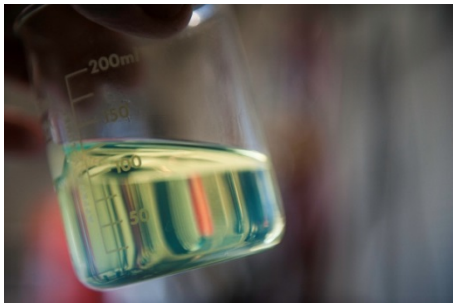
Single cylinder Engine



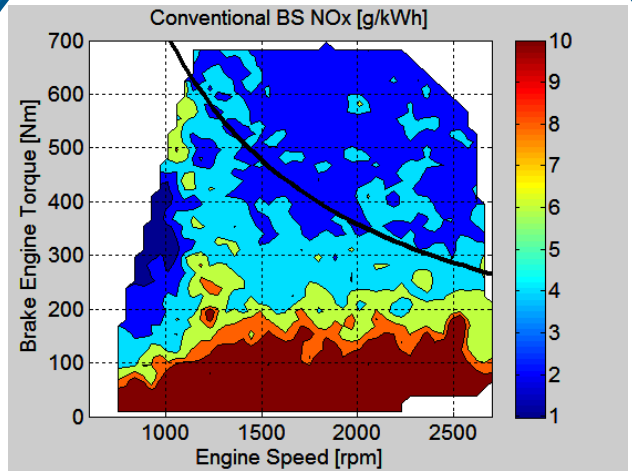
Multi-cylinder Engine



Chassis Dyno

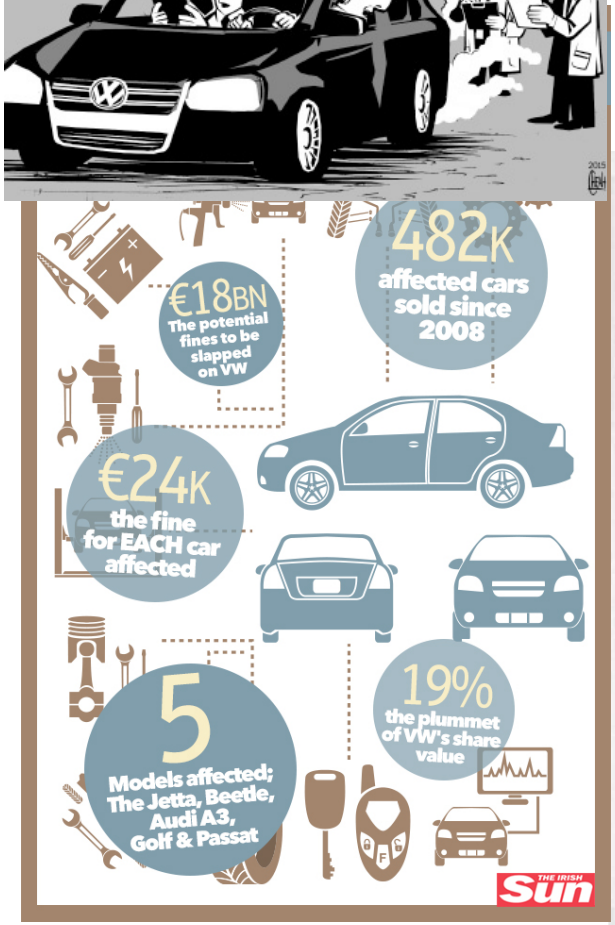


Fuel Analysis



On-Road

Why is PEMS Important: VW Controversy



Source: Arvind Thiruvengadam, Center for Alternative Fuels, Engines and Emissions at West Virginia University

It's More than Just Defeat Devices

Many other Studies Have also Shown In-use Emissions Increases

Study	Emissions Increase
More than half of the 14 Euro 6 diesel cars tested with SCR, LNT, or EGR systems…(1).	NOx emissions >6X higher than certified
Two cars, each with LNT or SCR systems...(1)	25X higher than certified
In a study of three vehicles the best performing SCR (2)	3-4X higher
In the same study the highest (EGR; and LNT+urea-SCR). (2)	5-7X the certified level in PEMS testing
Study of US Tier 3 light-duty diesel showed high in-use emissions--two cars with either an LNT or SCR (3)	4-20X the Bin 5 allowable NOx, depending on route. Most SCR emissions were in the range of 10X.
A Euro 6 gasoline direct injection (GDI) car (4).	2X higher PN emissions on the autobahn versus on the NEDC
In another study of two Euro 6 GDI cars (5)	10X higher PN emissions at 130 kph (km/hr) versus the NEDC.
GDI and MPI gasoline engines relative to LD diesels with DPFs. (6)	1.5 to 2.5 orders of magnitude higher hot-start solid PN emissions (10-15 second duration)

Johnson, T., "Vehicular Emissions in Review," SAE Int. J. Engines 7(3):2014, doi:10.4271/2014-01-1491.

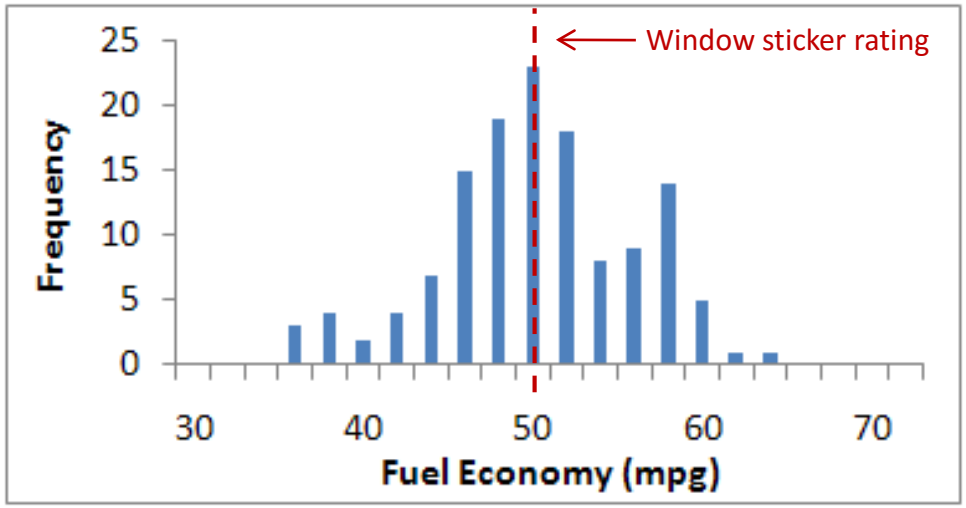
REFERENCES:

