CALIFORNIA
AIR RESOURCES BOARD

EMFAC202x

An Update to California On-road Mobile Source Emissions Inventory

Mobile Source Analysis Branch
Air Quality Planning and Science Division
California Air Resources Board

October 2, 2019

Public Process

- User needs workgroup – March 2019
- First public workshop – October 2019
- Second and third public workshop – summer/fall 2020
- New web-based interface
- EMFAC202x release (late 2020/early 2021)

Agenda for Today's Workshop (Methodology & Data Updates)

AM Session

i. Background
ii. Major Updates
iii. New EMFAC Application
iv. Fleet Characterizations
v. Vehicle Activity
vi. Emission Rates (Part 1)

PM Session

vii. Emission Rates (Part 2)
viii. Motorcycle activity and Emissions
ix. Plug-in Hybrid Electric Vehicle (PHEV) Module
x. Energy Module
xi. Freight Forecasting

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Background

- Supports California Air Quality Planning
  - U.S. EPA approves EMFAC model for use in California's State implementation Plans and Transportation Conformity
  - Can utilize regional-specific vehicle activity data from transportation planning agencies (e.g., MPOs, COGs)
  - Accounts for unique, California-specific regulations and fleet mix
- Informs Regulatory Development
  - Is used to develop regulatory specific criteria and greenhouse gas emissions inventories: e.g. HD Low NOx, Innovative Clean Transit
- Supports Updates to Scoping Plan

A Decade of EMFAC Updates

- Integrating In-Use Diesel Regulations
- Modular approach

EMFAC2011
Released: Sep. 2011

- Single Package
- Reflecting Advanced Clean Cars, 2014 Amendments to Truck and Bus Rule, and Heavy duty GHG Regulations

EMFAC2014
Released: Dec. 2014

- 3-Year Cycle
- An extension of the EMFAC2014 framework
- Reflecting measures adopted before 2018

EMFAC2017
Released: Dec. 2017

EMFAC202x
Release: 2020/2021 (*tentative*)

- New web based interface
- New modules for advanced vehicle technologies
- Reflecting measures adopted before 2021
- Latest available fleet, activity, and emissions data

EMFAC202x Major Updates

Fleet Database

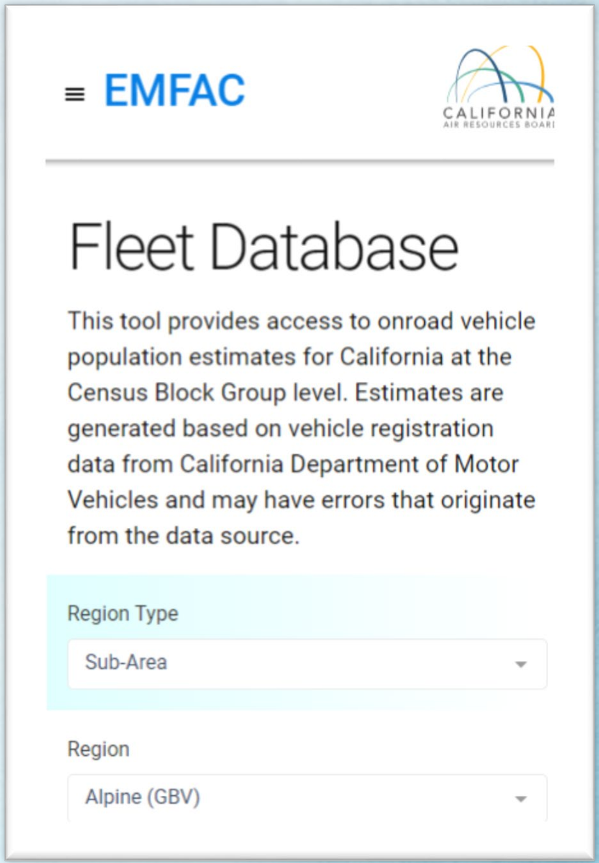
- Web-based tool to provide access to on-road vehicle population estimates at very high spatial resolution

Latest DMV data

Higher Spatial Resolution

Fleet size information

Classification by electric range



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In-Use Emissions Data

Light Duty Surveillance Program

In-Use Verification Program

Truck & Bus Surveillance
(Class 7 – 8 trucks)
(including Alt. Diesel Fuel)

Medium Heavy Duty Truck
(Class 4 – 6)

Medium Duty Vehicle
(Class 2b – 3)

Alternative Fueled Trucks
CE-CERT/WVU

Motorcycles Dynamometer & PEMS
(Data from this test program will be used to support ONMC rulemaking)

In-Use Emissions Data (Cont.)

CARB Heavy Duty OBD Data Collection

Extramural Contract to collect HD In-Use Performance Data through near-road tests and telematics

Real World Emission Testing of Plug-in Hybrids

Brake-wear emissions testing

Activity Profiles

California Vehicle Inventory and Use Survey

Replaces the Federal VIUS (discontinued)

Data collected using a combination of surveys & instrumented vehicles

Collection of truck activity data through Telematics service providers

Information on:

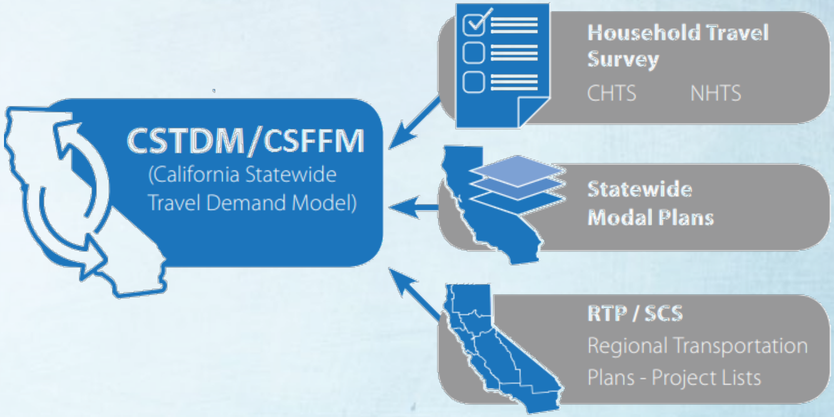
- Vehicles miles traveled
- Idling/hoteling
- Drive cycles

Conceptual Forecasting Frameworks

ZEV forecasting

CEC's Vehicle Choice Models

Improved methodology and inputs



Utilizing Statewide Travel Demand Models to Forecast Vehicle Activity

New Features




Vocational Truck Categories

Three Level Categorization:

1. GVWR
2. Instate/IRP/OOS
3. Body Type

PHEV Module to separately categorize plug-in hybrids

Models high power start emissions

Accounts for electric VMT and charging behavior

Energy Module

Estimates energy consumption by plug-in electric vehicles

Data from more than 50k vehicles are analyzed

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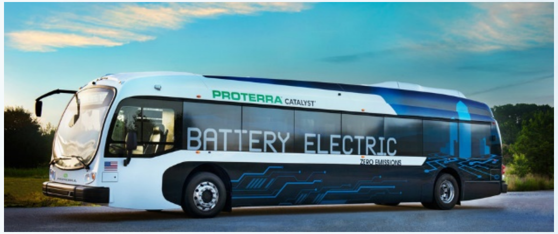
Regulations (Part 1)

Amendments to HD Engine Warranty Requirements

Amendments to HDVIP/PSIP

HD Inspection and Maintenance Program (HD I&M)



Innovative Clean Transit

Airport Shuttle Bus

Advanced Clean Truck Rule

Regulations (Part 2)

Low NOx Omnibus

Advanced Clean Cars 2.0

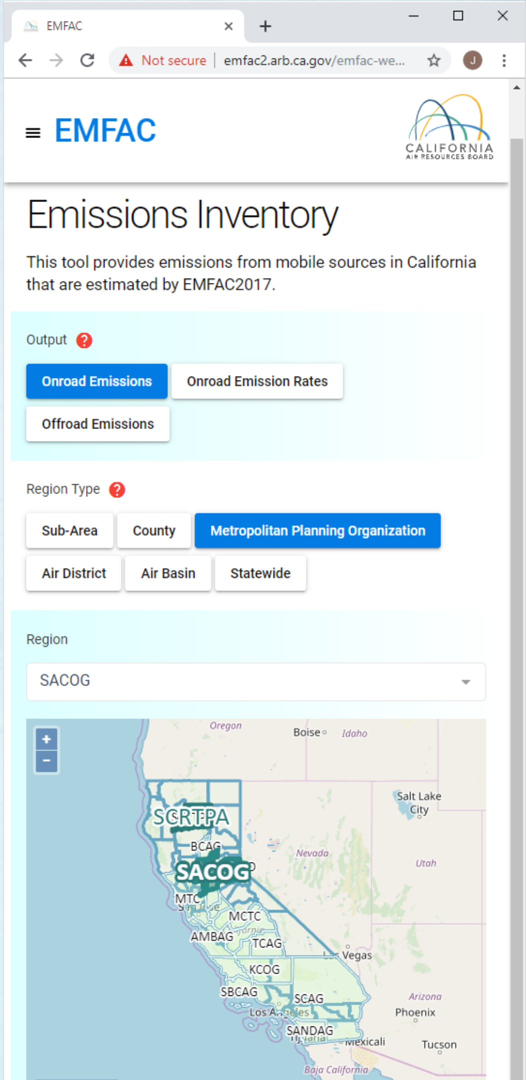
On-Road Motorcycle (ONMC) Rule-making

New EMFAC Application

Integrated Mobile Source Emissions Inventory Web Application

- Provide all features of EMFAC (including “emission rate” and “custom activity” modes) on the web
- Responsive/modern web design to support devices of various screen sizes.
- Interactive user-interface and preprocessed data will be implemented to provide quick access to requested data

Current beta version



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EMFAC202x Windows Application

- Windows Application developed with Python and MySQL
- Now developed in Python 3, more robust testing, streamlined development environment
- Parallelized to take advantage of multiple CPUs
  - ✓ A full EMFAC run (i.e. a statewide run for 2000 to 2050) used to take more than a week. With the parallelization, this will take 30x faster (e.g. ~5 hours in a PC with 50 CPUs).
- Since the new Web Application is provided, the Windows Application would be mostly used to prepare preprocessed data for the web application as well as for research and development.

Light-Duty Vehicles

Fleet Characterization

Latest Vehicle Registration Data

- CARB receives a snapshot of California vehicle registration data every quarter (January, April, July, and October)
- EMFAC uses the counts of vehicle from the October snapshot
- CARB staff have made significant improvement in processing the registration data for use in EMFAC
- EMFAC202x will utilize DMV registration data from 2000 through 2019

Major Data Sources

- California DMV Registration Data (2000 – 2019)
- Polk/IHS VINTelligence Web Service
- CARB Certification Executive Orders (EO)
- VIN stems to identify fuel technologies (PHEV, BEV, BEVx, FCV)

Current Status and Improvements

- Completed analysis of October 2018 Vehicle Registration Data
- Improvements
  - Use Polk/IHS VINTelligence to determine the vehicle types
  - Descriptor fields (e.g., type license codes) used to mark off-road vehicles/trailers/vessels
  - A matching algorithm used to find vehicle type based on make/model for records that lack sufficient information

Vehicle Classes Modeled in EMFAC202x

Heavy-Heavy Duty Trucks

Medium Heavy Duty Trucks

Pickups / Vans

Motorcycles

Passenger Vehicles

School Buses

Transit Buses

Motorhomes

In the next few slides you will hear about…

Vehicle Categories		Gross Vehicle Weight	
Light-Duty Vehicles	Passenger Cars	N/A	
	Light-Duty Trucks	≤ 8,500 lbs.	
Light-Heavy Duty Trucks		8,501 – 14,000 lbs.	

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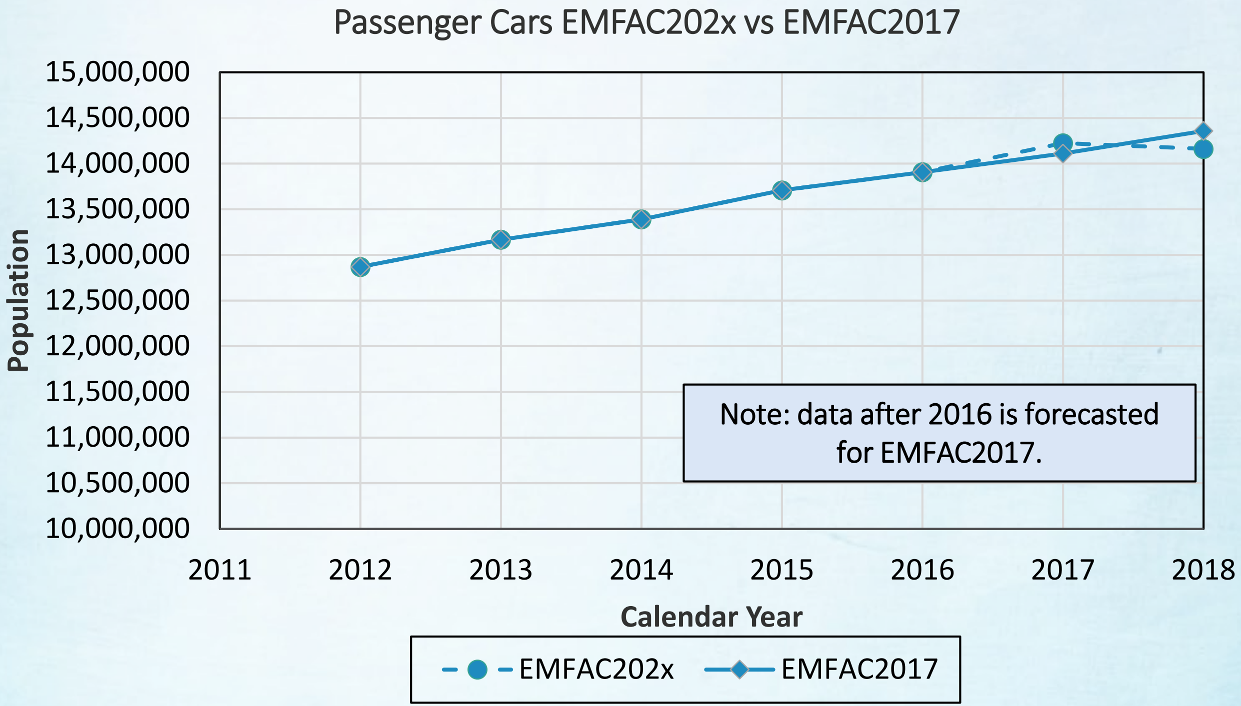
EMFAC202x vs EMFAC2017 Population Gasoline



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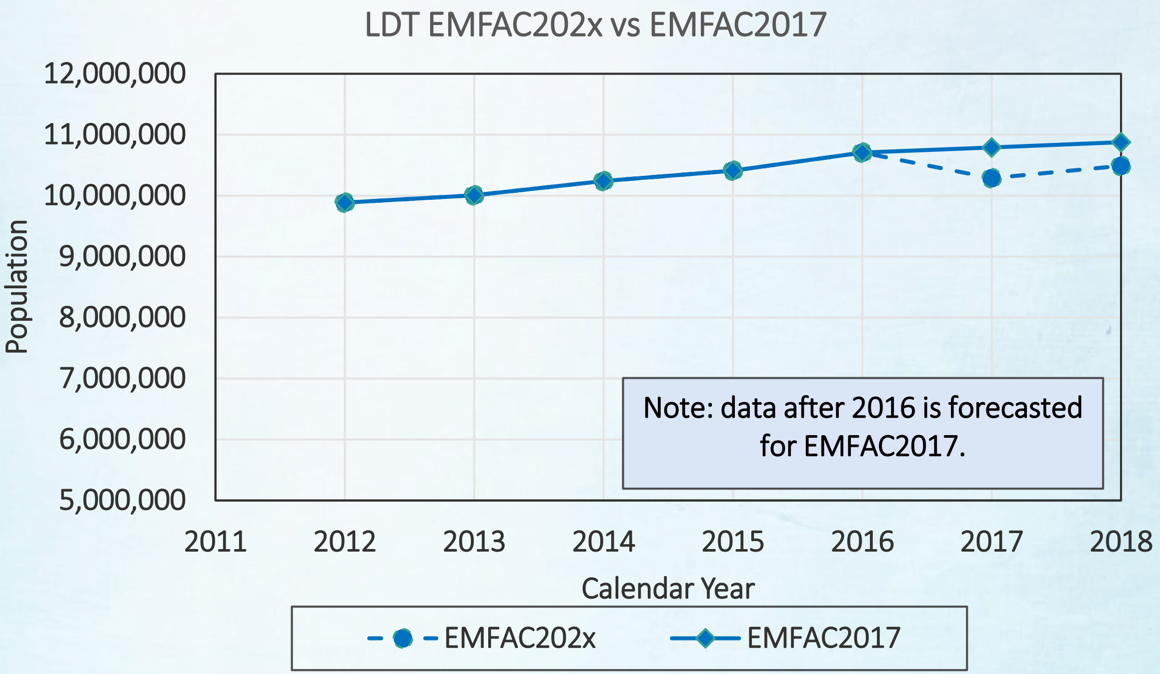
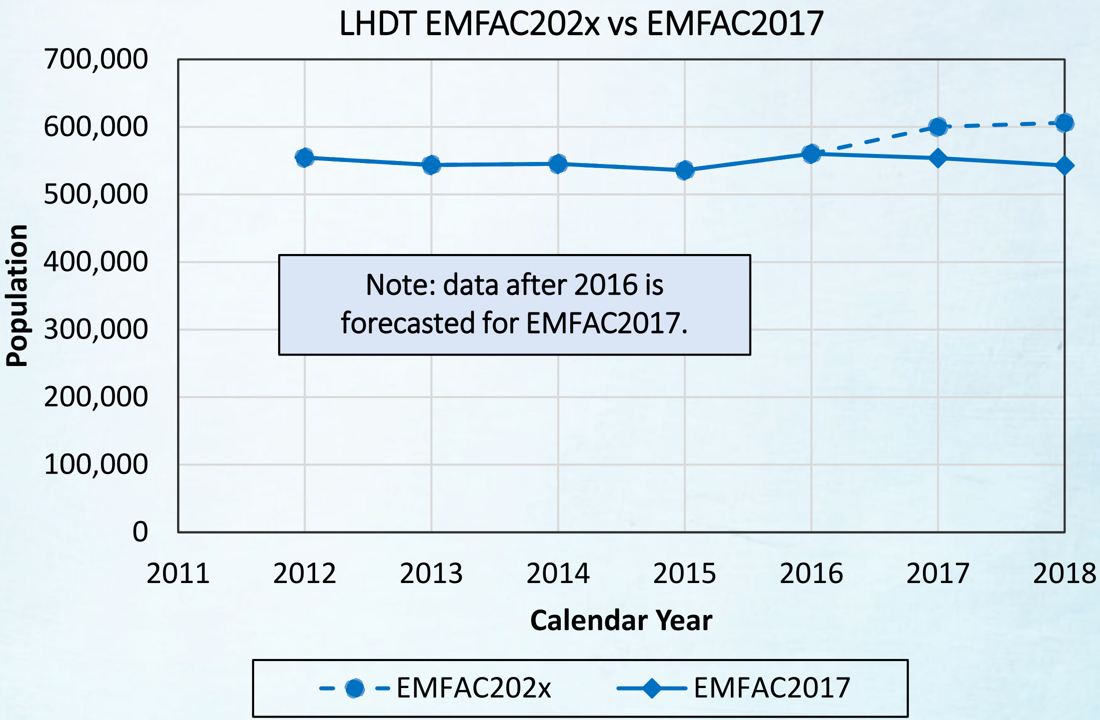


* LDT: Light Duty Trucks with GVWR ≤ 8,500 lbs.

EMFAC202x vs EMFAC2017 Population Gasoline



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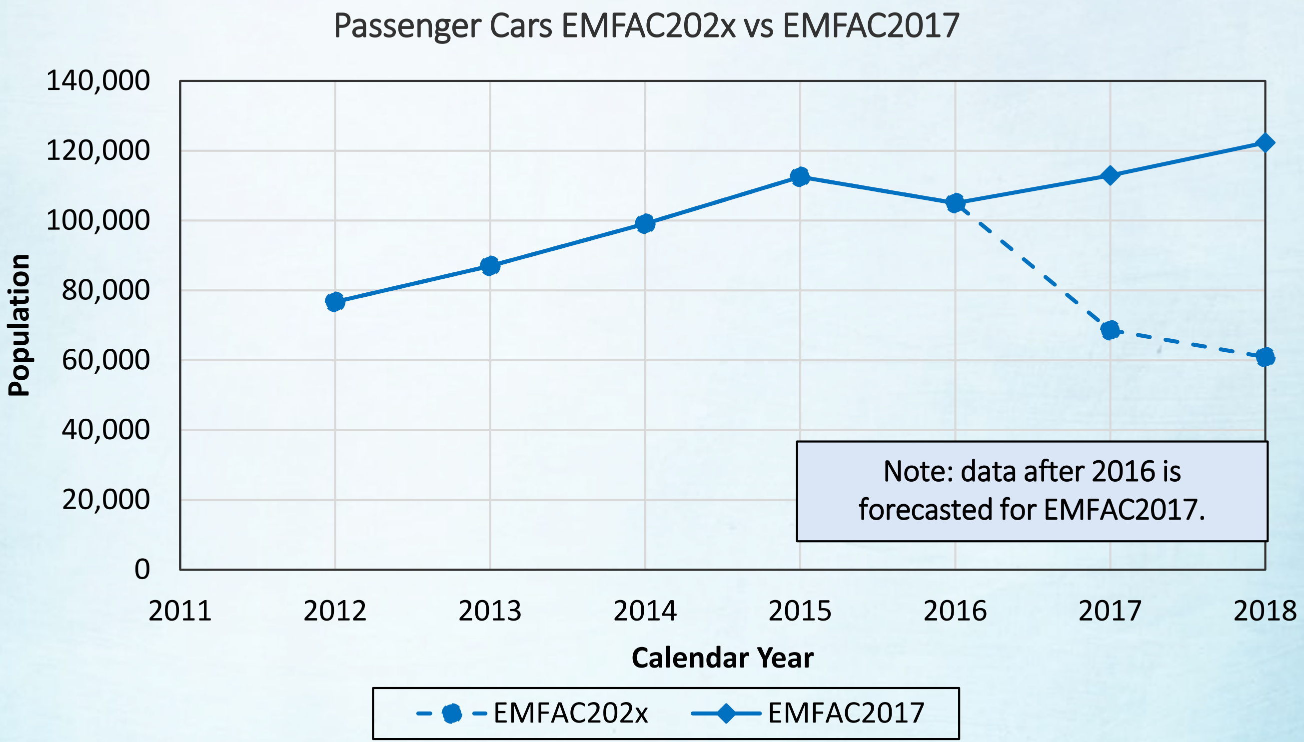
EMFAC202x vs EMFAC2017 Population Diesel



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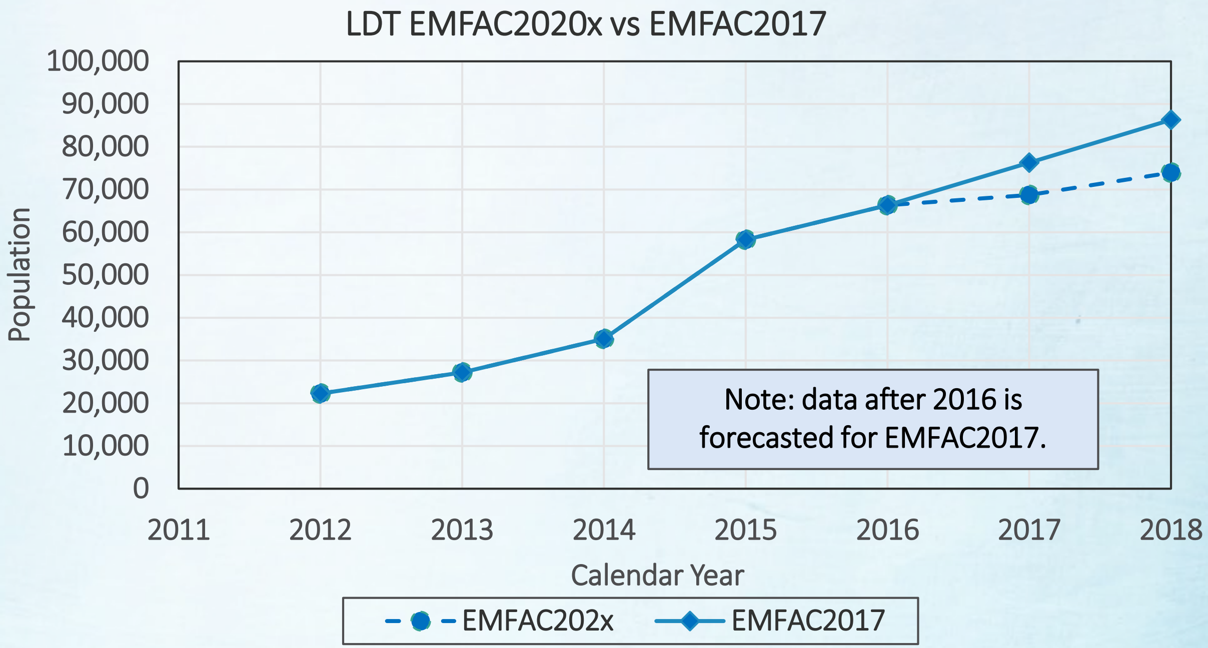
EMFAC202x vs EMFAC2017 Population Diesel



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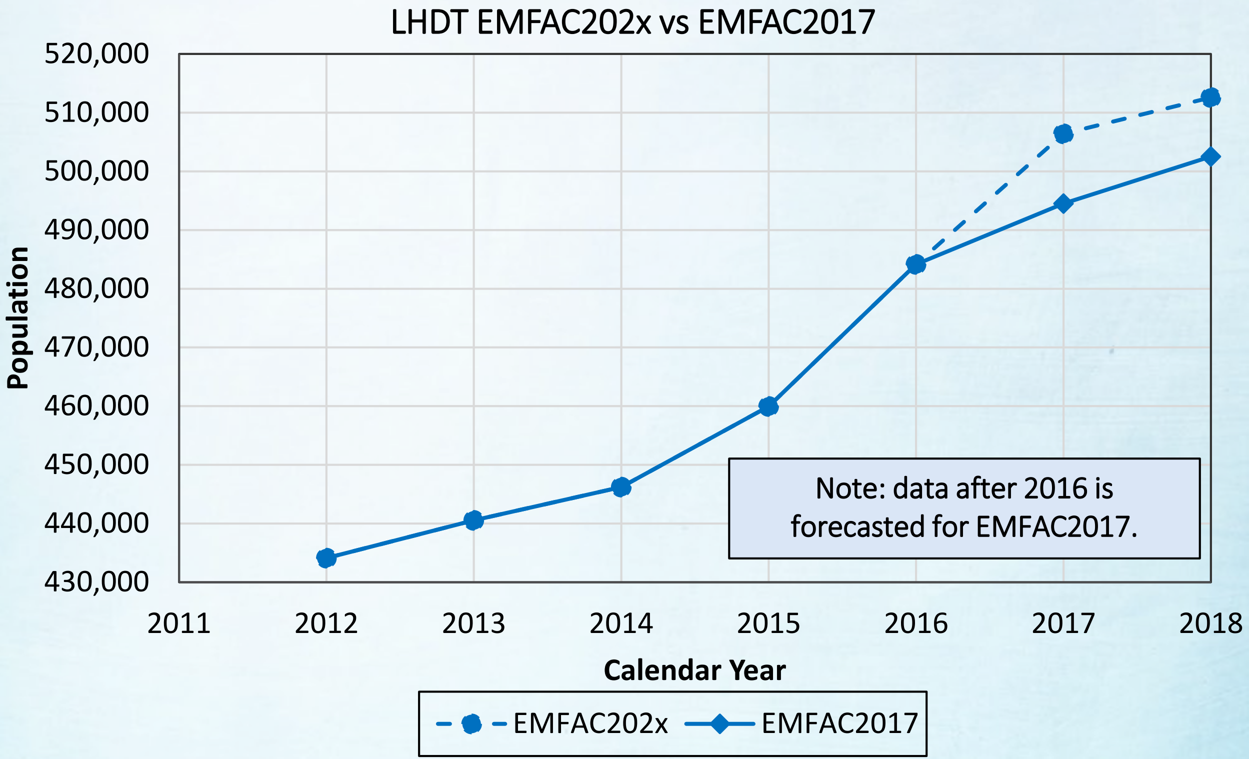
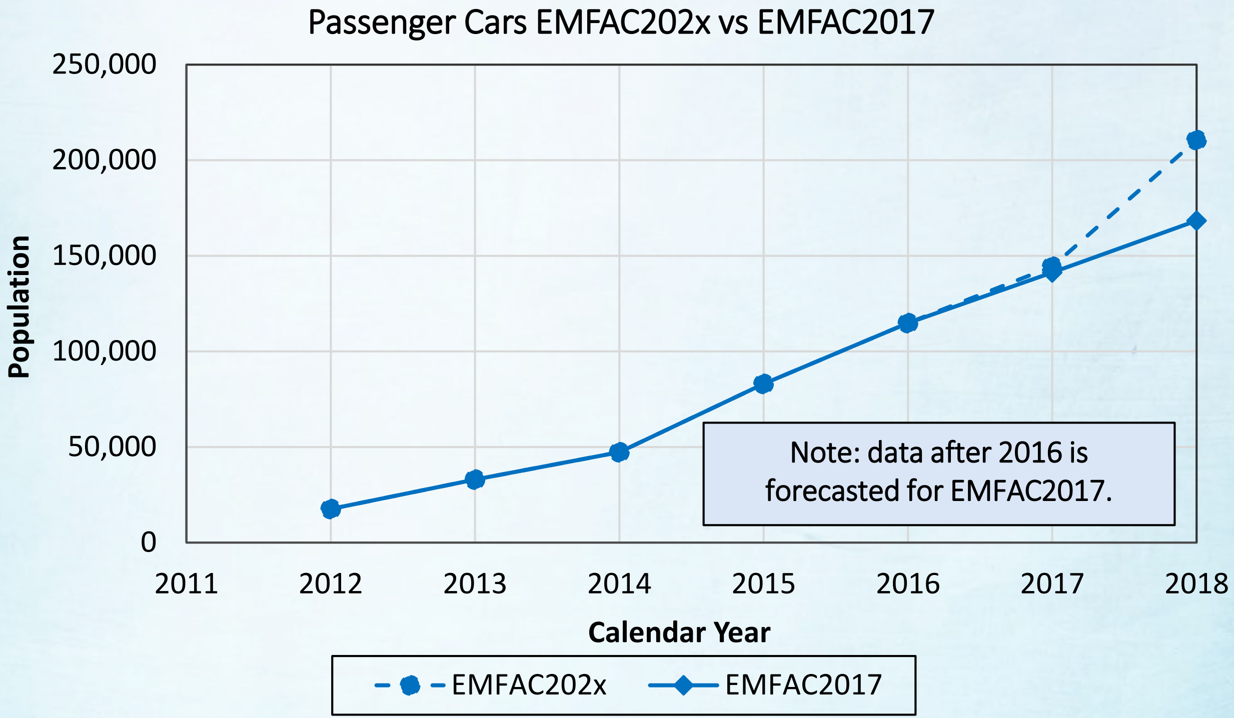
EMFAC202x vs EMFAC2017 Population Diesel



