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Medium- and Heavy Duty Vehicle Attributes and Their Effect on Fuel Economy

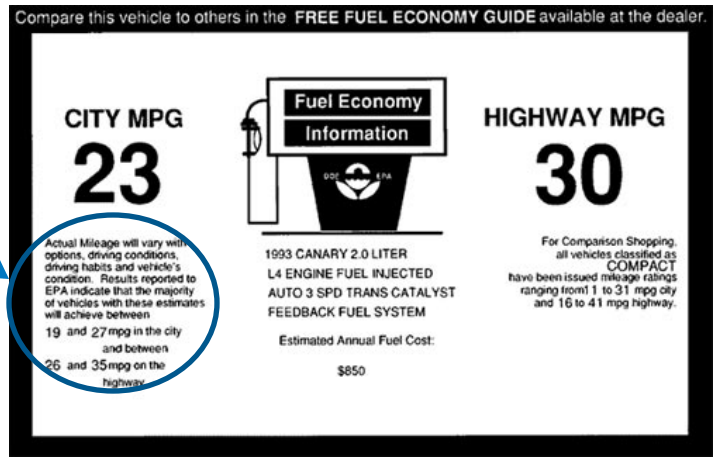
Kevin Walkowicz
National Renewable Energy Laboratory

Presented to the California Energy Commission
September 30 2015

MD & HD Attributes Analysis – A Few Points

MD & HD vehicle market is much different than LD

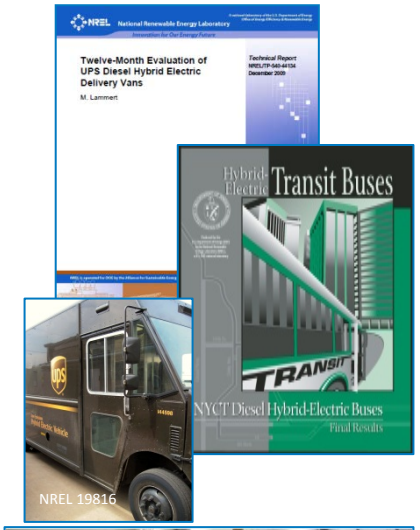
- Commercial customers are almost always focused on ROI, cost & duty cycle
- Many, many different duty cycles, engines, chassis, combinations
- Small build sizes compared to LD – very low volumes
- Fleets and OEMs would *like* to maximize profitability by using economy of scale, but 'Commonization' across platforms requires an in-depth understanding of vocational use and understanding of system performance across vocations
- Effects of vehicle parameters/attributes are different for each customer/vocation – don't expect same mileage for different fleets
- What works well in one application will not work well in another - i.e. 'actual mileage may vary'



NREL's Commercial Fleet Testing & Analysis Background

Using a proven protocol to deliver test results, aggregated data, and detailed analysis. Approach:

- **3rd party unbiased data:** Provides data that would not normally be shared by industry in an aggregated and detailed manner
- Over 6 million miles of advanced technology **MD and HD truck data have been collected, documented, and analyzed** on over 600 different vehicles since 2002
- **Data, Analysis, and Reports** are shared within DOE, national laboratory partners, and industry for R&D planning and strategy.
- **Results help:**
  - Guide R&D for new technology development – define barriers to better ROI/MPG
  - **Help define intelligent usage of newly developed technology**
  - **Help fleets/users understand all aspects of advanced technology**



NREL's Testing Approach: Effect of Variable Attributes

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 and Analyze:

- ❑ Drive cycle and system duty cycle analysis
- ❑ Subsystem performance data & metrics (ESS, engine, after-treatment, hybrid/EV drive focus)

To Assess:

- 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

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

Current Projects – a broad portfolio

Current DOE Projects				ARRA EV Fleet Data Collection Projects	
UPS HHV Solazyme biofuel		Miami HHV Refuse Trucks		Smith Newton	
Frito Lay EV		Natural Gas Refuse Trucks		Navistar eStar	
Fleet Platooning		Battery EV Transit Bus		Truck stop Electrification	
PG&E Electrified Utility Trucks		EV – V2G School Bus		Odyne PHEV	
SCAQMD • Fleet DNA • Zero Emissions Cargo Transport		**CA Air Resources Board (CARB)** • Heavy Hybrid Vehicle Analysis • Aerodynamics Device Testing		**EPA** Heavy-Duty Phase II GHG Drive Cycle Development	

Next Up for Evaluation: Autonomous & Connected Vehicles

Field Data & Analysis Tools / Approach

Data from Field Evaluations helps populate FleetDNA Database – define usage

DOE Analysis Tools (Autonomie, DRIVE, FASTSim, AFleet, etc.) used to analyze and investigate impacts of vehicle attributes & technology in specific usage

Published information and data used to identify which attributes have biggest effect on mpg, emissions, ROI

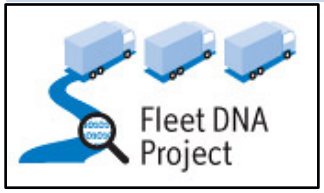
Collect Lab and Field Data

Capture, Store and Analyze

Explore & Optimize

Communicate & Inform

Quantify Technology Attributes for Individual Vocations



Database of Usage Data

Drive Cycle Characterization Tool

System Simulation Tool

Lifecycle cost / GHG tool (ANL)

Vehicle Modeling/ Simulation (ANL)

Fleet DNA: Define the Usage

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

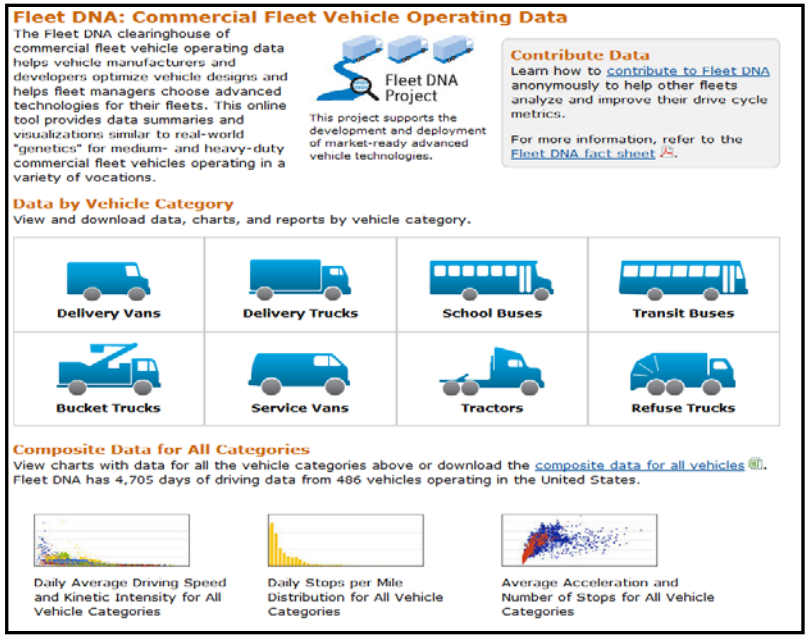
For OEMs: Real-world usage datasets provide concrete examples of customer use profiles