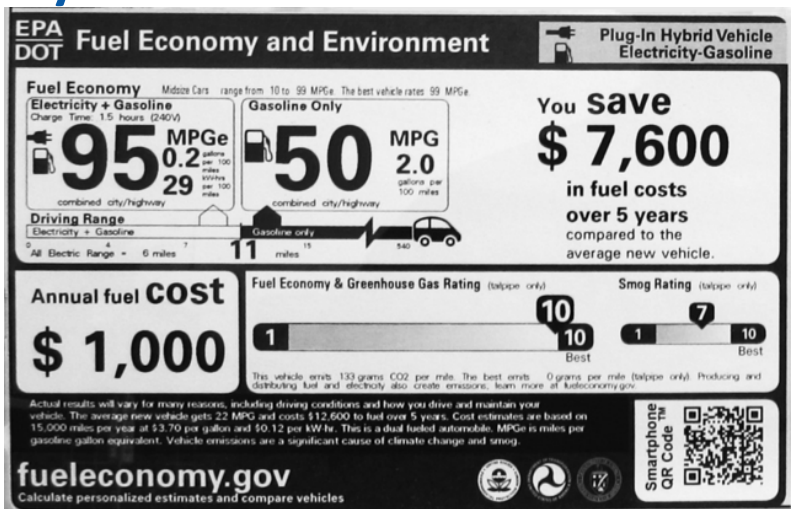
1. Mock, P.; Franco, V. "Developments in Automotive Emissions in the EU and Globally", presentation at BOSMAL 4th International Exhaust Emissions Symposium, Bielsko-Biala (Poland), May 22nd, 2014. See also www.TheICCT.org
2. May, J.; Bosteels, D.; Favre, C., "A Comparison of Light-Duty Vehicle Emissions over Different Test Cycles and in Real Driving Conditions", Paper F2014-CET-058, 2014 FISITA Conference, Maastricht, June 2014.
3. Thompson, Gregory J.; Carder, Daniel K.; Besch, Marc C.; Thiruvengadam, Arvind, Kappanna, Hemanth K., "In-Use Emissions Testing of Light-Duty Diesel Vehicles in the United States", study for International Council on Clean Transportation, website: www.TheICCT.org
4. Deutsche Umwelthilfe (DUH) press release, October 29, 2013. http://www.duh.de/pressemitteilung.html?&no_cache=1&tx_ttnews%5btt_news%5d=3200&cHash=58b125fbc6c5b932d5bbe17221354dd2
5. Kolke, R., "Die Grossen Herauseforderungen fuer Diesel-Pkw", 11th FAD Conference "Challenge - Exhaust Aftertreatment for Diesel Engines", Dresden, November 6-7,2013.
6. Khalek, I. A.; Badshah, H., "Particle Emissions from Vehicle Exhaust During Engine Start-Up", presentation at 18th ETH Conference on Combustion Generated Nanoparticles, June 23-25, 2014, Zurich.

Real-World Effects Emissions and Fuel Economy (CO_2)

"Your mileage will vary" based on driving style

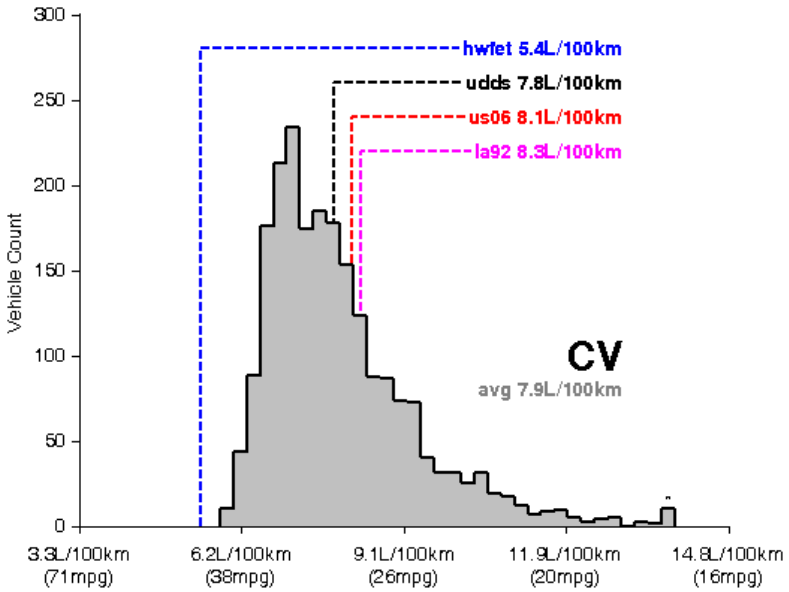
2010 Prius Fuel Economy Histogram for 133 Drivers*