EMFAC202x vs EMFAC2017 Population Electric



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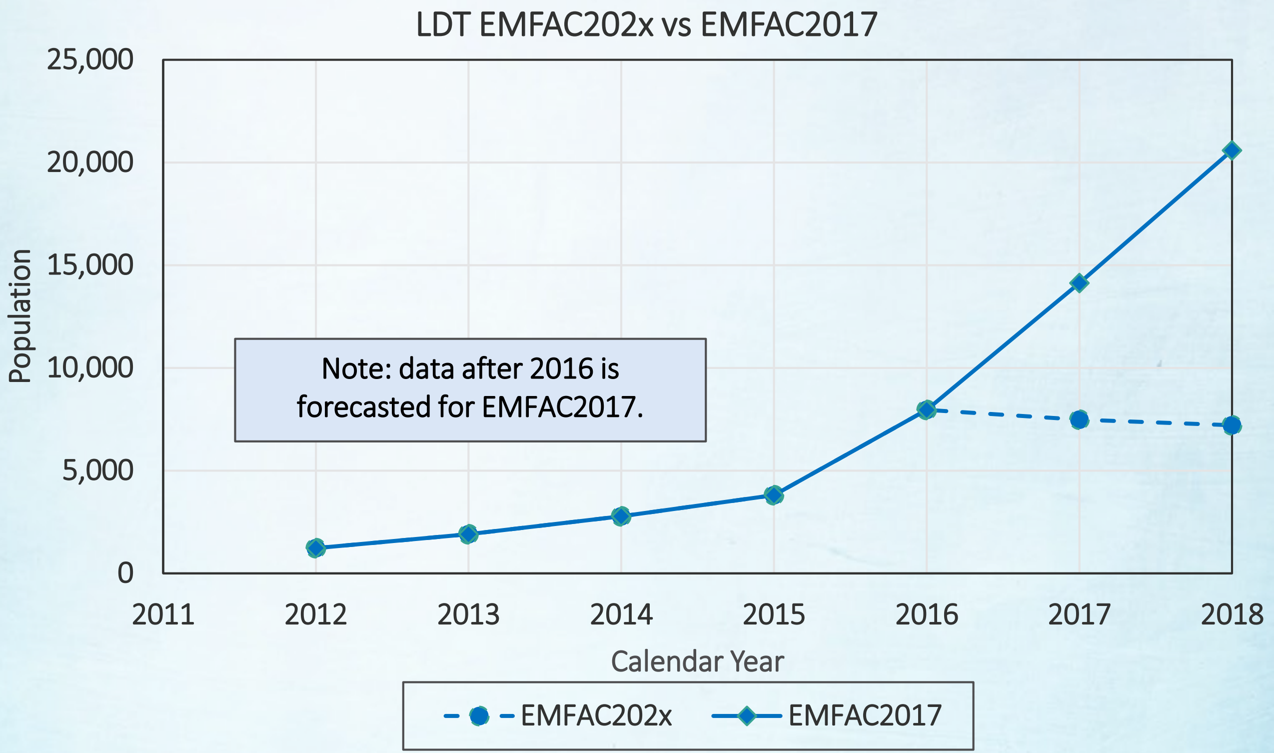
Electric Vehicles : Vehicles with Motive Power of Electric in DMV data (this may not include PHEVs)

EMFAC202x vs EMFAC2017 Population Electric



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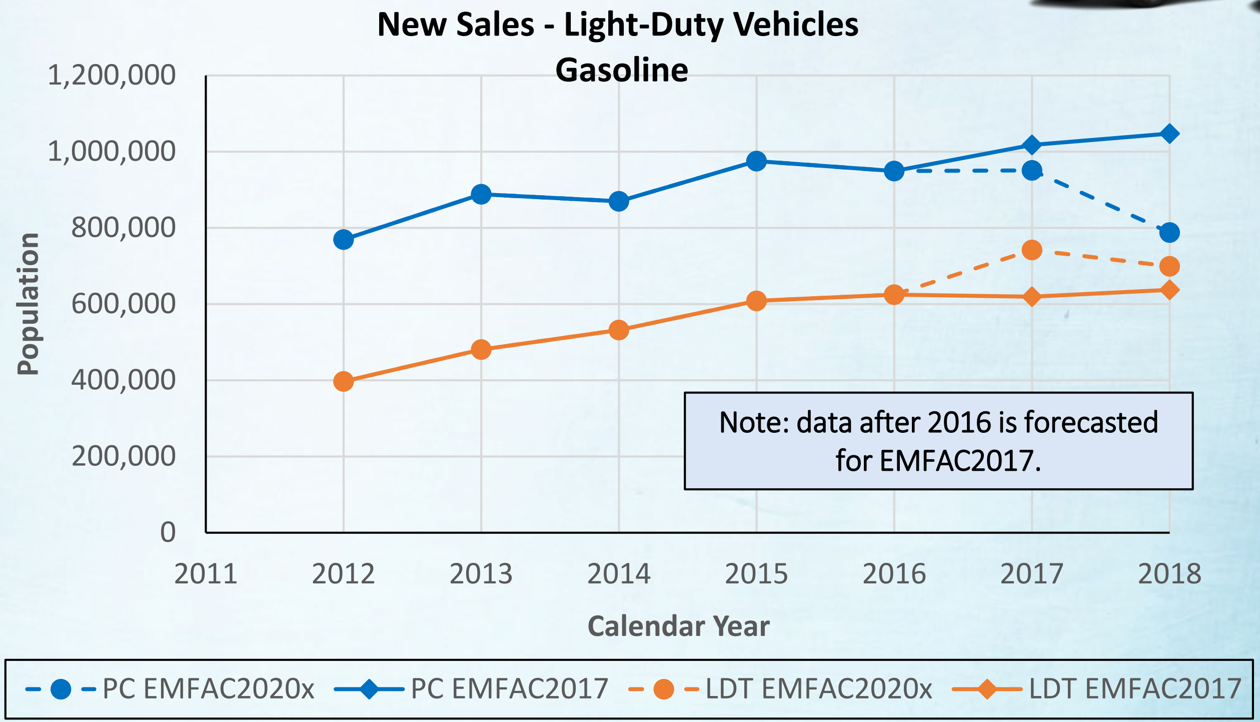
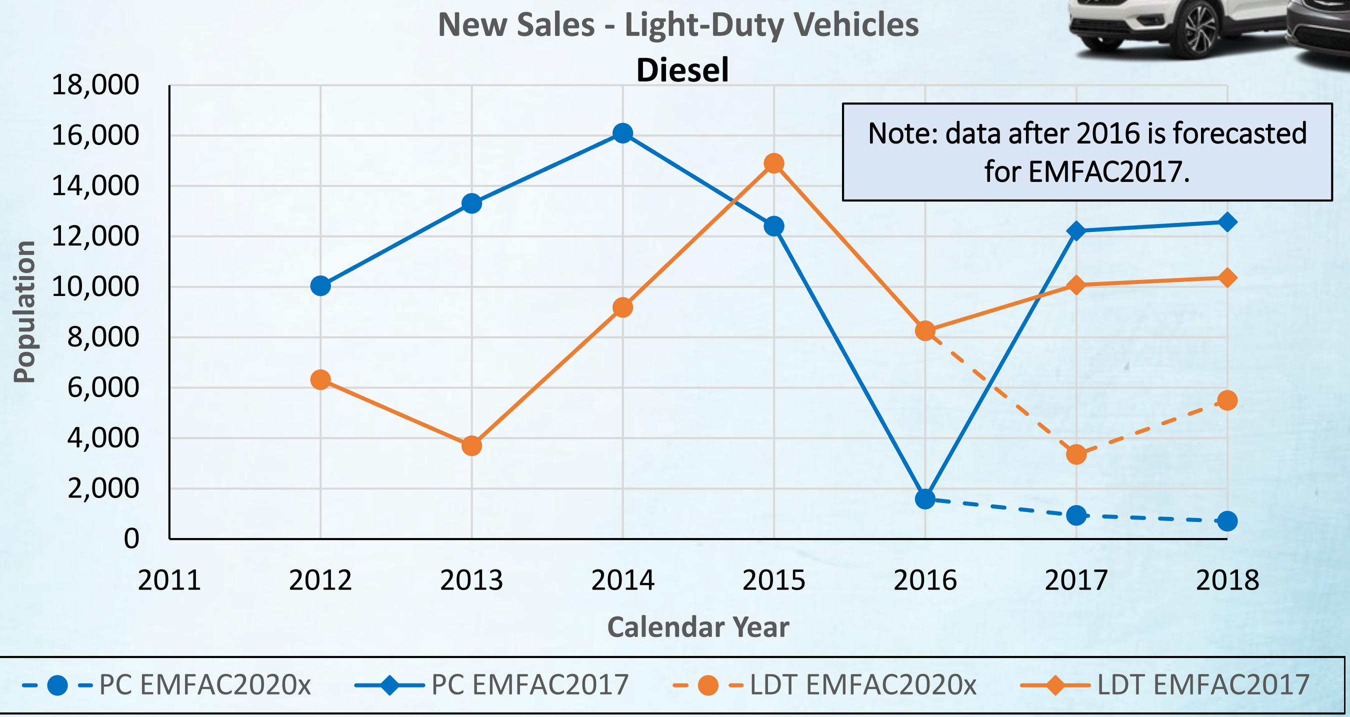
Electric Vehicles : Vehicles with Motive Power of Electric in DMV data (this may not include PHEVs)

New Sales – Light-Duty Vehicles Gasoline



New Sales – Light-Duty Vehicles Diesel



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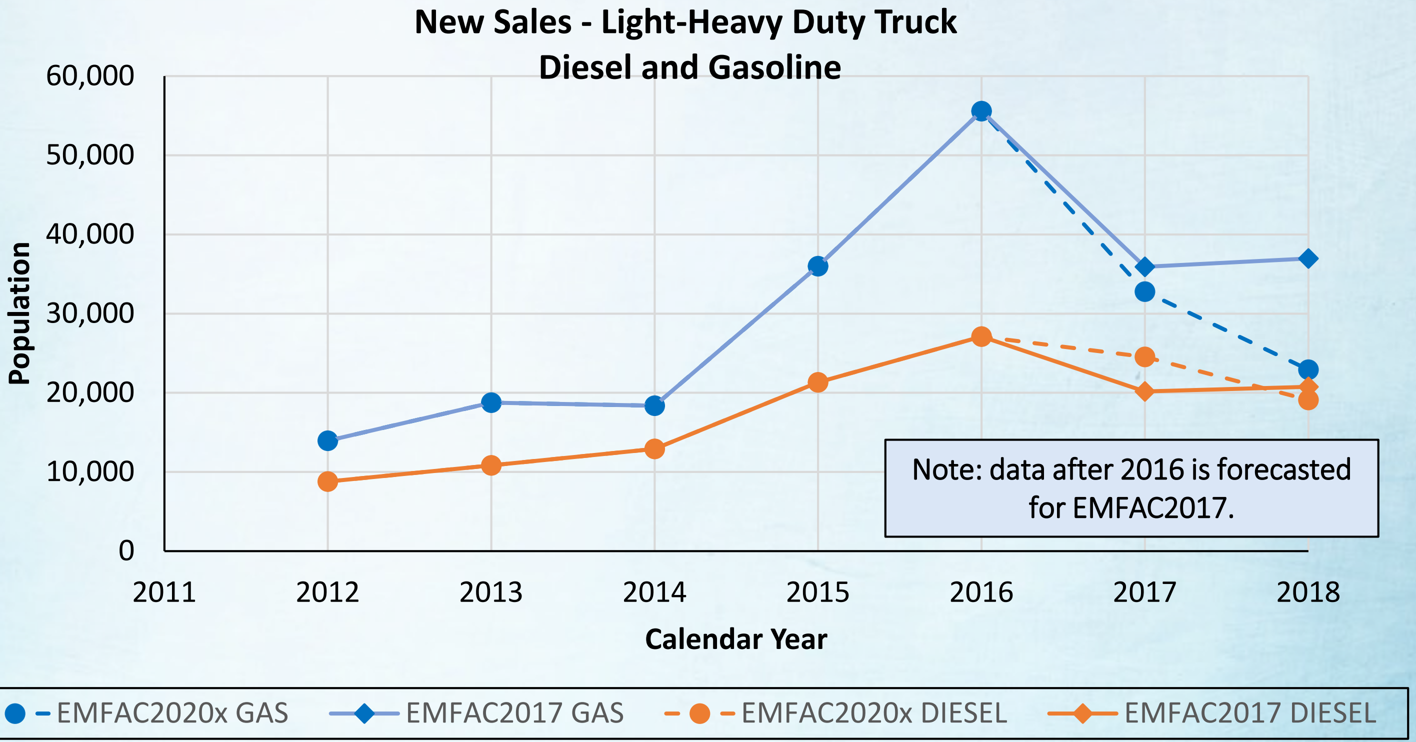
New Sales – Light-Heavy Duty Truck Diesel and Gasoline



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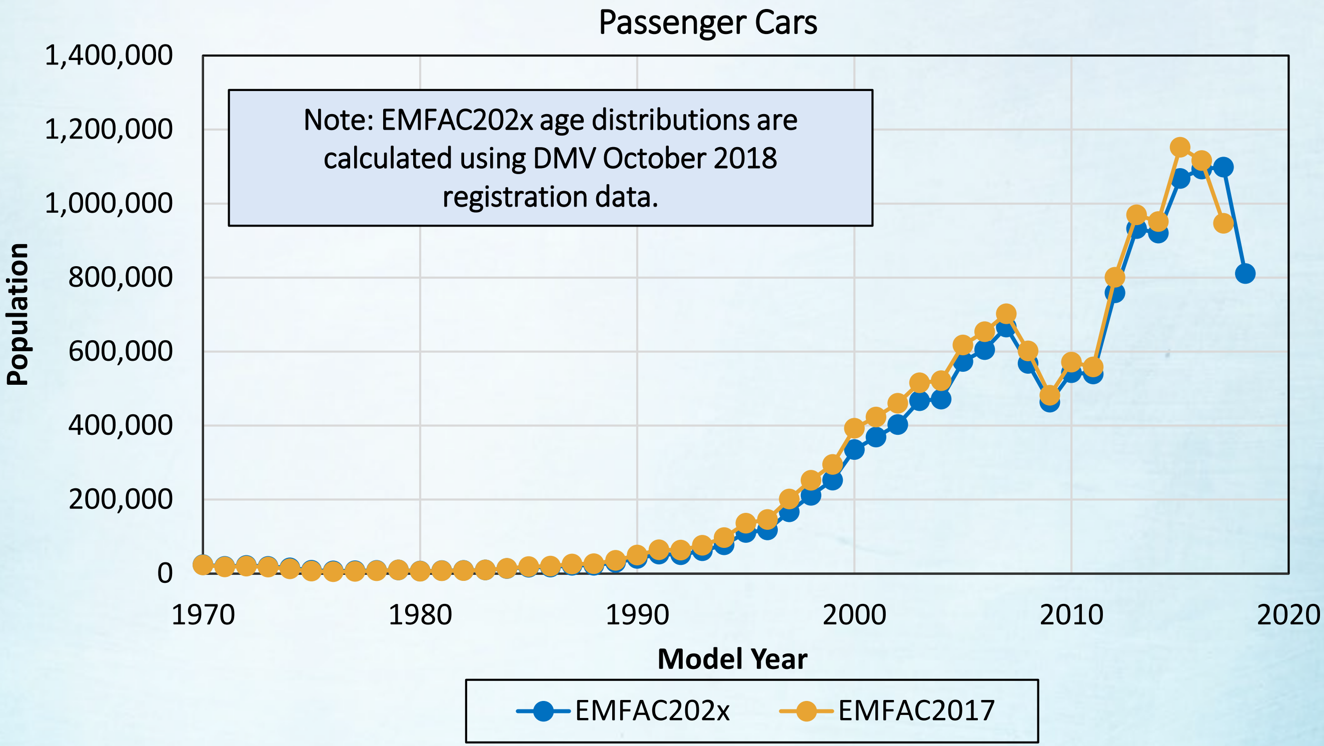
EMFAC202x Age Distribution
All Fuel Types



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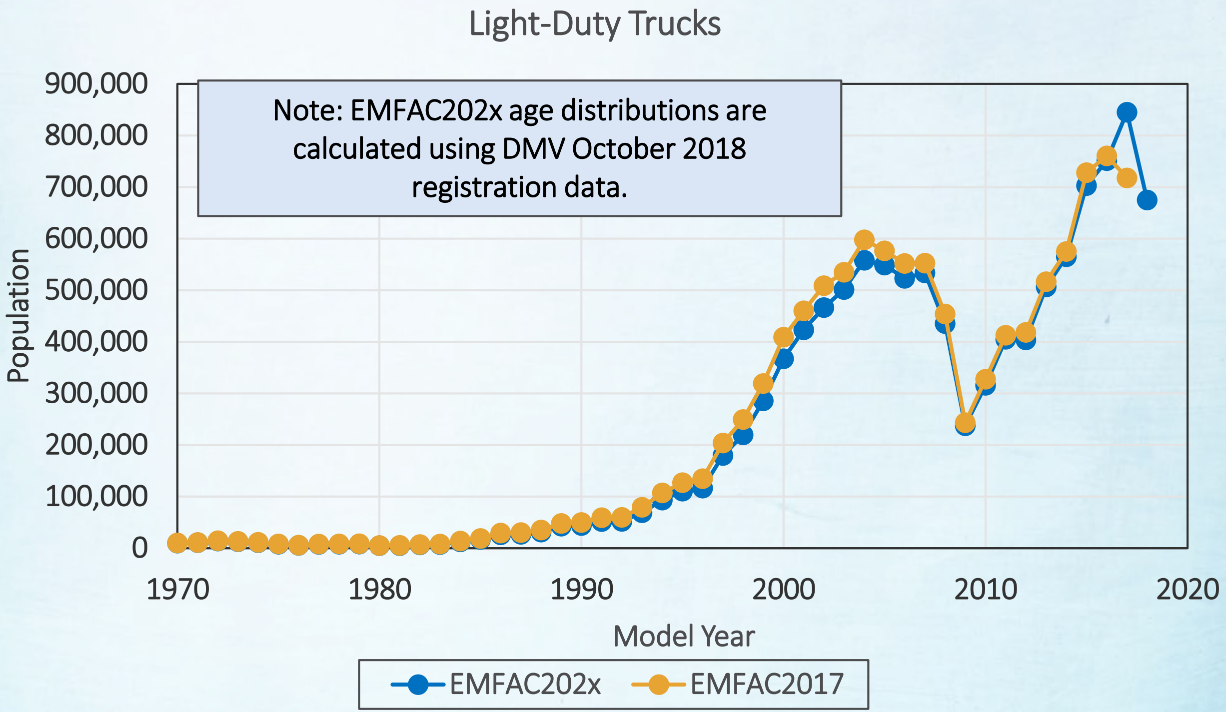
EMFAC202x Age Distribution
All Fuel Types



EMFAC202x Age Distribution
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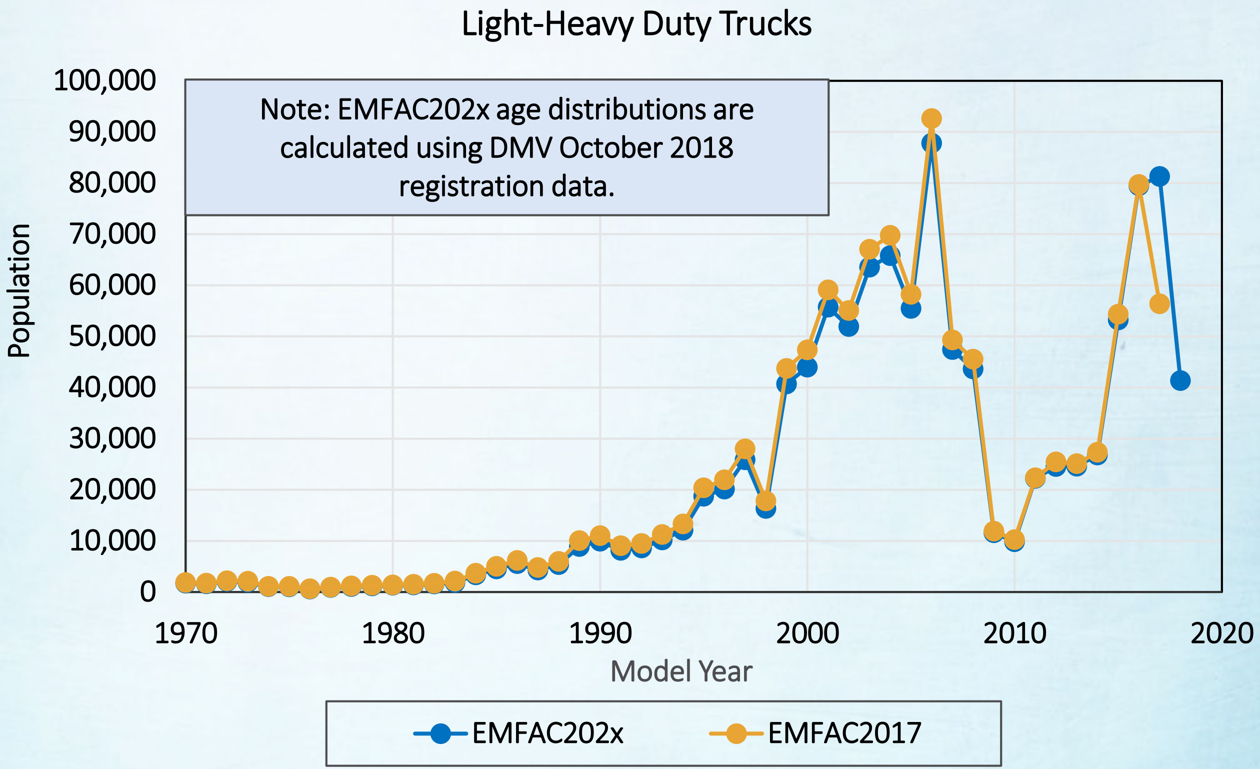

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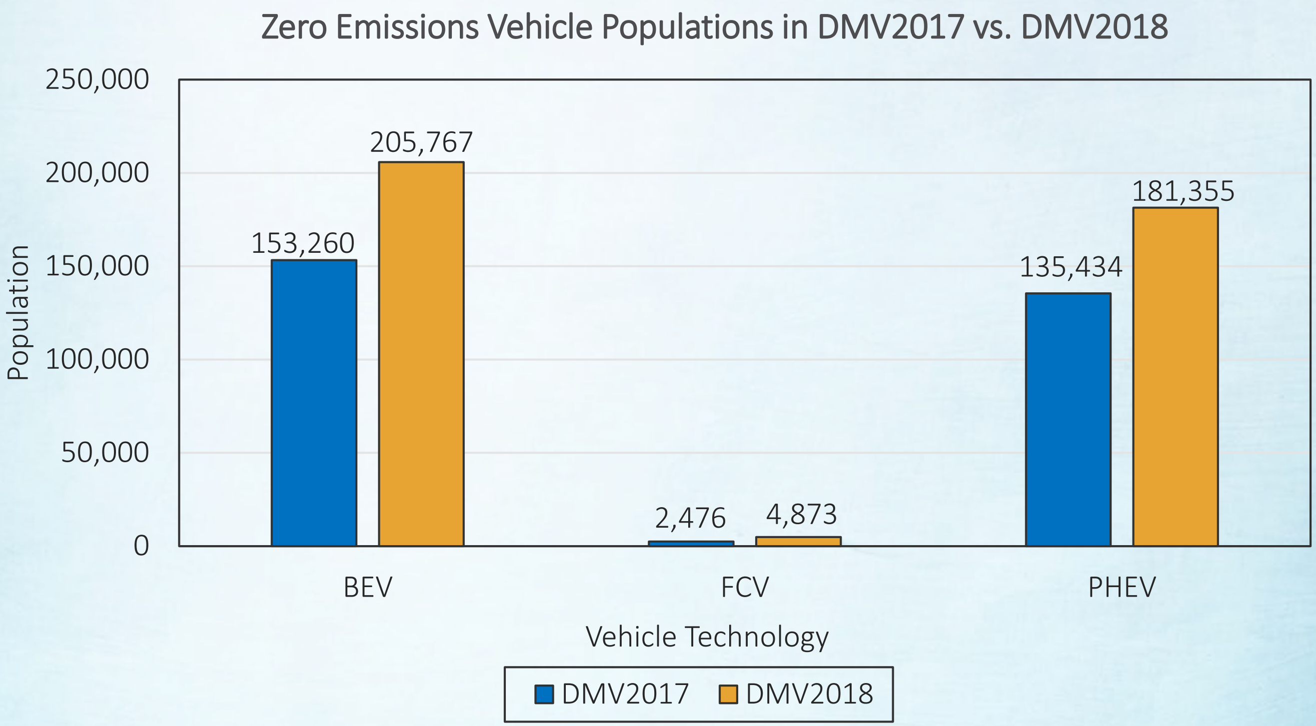
On-road Population of Zero Emission Vehicles



Please note this is the population of "currently" registered vehicles in CA DMV data and <u>is not</u> equivalent to cumulative sales

Population Counts for CA Registered Vehicles

Vehicle Category	Gross Vehicle Weight Rating	2016	2017	2018
Passenger Cars	N/A	14.6M	14.4M	14.4M
Light-Duty Trucks	GVWR < 6000 lbs.	6.9M	7.0M	7.1M
	6,001 - 8,500 lbs.	5.2M	5.4M	5.5M
Light-Heavy Duty Trucks	8,501-10,000 lbs.	872,000	911,000	918,000
	10,001-14,000 lbs.	185,000	197,000	201,000
Medium-Heavy Duty Trucks	14,001-16,000 lbs.	295,000	303,000	303,000
	16,001-19,500 lbs.			
	19,501-26,000 lbs.			
	26,001-33,000 lbs.			
Heavy-Heavy Duty Trucks	GVWR >33,000 lbs.	222,000	225,000	227,000
Buses	All	79,000	86,000	85,000
Total*		27.2M	27.0M	27.3M

*Totals were obtained from actual data and does not reflect rounding for each category.