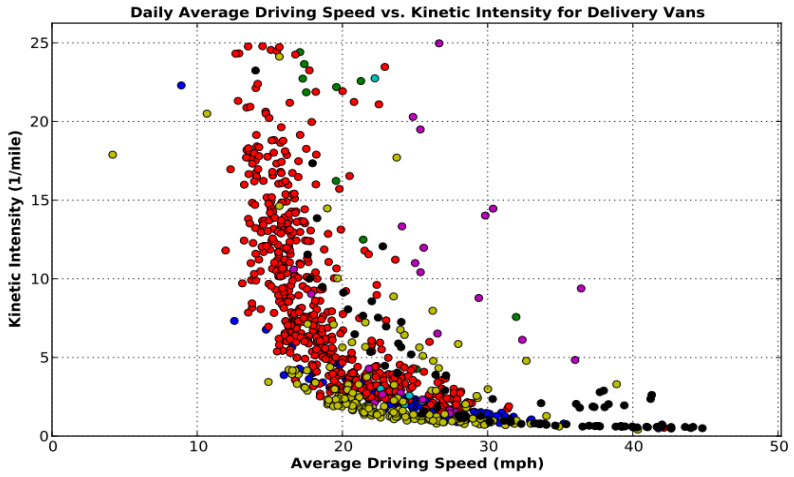
For Fleets: Vocational datasets help illustrate how to maximize return on technology investments

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

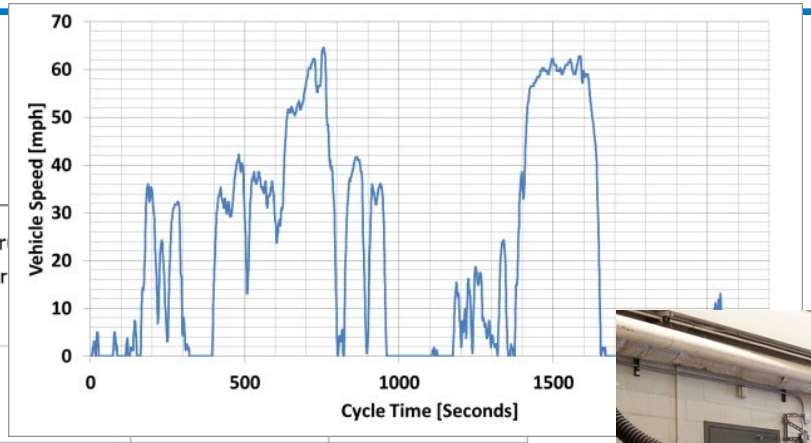
For Researchers: Provides a data source for modeling and simulation