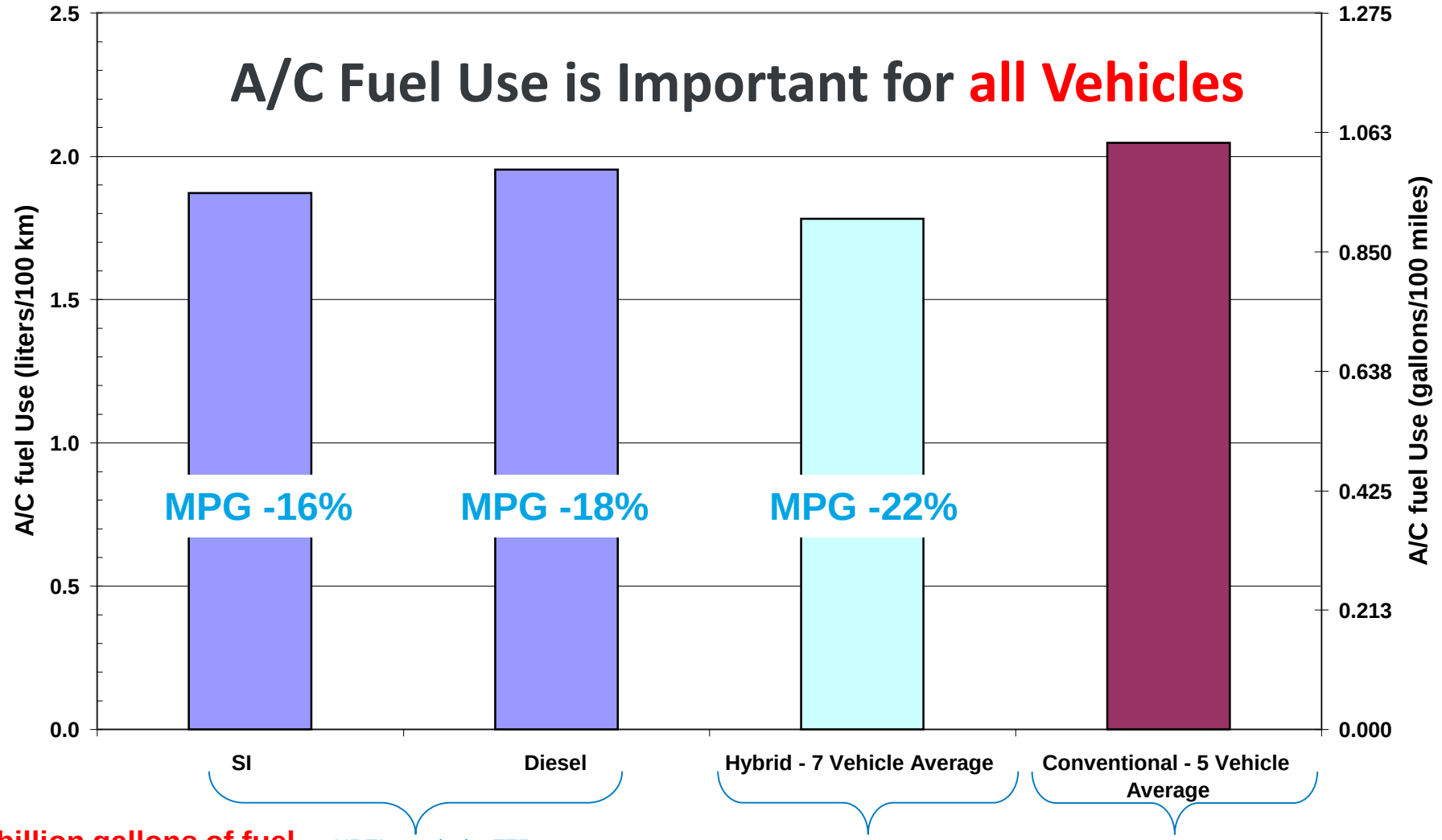
Cert vs. Real-World Variance

- Off-cycle impacts—drive cycle
- Auxiliaries, weather, elevation, driver behavior, traffic…



* Data accessed from www.fueleconomy.gov

The Impact of Climate and Auxiliary Loads on Fuel Economy (CO_2)



7 billion gallons of fuel used annually for vehicle A/C in the U.S.

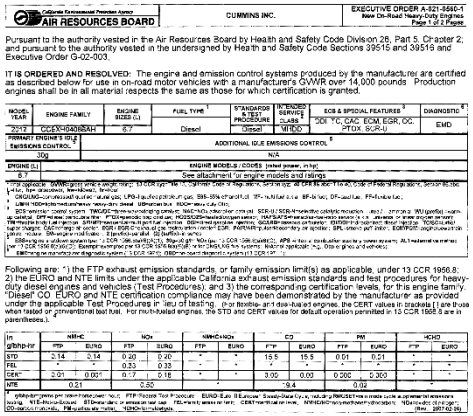
NREL, analysis, FTP

U.S. Dept. of Energy, Test, SAE J1634
http://avt.inl.gov/hev.shtml

U.S. EPA, Test, SC03, EPA420-D-06-002
http://www.epa.gov/fueleconomy/420d06002.pdf

Heavy-Duty: Even a More Complex Issue than LD?

Cummins ISB (Certified for use over 14,000 lbs. GVWR)



CUMMINS INC.

EXECUTIVE ORDER A-021-0660-1

Pursuant to the authority vested in the Air Resources Board by Health and Safety Code Division 26, Part 5, Chapter 2; and pursuant to the authority vested in the undersigned by Health and Safety Code Sections 39515 and 39519 and Executive Order G-02-003.

IT IS ORDERED AND RESOLVED: The engine and emission control systems produced by the manufacturer are certified as described below for use in on-road motor vehicles with a manufacturer's GVWR over 14,000 pounds. Production engines shall be in all material respects the same as those for which certification is granted.

MODEL YEAR	ENGINE FAMILY	ENGINE SIZE(S) (L)	FUEL TYPE	STANDARDS & TEST PROCEDURE	INTENDED SERVICE CLASS	ECS & SPECIAL FEATURES	DIAGNOSTIC
2012	CCEXH0408BAH	6.7	Diesel	Diesel	HHDD	SDI, TC, CAC, ECM, EGR, OC, PTOX, SCR-U	EMD

PRIMARY ENGINE'S OBD EMISSIONS CONTROL	ADDITIONAL IDLE EMISSIONS CONTROL
30g	N/A

ENGINE (L)	ENGINE MODELS / CODES (rated power, in hp)
6.7	See attachment for engine models and ratings

Following are: 1) the FTP exhaust emission standards, or family emission limit(s) as applicable, under 13 CCR 1956.8; 2) the EURO and NTE limits under the applicable California exhaust emission standards and test procedures for heavy-duty diesel engines and vehicles (Test Procedures); and 3) the corresponding certification levels, for this engine family. "Diesel" CO, EURO and NTE certification compliance may have been demonstrated by the manufacturer as provided under the applicable Test Procedures in lieu of testing. (For flexible- and dual-fuel engines, the CERT values in brackets [ ] are those when tested on conventional test fuel. For multi-fueled engines, the STD and CERT values for default operation permitted in 13 CCR 1968.5 are in parentheses.).

In g/bhp-hr	NMHC		NOx		NMHC+NOx		CO		PM		HCHO	
	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO
STD	0.14	0.14	0.20	0.20	*	*	15.5	15.5	0.01	0.01	*	*
FEL	*	*	0.33	0.33	*	*	*	*	*	*	*	*
CERT	0.01	0.001	0.17	0.18	*	*	3.00	0.00	0.000	0.000	*	*
NTE		0.21		0.50		*		9.4		0.02		*

BE IT FURTHER RESOLVED: Certification to the FEL(s) listed above, as applicable, is subject to the following terms, limitations and conditions. The FEL(s) is the emission level declared by the manufacturer and serves in lieu of an emission standard for certification purposes in any averaging, banking, or trading (ABT) programs. It will be used for determining compliance of any engine in this family and compliance with such ABT programs.

BE IT FURTHER RESOLVED: Except in vehicle applications exempted per 13 CCR 1956.8(a)(6)(B), engines in this engine family certified under 13 CCR 1956.8(a)(6)(C) (.30 g/hr NOx) and section 35 B.4 of the incorporated "California Exhaust Emissions Standards and Test Procedures for 2004 and Subsequent Model Heavy-Duty Diesel Engines and Vehicles" (HDDE Test Procedures) adopted Dec. 12, 2002, as last amended Sep. 27, 20*0, shall be provided with an approved "Certified Clean Idle" label that shall be affixed to the vehicle into which the engine is installed.