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Major Findings

- EMFAC2017 underestimated gasoline truck populations
  - Higher vehicle population for calendar years 2017 and 2018
- Lower passenger car sales and higher light-duty truck sales after 2016
- Counts of electric vehicles are increasing at a rapid rate
- No significant change in the counts of light-duty vehicles by model year is observed (small increase after 2015)

EMFAC vs. GHG: PC and LDT Classification

- The current EMFAC vehicle classification is based on the criteria pollutant certifications – We use the manufacturer certifications to determine vehicle categories
- Federal/CA GHG standards have slightly different definition for cars and trucks than Federal/CA criteria pollutant standards
- An additional field will be added to DMV data to classify passenger cars and trucks according to GHG standards
- Examples of classification discrepancy:

Make Name	Series Name	EMFAC Classification	GHG Classification
Tesla	Model X	Truck	Car
Cadillac	SRX	Truck	Car
Hyundai	Tucson	Car/Truck	Car
Honda	Pilot	Car/Truck	Truck
Acura	MDX/ZDX	Car/Truck	Truck
Buick	Encore	Car	Car/Truck*
Fiat	500X	Car	Car/Truck*

* depending on powertrain, 2WD counts as a car, AWD counts as a truck.

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GHG: Definition for LT vs. PC

	DOT Definitions (49 CFR Part 523; NHTSA CAFE and EPA GHG Stds.)	
Vehicle Characteristic	**Passenger Car**	**Light Truck***
GVWR (lbs.)	<=10,000	<=8,500
Curb Weight (lbs.)	<=6,000	<=6,000
Frontal Area (ft.^2)		<=45
Primary Purpose: Transportation of Persons/Property	Persons	
Total Passenger Capacity	<=10	>10
Provides Temporary Living Quarters		Yes
Open Bed for Transportation of Property		Yes
Ratio: Cargo Volume/Passenger Volume (all seats installed)		>1.0
Expandable Cargo Area (3-row seat min.)		Yes
4-wheel Drive or AWD		Yes
GVWR (lbs.)		>6,000
Approach Angle (degrees)		>=28
Breakover Angle (degrees)		>=14
Departure Angle (degrees)		>=20
Running Clearance (cm.)		>=20
Axle Clearances (cm.)		>=18
Rear Passenger Capacity		
Open Cargo Area Length (in.)		

* A vehicle can be classified as a truck under DOT definitions if it meets one of the following conditions:

1. GVWR <=8,500 lbs., Curb Weight <=6,000 lbs., Frontal Area <=45 ft.^2, and has one of the characteristics in the yellow boxes.
2. GVWR <=8,500 lbs., Curb Weight <=6,000 lbs., Frontal Area <=45 ft.^2, and has one of the characteristics in the orange boxes and 4 out of the 5 characteristics in the green boxes.

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EMFAC vs. GHG classification Results Comparison

Model Year 2012 – 2018

	DMV	GHG Definition		
		Passenger car	Light-Duty Truck	Grand Total
Criteria Definition	Passenger car	60%	1%	**61%**
	Light-duty truck 1 (GVWR <6000 lbs., ETW <= 3750 lbs.)	3%	1%	**5%**
	Light-duty truck 2 (GVWR <6000 lbs., ETW 3751-5750 lbs.)	8%	12%	**20%**
	Medium-duty vehicle (GVWR 6000-8500 lbs.)	0%	14%	**14%**
Grand Total		**71%**	**29%**	**100%**

Model Year 2018 Only

	DMV	GHG Definition		
		Passenger car	Light-Duty Truck	Grand Total
Criteria Definition	Passenger car	52%	1%	**54%**
	Light-duty truck 1 (GVWR <6000 lbs., ETW <= 3750 lbs.)	2%	2%	**4%**
	Light-duty truck 2 (GVWR <6000 lbs., ETW 3751-5750 lbs.)	10%	16%	**26%**
	Medium-duty vehicle (GVWR 6000-8500 lbs.)	0%	17%	**17%**
Grand Total		**65%**	**35%**	**100%**

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Heavy-Duty Vehicles

Fleet Characterization

Heavy Duty Trucks are Diverse!

New Vehicle Categories

- New fleet groups are desired to assist with more focused emissions reduction programs
  - Freight hubs, advanced clean trucks, local communities, etc.

As e-commerce continues to flourish, last mile trucks become increasingly large contributors to regional VMT

- Medium Heavy Duty Trucks (i.e., T6) are now divided into four different weight classes (Class 4–7)
- New weight splits and fleet groups will allow for more specificity in EMFAC activity & emission rate updates to better support high priority programs

On-Road Vehicle Population

- Primary Data Sources Include:
  - DMV Vehicle Registration Database
  - International Registration Plan (IRP) Clearinghouse Data
  - International Fuel Tax Agreement (IFTA) Data
- Other Sources Used for HD Vehicle Characterization
  - List of VINs from California Highway Patrol (CHP) School Bus Inspections
  - TRUCRS data for diesel Truck and Bus Rule
  - National Transit Database (NTD) data
  - List of VINs from Major Ports

State of California Department of Motor Vehicles

INTERNATIONAL REGISTRATION PLAN, INC.

CALIFORNIA HIGHWAY PATROL

Federal Transit Administration

THE PORT OF LOS ANGELES LA

Port of LONG BEACH The Green Port

PORT OF OAKLAND

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Identifying Fleet Groups

- Fleet Groups based on DMV Body Type Information:
  - Heavy Heavy Duty Single Concrete/Transit Mix Trucks
  - Heavy Heavy Duty Single Dump Trucks
  - Heavy Heavy Duty Solid Waste Collection Vehicles
  - Medium and Heavy Heavy Duty Instate Tractors
  - Medium Heavy Duty Instate Delivery Vehicles

- Fleet Groups based on Other Data:
  - CAIRP uses DMV's annual CAIRP list
  - Public uses DMV Type License Codes
  - Port uses VIN lists from the Ports
  - Utility uses DMV names/addresses
  - Out of State uses IRP and IFTA data

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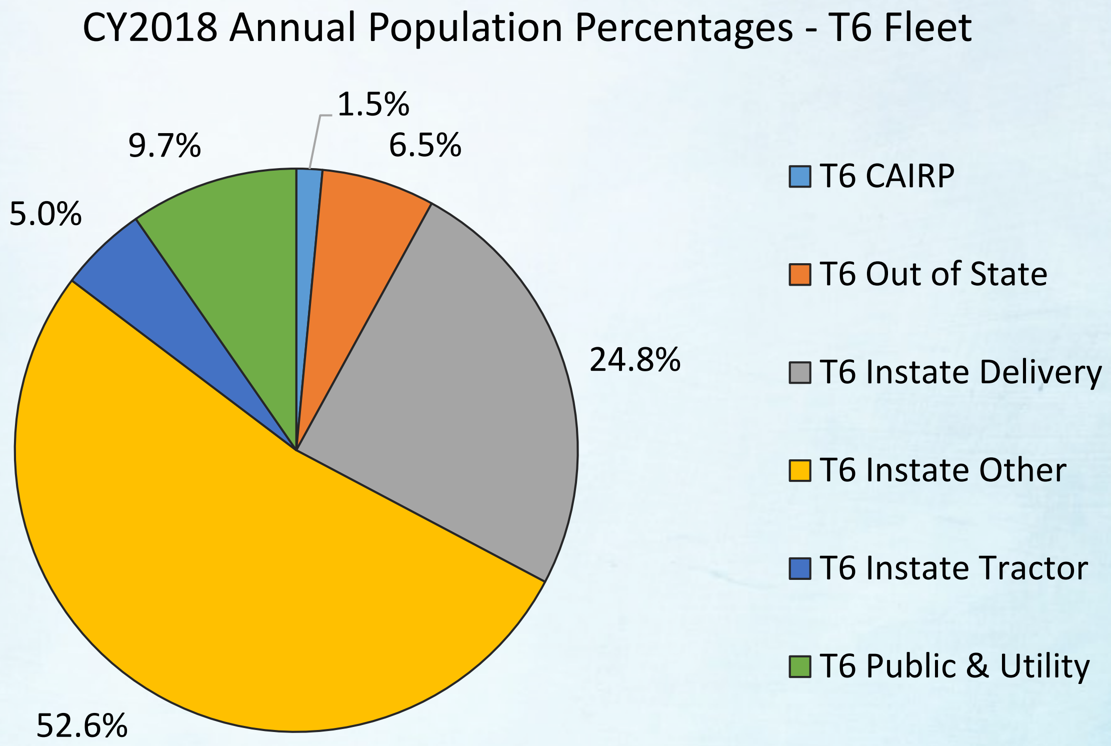
Medium Heavy Duty Trucks (i.e., T6)



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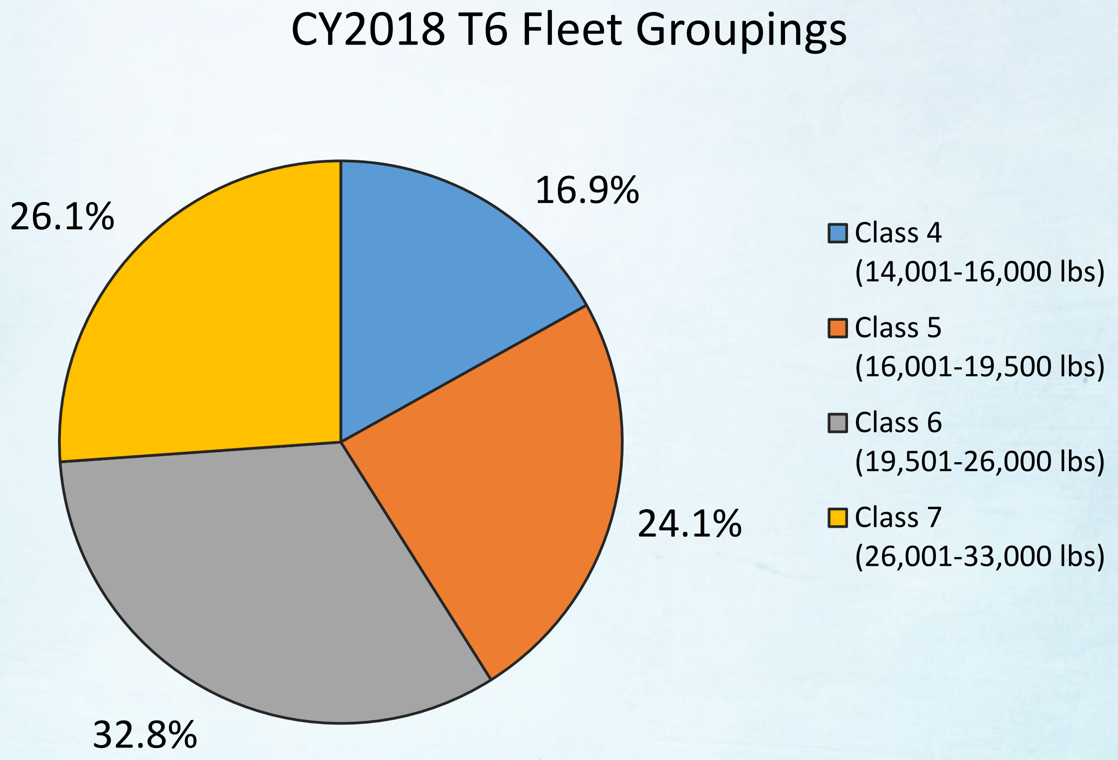
Preliminary-Draft

Medium Heavy Duty Truck Weight Groupings



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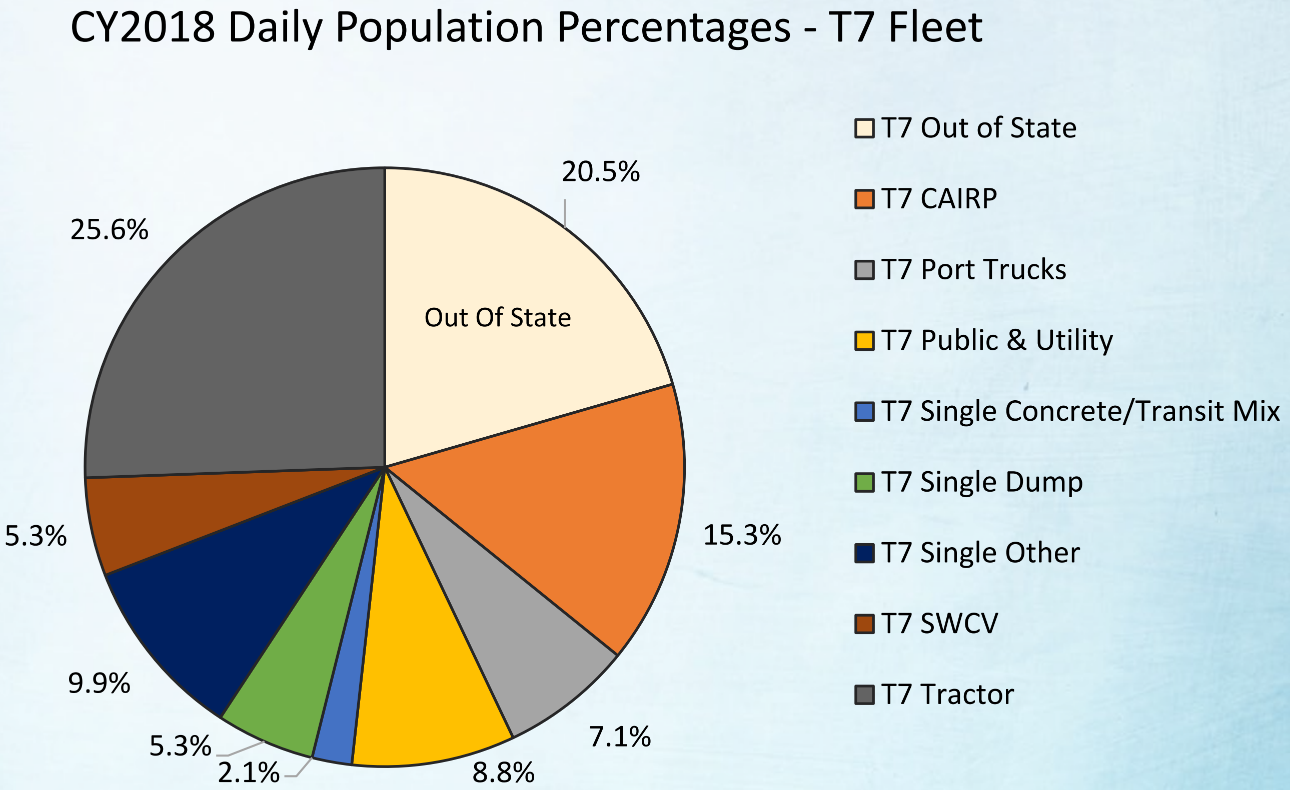
Heavy Heavy Duty Trucks (i.e., T7)



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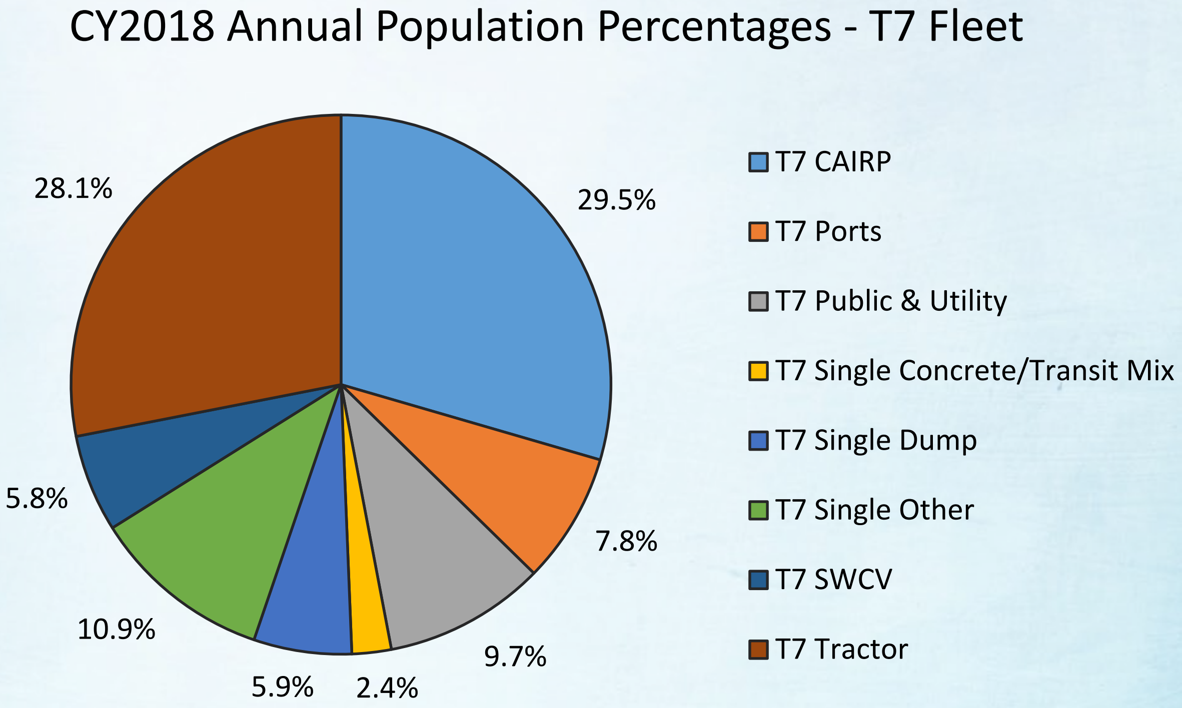
Heavy Heavy Duty Truck Fleet Groupings – Instate Only



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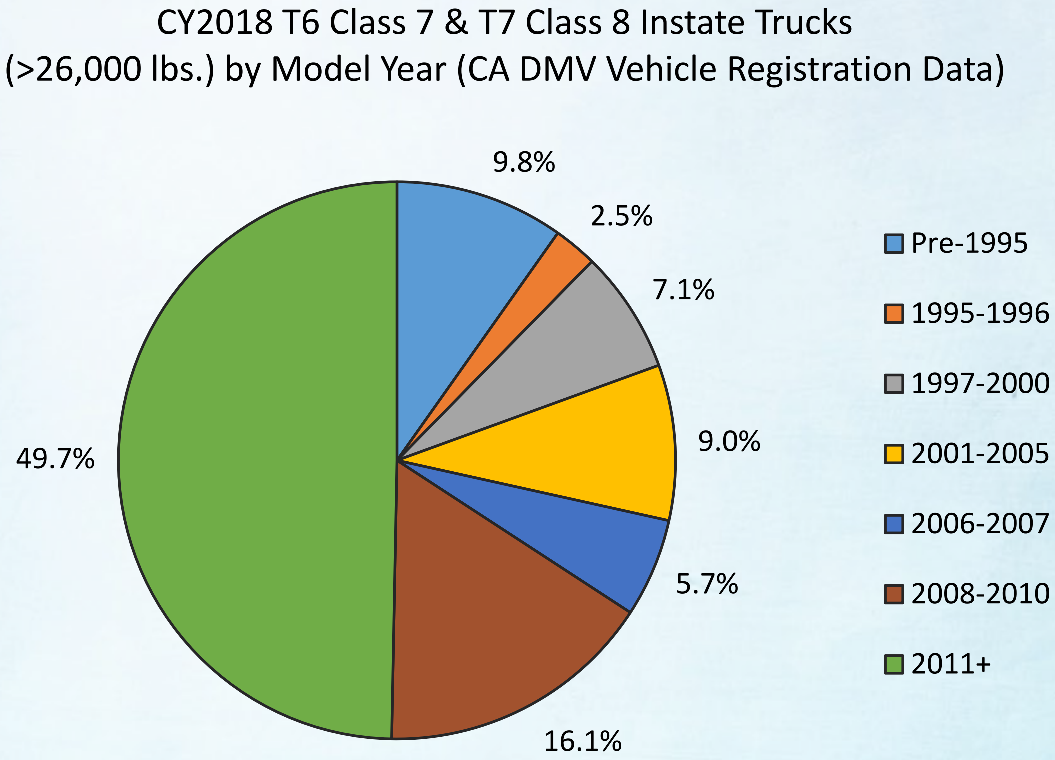
Preliminary-Draft

Class 7 – 8 Heavy Duty Trucks by Model Year



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Preliminary-Draft

Summary & Next Steps

- Updated EMFAC HDV fleet categories will allow for more specific activity and emission rates in EMFAC202x+ inventories as data is available

- Impacts of the updated inventory will be presented in a future EMFAC202x workshop

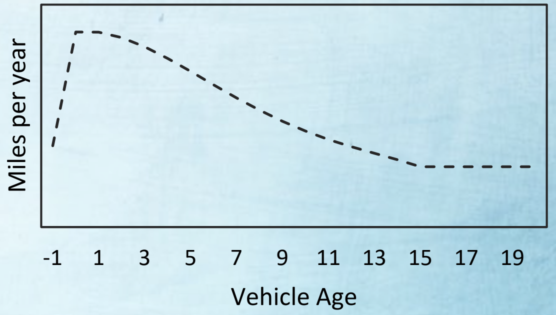
Heavy-Duty Vehicles

Vehicle Activity

Background

- HDV mileage data in EMFAC2017 is based on 2002 Vehicle In-Use Survey (VIUS)
  - Out of date (almost 20 years old)
  - May not be representative of the current trucking industry
- EMFAC202x will
  - Update annual accrual rates and odometer mileages
  - Reflect more current activity trends

Annual Accrual



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New Data Sources

- Aggregate vehicle mileage data through a Telematics Service Provider (Geotab)
  - Over 1.3 million GPS tracking devices in operation on HDVs
- California Vehicle Inventory and Use Survey (CA-VIUS) in 2018 from Caltrans
  - <u>Purpose</u>: To update CA portion of discontinued national VIUS
  - <u>Method</u>: Stratified sampling to be representative by region, fleet sizes, model year groups and vehicle types


ERG

Heavy-Duty Vehicle Accrual Rates

Final Report

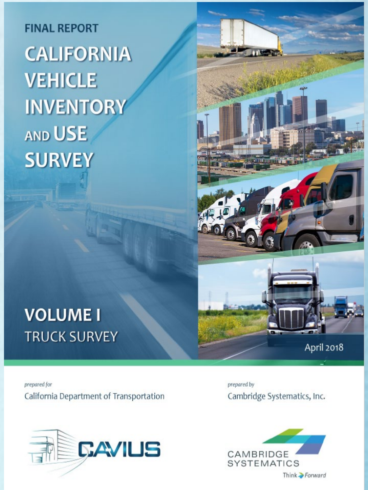
Prepared for:

California Air Resources Board

Prepared by:

Eastern Research Group, Inc.

June 14, 2019



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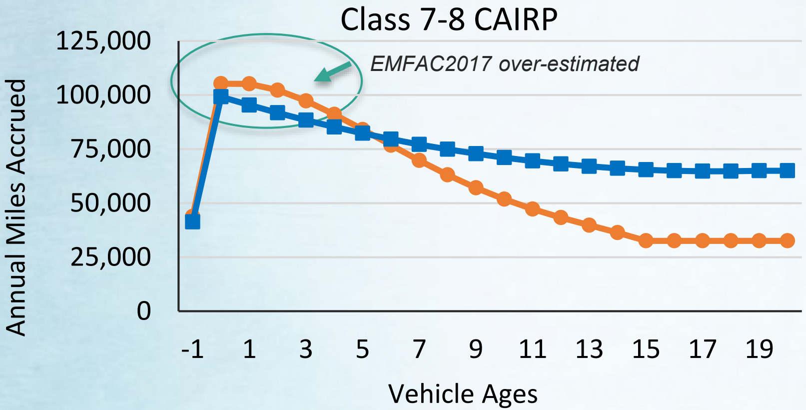
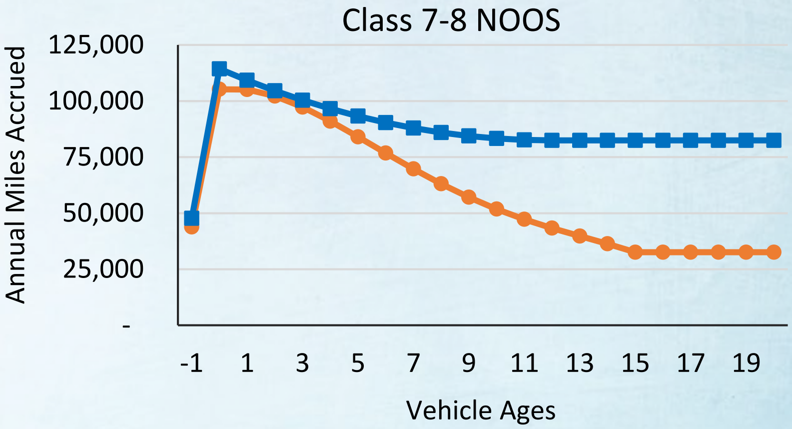
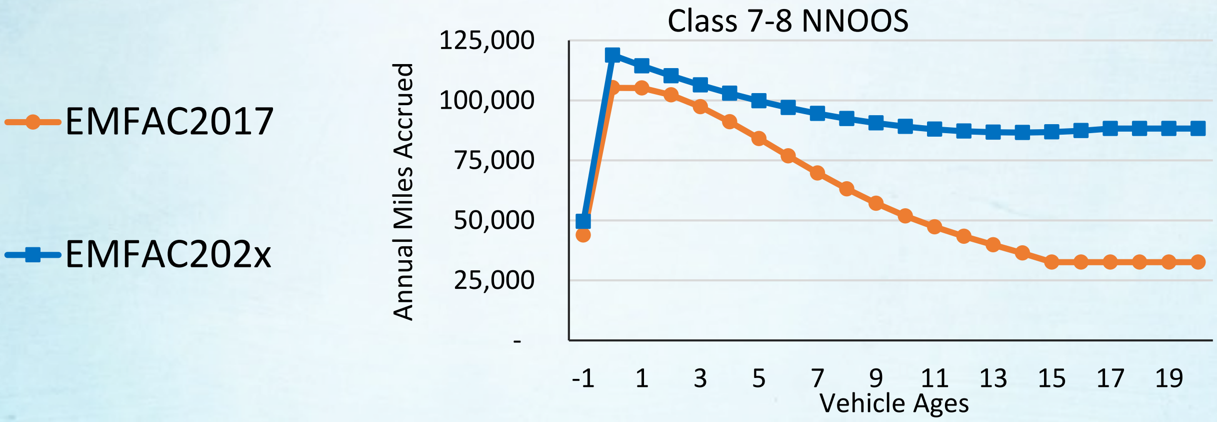
Class 7 – 8 Interstate (Long-Haul) Tractor