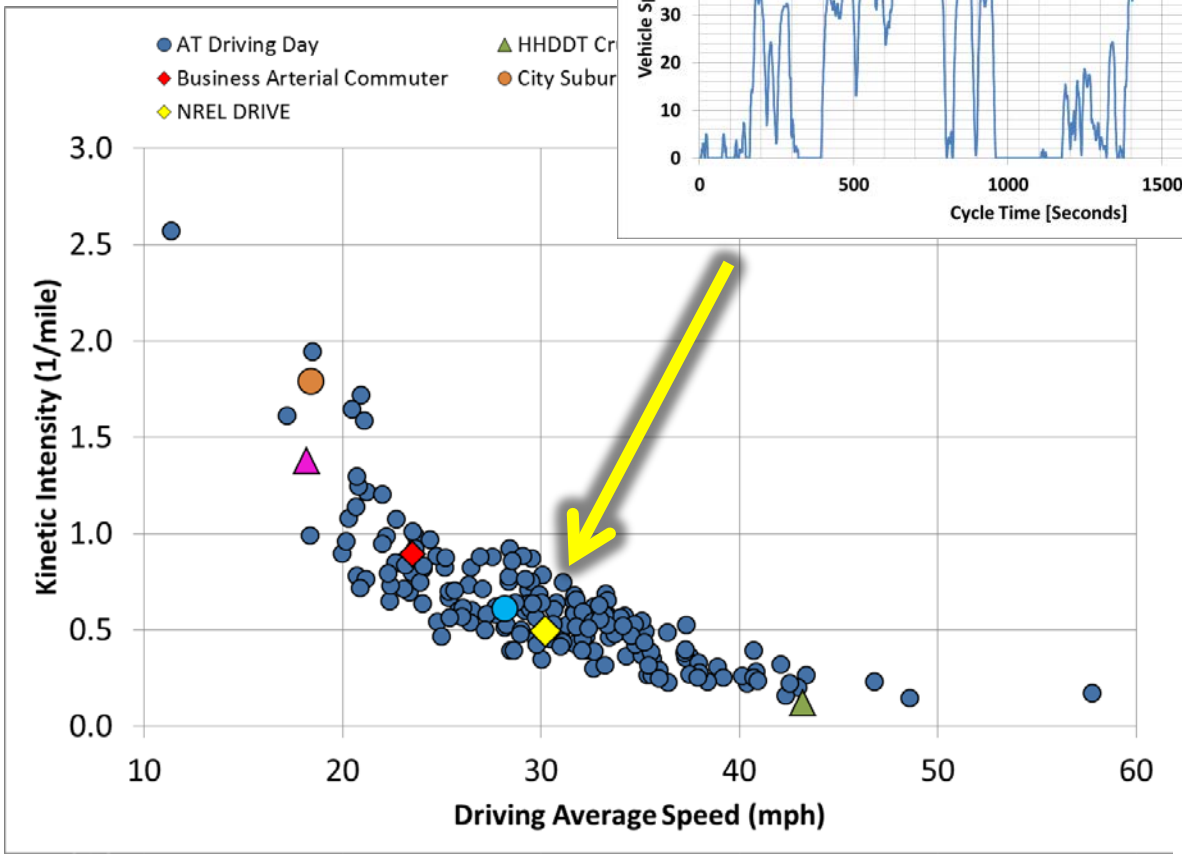
www.nrel.gov/fleetdna





Usage Analysis: DRIVE Tool

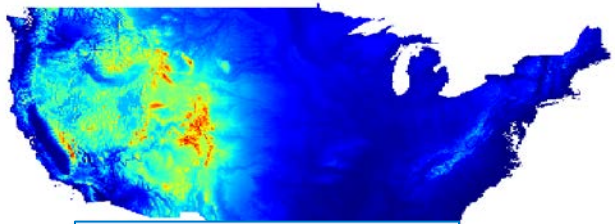




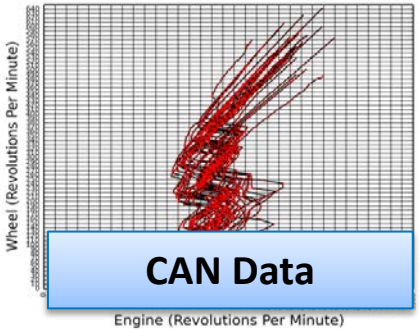
DRIVE Analysis Tool

Data Fusion –other duty cycle inputs

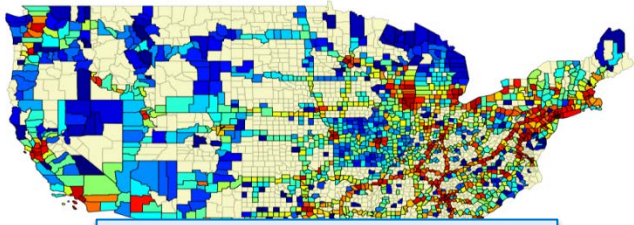
Geography and Infrastructure	Vehicle Data	Population
DOHS US Infrastructure	CAN	RL Polk
Navteq Road Layer	GPS	US Census
Tom Tom Road Network	Standard Cycles	EPA Moves
Tom Tom Road Grade	Dyno Results	EMFAC
National Elevation Dataset		TEDB



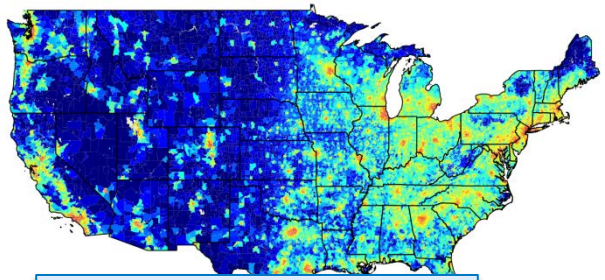
Elevation / Grade



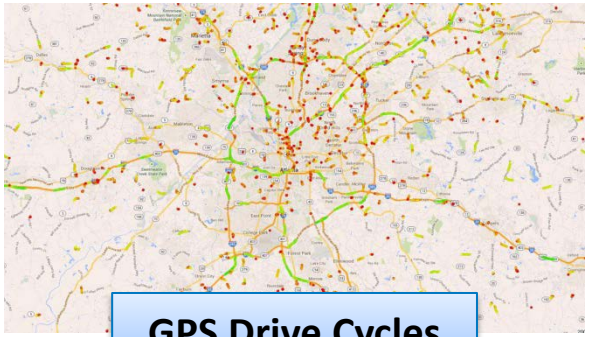
CAN Data



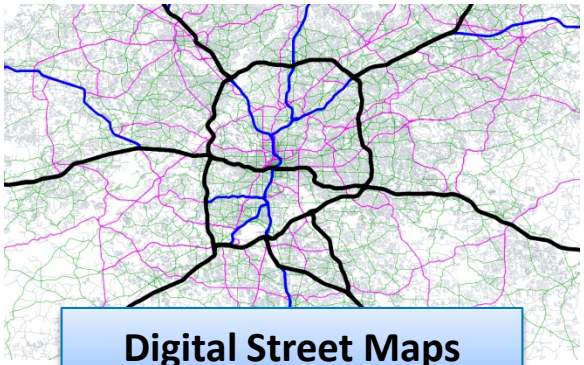
EPA MOVES



Vehicle Registrations



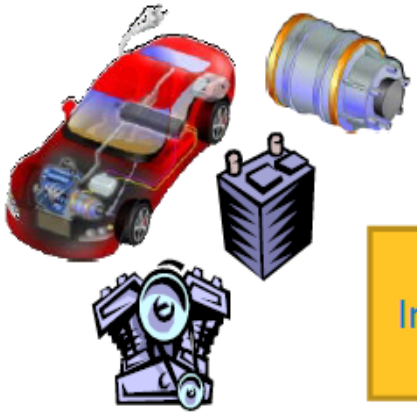
GPS Drive Cycles



Digital Street Maps

Applying Tools + Data: understanding attributes across variable drive cycles and duty cycles

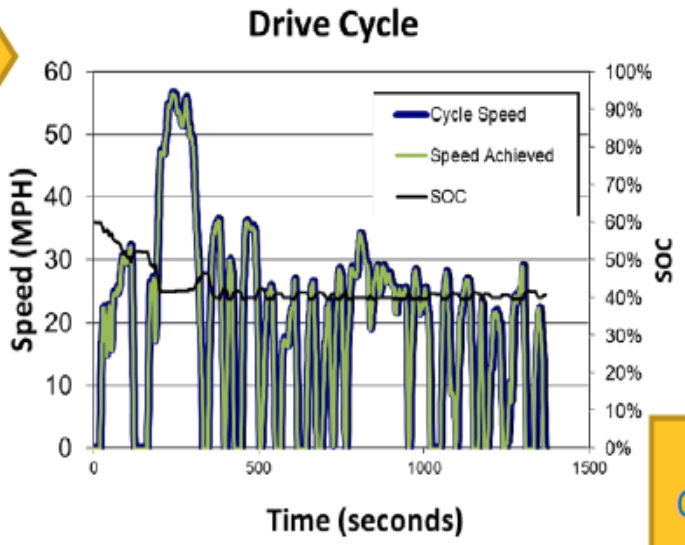
Future **A**utomotive **S**ystems **T**echnology **Sim**ulator (FASTSim)



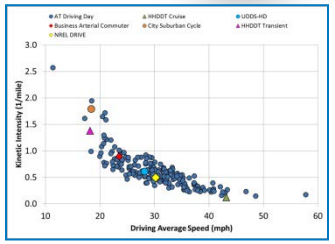
Component Sizes and Vehicle Characteristics