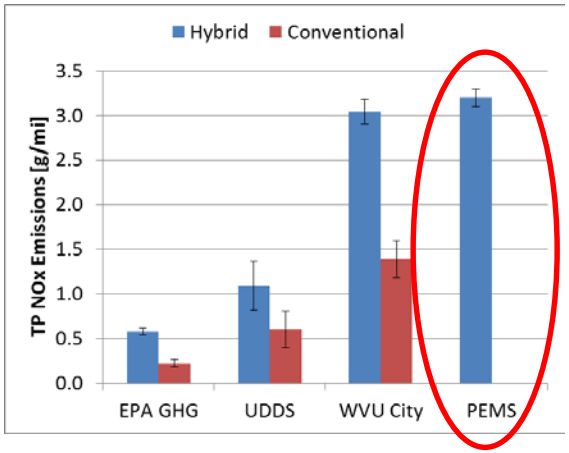
BE IT FURTHER RESOLVED: That the manufacturer has elected to include engine models in this engine family which are identified for "emergency vehicle use only". These "emergency vehicle use only" engines are exempt from requirements imposed pursuant to California law and the regulations adopted pursuant thereto for motor vehicle pollution control devices per California Vehicle Code Section 27156.2. The manufacturer must clearly label these engines for "emergency vehicle use only" on the engines' emission control label.

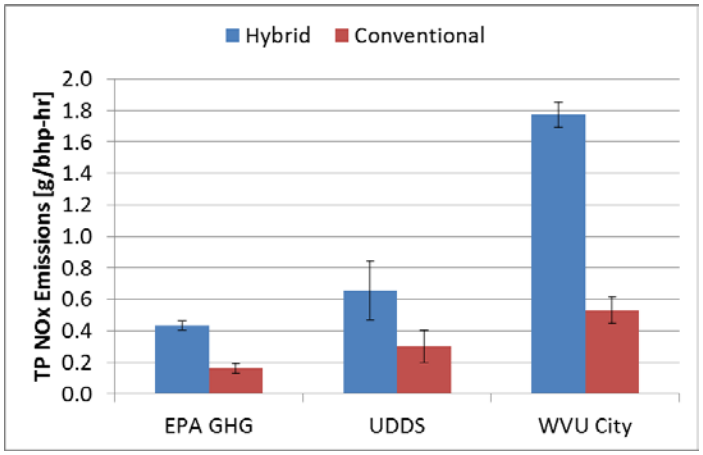
BE IT FURTHER RESOLVED: For the listed engine models the manufacturer has submitted the materials to demonstrate certification compliance with 13 CCR 1965 (emission control labels); 13 CCR 1971 (engine manufacturer diagnostic) and 13 CCR 2035 et seq. (emission control warranty).

Vehicle class range: 2b-7

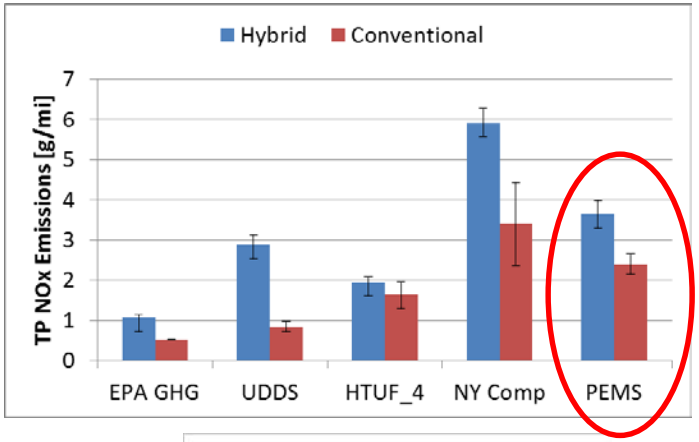
Emissions Impact Example-Hybrid Trucks

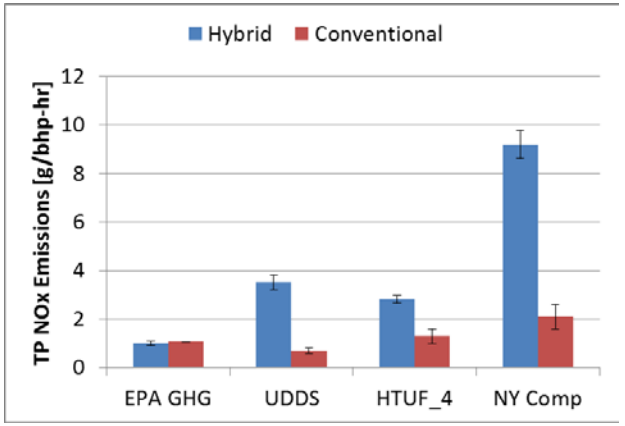
Straight Truck with ISB-Beverage Delivery

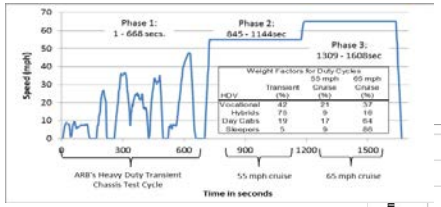




Step Van with ISB -Parcel Delivery

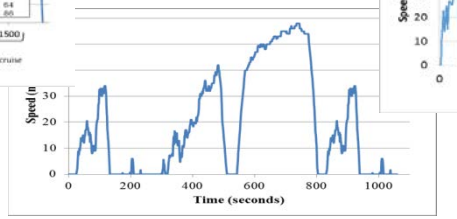


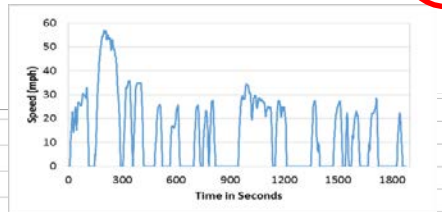




Environmental Protection Agency Greenhouse Gas Cycle (EPA GHG) or HHDDT

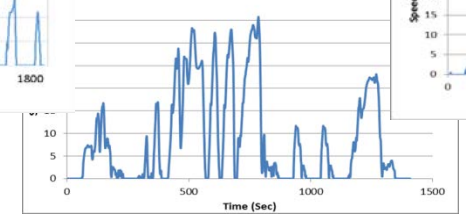
Urban Dynamometer Driving Schedule (UDDS)

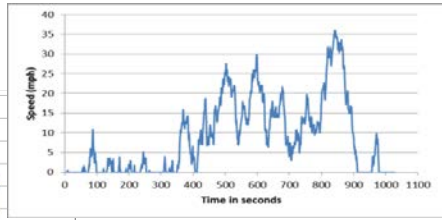




Hybrid Users Truck Forum Class 4 Driving Schedule (HTUF 4)