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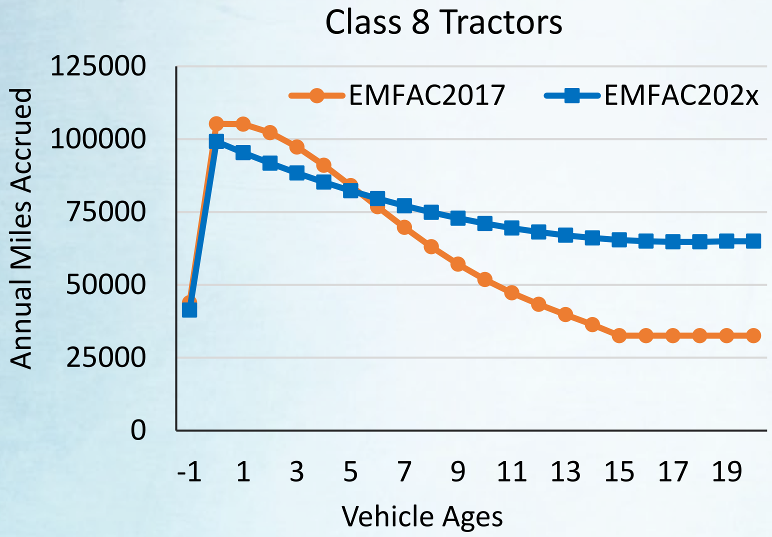
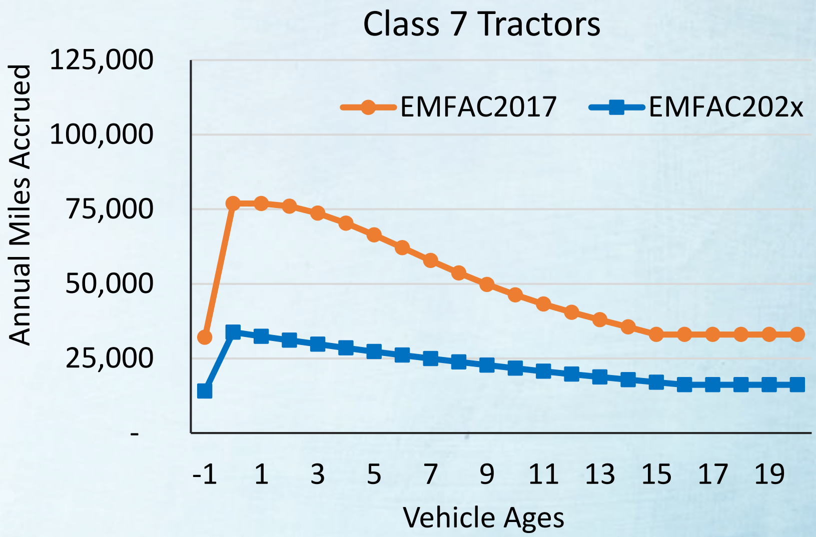
EMFAC2017 mostly under-estimated annual accrual rates

Class 7 – 8 Instate Tractors





EMFAC2017 over-estimated annual accrual rates at lower ages, and under-estimated at higher ages

EMFAC2017 over-estimated annual accrual rates

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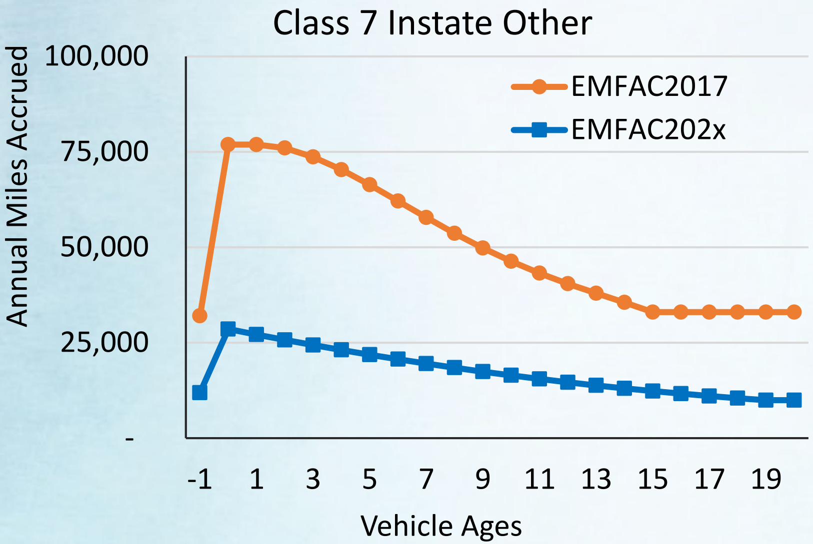
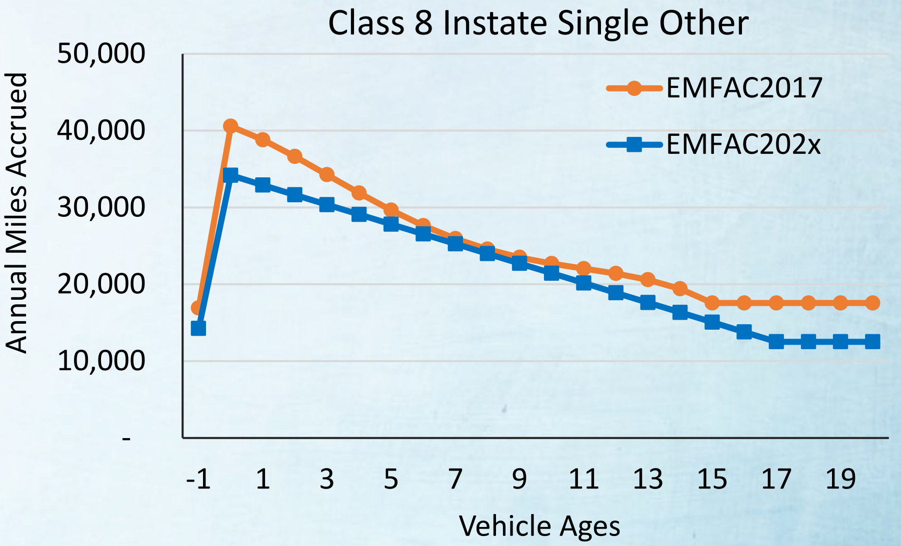
Class 7 – 8 Instate Other





EMFAC2017 over-estimated annual accrual rates

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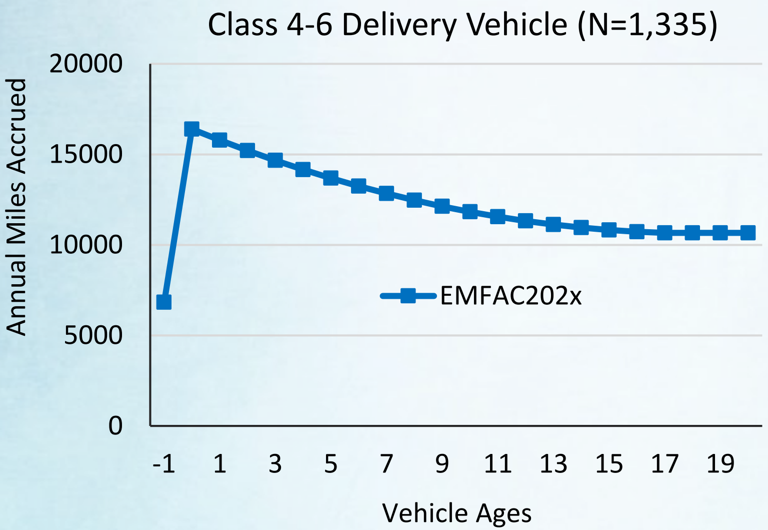
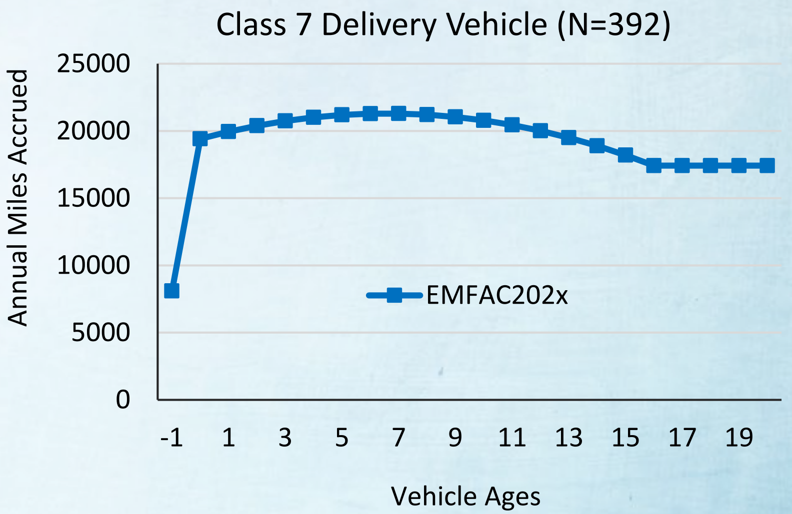
Delivery Vehicles





EMFAC2017 did not have this Fleet Category to make any comparisons

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Summary And Next Steps

- EMFAC2017 underestimated annual accrual rates for some fleets, including:
  - Interstate Tractors, Public/Utility Trucks and Solid Waste Collection Vehicles
- EMFAC2017 overestimated annual accrual rates for some fleets, including:
  - T7 Tractors, T6 Heavy Instate Other and T7 Single Other Vehicles and School Buses
- Updated annual accrual rates will reflect more current activity trends
- Inventory impacts for EMFAC202x updates will be presented in a future workshop

Heavy-Duty Vehicles

Odometer Schedule Update

Introduction: Heavy-Duty Odometer Schedule

EMFAC uses odometer schedules to model increases in the emission (ER) rate due to deterioration

$$ER\left(\frac{g}{mile}\right) = (ZMR + DR \times \boldsymbol{Odometer}) \times SCF$$

- Zero-mile emission rate (ZMR) – Fleet average UDDS emission rates while trucks are new
- In-Use Emission Deterioration (DR) – Increase of emissions over time within the in-use fleet caused by tampering, malfunction and mal-maintenance of engine components, and emission control systems
- Speed Correction Factors (SCF) – A method to correct emission factors at different driving speeds

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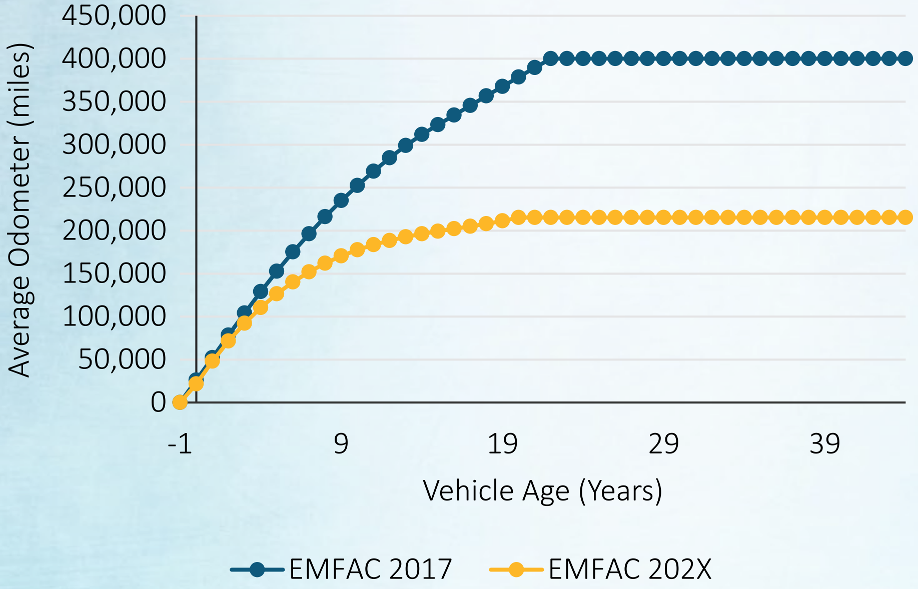
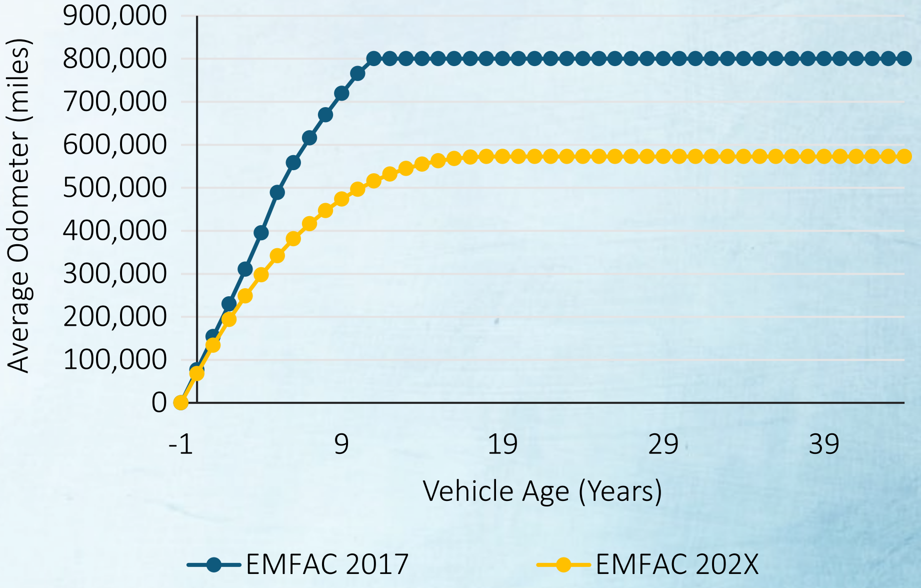
Updated Intrastate Odometer Schedules using CA-VIUS Data

T6 – medium heavy-duty trucks (N = 6,016)



T7 – heavy-heavy in-state tractors (N = 1,460)



EMFAC 2017 overestimates odometer schedules for T6 and T7 in-state tractors

Lower odometer mileage → lower deterioration-related emissions

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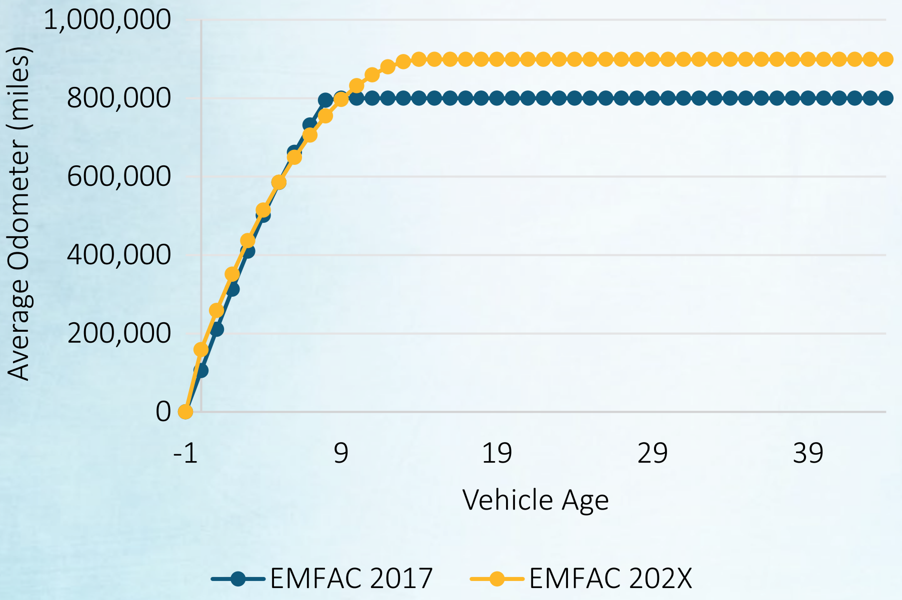
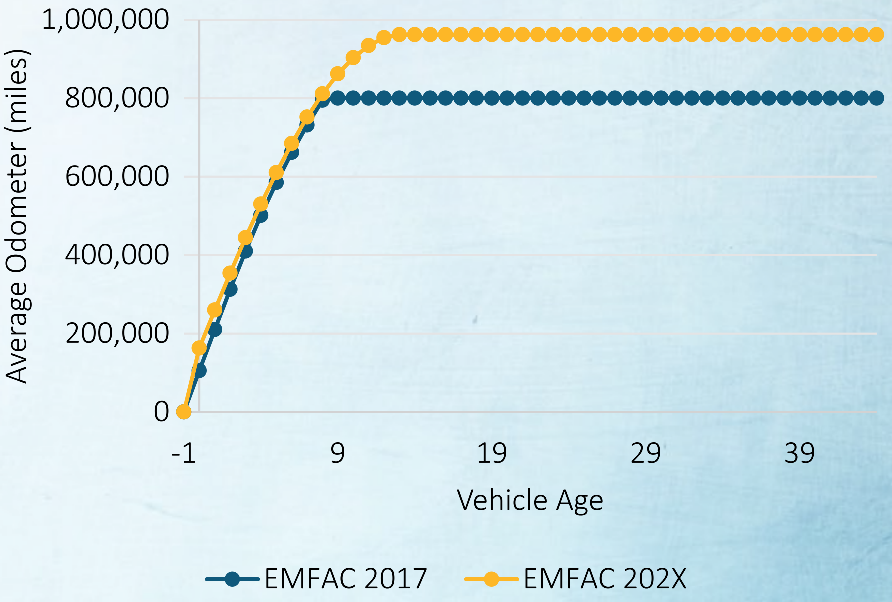
Updated Interstate Odometer Schedules using CA-VIUS Data

T7 – International Registration Plan (N = 1,324)



T7 – Out-of-State (N = 1,565)



T7 IRP and out-of-state categories explicitly broken out in EMFAC 202X
EMFAC 202X shows slightly higher odometer mileages

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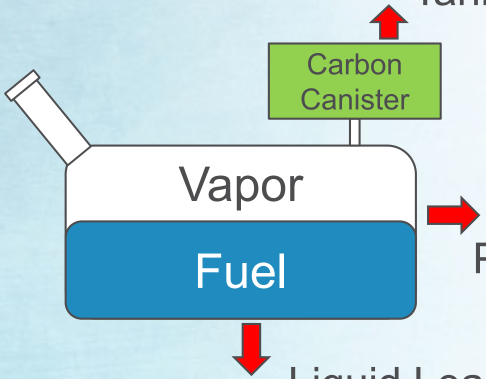
New Evaporative Emission Module

Evaporative Emissions

- A major source of gaseous hydrocarbon emissions from gasoline vehicles
- Three major processes of evaporative emissions:



Tank Vapor Venting

Fuel vapor is vented out (or "breakthrough") when carbon canister is saturated (or cannot contain all of the generated fuel vapor)

Permeation

Fuel escapes through materials in the fuel system (the tank walls, hoses, and seals)

Liquid Leaks

Non-vapor form of fuel escaping the fuel system (i.e. dripping fuel), ultimately evaporating

New Evaporative Emission Module in EMFAC202x

- EMFAC2017 and earlier versions modeled evaporative emissions using test types created for certification
- EMFAC202x presents a new module (similar to MOVES model) to represent the real world physical mechanisms of evaporative emissions
- EMFAC202x relies on U.S. EPA's substantial research and data collection efforts on evaporative emissions to better represent evaporative emissions

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Modeling Evaporative Processes: EMFAC2017 and earlier vs. EMFAC202x

Physical Processes	EMFAC2017 and earlier	EMFAC202x
From the tank while the vehicle is parked and cooled-off	Diurnal / Resting Loss	Tank Vapor Venting (cold soak)
From the tank while the vehicle is parked and still hot	Hot Soak	Tank Vapor Venting (hot soak)
From the tank while the vehicle operating	Running Loss	Tank Vapor Venting (operating)
By the permeation of liquid fuel through fuel tank and hose	Diurnal / Resting Loss / Running Loss / Hot Soak	Permeation (cold soak, hot soak, operating)
By leaks of liquid fuel through tank/hose connections	Diurnal / Resting Loss / Running Loss / Hot Soak	Liquid Leaks (cold soak, hot soak, operating)

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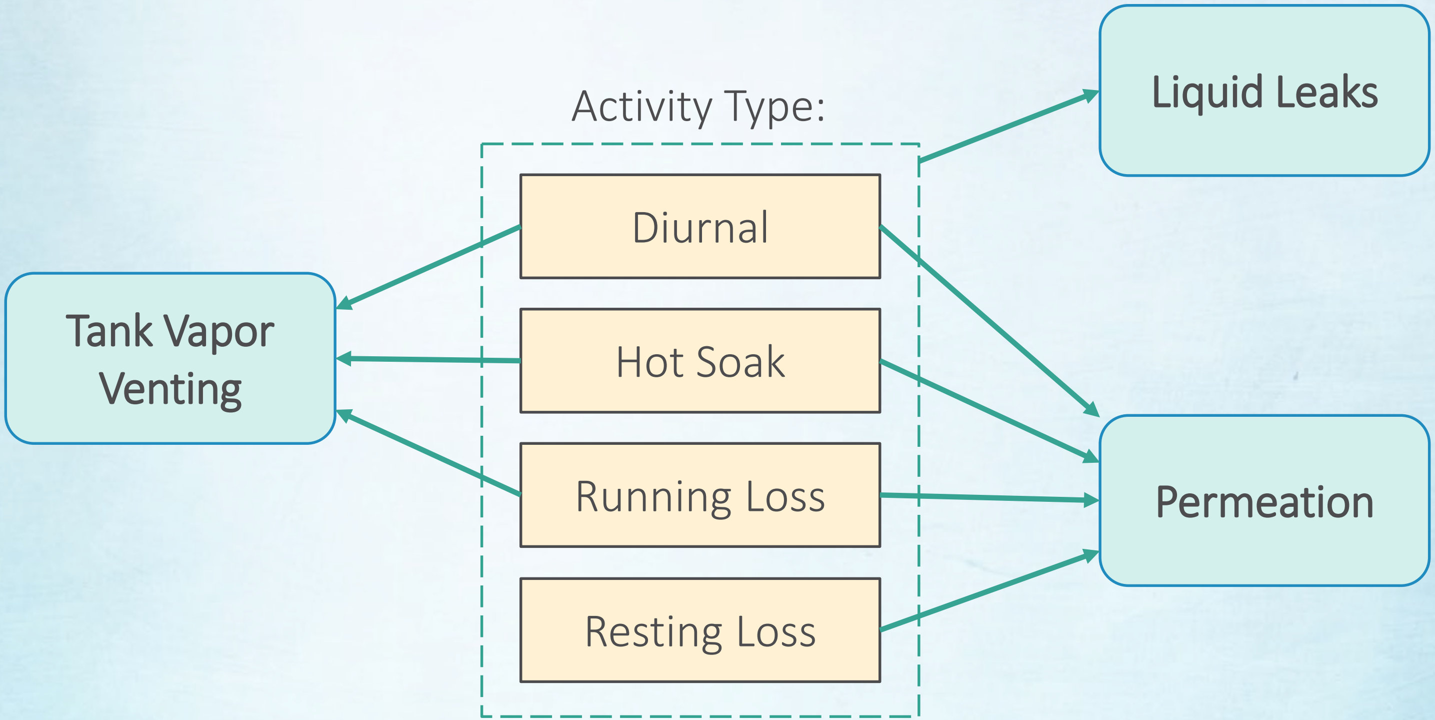
Mapping Evaporative Processes



Implementation of New Evaporative Module

- Employ the methods and data implemented in the evaporative emissions module in the most recent MOVES model
- Streamlined by preprocessing certain key parts with MOVES and by implementing California-only conditions
- Use 2010 – 2012 California Household Travel Survey (CHTS) data as an input of vehicle start, trip and parking activity to MOVES
- Emission testing projects are planned to further update the module with revised emission rates for evaporative emissions of Californian vehicles

Preprocessing with MOVES for EMFAC202x

- Preprocessing approach for simpler implementation and less computational burdens
  - MOVES used to generate tank temperature with California-specific meteorology inputs
  - MOVES used to preprocess a major part of multiday tank vapor venting process with California-specific vehicle trip information from CHTS

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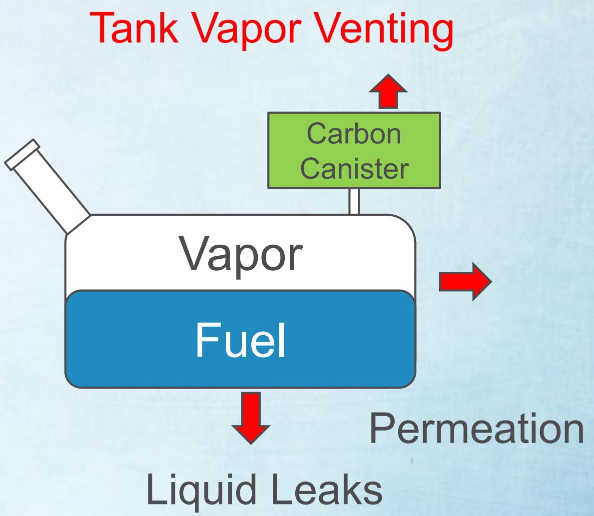
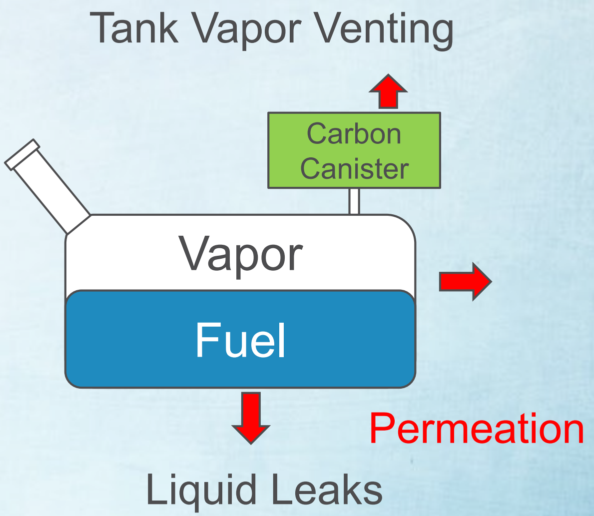
Tank Vapor Venting

- Canisters are supposed to contain fuel vapors in the fuel tank. However, vapor is vented from carbon canisters if the canisters are saturated and cannot adsorb more vapor.
- Tank vapor venting depends on ambient and tank temperature, atmospheric pressure, canister size, the number of parking days, fuel tank size, tank fill fraction, and so on.



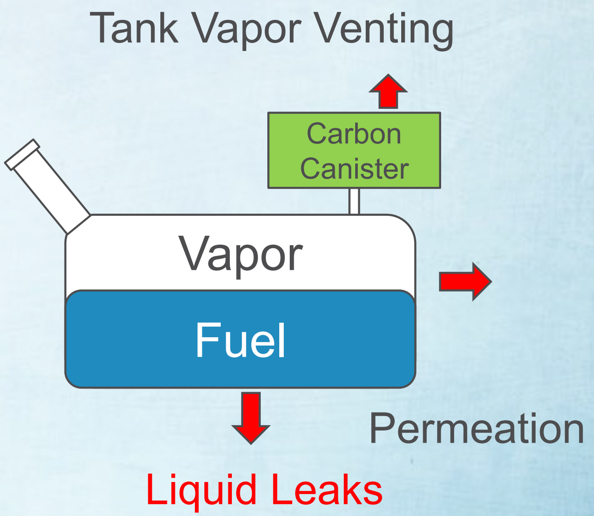
Permeation

- Hydrocarbon compounds that escape through micro-pores in pipes, fittings, and other vehicle components
- Base permeation rates are 0.003 to 0.311 g/hr, depending on model year and age.
- Adjusted for tank temperature (preprocessed) and ambient temperature



Liquid Leaks

- Any non-vapor form of fuel escaping the fuel system
- Average emission rates of 0.009 to 4.230 g/hr across all vehicles (except for LEV III)
- Average emission rates of 0.007 to 3.258 g/hr for LEV III due to improved system design and integrity.