Inputs

- Excel Based Modeling Software
- Speed vs. time drive cycles
- Drive cycle based results
- Fast and easy to use (2.5 seconds per run)



Simulated through a Drive Cycle

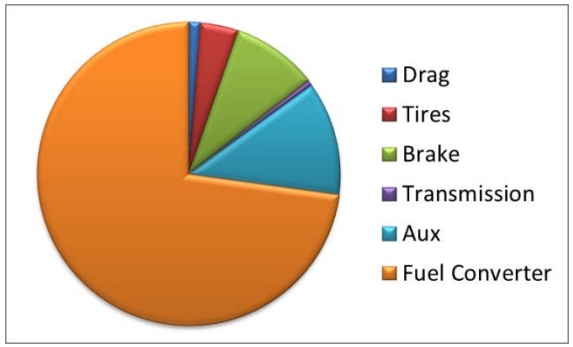


Outputs

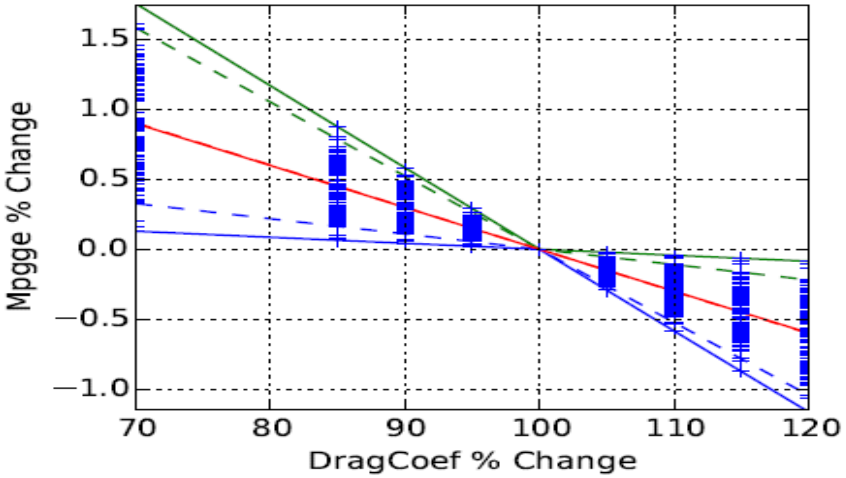
Fuel Economy

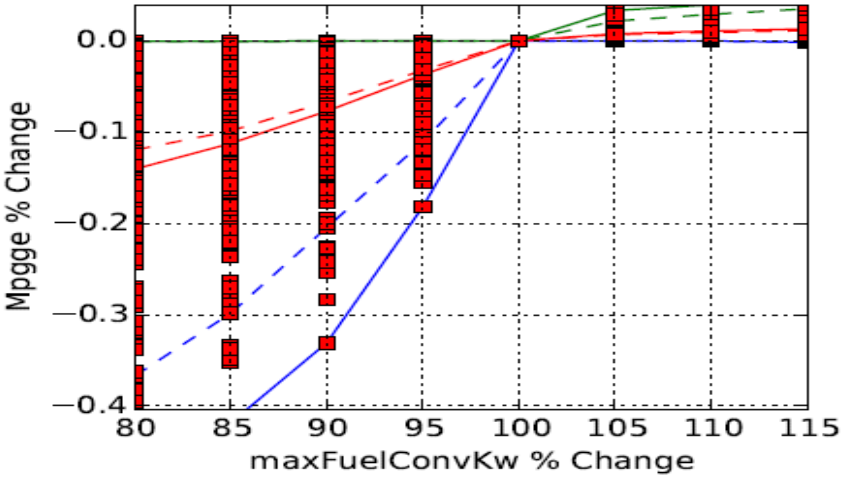
Vehicle Price

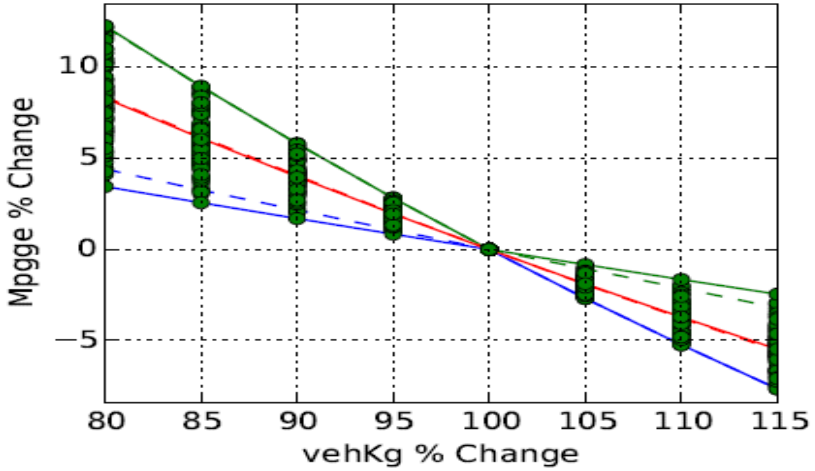
Acceleration

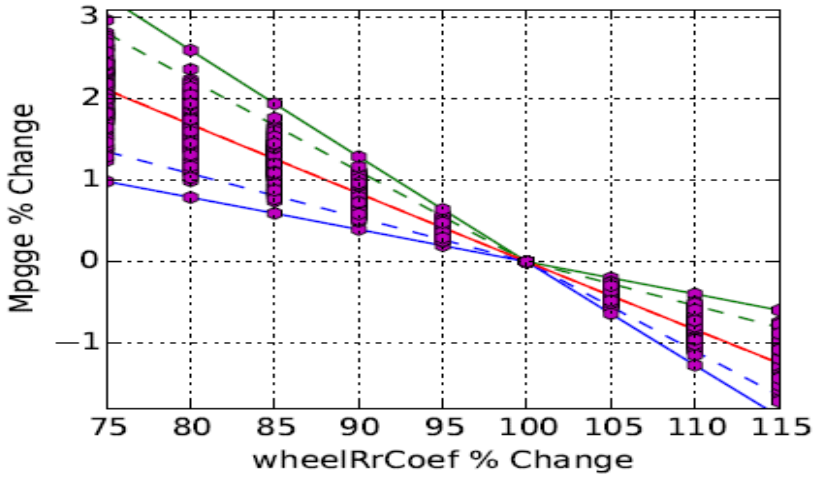


Variable Attributes– Exploring Benefits of Technologies