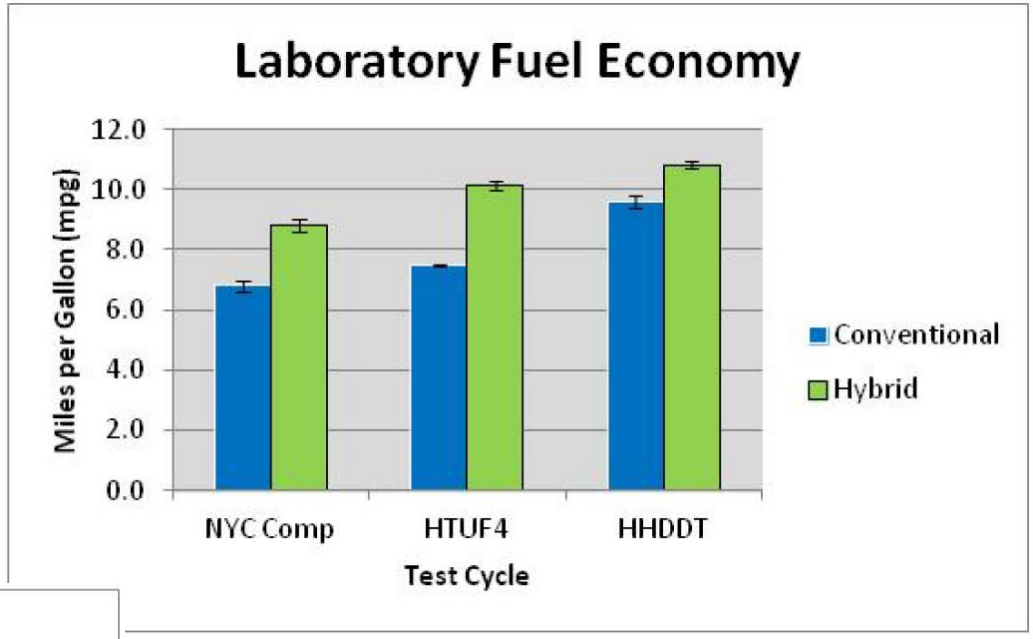
West Virginia University City Cycle (WVU City)

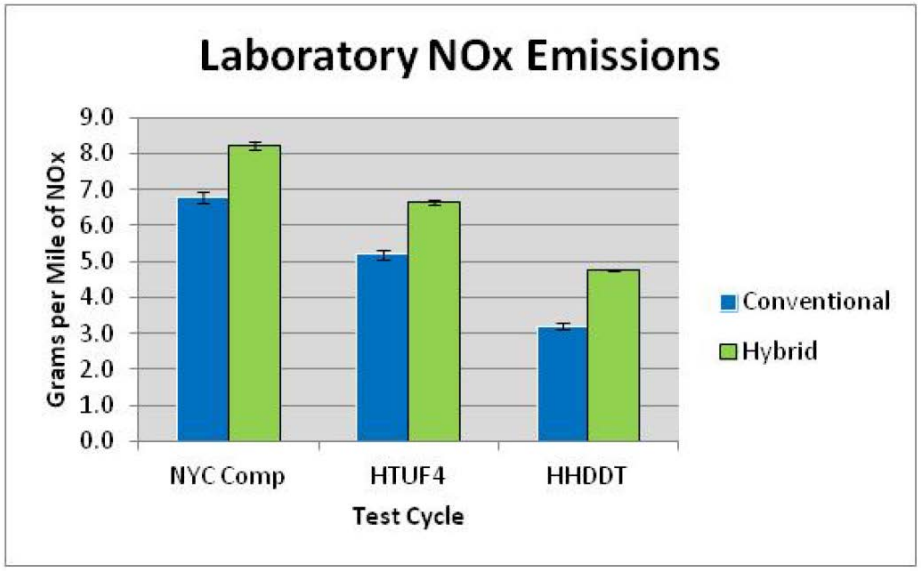




New York City Composite Cycle (NYCC)

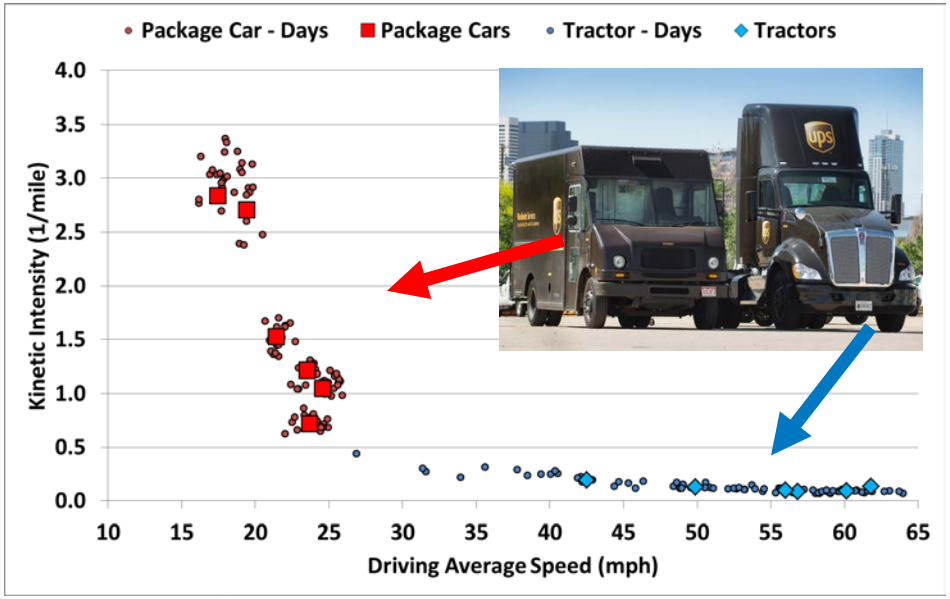
UPS Diesel HEV Class-6 Walk-In Step Vans

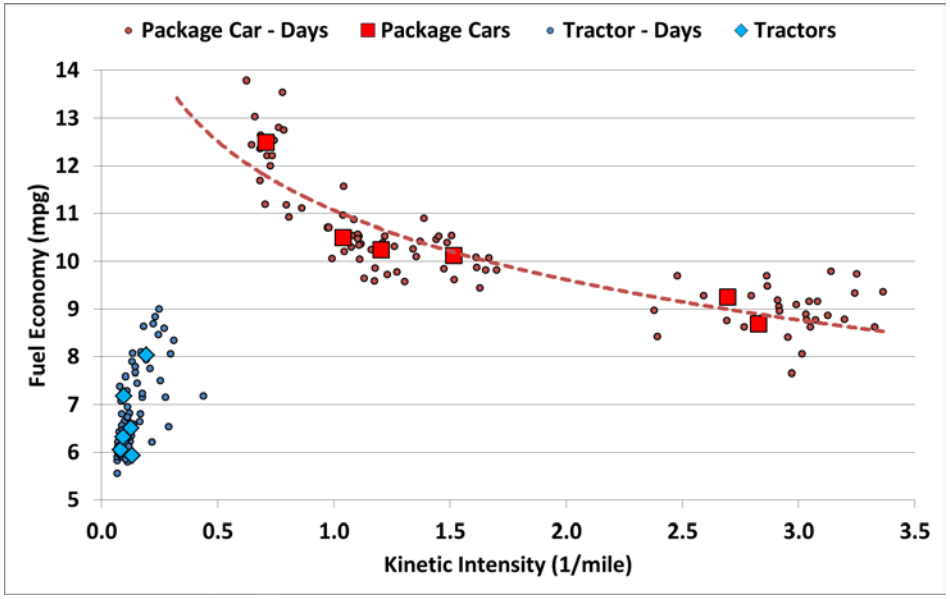




Gravimetric Fuel Economy	NYC Comp	HTUF4	HHDDT
Conventional P100D	6.8	7.5	9.6
Hybrid P100H (mpg)	8.8	10.2	10.9
Hybrid Advantage	29%	36%	13%
T test P Value	0.0001	0.0000	0.0002