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Next steps

- Complete the implementation of the new evaporative module in EMFAC202x
- QA/QC on the implementation and the module outputs
- Conduct testing and research to better reflect California vehicles and fuel
  - Permeation and vapor generation rates, speciation profiles for LEV II/LEV III/hybrid vehicles
  - California specific tampering and mal-maintenance rates (leaks)
  - Summer and winter volatility of fuel used in California (E10)
  - New test procedures to isolate permeation from vapor generation and leaks

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Light-Duty Vehicles

Emission Rates

Outline

- Background and Methodology Update
- Preliminary Results
  - LEVI Running Exhaust
  - LEVI Starts Exhaust
  - LEVII Running Exhaust
  - LEVII Starts Exhaust
- Other Results and Status

Background

- For EMFAC2017, Light-Duty (LD) Running Exhaust and Starts Emission Rates were updated for the first time since EMFAC2000
- Soak Correction Factor Curves updated with new data from Vehicle Surveillance Program (VSP)
- Major Methodology Updates
  - Starts Exhaust Emission Rate – A new approach
  - Three regime approach adopted to model the effect of deterioration on running/starts emissions

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EMFAC2017 Three Regime Approach

- Base Emission Rates are comprised of Regime Fractions (RFs), and Regime Emission Rates (ERs)

$$BER = RF_N(odo)*ER_N + RF_M(odo)*ER_M + RF_H(odo)*ER_H$$

Odo = Odometer

Normal Regime < X 1.0 STD

1.0 X STD < Moderate < 2.0 x STD

2.0 X STD < High

- RFs developed from In-Use Verification Program (IUVP)
  - For each pollutant, a vehicle's FTP ER is used to assign vehicle to a regime
  - The % of vehicles, in each regime (wtd by sales), is computed for different mileage bins
  - $RF_N(odo) + RF_M(odo) + RF_H(odo) = 1$
- ERs developed from CARB Vehicle Surveillance Program (VSP)
  - For each pollutant, a vehicle's FTP ER is used to assign a vehicle to a regime
  - Regime UC_{P1}, UC_{P2}, and UC_{P3} ERs are determined as the mean ER of all vehicles in the regime

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Data Sources

- **Manufacturer's In-Use Verification Program**
  - Requires OEMs to test in-use vehicles to ensure emission control systems still work
  - Started in 2000, replaced much of the certification and track durability tests done prior
  - Vehicles tested from 10kmi to 50kmi and from 50kmi to 75% of durability rating
  - For an engine family w/50k-250k sales: 3 low-mileage and 5 high-mileage vehicles tested

- **CARB Vehicle Surveillance Program**
  - Long standing testing program at CARB
  - Vehicles randomly selected
  - Results used to improve EMFAC, understand the fleet trends, and inform policies

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EMFAC202x Update

- For EMFAC202x, UC BERs will be updated with 3 years of new data from IUVP and VSP programs
  - Affects both running and starts exhaust emission rates: HC, NOx, CO
  - New data may be used to replace Ratio of Standards (ROS) LEVIII BERs that were derived from LEVII BERs

    ROS Example

    LEVII SULEV30: HC 10 mg/mi, NOx 20 mg/mi, HC + NOx = 30 mg/mi

    LEVIII SULEV20: HC + NOx = 20 mg/mi

    → ROS Estimate: BER(SULEV20) = 20/30 x SULEV30
- Method of BER determination similar to EMFAC2017, however a new "Low" emission regime has be added to model deterioration at lower emission levels

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New Four Regime Approach

EMFAC2017

Normal Regime < X 1.0 STD

1.0 X STD < Moderate < 2.0 x STD

2.0 X STD < High 

EMFAC202x

Low Regime < 0.5 x STD

0.5 x STD < Normal Regime < X 1.0 STD

1.0 X STD < Moderate < 2.0 x STD

2.0 X STD < High 

New "Low" emission regime allows for the incorporation of deterioration occurring at lower emission levels (lower mileages)

Preliminary Analysis

- In March 2019, staff computed preliminary HC/NOx/CO UC BERs:
  - Used updated method with low emission regime
  - MY < 2018
  - LEVI and LEVII only (not enough data for LEVIII)

Sample of Results: LEVII LEVs: Hydrocarbons

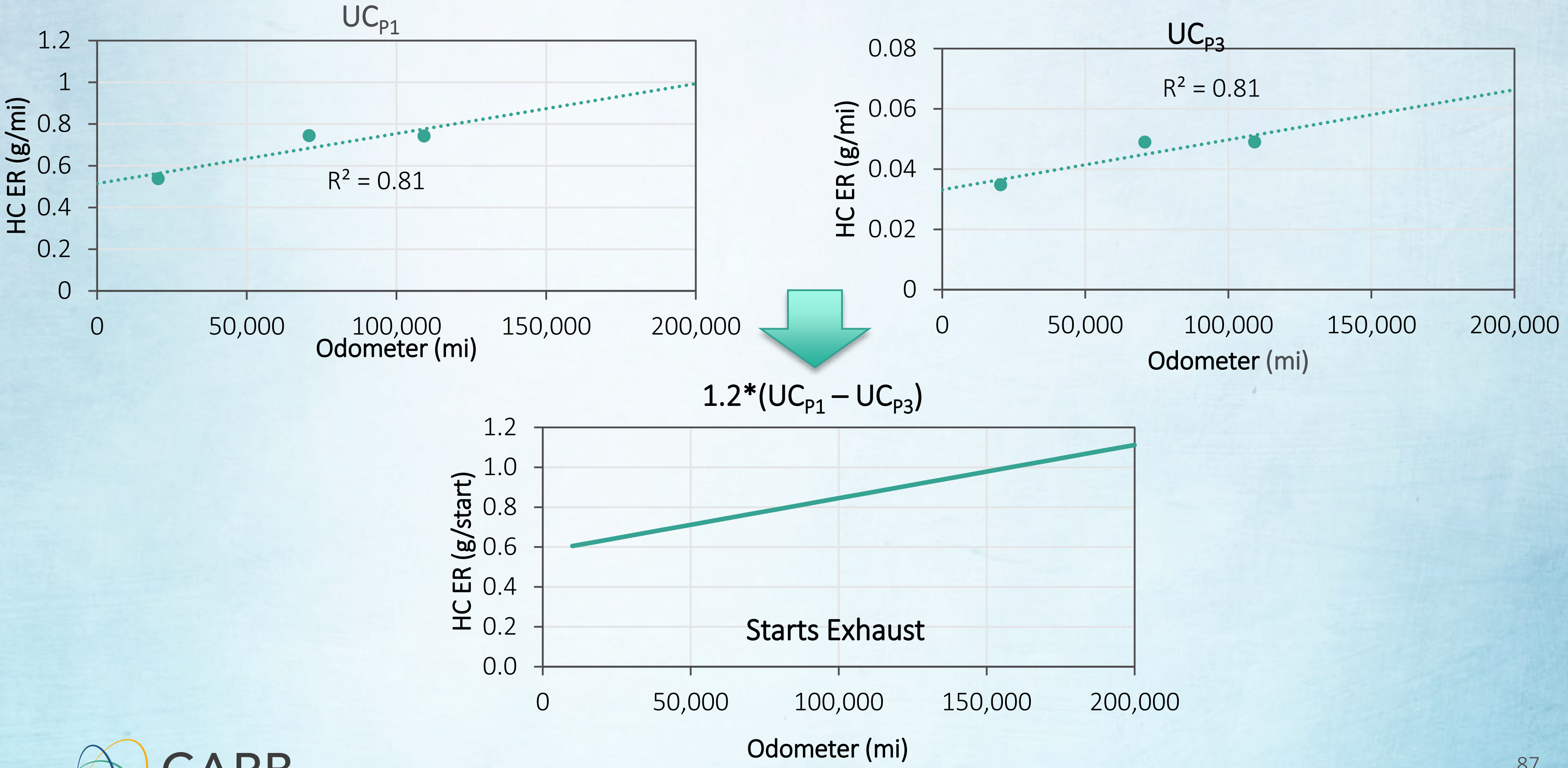
IUVP Data

	Regime	Count	RF	Sales Wtd RF
0-50kmi	L	214	0.88	0.80
	N	27	0.11	0.19
	M	2	0.01	0.01
	H	0	0.00	0.00
50-100kmi	L	190	0.56	0.39
	N	138	0.41	0.57
	M	8	0.02	0.03
	H	1	0.00	0.00
100-150kmi	L	26	0.48	0.39
	N	26	0.48	0.59
	M	2	0.04	0.02
	H	0	0.00	0.00

VSP Data

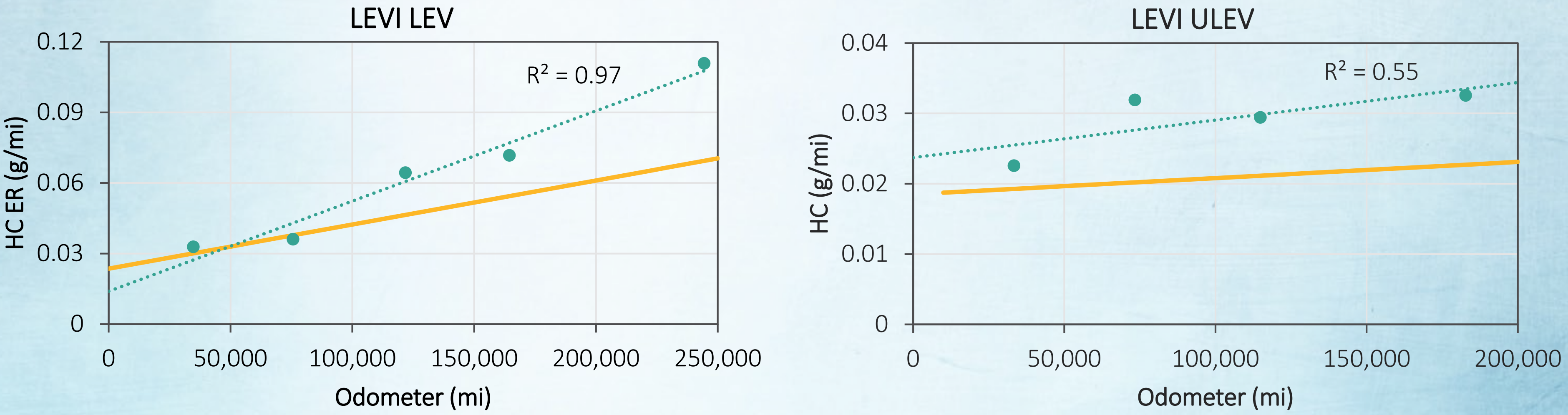
	Regime	Count	UC Phase	Mean HC (g/mi)
UC_{P1}	L	12	1	0.440
	N	13	1	0.927
	M	5	1	1.045
	H	1	1	2.080
UC_{P2}	L	12	2	0.014
	N	13	2	0.014
	M	5	2	0.037
	H	1	2	0.037
UC_{P3}	L	12	3	0.028
	N	13	3	0.062
	M	5	3	0.076
	H	1	3	0.076

Sample of Results: LEVII LEV Hydrocarbons



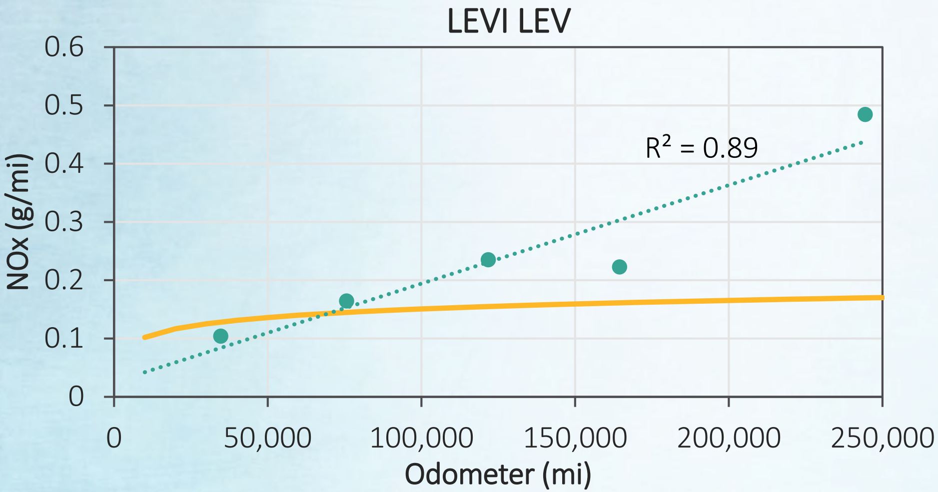
EMFAC202X Alpha
EMFAC2017

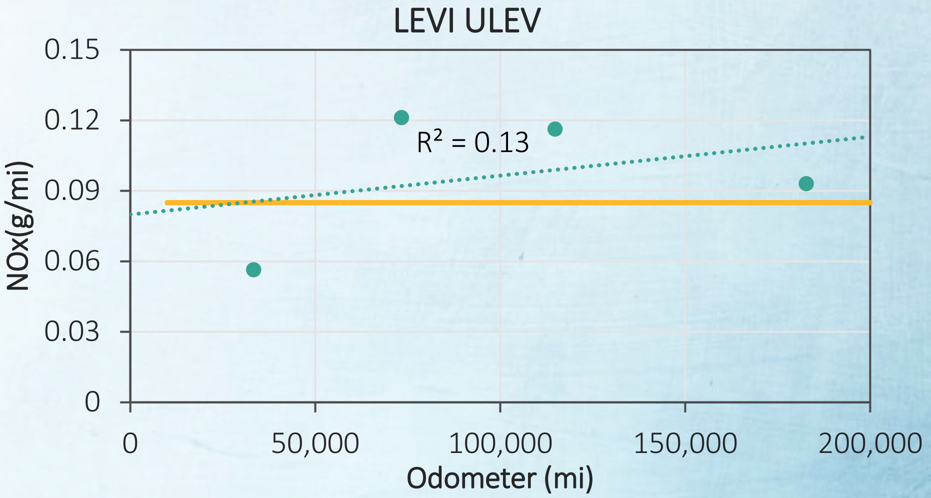
LEVI Running Exhaust: Hydrocarbons



EMFAC202X Alpha
EMFAC2017

LEVI Running Exhaust: NOx





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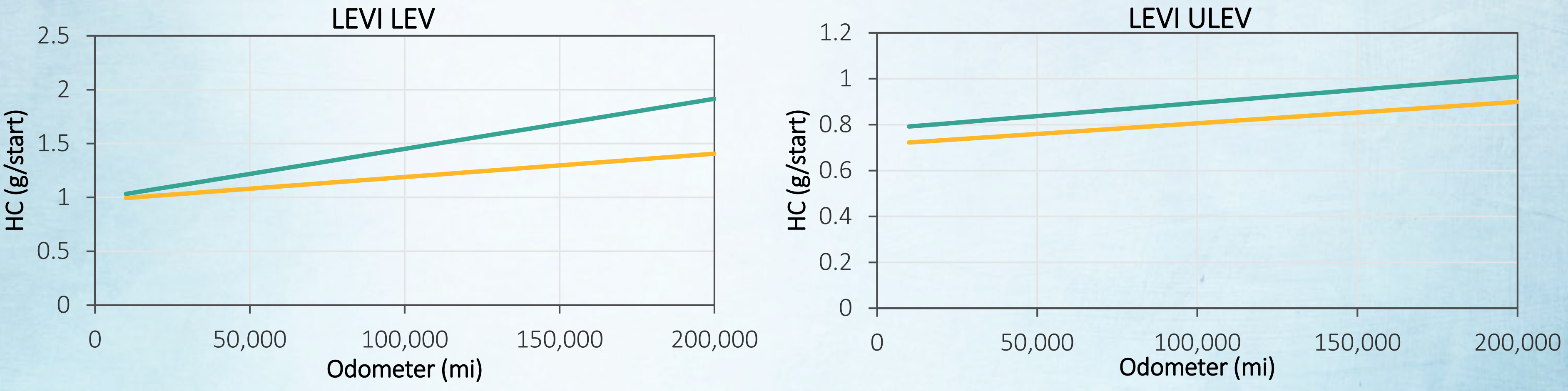
EMFAC202X Alpha
EMFAC2017

LEVI Starts Exhaust: Hydrocarbons



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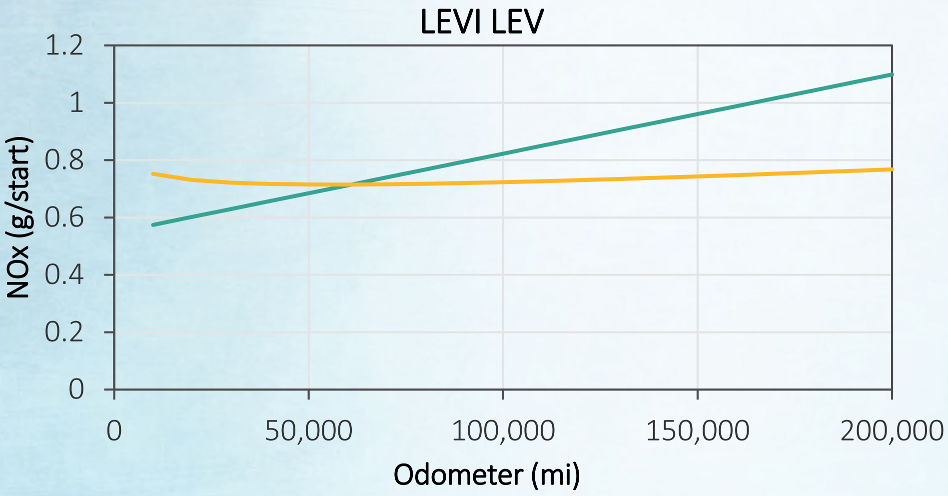
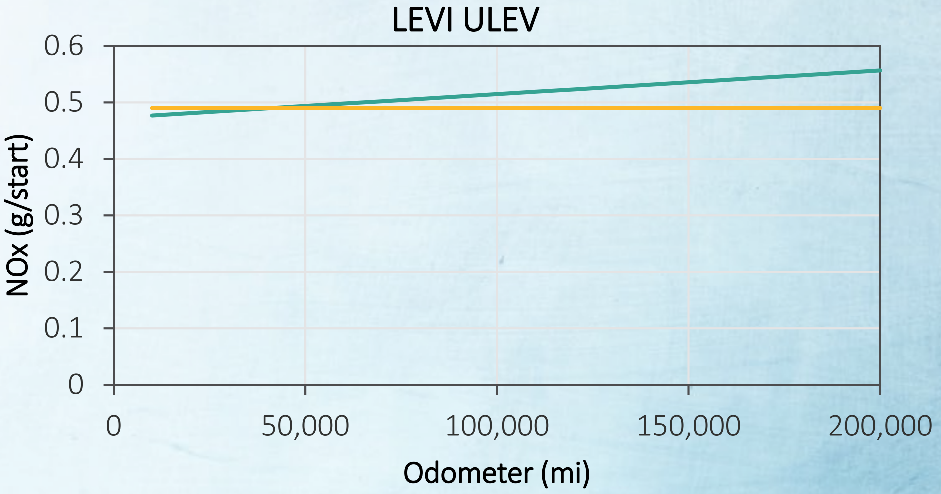
EMFAC202X Alpha
EMFAC2017

LEVI Starts Exhaust: NOx





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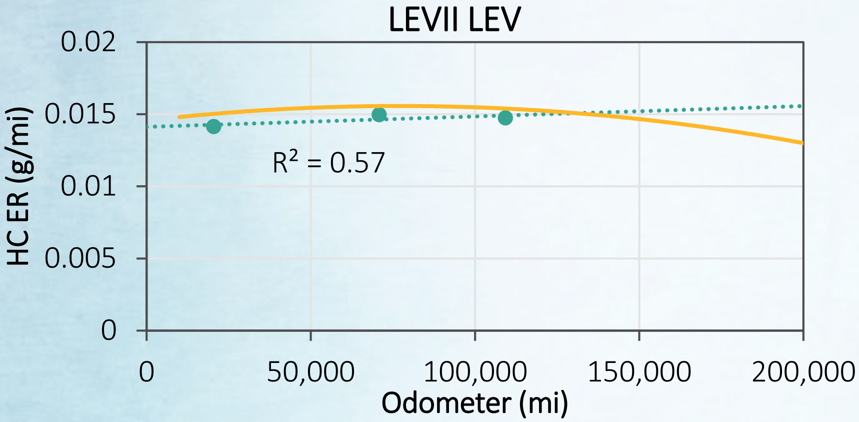
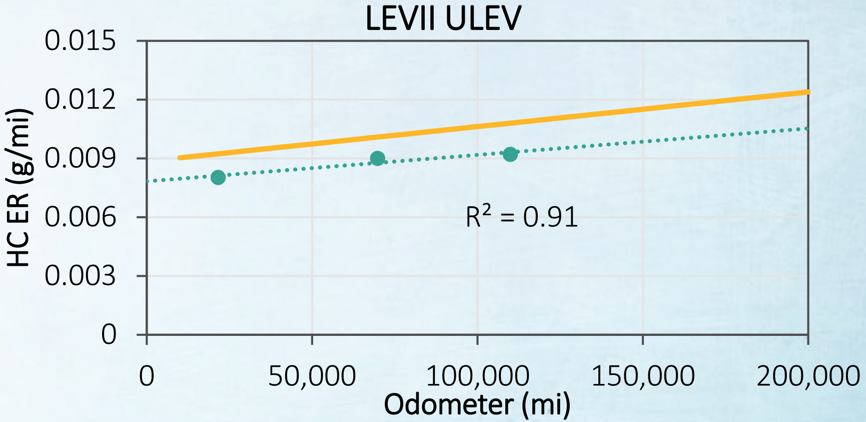
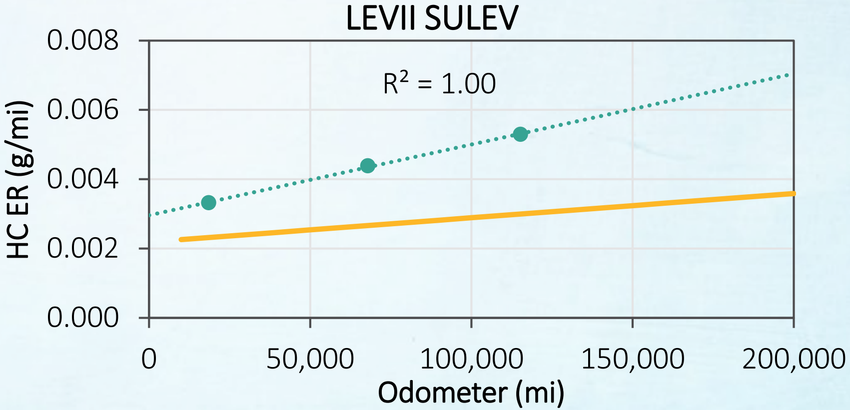
EMFAC202X Alpha
EMFAC2017

LEVII Running Exhaust: Hydrocarbons







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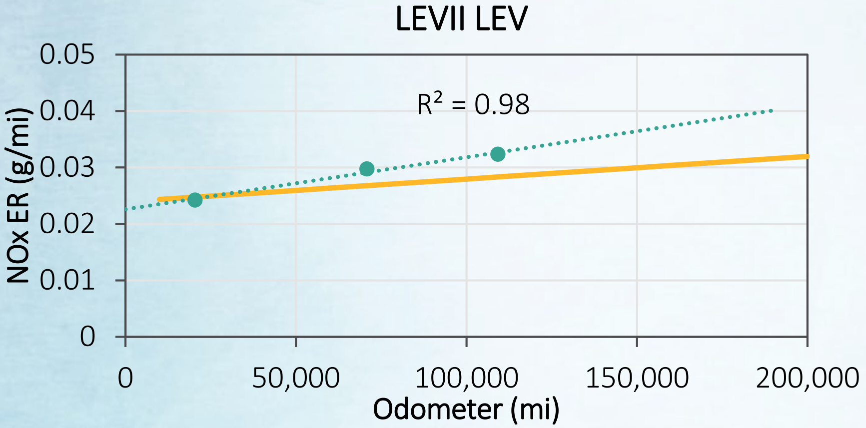
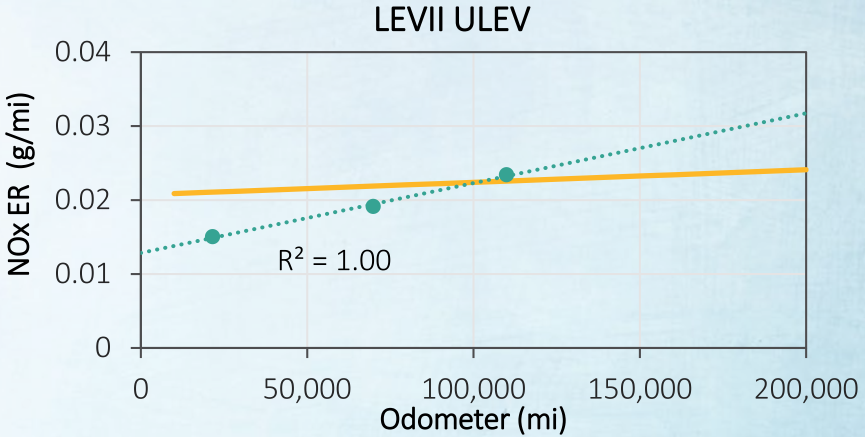
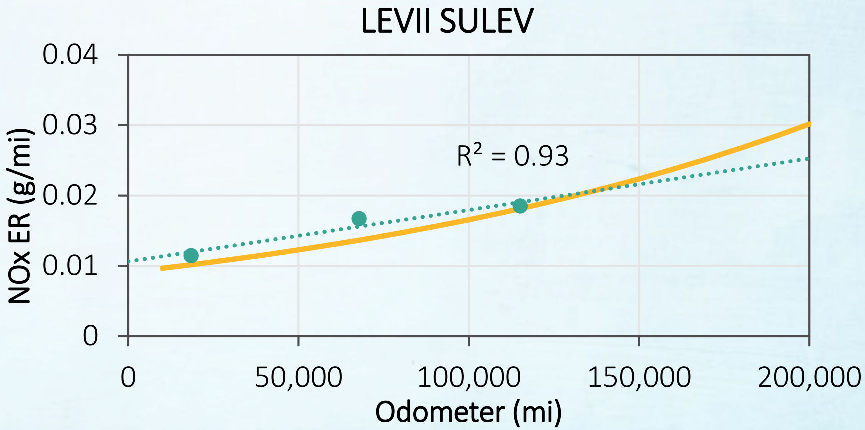
EMFAC202X Alpha
EMFAC2017

LEVII Running Exhaust: NOx

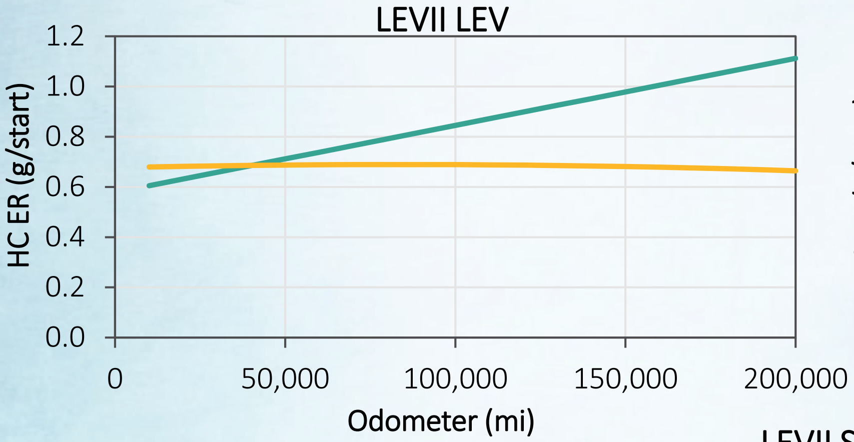


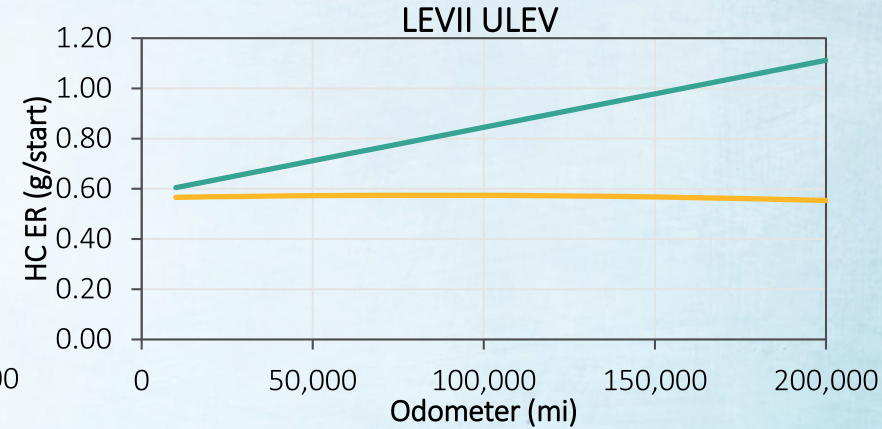


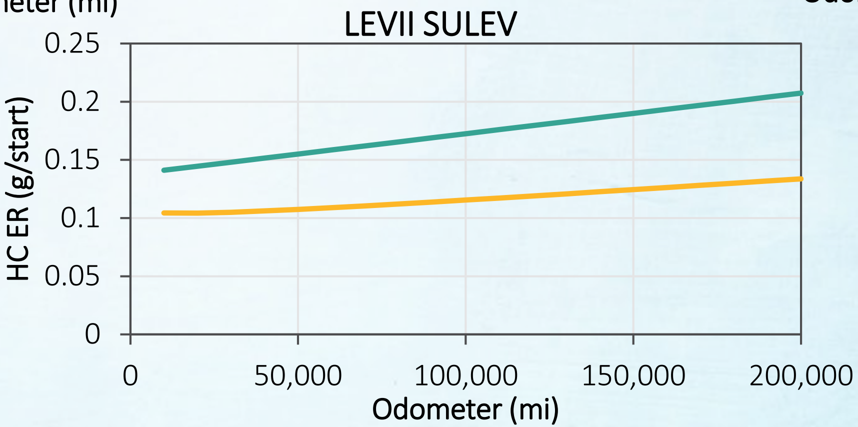


EMFAC202X Alpha
EMFAC2017

LEVII Starts Exhaust: Hydrocarbons







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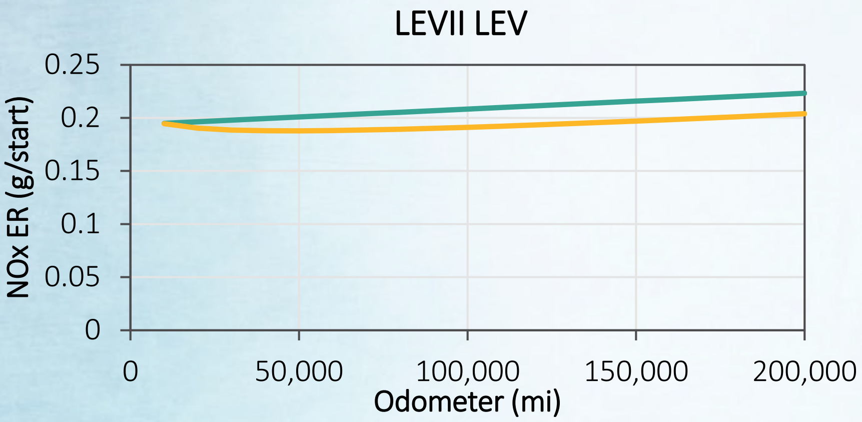
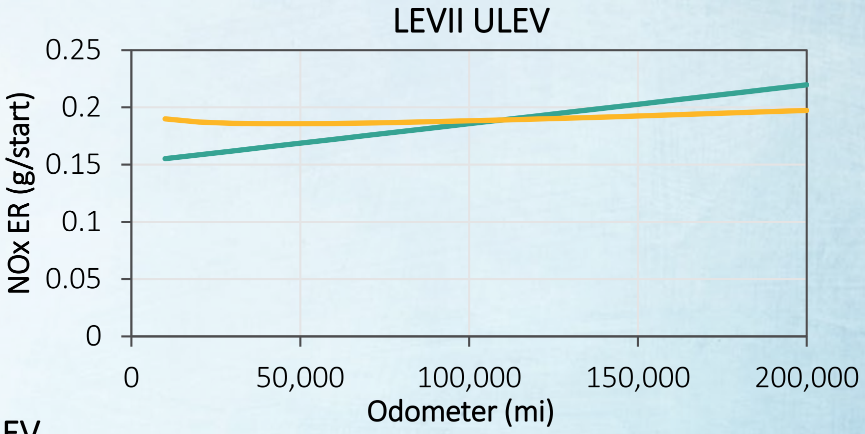
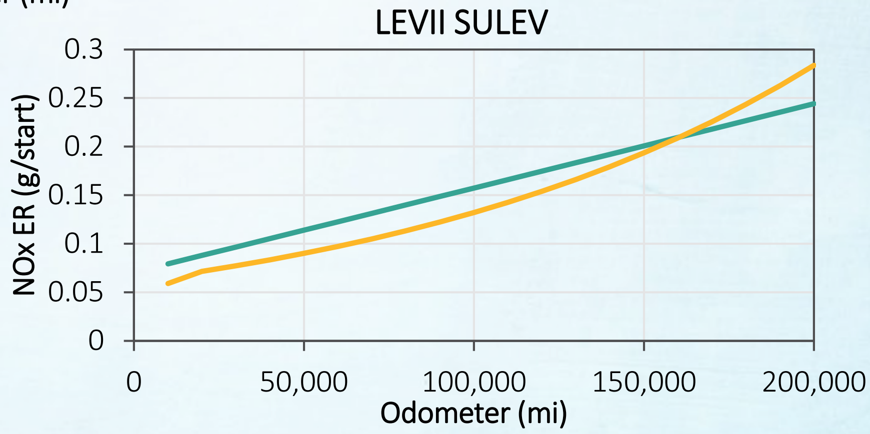
EMFAC202X Alpha
EMFAC2017