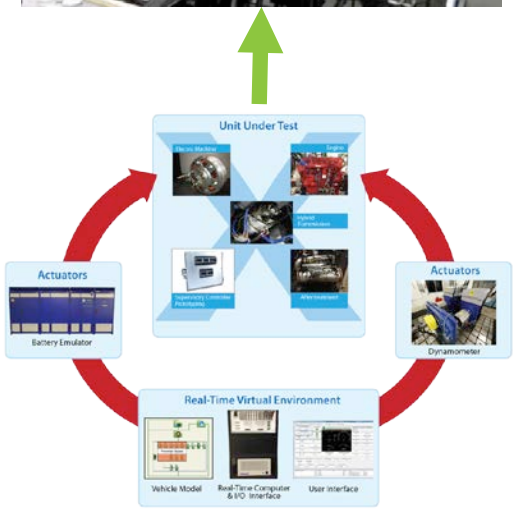


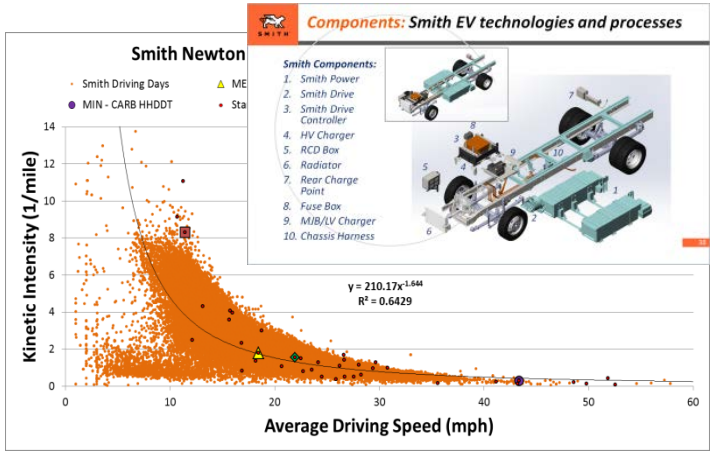


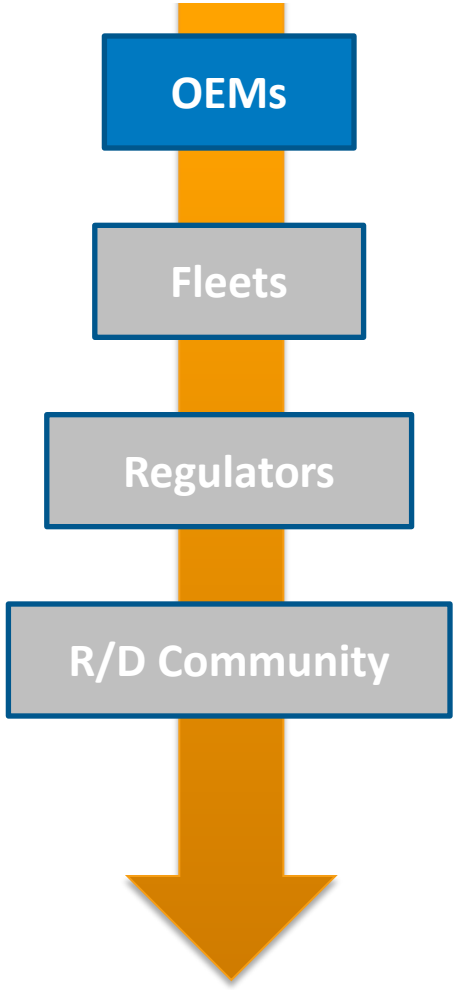


Powertrain Design – Multi-Speed Transmissions for MD/HD PEVs

Accurate knowledge of duty cycle enables intelligent design



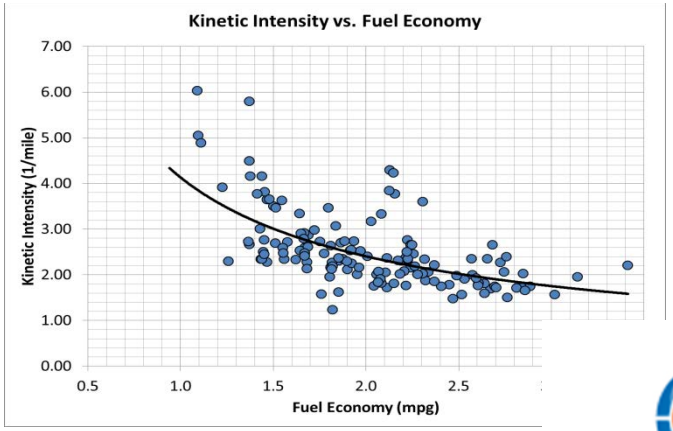




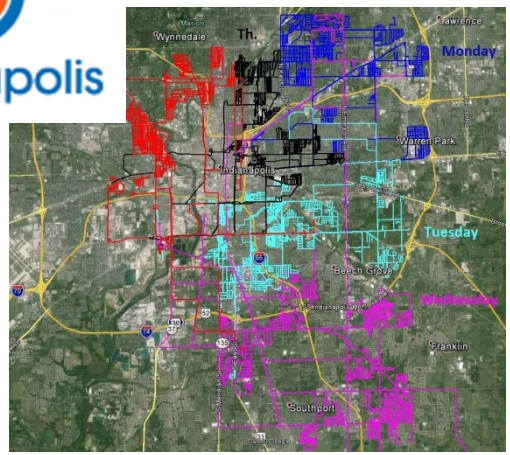
Attribute Options: CNG and Shift Points

Field Evaluations – City of Indianapolis Refuse Trucks

Inform vehicle investment decisions with vocation/route specific MPG and payback calculations