UPS Step Van and Tractor Fuel Economy





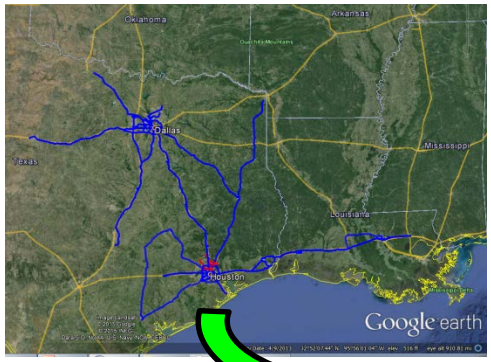
Field Data showing range of duty cycles for a sample of UPS tractors and package delivery vehicles

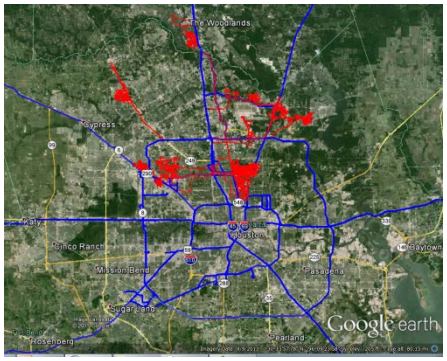
3-weeks on-road data collection

- Six class 4 package vans
- Six class 8 tractors

Kinetic intensity clusters indicative of low-speed urban delivery vs. high-speed regional haul duty cycles – note range of operation

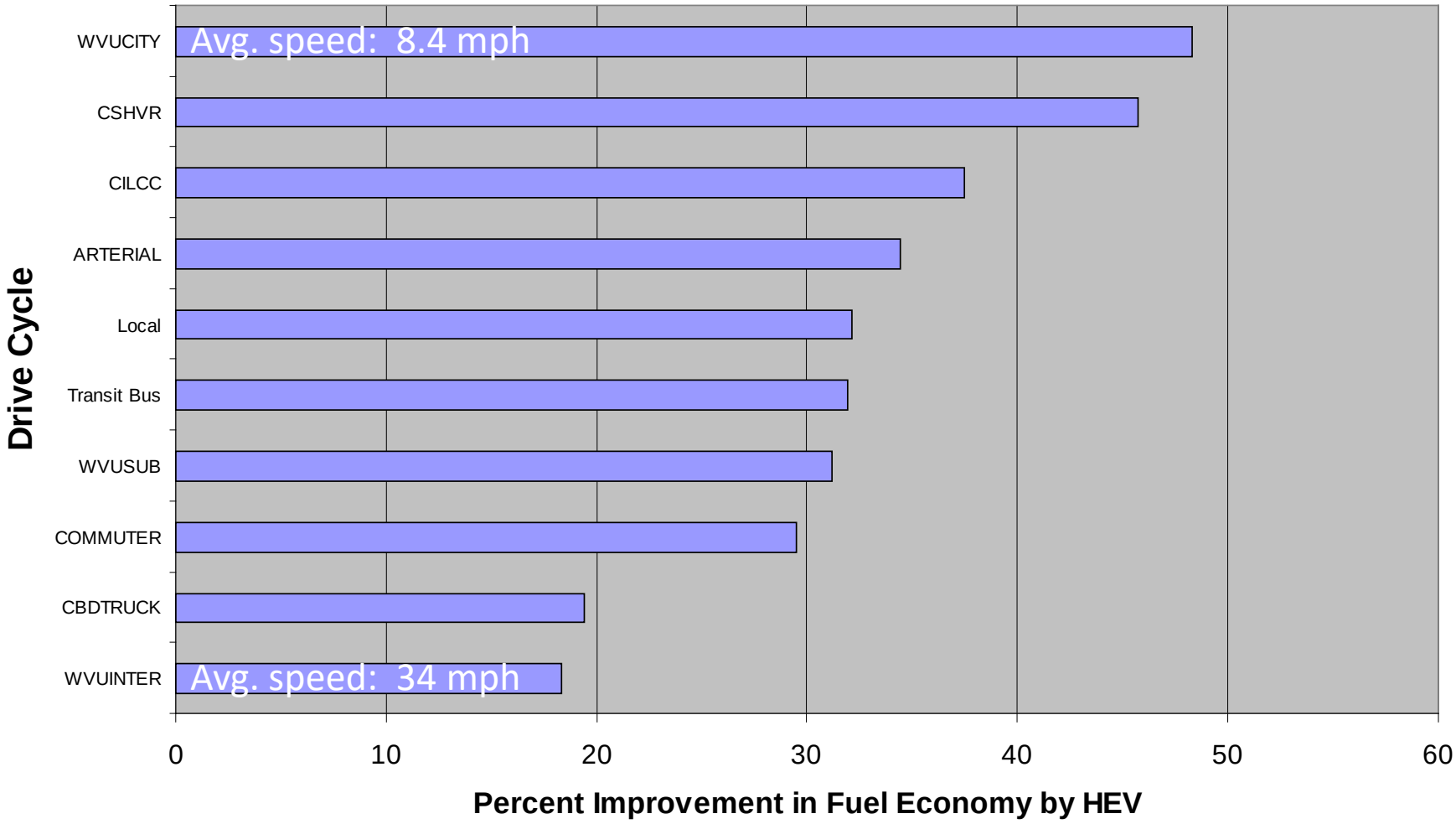
CAN-based fuel efficiency correlated to duty cycle parameters – showing influence of duty cycle on fuel efficiency





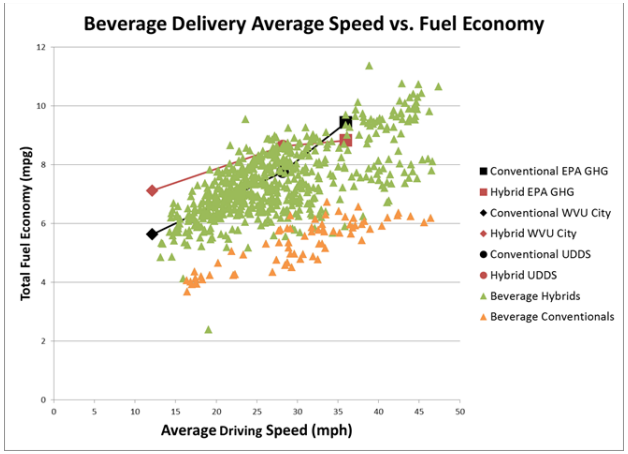
It's All About the Duty Cycle

Example: hybrid technology benefit on different cycles



Activity Data is Key for Understanding Real-World Impacts

- **Evaluate real-world emissions and fuel-saving opportunities for technologies difficult to assess with standard certification cycles**
  - DOE and regulatory bodies want to maximize real-world fuel savings
  - Manufacturers want to get credit for actual emissions and fuel savings achieved