LEVII Starts Exhaust: NOx







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Other Results and Status

- LEVIII: Not currently enough vehicles tested to develop UC BERs for the six different LEVIII emission groups
  - We may use ratio of standards again, or focus testing efforts on the more common LEVIII emission groups (ULEV125 and SULEV30)
- IUVP and VSP testing are ongoing
- We will re-evaluate all regime fractions and UC emission rates prior to release of EMFAC202x

Light Heavy-Duty Trucks

Emission Rates

Light Heavy-Duty Trucks (LHDT)

- Vehicles with GVWR from 8,501 to 14,000 lbs
- Either chassis or engine certified; >95% chassis certified
- Further divided into two groups
  - LHDT1: 8,501-10,000 lbs (MDV4 under LEV regulations)
  - LHDT2: 10,001-14,000 lbs (MDV5 under LEV regulations)
- Emissions modeling method same as that for PC & LDT
- Emission rates not updated since EMFAC2000

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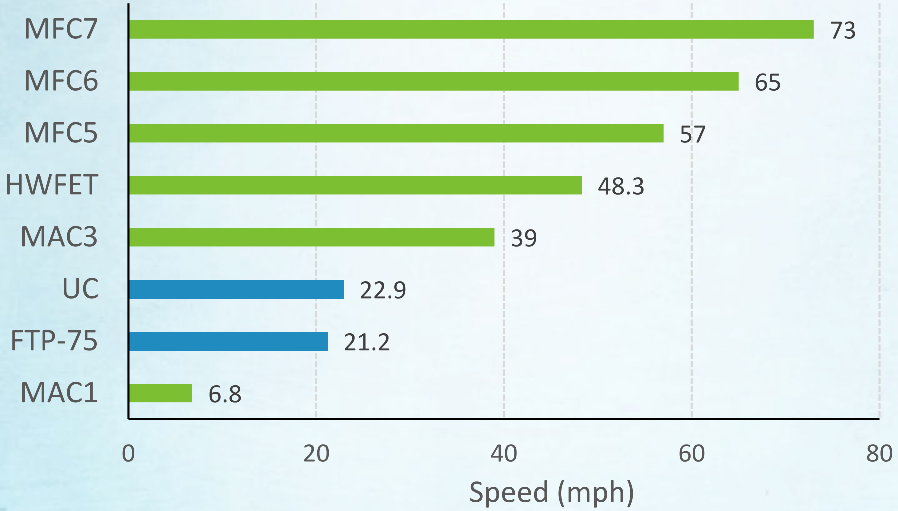
CARB LHDT Emissions Testing

NEW

- (7) 2015&2017 MY diesel, (2) 2015 MY gasoline, (2) 2006 MY diesel vehicles tested on dynamometer over 8 test cycles
- All vehicles also tested with PEMS on 3 routes



PEMS Route	Driving Type
Downtown LA	Urban
Oxnard	Freeway
Mt Baldy	Uphill / Downhill

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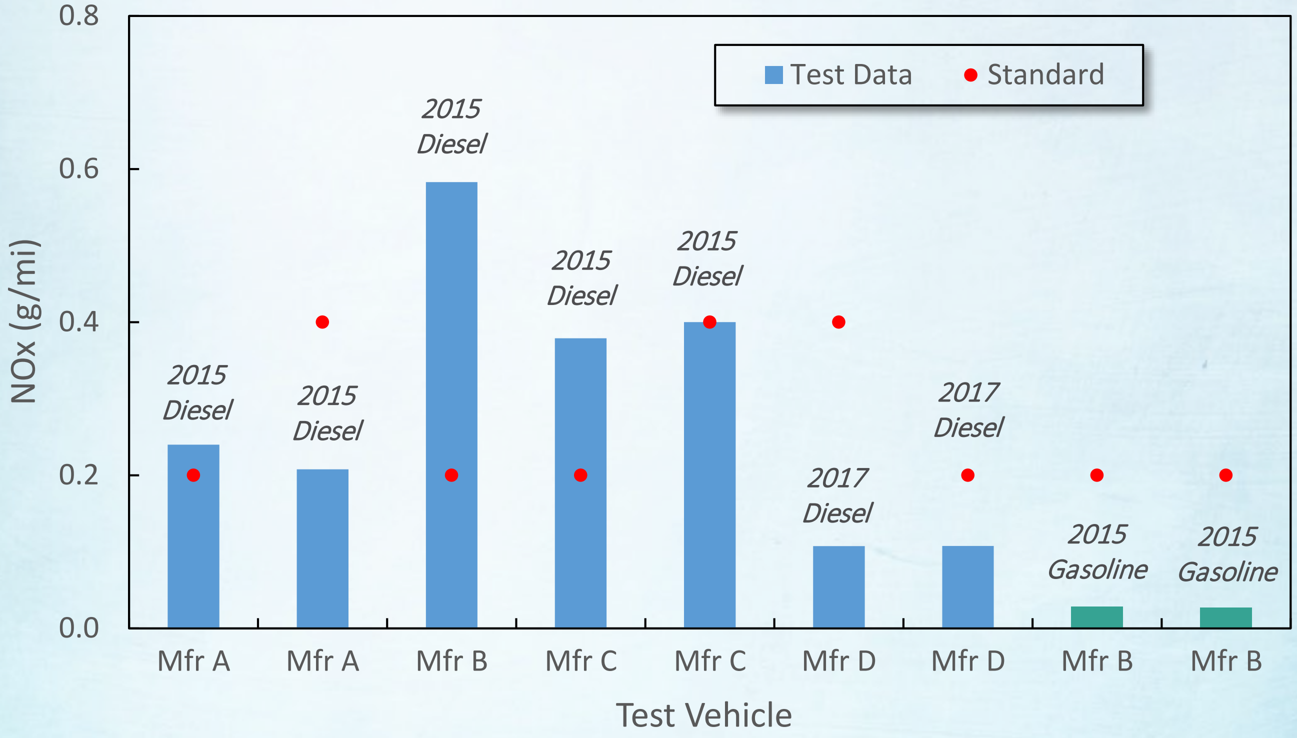
2015 & 2017 MY LHDT FTP NOx



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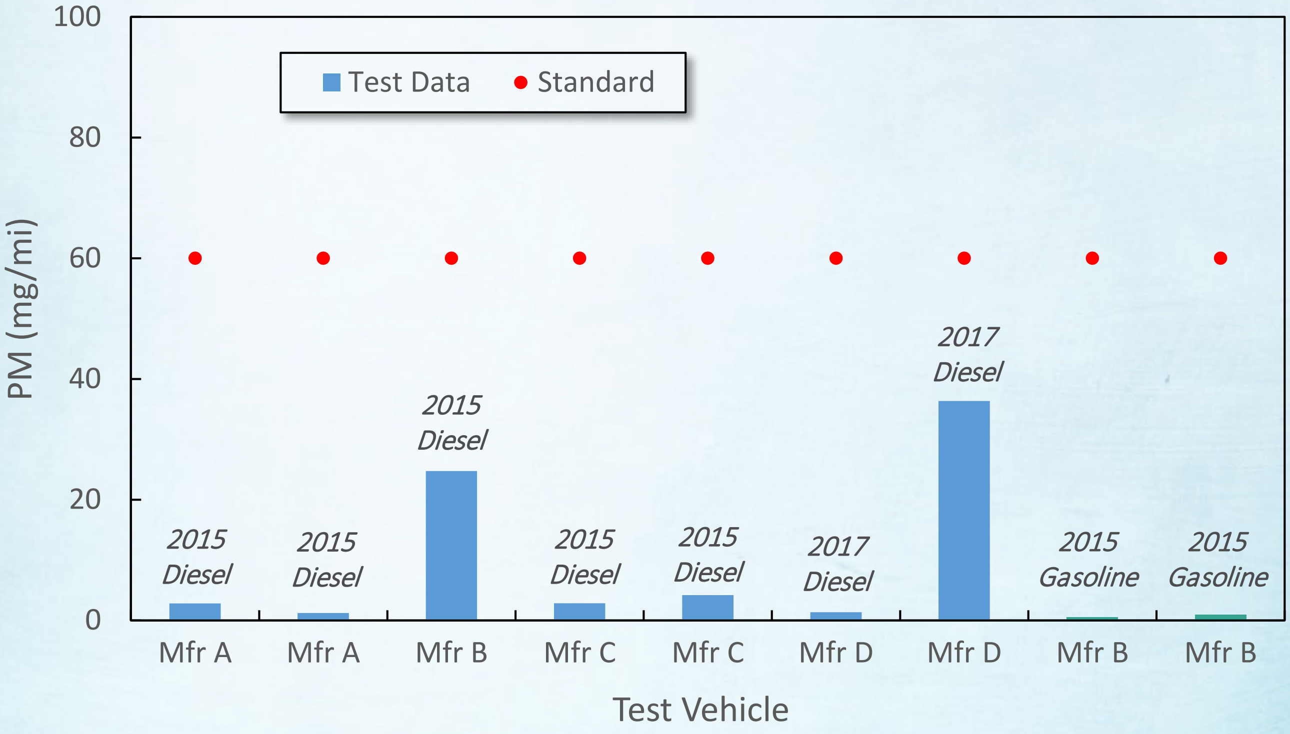
2015 & 2017 MY LHDT FTP PM



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Planned Revision of LHDT Emission Rates

- Revise emission rates using dynamometer data
  - 2007-2021 MY diesel (ULEV340 & ULEV570; EPA2007)
  - 2008-2021 MY gasoline (ULEV340, EPA2008)
  - 2004-2009 MY diesel (ULEV)
- Calculate ZMR & DR by scaling ZMR & DR of EMFAC2017
- Revise speed correction factors using dynamometer data of multiple test cycles

Revised LHDT NOx Running Exhaust Emission Rates

Model Year	Fuel	EMFAC 2017		EMFAC 202x	
		ZMR	DR	ZMR	DR
2007-2021 (ULEV340)*	Diesel	0.19	0.010	0.39	0.022
2007-2021 (ULEV570)*	Diesel	0.19	0.010	0.43	0.024
2008-2021 (ULEV340)*	Gasoline	0.033	0.035	0.010	0.004
2004-2009 (ULEV)	Diesel	4.33	0.010	4.72	0.011

* Rates for other ULEV & SULEV standards to be calculated using ratio-of-standards

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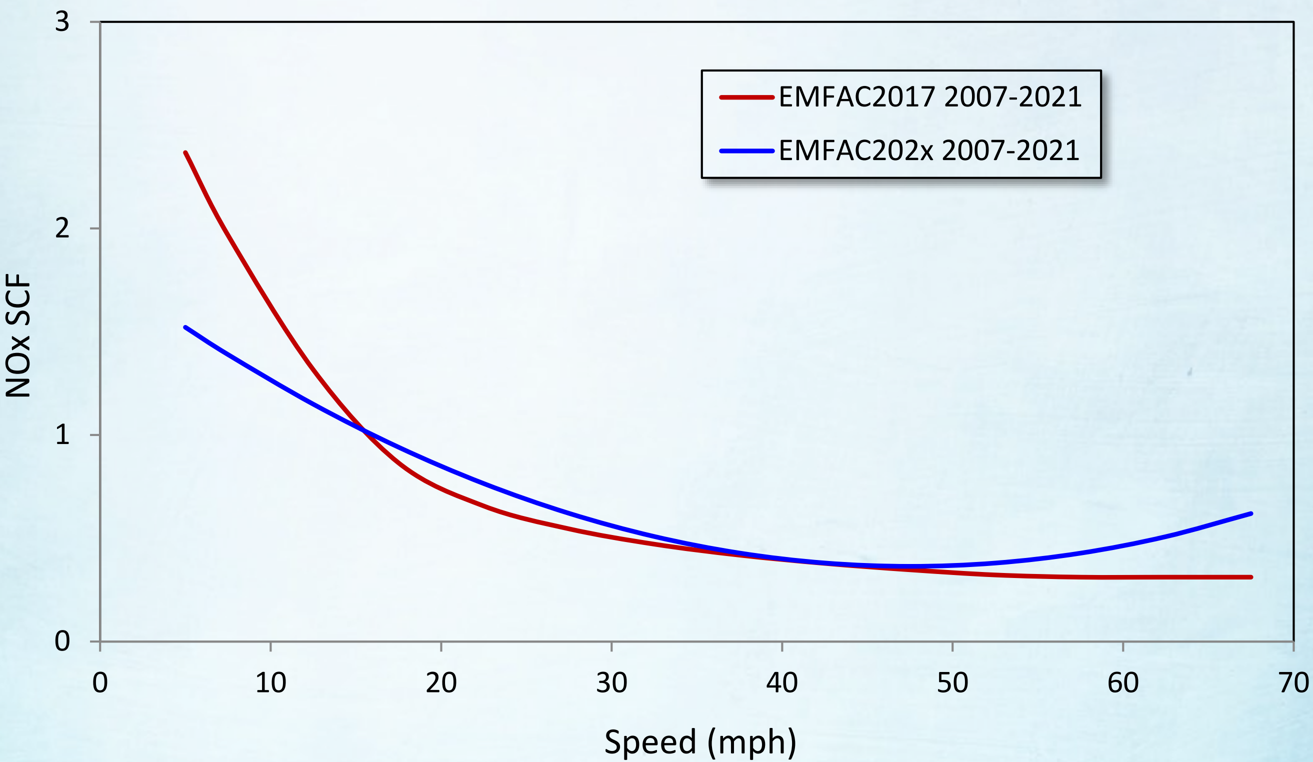
Diesel LHDT NOx SCF



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Revised LHDT PM Running Exhaust Emission Rates

Model Year	Fuel	EMFAC 2017		EMFAC 202x	
		ZMR	DR	ZMR	DR
2007-2021 (ULEV340)*	Diesel	0.0071	0.0017	0.0069	0.0017
2007-2021 (ULEV570)*	Diesel	0.0071	0.0017	0.0076	0.0018
2008-2021 (ULEV340)*	Gasoline	0.004	0.0	0.002	0.0
2004-2009 (ULEV)	Diesel	0.071	0.002	0.262	0.006

* Rates for other ULEV & SULEV standards to be calculated using ratio-of-standards

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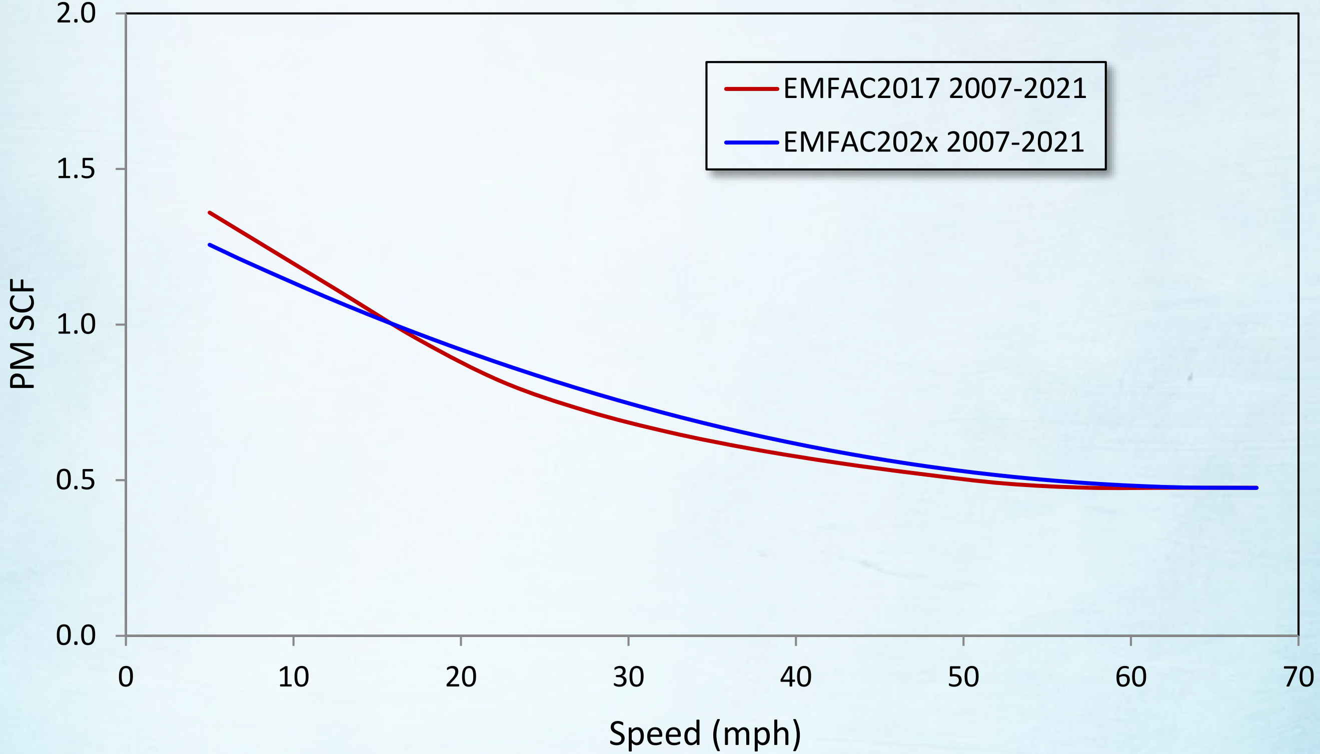
Diesel LHDT PM SCF



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Medium & Heavy Heavy-Duty Vehicles

Emission Rates

Heavy Duty Truck Emissions Modeling Method

$$ER(g/mi) = (ZMR + DR \times Odometer) \times SCF$$

- **ZMR** (Zero-mile emission rate) – Fleet average UDDS emission rates for new trucks
- **DR** (Deterioration rate) – Increase in emissions of in-use fleet over time
- **SCF** (Speed Correction Factors) – For determining emission rates at different driving speeds

Review of EMFAC2017 HD Emission Rate Revision

- Heavy heavy-duty trucks (HHDT):
  - Revised running exhaust emission rates of 2010+ MY trucks using dyno data from CARB, SCAQMD, & EMA
  - Revised start emission rates using CARB PEMS data
  - Revised idle emission rates using CARB & TTI PEMS data
- Medium heavy-duty truck (MHDT) emission rates updated by scaling HHDT emission rates

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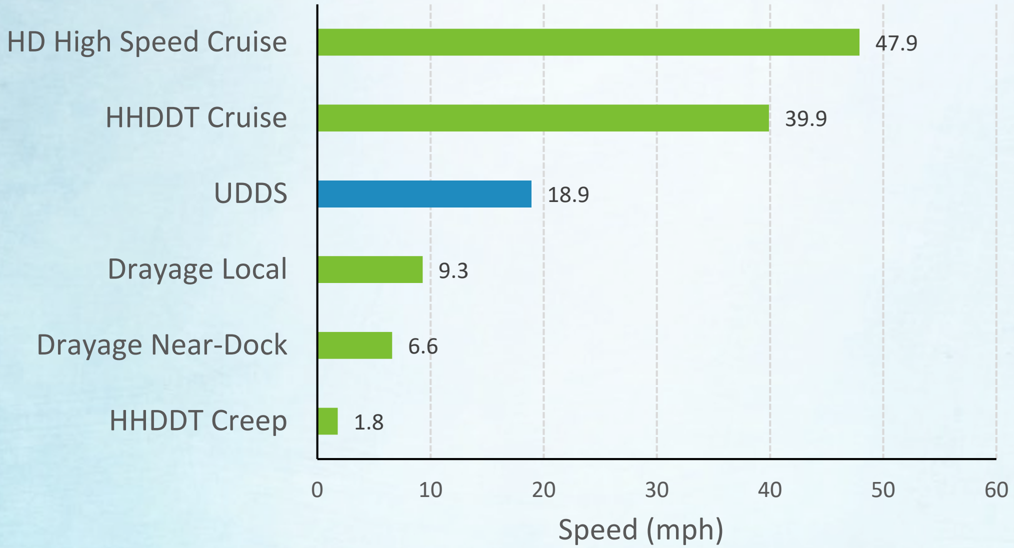
Planned Revision of HHDT Emission Rates

- Revise running exhaust emission rates of 2013+ MY using dynamometer test data of CARB TBSP
- Revise start emission rates of 2013+ MY using PEMS data of CARB TBSP
- Revise natural gas vehicle emission rates based on data from CEC-SCAQMD project

CARB Truck and Bus Surveillance Program (TBSP)

- To date, (35) 2013+ MY trucks tested on dynamometer over 6 test cycles
- Most trucks also tested with PEMS on 4 routes



PEMS Route	Driving Type
DP-WSAC-ART	Arterial
DP-WSAC-ART	Arterial / Freeway
DP-WSAC-INDEXT	Low Load / Low Speed
DP-PLAC	Uphill / Downhill

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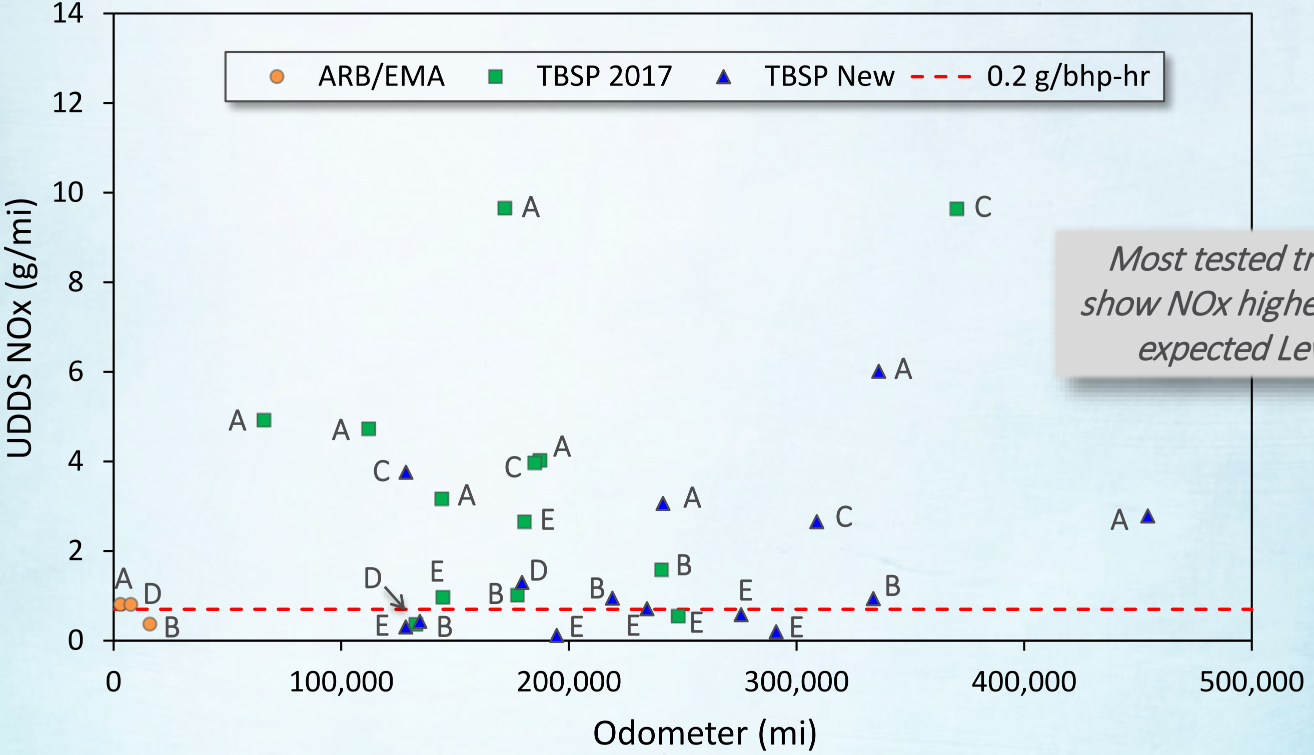
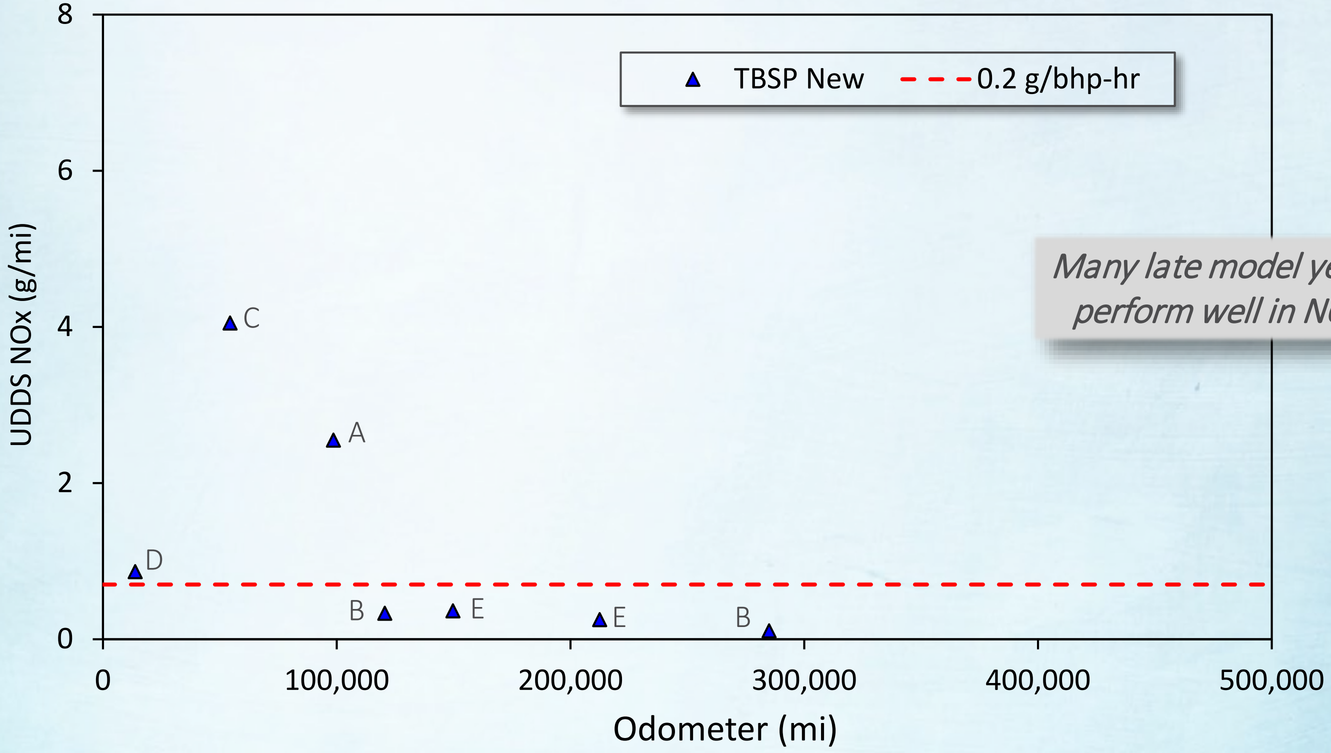
2013-2015 MY HHDT UDDS NOx