Indianapolis



Truck Number	120140	120138	100983	110030	120135	110034	120139	120136	100978	10
ISAAC Logger ID	2	3	4	5	6	8	9	10	11	
Engine	ISC8.3 330	ISC8.3 330	ISC 330	ISM 350V	ISC8.3 330	ISM 350V	ISC8.3 330	ISC8.3 330	ISC 330	ISC
Engine Family	8CEXH05 05CAC	8CEXH05 05CAC	9CEXH05 05CAZ	9CEXH06 61MAE	8CEXH05 05CAC	9CEXH06 61MAE	8CEXH05 05CAC	8CEXH05 05CAC	9CEXH05 05CAZ	9CEXH05 05CAZ
Loading	Rear	Side	Side	Side	Side	Side	Side	Side	Side	Side
Total Time [hr]	14	77	73	86	73	96	80	64	71	75
Total Distance [mi]	66	600	469	667	474	569	585	498	559	465
Total Work [kWh]	437	3186	2751	4375	2538	3496	3357	3046	4174	3051
Average Speed [mph]	4.8	7.8	6.4	7.8	6.5	5.9	7.3	7.8	7.9	6.2
Average Exh Flow [kg/hr]	288.4	335.7	10.4	13.1	288.3	9.5	333.5	357.1	15.7	11.2
Average Boost P [kPa]	32.9	45.1	38.8	33.8	32.8	20.9	43.6	50.7	62.1	42.9
Average Int. Man. [C]	46.3	47.9	50.2	38.2	46.5	34.9	46.4	48.3	49.7	46.0
Average DOC In [C]	261.5	298.9	279.6	287.8	285.5	238.2	297.7	317.2	309.3	269.2
Average DPF Out [C]	265.8	307.4	X	X	292.3	X	302.1	323.4	X	X
Average SCR Out [C]	235.5	280.3	X	X	261.7	X	274.6	296.4	X	X
NOx SCR In [g/kWh]	5.9	5.6			5.3		5.3	5.1		
NOx SCR Out [g/kWh]	0.99	0.41	X	X	0.90	X	0.81	0.39	X	X
NOx SCR Out [g/mile]	6.52	2.18			4.84		4.63	2.35		
NOx SCR Out [g]	432	1310	X	X	2295	X	2704	1173	X	X
SCR Conv. Eff. [%]	83.3	92.7			82.9		84.9	92.5		
BSFC [g/kWh]	240.6	236.7	276.9	257.5	239.7	261.5	235.9	241.2	265.8	273.4
Fuel [L]	122.3	876.9	885.5	1310.0	707.3	1063.2	920.9	854.1	1290.0	970.1
Fuel [Gallons]	32.3	231.7	233.9	346.1	186.8	280.9	243.3	225.6	340.8	256.3
Fuel Econ. [mpg]	2.0	2.6	2.0	1.9	2.5	2.0	2.4	2.2	1.6	1.8

Characteristic Acc [m/s2]	0.18	0.20	0.19	0.23	0.19	0.17	0.22	0.25	0.30	0.22	0.22	0.18	0.25	
V Aerodynamic [m/s]	11.13	12.74	11.96	13.24	11.65	10.85	12.83	13.71	13.86	11.54	12.41	11.51	12.75	
KI [1/km]	1.42	1.24	1.31	1.32	1.36	1.41	1.37	1.35	1.58	1.69	1.43	1.36	1.56	
KI [1/mi]	2.28	2.00	2.11	2.12	2.20	2.27	2.20	2.18	2.54	2.71	2.29	2.18	2.52	

OEMs

Fleets

Regulators

R/D Community

Attributes and Regulations

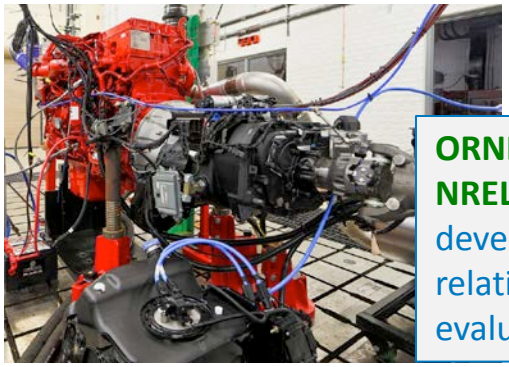
EPA P2 GHG Regulations – National Lab Support

Accurate measures of trucking activity help regulations reflect what happens in the real world and assess impacts on vehicle performance

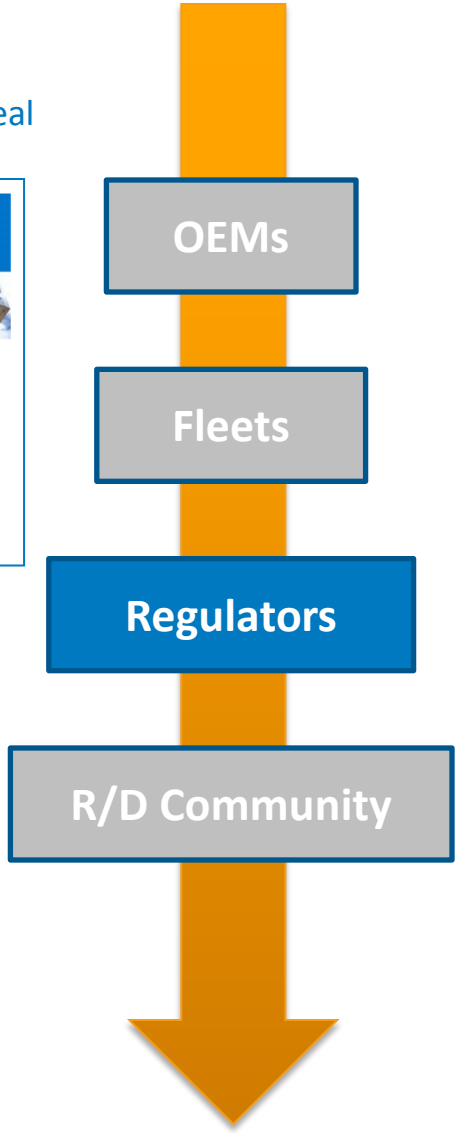
EPA GHG Certification of Medium- and Heavy-Duty Vehicles: Development of Road Grade Profiles Representative of US Controlled Access Highways

NREL is working with **EPA** to refine MD/HD duty cycles to be used in GEM models for GHG regulation

1. Development of vocational duty cycles
2. Generation of road grade profiles for highway cruise cycles



ORNL is working with **EPA**, and in cooperation with **NREL**, **CARB**, **Cummins**, **Eaton**, **Allison**, and **ICCT** to develop a host of proposed test procedures relating to "power pack" and engine-in-the-loop evaluation of MD and HD trucks



Attribute: Aerodynamic Drag

Advanced Powertrain & ITS Evaluations – Truck Platooning

Guide R/D process with real world estimations of expected benefit

Objectives:

- Evaluate fuel savings potential of semi-automated truck platooning of line haul trucks under controlled track testing;

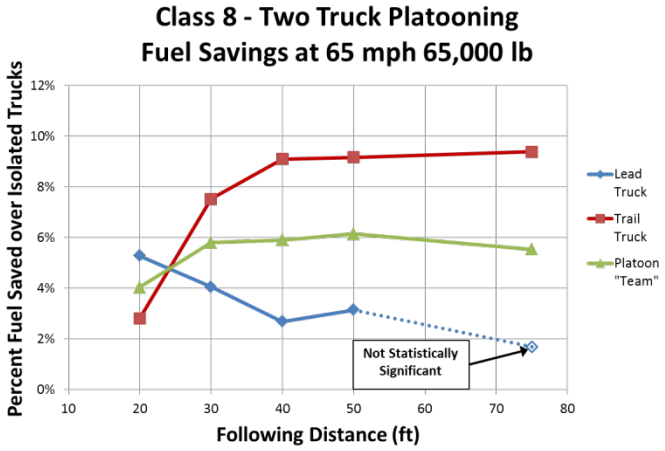
Project Partners:

- NREL – test design, project coordination, and analysis;
- Peloton – vehicle platooning hardware and controls, technical data and information;
- Intertek – vehicle procurement and track testing;
- PACCAR – test trucks.