- **Example technologies:**
  - Engine Cold Start
  - Hybridization-Start-stop
  - High-efficiency alternators
  - Catalyst Insulation
  - Glazing technology
  - Connected vehicle applications

- **DOE labs such as NREL can provide objective inputs**
- **Relevant existing capabilities**
  - **Evaluation of energy efficiency technologies**
  - **On-road driving data**
  - **Fusion of large datasets capturing range of real-world operating conditions**

Medium- and Heavy- Vehicle Field Testing Approach

Evaluate the performance of alternative fuels and advanced technologies in medium- and heavy-duty fleet vehicles - in partnership with commercial and government fleets and industry groups vehicles.

Collect, analyze and publicly report data:

- Drive cycle and system duty cycle analysis
- Operating cost/mile
- In-use fuel economy
- Chassis Dynamometer emissions and fuel economy
- Scheduled and unscheduled maintenance
- Warranty issues
- Reliability (% availability, MBRC)
- Implementation issues/barriers
- Subsystem performance data & metrics (ESS, engine, after-treatment, hybrid/EV drive focus)

Data stored in FleetDNA for security and limited public accessibility

Frequent interactions and briefings with stakeholders – fleets, technology providers, researchers, and government agencies

Fleets

UPS, FedEx, Coke, Frito-Lay, Foothill Transit, PG&E, Miami-Dade, Verizon, Walmart, Waste Management

+

Vehicle & Equip Mfg's

Proterra, Navistar, Smith EV, Eaton, Allison, BAE, EDI, Altec, International, PACCAR, Oshkosh, Odyne, Parker-Hannifin, Cummins

=

Useful Data, Analysis and Published Reports

NREL Field Data, Testing, & Analysis Tools

Data from Field Evaluations helps populate FleetDNA database

DOE Fleet Tools (DRIVE, FASTSim, AFleet, etc.) used to analyze and investigate impacts – data used to validate and improve tools

Published information and data used by fleets, industry, DOE and other research programs, and other agencies

Collect Lab and Field Data

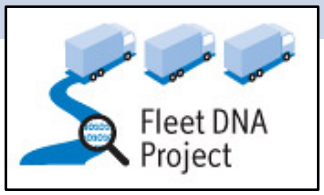
Capture, Store and Analyze

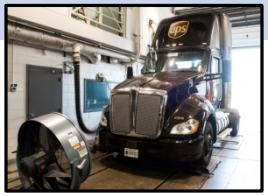
Laboratory Testing

Explore & Optimize

Communicate & Inform

Identify Barriers, New R&D Opportunities, Validate Efforts





National Clean Fleets Partnership
U.S. Department of Energy

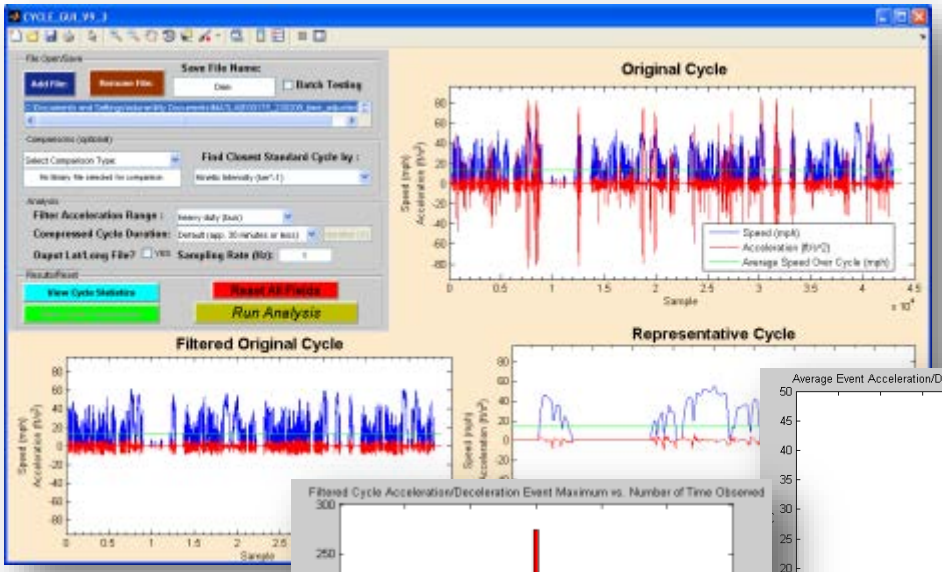
21st Century Truck Partnership

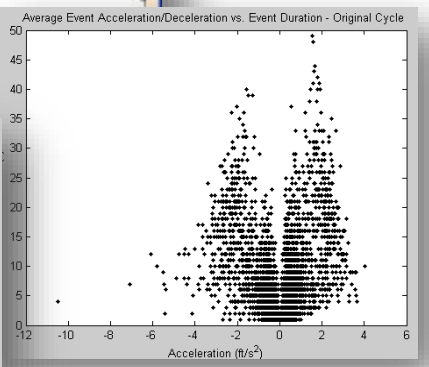
Partnership with Fleets and Technology Providers = Relevant Results & Optimized Solutions for Real World Applications

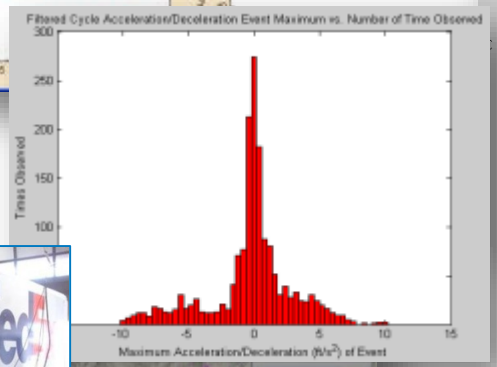
Applying Fleet DNA – NREL's DRIVE Tool

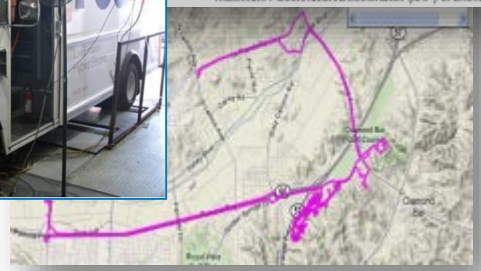
Drive-cycle Rapid Investigation, Visualization and Evaluation Tool (DRIVE™)