Most tested trucks show NOx higher than expected Level

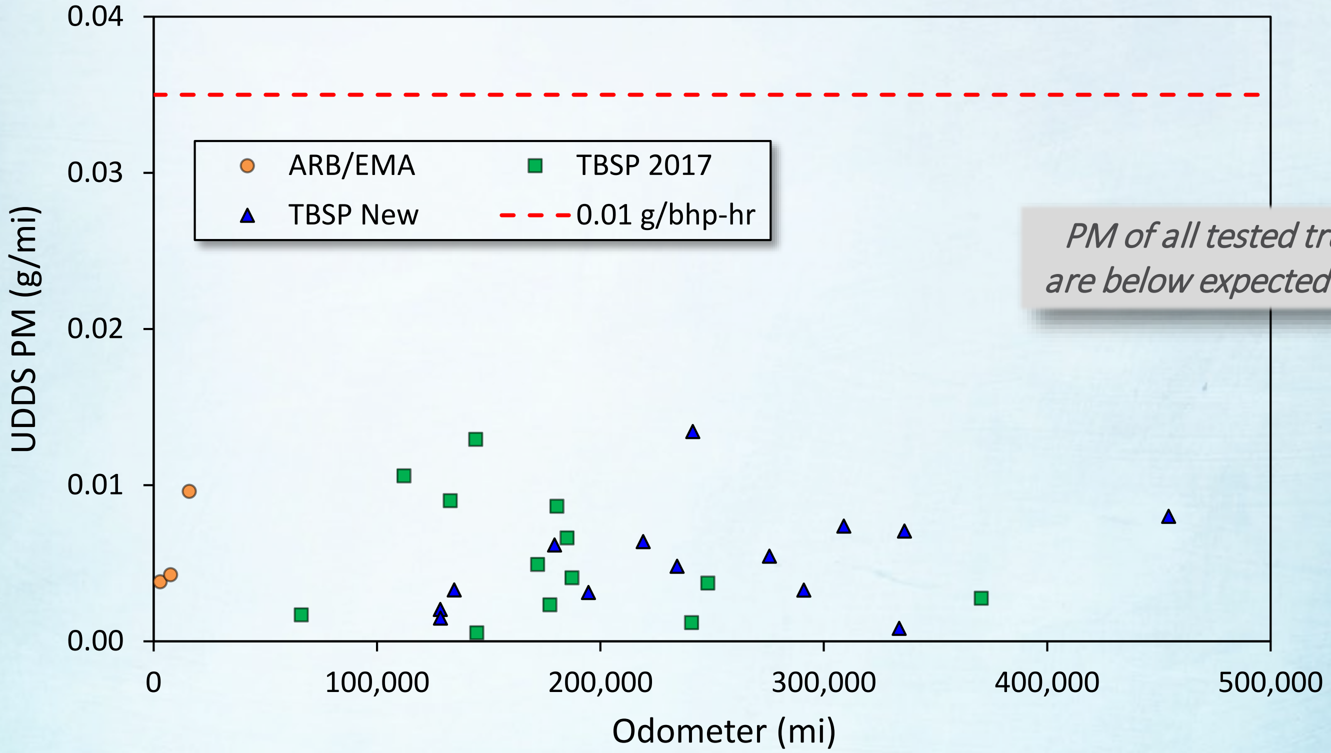
2016+ MY HHDT UDDS NOx



Many late model years perform well in NOx

CARB

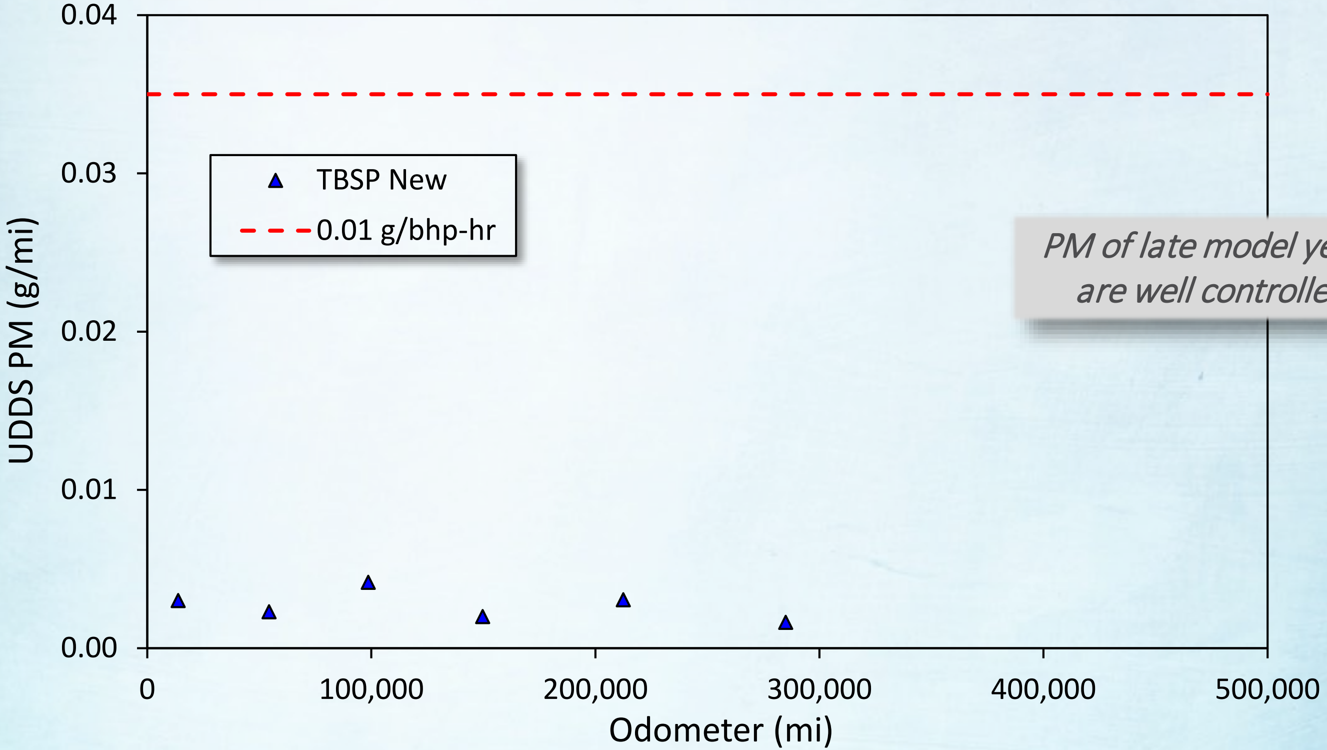
2013-2015 MY HHDT UDDS PM



PM of all tested trucks are below expected Level

CARB

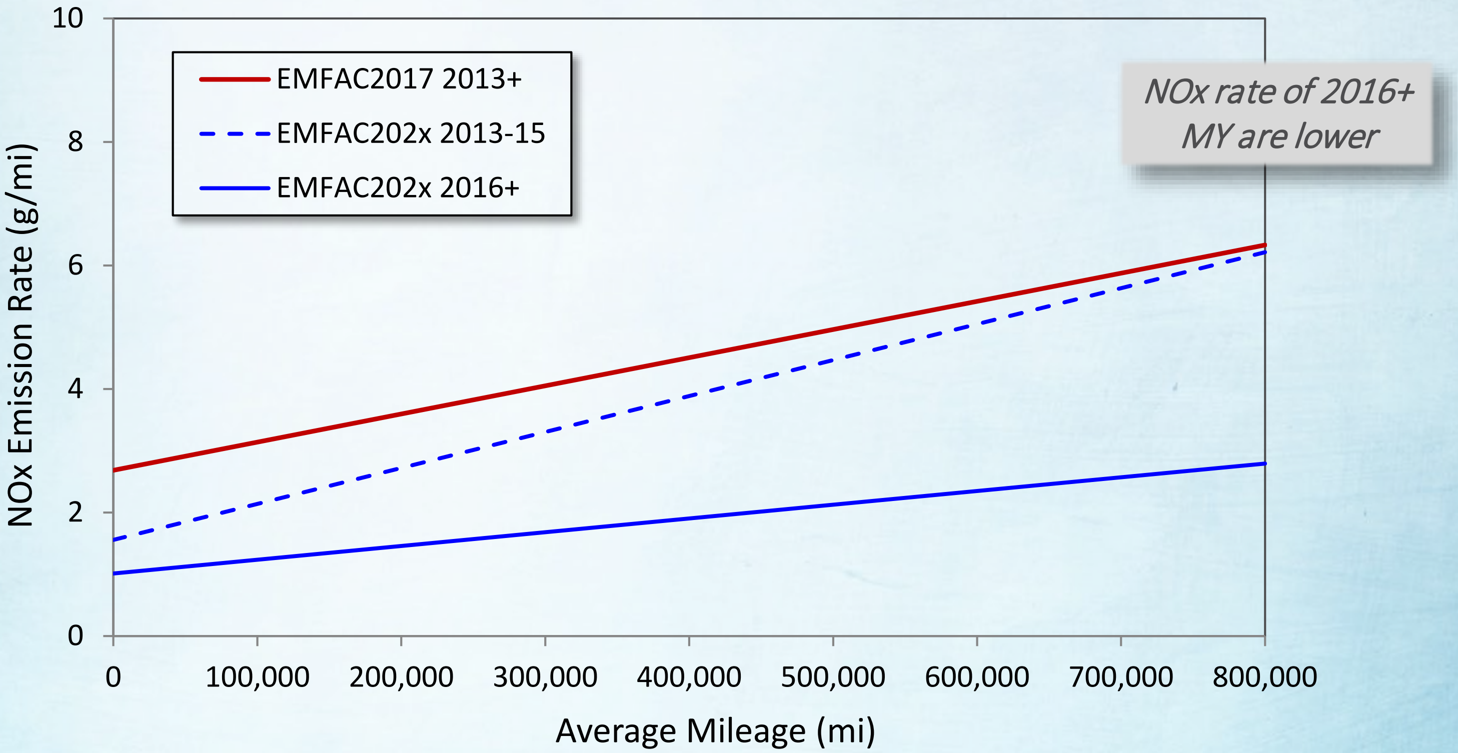
2016+ MY HHDT UDDS PM



PM of late model years are well controlled

CARB

HHDT NOx Emission Rates



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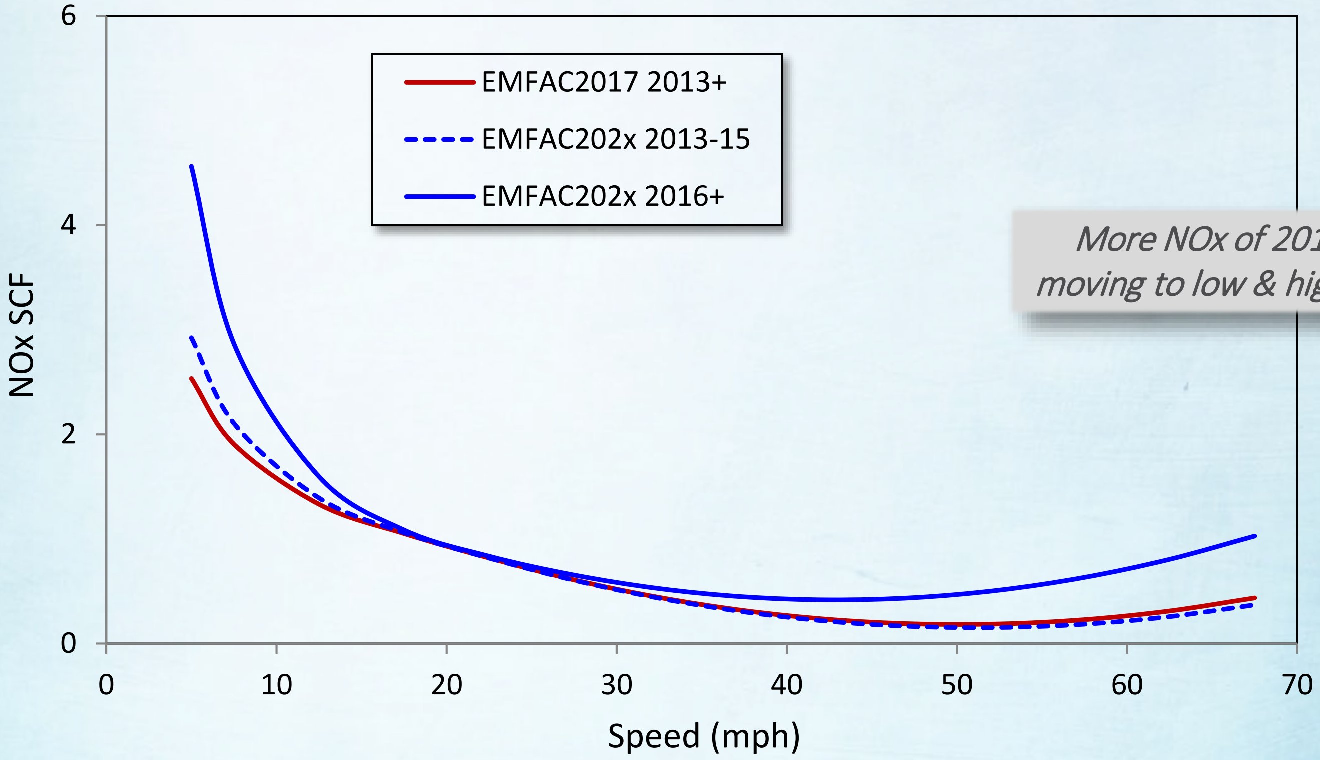
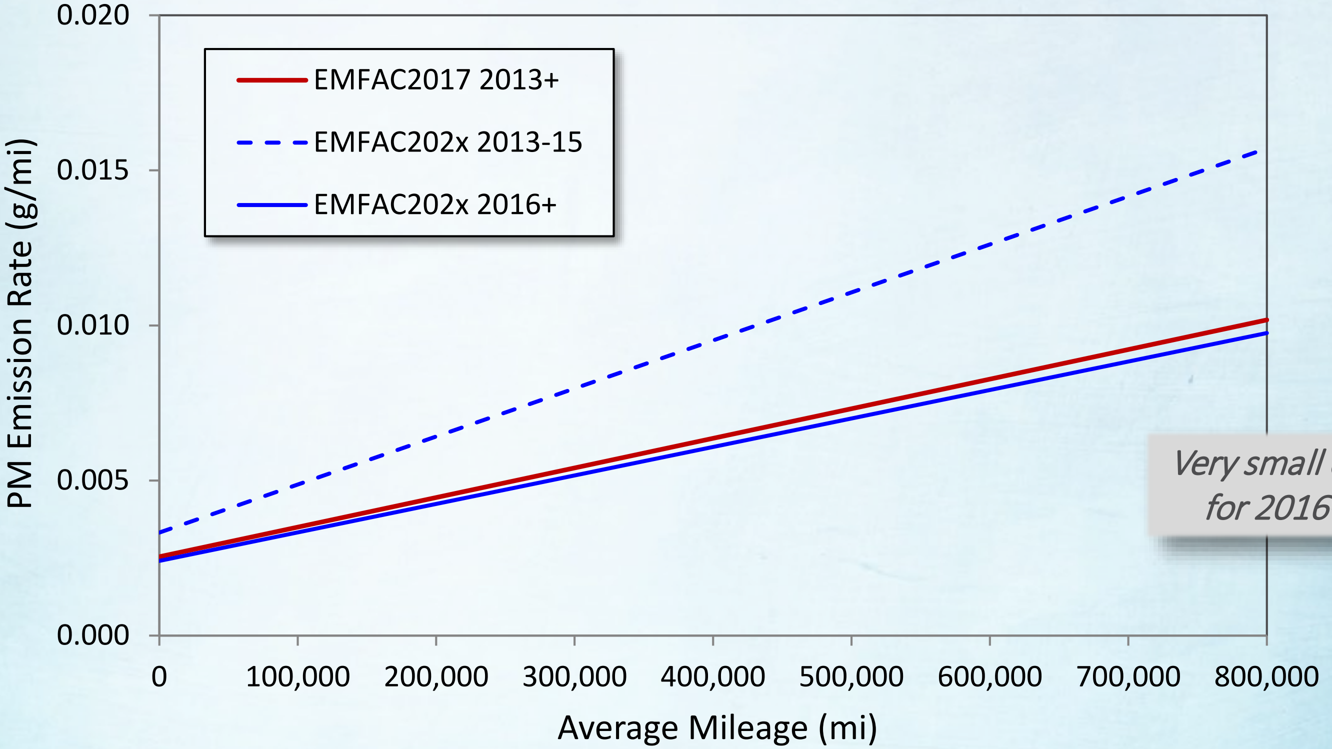
HHDT NOx SCF



More NOx of 2016+ MY moving to low & high Speeds

CARB

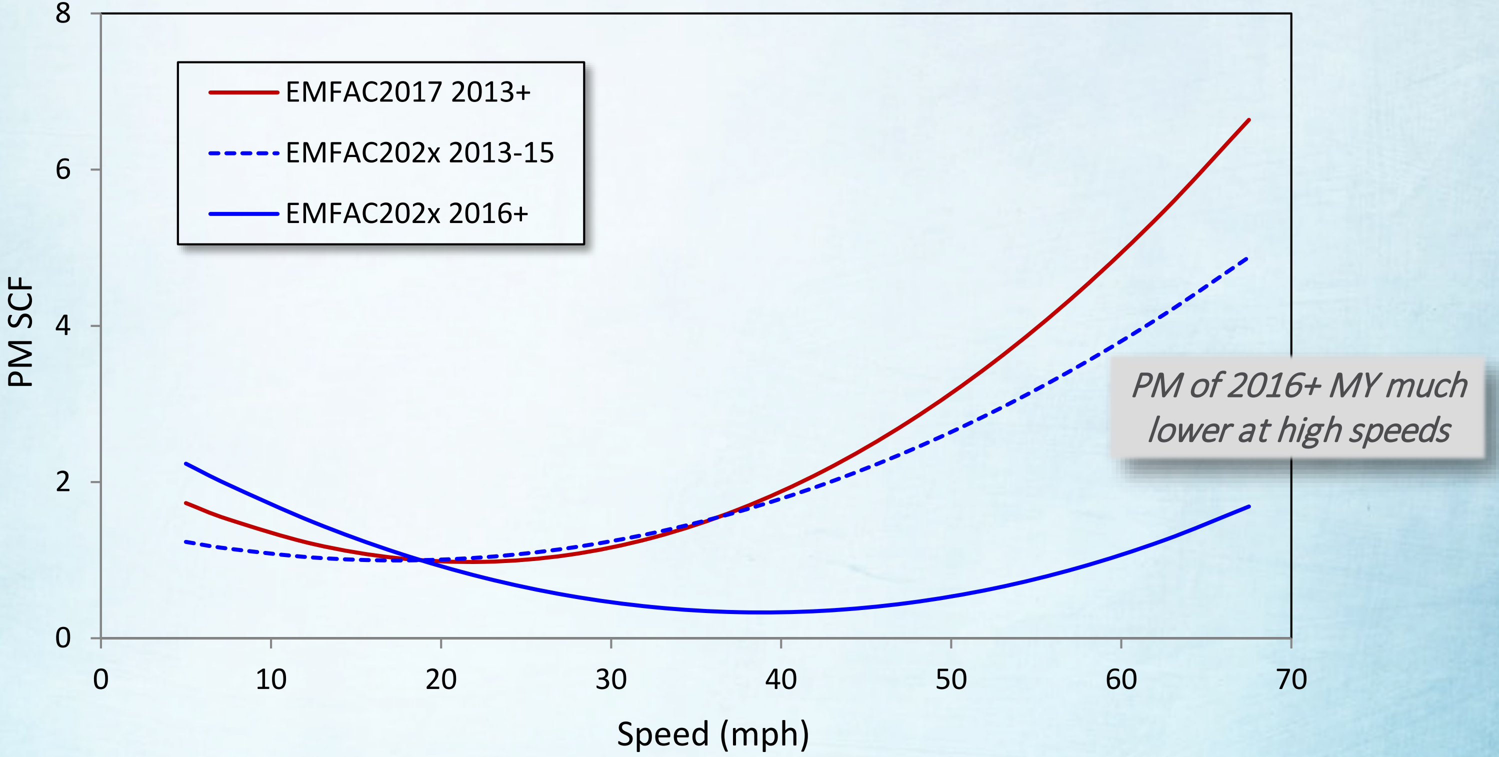
HHDT PM Emission Rates



Very small change for 2016+ MY

CARB

HHDT PM SCF



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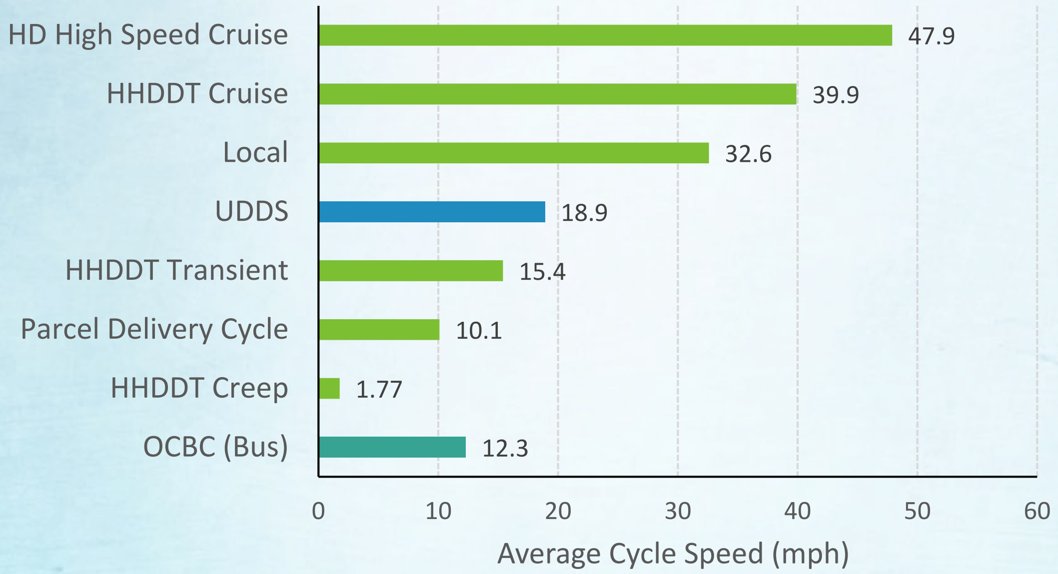
CARB Surveillance Program for Class 4-6 Vehicles

NEW

- To date, (3) 2013+ MY trucks tested on dynamometer multiple test cycles
- Selected vehicles to be tested with PEMS on 2 routes



PEMS Route	Driving Type
Downtown LA	Urban
Oxnard	Freeway

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Next Steps

- Heavy duty truck testing at CARB ongoing
  - Additional data expected before EMFAC update cutoff date
- Incorporation of revised emission control failure rates
- Analysis of CARB HD truck PEMS data for revision of start emissions
- Analysis of test data of natural gas vehicles from CEC-AQMD testing project

Heavy-Duty Vehicles

Deterioration Rates

Introduction: Heavy-Duty Deterioration in EMFAC

Emission Impact Rate (EIR) = Frequency of Engine Component or After-treatment system failure × % Emission Increase from Engine Component or After-treatment system failure

Current EMFAC assumptions

- Emissions from diesel powered trucks remain stable in the absence of tampering, malfunctions, and mal-maintenance.
- The EIRs are based upon assumptions of the frequency (FREQ) of occurrence and the emissions increase of specific instances of tampering, malfunctions, and mal-maintenance (TM&M)

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Modeling Heavy-Duty Deterioration in EMFAC

$$ZMR\left(\frac{g}{mile}\right) = \frac{ER_{avg}}{\left(1 + EIR \times \frac{Odo_{avg}}{1{,}000{,}000}\right)}$$

$$DR\left(\frac{g}{mile * 10\text{K}\ mi}\right) = \frac{ZMR \times EIR}{100}$$

$$ER\left(\frac{g}{mile}\right) = (ZMR + DR \times Odometer) \times SCF$$

Zero-mile emission rate (**ZMR**) – Fleet average UDDS emission rates while trucks are new

In-Use Emission Deterioration (**DR**) – Increase of emissions over time within the in-use fleet caused by tampering, malfunction and mal-maintenance (TM&M) of engine components, and emission control systems

Speed Correction Factors (**SCF**) – A method to correct emission factors at different driving speeds

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Reasons for Updating Estimates of Heavy-Duty Deterioration

- Current understanding of emissions performance in EMFAC for MY2013+ are outdated
- Heavy-duty in-use emissions performance is an important component of CARB's air quality policies
- CARB is planning to implement a heavy-duty inspection and maintenance program to ensure low emissions over the vehicle's lifetime
- Need better estimates of emissions benefits and costs for a heavy-duty inspection & maintenance program

Use On-Board Diagnostics (OBD) Data to Update Heavy-Duty Deterioration Assumptions

- On-board diagnostics (OBD) system are available for heavy-duty trucks with MY 2013+
- Heavy-duty truck OBD regulation requires that emissions control equipment be monitored for deterioration and malfunction
- Malfunction indicator lamp (MIL) status and emission-related fault codes can be used to improve deterioration assumptions

Use On-Board Diagnostics (OBD) Data to Update Heavy-Duty Deterioration Assumptions

- CARB is conducting an extramural contract to collect a large volume of OBD from model year (MY) 2013+ heavy-duty trucks to update deterioration assumptions

TM&M Category	EMFAC2017	
	2010-12 MY	2013+ MY
NO_X Sensor	36%	24%
Replacement NO_X Sensor	1.8%	1.2%
SCR System	40%	27%
EGR Disabled / Low Flow	16%	11%
DPF Leaking	10%	6.7%

Rates at 1,000,000 miles

Data can be used to update TM&M frequencies for MY2013+ trucks

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Progress on Heavy-duty In-Use Deterioration Contract