Results:

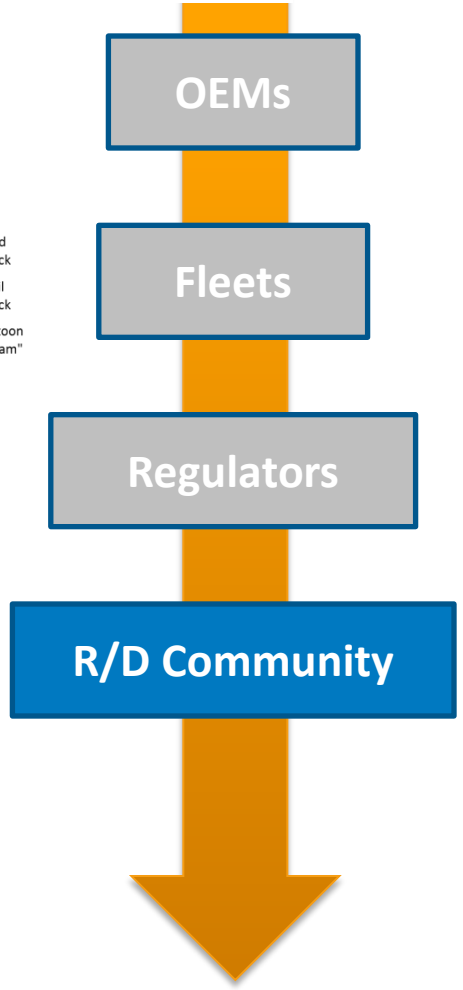
Significant line-haul fuel savings possible through platooning:

- Tests showed fuel savings for the lead (up to 5.3%) and trailing (up to 9.7%) trucks
- The demonstrated *"team" savings of 6.4%* could be an attractive return on investment for a fleet

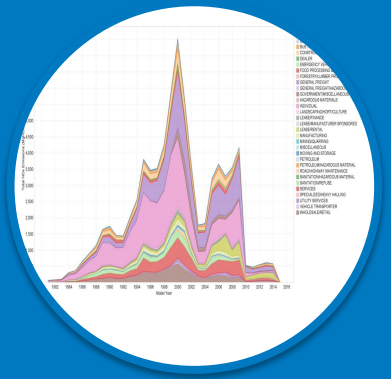


Next Step:

Analysis of in-use fleet operations-logistics data to evaluate "Big Picture" fuel savings potential at fleet and national levels



SCAQMD Fleet DNA Approach: NOx



Task 1: Identification of Appropriate Vocations & Fleets

Task 2: Field Instrumentation for Drive Cycle Data Collection

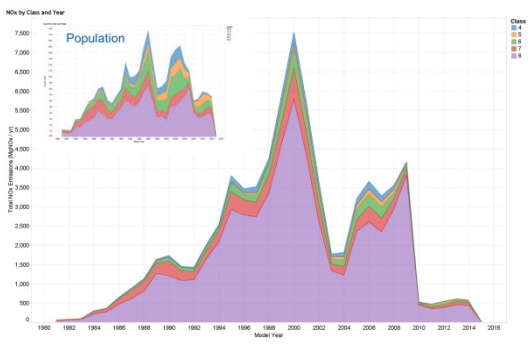
Task 3: Simulation and Analysis for Powertrain and Technology Assessment

Q4- CY2014 → **Q1-Q3 - CY2015** → **Q3-Q4 – CY2015**

SCAQMD Fleet DNA Project : Task 1

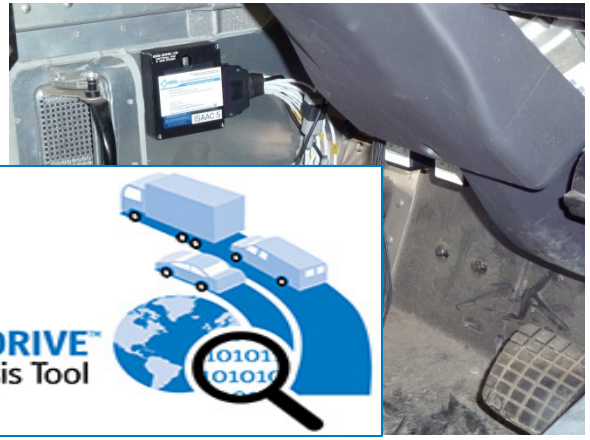
Lead: Mike Lammert (PI), National Renewable Energy Laboratory (NREL)

Funded by: South Coast Air Quality Management District (AQMD) — *Cleaning the air that we breathe...*



Goals/Objectives

- Task 1: Identification of Appropriate Vocations & Fleets
  - Utilized registered vehicle population database, vehicle miles traveled (VMT) database, fuel consumption databases and emissions studies
- Task 2: Field Instrumentation for Drive Cycle Data Collection
  - Top 3 identified vocations from Task 1 chosen
  - At least 30 vehicles for 3 weeks from each vocation; multiple operators
  - Approximately 450 vehicle days of operation *for each vocation* analyzed together using NREL's Drive Analysis Tool
    - Raw data stays with NREL not delivered to SCAQMD
  - Statistics and aggregates used to form a picture of the bell curve of real world operation for each vocation
    - Not looking at individual driving events & activities
- Task 3: Simulation and Analysis for Powertrain and Technology Assessment
  - Exercise models of vehicles on all real observed days of operation
  - Sweep technology solution options such as aerodynamics, low rolling resistance, engine sizing, EV, PHEV, HEV & HHV, B20 & natural gas to estimate impact, benefit & feasibility