- Created to help fleets and OEMs analyze vehicle usage data for proper vehicle placement, design and testing
- Combines large amounts of user data then filters, creates new cycles & identifies best fitting existing cycle
- Quickly processes and analyzes data :
  - Over 250 metrics
  - Histograms
  - Scatter plots
  - Creates custom cycle
  - Recommends standard cycles









DRIVE™ Analysis Tool

Transportation Data Centers at NREL

Real-World Data and Analysis to Support Decision Making

Alternative Fuels Data Center (AFDC)
Public clearinghouse of information on the full range of advanced vehicles and fuels

National Fuel Cell Technology Evaluation Center (NFCTEC)
Industry data and reports on hydrogen fuel cell technology status, progress, and challenges

Transportation Secure Data Center (TSDC): *Detailed individual travel data, including GPS profiles*

Fleet DNA Data Collection
Medium- and heavy-duty drive-cycle and powertrain data from advanced commercial fleets

FleetDASH: *Business intelligence to manage Federal fleet petroleum/alternative fuel consumption*

Features	AFDC	NFCTEC	TSDC	Fleet DNA	Fleet DASH
Securely Archived Sensitive Data		Y	Y	Y	Y
Publicly Available Cleansed Composite Data	Y	Y	Y	Y	
Quality Control Processing	Y	Y	Y	Y	Y
Spatial Mapping/GIS Analysis	Y	Y	Y	Y	Y
Custom Reports		Y		Y	Y
Controlled Access via Application Process			Y		
Detailed GPS Drive-Cycle Analysis			Y	Y	

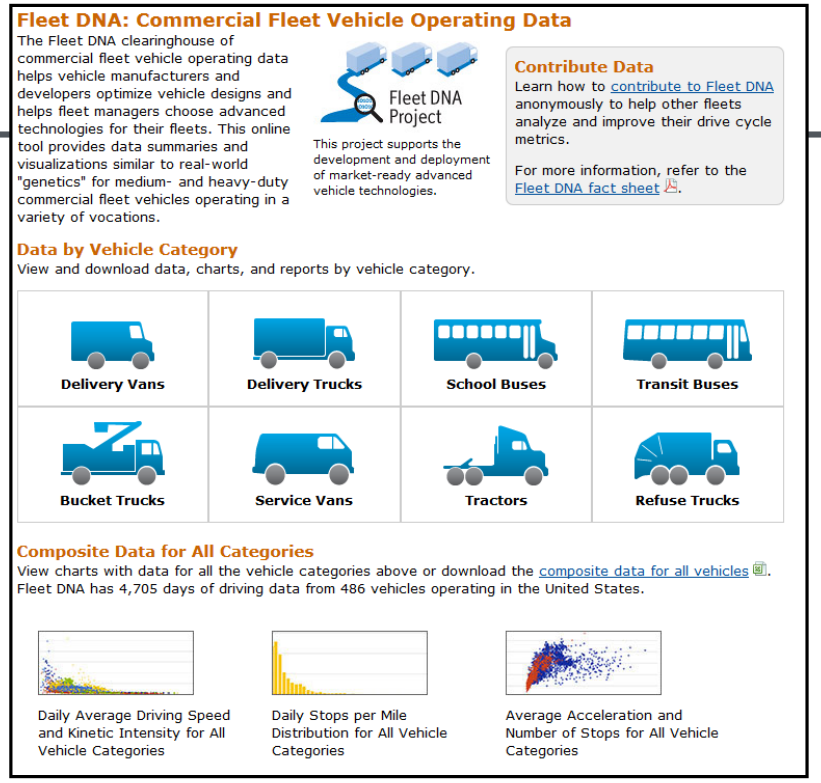
Additional Information

Available through Fleet DNA

www.nrel.gov/fleetdna

Objectives:

- Capture and quantify drive cycle and technology variation for the multitude of medium- and heavy-duty vocations
- Provide a common data storage warehouse for medium- and heavy-duty vehicle data across DOE activities and labs – www.nrel.gov/fleetdna
- Integrate existing DOE tools, models, and analyses to provide data driven decision making capabilities



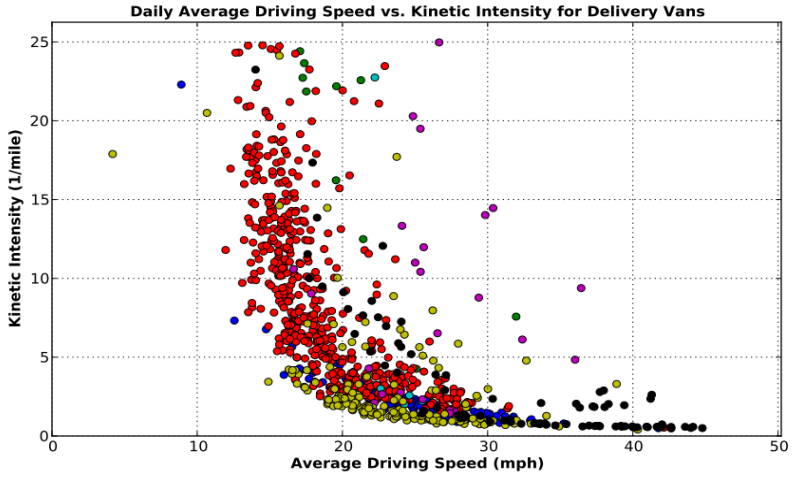
For Government : Provide in-use data for standard drive cycle development, R&D, tech targets, and rule making

For OEMs: Real-world usage datasets provide concrete examples of customer use profiles

For Fleets: Vocational datasets help illustrate how to maximize return on technology investments

For Funding Agencies: Reveal ways to optimize impact of financial incentive offers

For Researchers: Provides a data source for modeling and simulation



Conclusion

- PEMS has important role in collecting real-world data and it's importance is growing
- Off-cycle and environmental impacts can impact emissions and fuel economy greatly
- Advanced technology and alternative fuel can accentuate impacts and are becoming bigger players
- Activity data is key to properly quantifying impacts
- Opportunity for benefits--not just negative impacts

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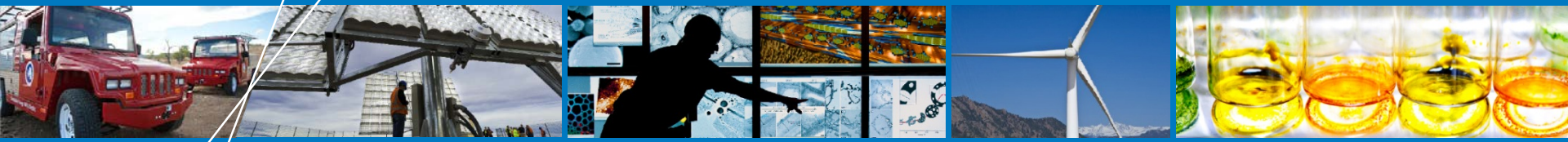
Questions?



Thank You!

Additional Information:

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