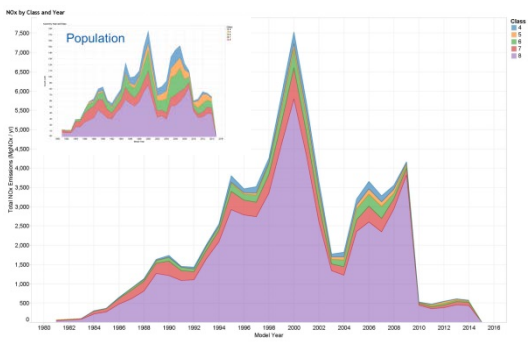
Background and Value

- Identifies workable technology solutions for high impact vehicle populations from a data driven analysis view rather than a top down assumed vocation & technology fix view
  - Biggest bang for the buck approach

SCAQMD Fleet DNA Project : Task 2

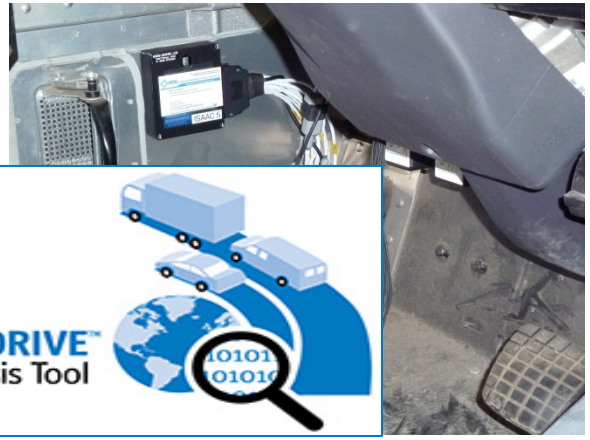
Lead: Mike Lammert (PI), National Renewable Energy Laboratory (NREL)

Funded by: South Coast Air Quality Management District — *Cleaning the air that we breathe...*



Goals/Objectives

- Task 1: Identification of Appropriate Vocations & Fleets
  - Utilized registered vehicle population database, vehicle miles traveled (VMT) database, fuel consumption databases and emissions studies
- Task 2: Field Instrumentation for Drive Cycle Data Collection
  - Top 3 identified vocations from Task 1 chosen
  - At least 30 vehicles for 3 weeks from each vocation; multiple operators
  - Approximately 450 vehicle days of operation *for each vocation* analyzed together using NREL's Drive Analysis Tool
    - Raw data stays with NREL not delivered to SCAQMD
  - Statistics and aggregates used to form a picture of the bell curve of real world operation for each vocation
    - Not looking at individual driving events & activities
- Task 3: Simulation and Analysis for Powertrain and Technology Assessment
  - Exercise models of vehicles on all real observed days of operation
  - Sweep technology solution options such as aerodynamics, low rolling resistance, engine sizing, EV, PHEV, HEV & HHV, B20 & natural gas to estimate impact, benefit & feasibility



DRIVE™ Analysis Tool

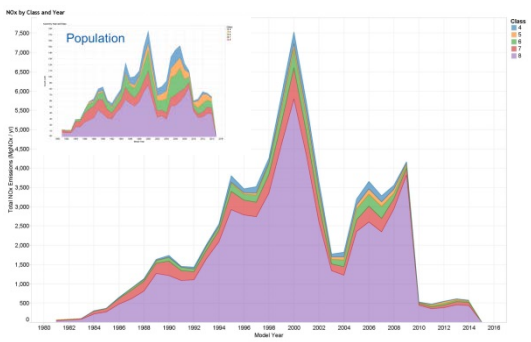
Background and Value

- Identifies workable technology solutions for high impact vehicle populations from a data driven analysis view rather than a top down assumed vocation & technology fix view
  - Biggest bang for the buck approach

SCAQMD Fleet DNA Project : Task 3

Lead: Mike Lammert (PI), National Renewable Energy Laboratory (NREL)

Funded by: South Coast Air Quality Management District — *Cleaning the air that we breathe...*



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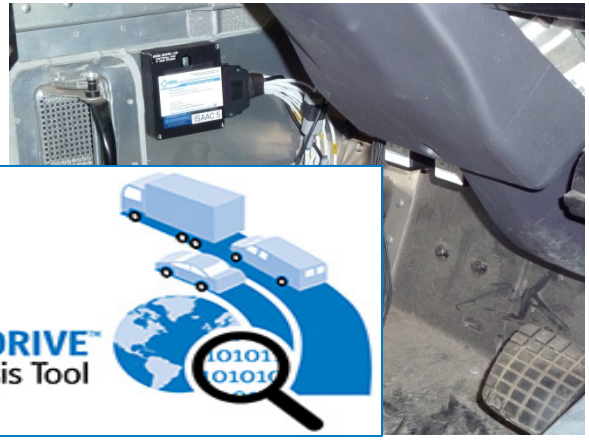

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Follow on SCAQMD / NREL Project

SCAQMD Commercial Zero Emission Vehicles (ComZEV) Roadmap

Project Goals:

- NREL and Ricardo propose the development of a detailed commercial vehicle technology roadmap to accelerate adoption of near-zero and zero-emissions vehicles operating in Southern California that:
  - evaluates vehicle technology options
  - Identifies emissions benefits (both NO_x and CO_2)
  - Defines current cost and realistic expectations of future cost reductions
  - Identifies ***total cost of ownership*** and other corporate benefits

- Enables prediction of potential ***technology adoption rates*** and impacts on fleet (vehicle parc)emissions, including NO_x and CO_2

- The time frame for the roadmap would focus on commercial vehicle technology options through 2023, 2032, 2050.

Data Driven Approach to Analyze Attributes

Data from Field Evaluations helps populate FleetDNA Database – define usage

DOE Analysis Tools (Autonomie, DRIVE, FASTSim, AFleet, etc.) used to analyze and investigate impacts of vehicle attributes & technology in specific usage

Published information and data used to identify which attributes have biggest effect on mpg, emissions, ROI

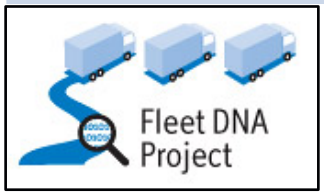
Collect Lab and Field Data

Capture, Store and Analyze

Explore & Optimize

Communicate & Inform

Quantify Technology Attributes for Individual Vocations



Database of Usage Data

Drive Cycle Tool

System Simulation Tool

Lifecycle cost / GHG tool (ANL)

Vehicle Modeling/ Simulation (ANL)

Thank You!

Questions?

Kevin.walkowicz@nrel.gov