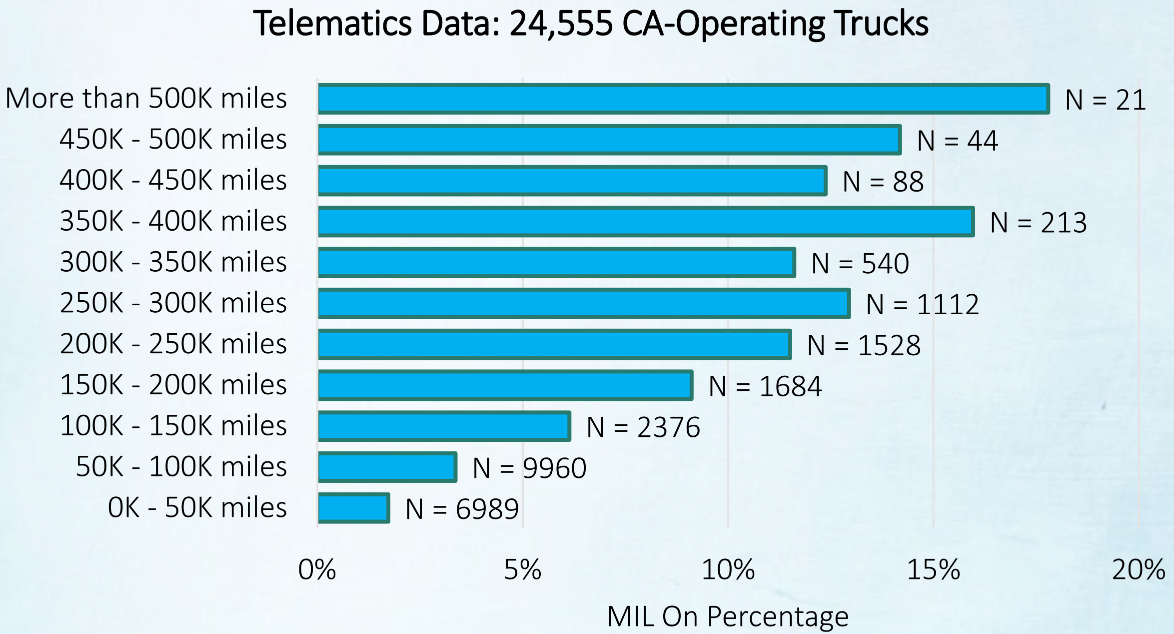
Telematics data from 24,555 CA Vehicles and 190,000 US Vehicles GVWR > 14,000 lbs

300 Vehicles Collected through from Truck Stops, Ports, and Repair Shops

End of 2019: Field and telematics data collection will be complete

Mid - 2020: Data analysis and method development will be complete

Progress on Heavy-duty In-Use Deterioration Contract



Overall MIL On rate (Average odometer 101,000 miles)
7%

Fleets that use telematics services may have different maintenance practices and therefore may not have MIL ON rates that are representative of on-road fleet

Anticipated Methods for Updating Deterioration Rates

- Emissions-related fault codes (thousands) that illuminate a truck's MIL will be grouped into broader tampering, mal-maintenance and malfunction (TM&M) categories
- The malfunction frequency for each TM&M category will be quantified in 50,000 mile odometer bins
- Model frequency as a function of odometer
- Combine frequencies with % increase in emissions to get new deterioration rates for MY2013+ heavy-duty trucks

Emissions % Increase from TM&M Actions

- To estimate % emissions increase, EMFAC uses emissions test data from manufacturer-submitted durability demonstration vehicle (DDV) reports
- Baseline FTP/RMC-followed by introduction of one malfunction at a time and reevaluating emissions
- Data therefore provides emissions increase and systems ability to detect malfunction below OBD threshold (MIL light)
- Components tested include: SCR catalyst, DEF doser, NOx sensors, DOC, EGR, fuel system, boost control and PM filter leak

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Current Model Assumptions for Emission Impact of After-treatment Malfunction

Control Malfunction	EMFAC2017 NOx	EMFAC2017 PM
SCR Malfunction	300%	15%
NOx Sensor Malfunction	200%	0%
DPF Leaking	0%	5200%

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Revised Emission Increase of NOx Control Malfunction

Control Malfunction	OBD DDV Reports	Emissions Test Data	EMFAC2017 2013+ MY	EMFAC202x 2013 - 2015 MY	EMFAC202x 2016+ MY
NOx Sensor Malfunction	185%	--	200%	185%	185%
SCR Malfunction	360%	250%-1100%	300%	540%	360%

In-use emissions percentage increases higher than indicated by DDV reports → higher deterioration-related emissions

Next Steps

- Process and analyze OBD data collected from heavy-duty trucks
- Use processed OBD data and results from Ramboll Pilot Survey of Repair Facilities to revise TM&M frequencies for MY2013+ newer heavy-duty trucks
- Update % emissions increase for NOx sensor and SCR malfunction from in-use testing data
- Assess the impact of updated deterioration assumptions on heavy-duty truck emissions

PM Brake Wear (Light and Heavy-Duty Vehicle)

Emission Rates

Background

- Currently
  - Old data (2000/2003)
  - No cycle or speed effects
  - Data extrapolated to cover all technology groups/drive cycles
- New Emission Factor Development
  - CA representative vehicles and brake components
  - Light-, Medium-, and Heavy-Duty Vehicle brakes and cycles
  - Identify speed dependent braking cycle reflecting CA behavior
  - Use methods being adopted by JRC (Enclosed brake dyno)
  - Maintain realistic temperatures
  - Develop method to simulate regenerative braking

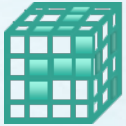
Ongoing Brake Wear Work

LDVs

Market Share Analysis → 6-7 vehicle choices → On-road testing → Final drive cycles, real temperatures

Real world CA activity data ↓

Validated enclosed dyno and PM sampling systems → ~90 tests by 3/2020



Vehicle N:
Front brake pads
Rear brake pads/drums
Popular aftermarket pads
Loaded/unloaded
Replicates

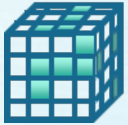
ERG

LINK

HDVs

Market Share Analysis → 4-5 vehicle choices → On-road testing → Final drive cycles, real temperatures

Validated enclosed dyno and PM sampling systems → ~40 tests by 1/2021



Caltrans

United States Environmental Protection Agency

CARB

Expected Findings and Improvements

- Updated emission factors
  - Cycle based - Speed dependent
  - Regenerative braking effects
  - Effects of load, vehicle type, pad type
- On different time scales, explore various effects on mass, PN, PM size:

Cycle Averaged	Micro-trip Averaged	Individual Brake Events
Vehicle configuration Pad material Repeatability	Speed Driving behavior Repeatability	Braking power Temperature Repeatability

- Chemical composition

On-Road Motorcycles

Activity & Emissions

Background

- EMFAC on-road motorcycle activity and emission factors have not been updated since 2000
- Accrual rates
  - Provided by Motorcycle Industry Council (MIC) survey in 1990 and by MPOs in late 1990's
  - CA does not have a motorcycle Smog Check program to collect odometer data to determine annual mileage
- Emission rates
  - EMFAC uses 1978-1980 motorcycle exhaust FTP data and 1998 Unified Cycle (UC) test data (125 motorcycles 1998 and older)
  - Evaporative emission factors are based on light-duty automobiles

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Major Updates Are Coming!

- Motorcycle population will be updated using latest DMV Registration Data
- CARB is conducting extensive emissions testing on motorcycles (using both dynamometers and PEMS) to better understand emissions from motorcycles
- CARB testing will include tampered motorcycles
    - A CARB study showed a 32% tamper rate
- Motorcycle accrual rates will be updated using 2017 National Household Travel Survey

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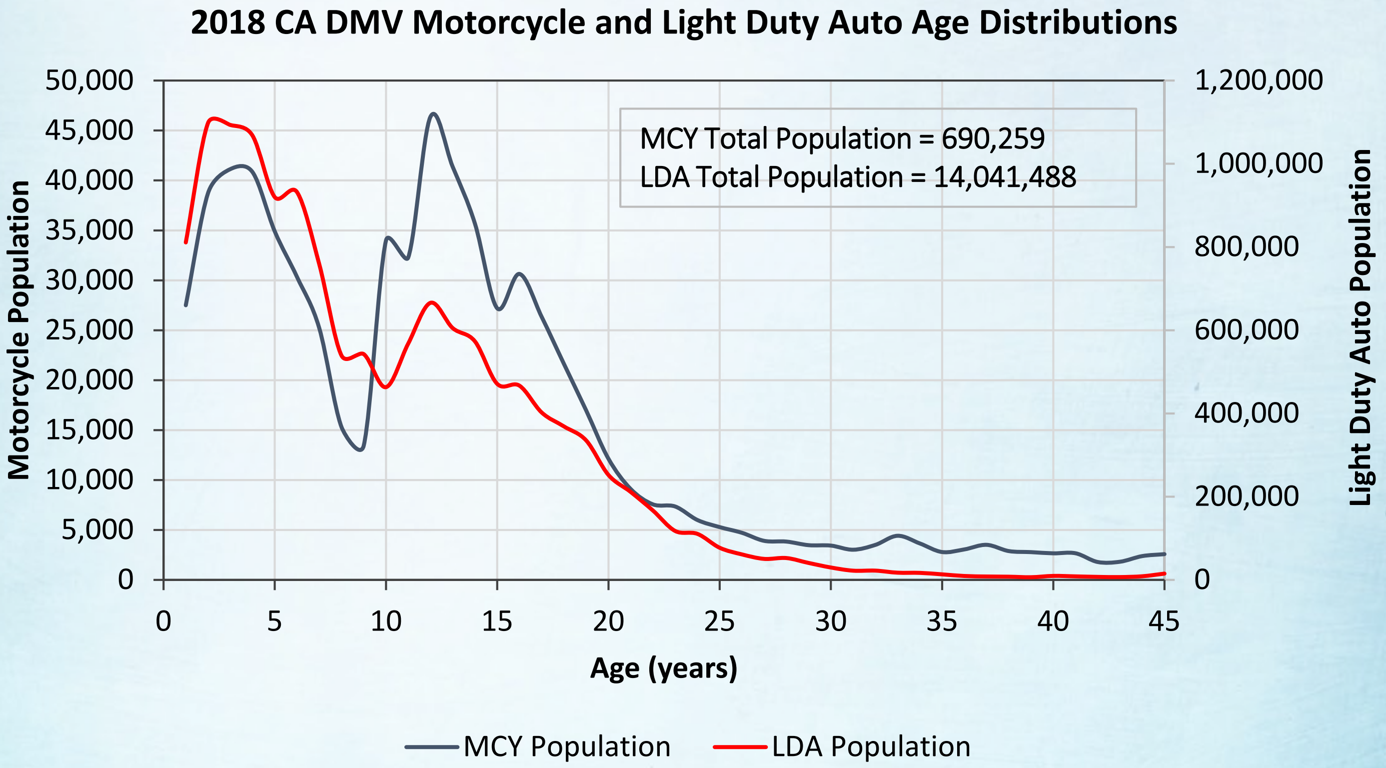
Population and Age Distribution



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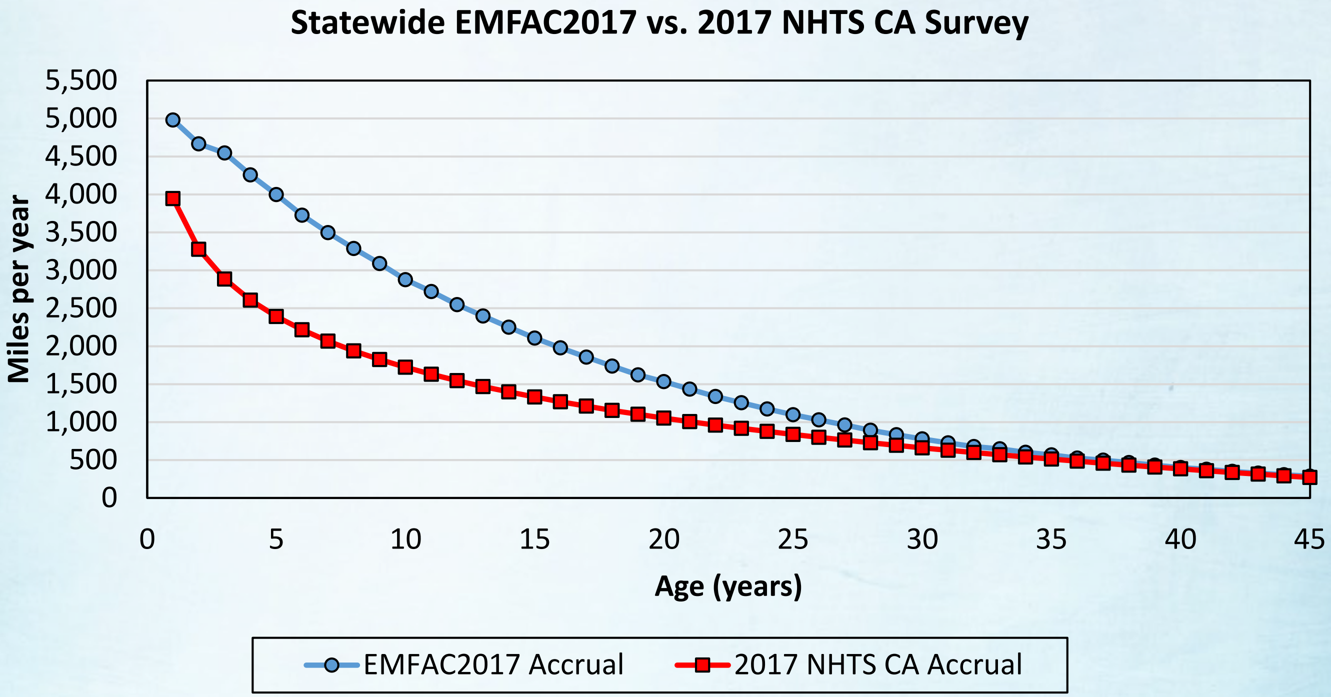
Activity: Proposed Accrual Rates



- Staff propose to update EMFAC with most recent NHTS CA accrual rate

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Motorcycle Tampering Rate

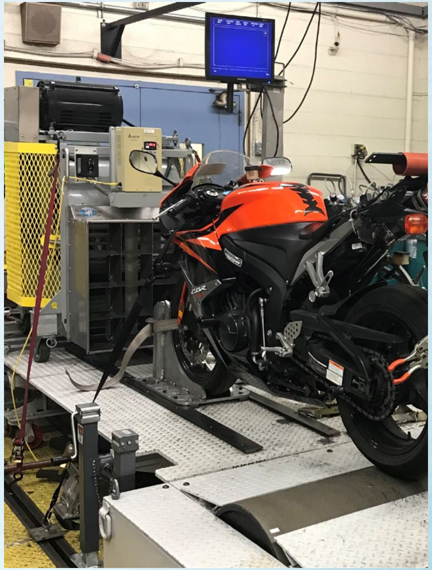
- CARB staff analyzed 1,000 CA motorcycle sales advertisements from Aug 2016 - Feb 2017 to evaluate tampered components
- Consulted CARB Executive Orders for MCYs and aftermarket parts, manuals and relevant sources to determine tampering
  - 937 Class 3 motorcycles (>280cc), and 63 Class 1-2 showed an overall tampering rate of <u>32%</u>
  - 34% of Class 3 motorcycles tampered, 8% of Class 1-2 tampered

Emissions: On-Road Motorcycle Testing

- 18 motorcycles from private owners (2010-2018 models)
- 7 state-owned bikes (3 are 2019 models, 3 are 2008 models, 1 is 2006)
- Exhaust tests:
  - Federal Test Procedure (FTP)
  - Unified Cycle (UC)
  - World Motorcycle Test Cycle (WMTC)
- Evaporative SHED tests:
  - 1-hour hot soak test
  - 7-day diurnal test

Emissions: On-Road Motorcycle Testing Cont.

- Tamper Emissions Testing
  - 7 state owned motorcycles
  - FTP, UC and WMTC
  - Stock configuration
  - Tampered configuration



- Idle Exhaust Testing
  - Follows WMTC Test
  - Data may be used for potential development of an Inspection and Maintenance (IM) program for motorcycles

Next Steps

- EMFAC202x will present a major update to motorcycle emissions and activity
- Data collected through CARB's motorcycle test plan will be used to update exhaust and evaporative emission rates in EMFAC
- Impact of these updates will be presented in the next workshop
- Support upcoming on-road motorcycle regulation and develop inventory by Fall 2020

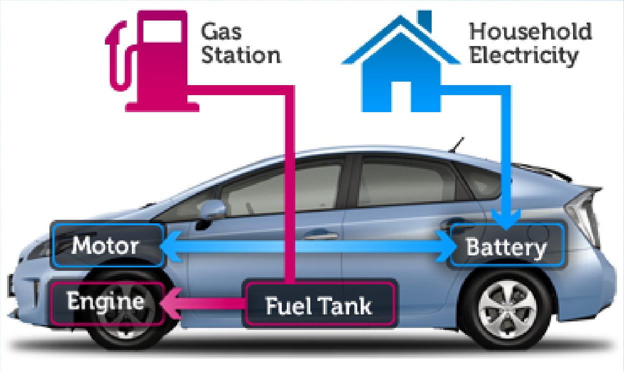
Light-Duty Vehicles

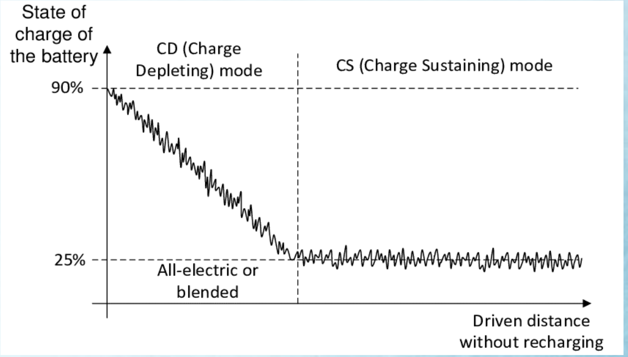
PHEV Module

Background

- What is Plug-in Hybrid Electric Vehicle (PHEV)?
  - Vehicle with both an electric motor and a gasoline engine
  - Battery can be recharged by plugging into a power source
  - Vehicle runs on charge-depleting (CD) mode, then switches to charge-sustaining (CS) mode

- Why so many PHEVs are sold in California?
  - Manufacturers earn zero-emission vehicle (ZEV) credits as part of the Advanced Clean Cars (ACC) program
  - Consumers get better fuel efficiency and carpool lane access





Source: "Aspects of Electric Vehicles and Demand Response in Electricity Grids", Rautianien, A., 2015

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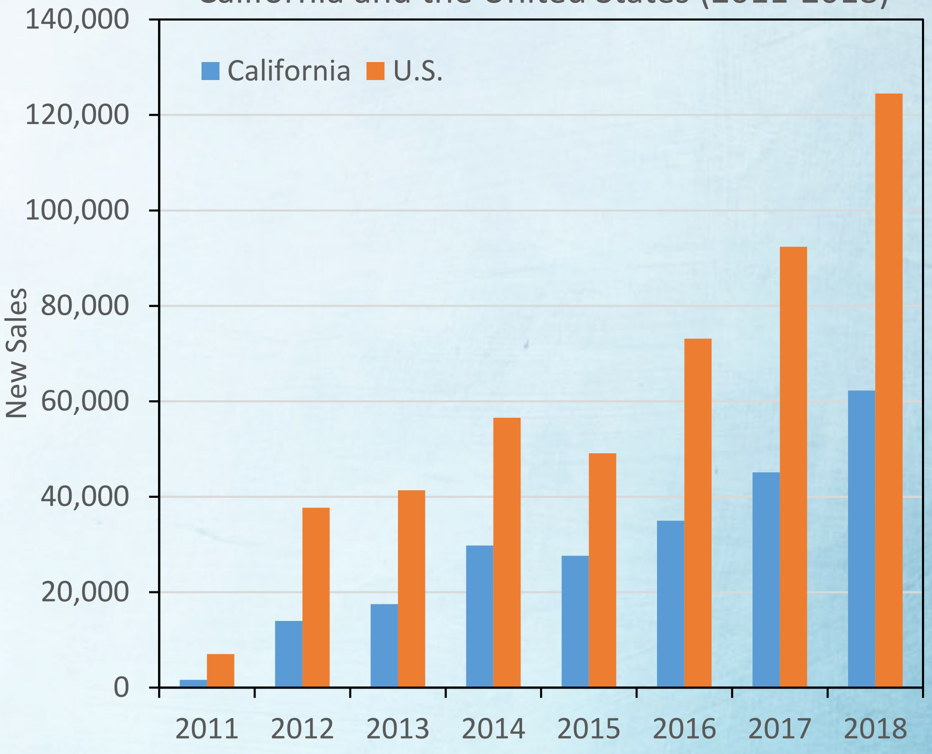
Background

- PHEVs in California
  - PHEVs showed significant increase in sales from 2011 to 2018
  - Total PHEV population is ~181k, including 18 makes across 36 models with model year ranging from 2011 to 2019 (2018 California DMV currently registered)
  - 74% PHEVs have an EV mile range of 0-50, and 25% in the EV mile range of 51-100 (2017 California DMV)

PHEV Annual Sales in California and the United States (2011-2018)



Source: autoalliance.org

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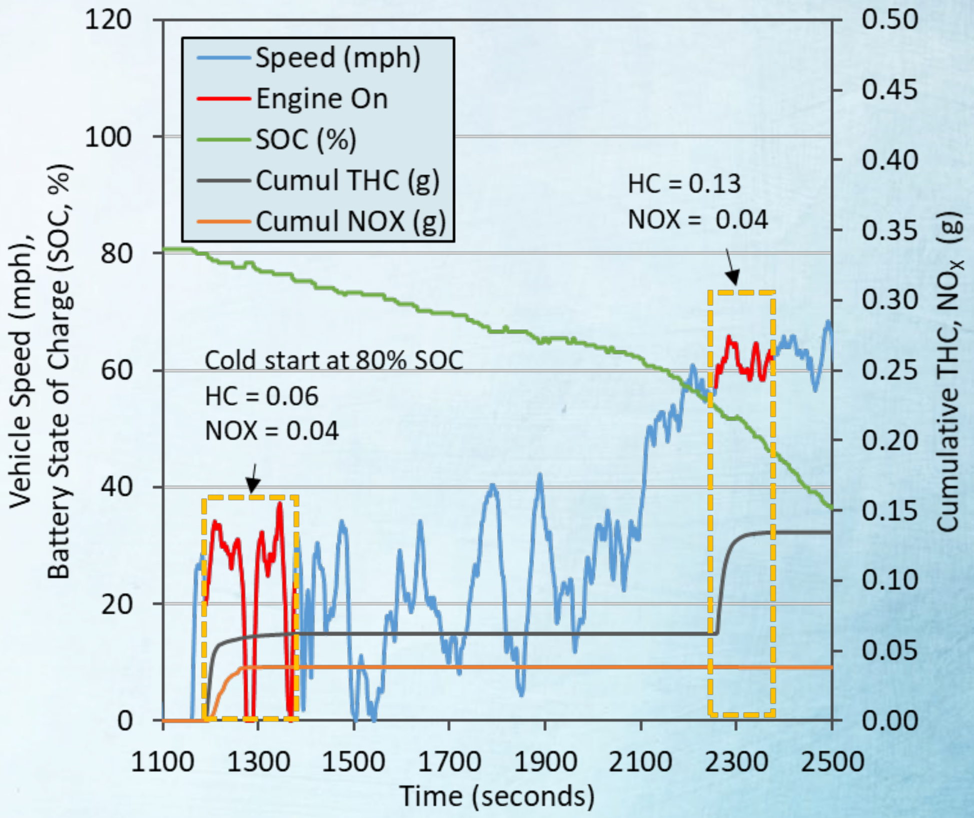
Motivation

- PHEVs have different type of engine operations than conventional vehicles
- Engine starts can occur anytime during the trip based on vehicle's battery level and energy demand
- When running on battery power alone, PHEVs do not generate tailpipe emissions
- PHEVs are characterized by "high-power cold starts", which could have 2-5+ times higher cold start emissions than conventional vehicles
- Such starting event is not modelled in the current EMFAC model



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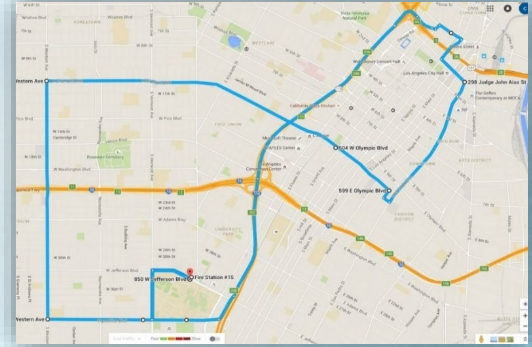
Data Sources

- Emission
  - Real-world emission testing by CARB
  - Total of 11 PHEVs across different make and models
  - On-road Portable Emissions Measurement System (PEMS) data
- Activity
  - Through extramural contract, CARB has collected sec-by-sec activity data for nearly 170 PHEVs over the course of 200-300 days
  - One of the most extensive activity datasets collected so far

PEMS Testing Setup



Example DTLA Route

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CARB Emission Testing - Routes

Route	Distance (mile)	Travel Time (min)	Average Speed (mph)	Route Characteristics	Elevation Gain (m)
Downtown Los Angeles (DTLA)	16	60	15	Typical city driving	75
Freeway around El Monte	18	30	35 – 40	Freeway with higher power demand	50
Local roads in El Monte	1.3	3 – 6	10 – 15	Various soak periods	10
El Monte to Lake Pyramid	65	95	45 – 50	Longer arterial and freeway with high road grade	800

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CARB Emission Testing - List of Test Vehicles

1. 2017 Toyota Prius
(LEV3 SULEV30)

2. 2017 Audi A3 E-Tron
(LEV3 SULEV30)

3. 2012 Chevy Volt
(LEV2 SULEV)

4. 2014 Ford Fusion
(LEV2 SULEV)

5. 2016 Ford C-Max
(LEV2 SULEV)

6. 2016 Hyundai Sonata
(LEV3 SULEV30)

7. 2017 BMW 330e
(LEV3 ULEV125)

8. 2016 Porsche Cayenne Hybrid
(LEV2 ULEV)

9.2016 Mercedes C350e
(LEV3 SULEV30)

10. 2014 Toyota Prius
(LEV2 SULEV)

11. 2017 Chevy Volt
(LEV3 ULEV125)

CARB Emission Testing - Example Time Plots 1

Speed (mph)

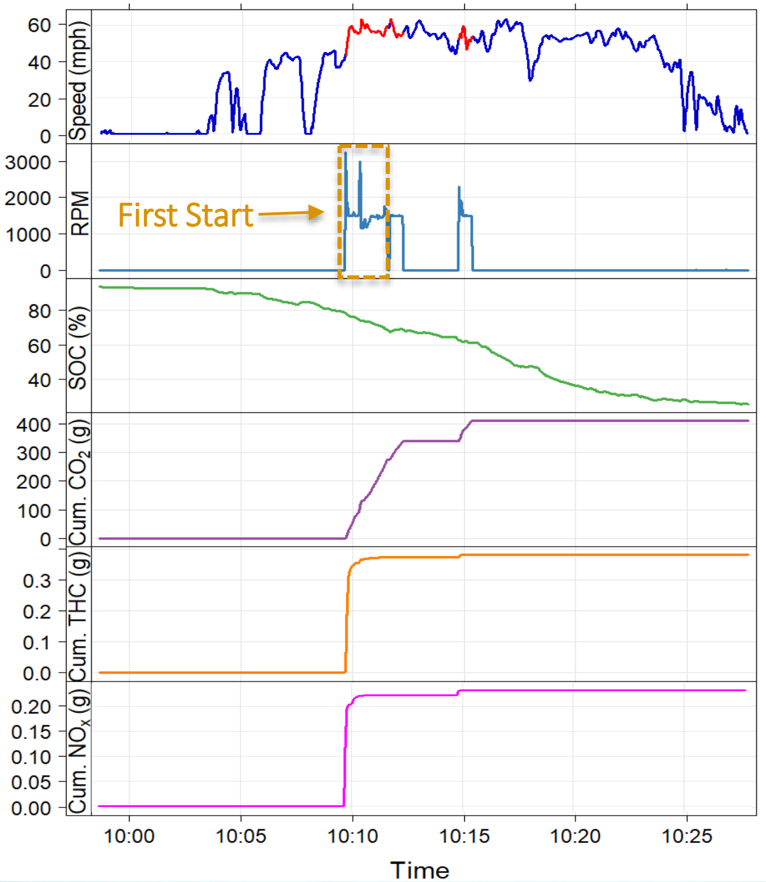
RPM

SOC (%)

Cum. CO_2 (g)

Cum. THC (g)

Cum. NO_x (g)



Red: engine on

Blue: engine off

- Vehicle 4 (2014 Ford Fusion), Freeway
- High-power cold start: Engine was turned on during charge-depleting model while accelerating at high speed (high power demand) even-though SOC level is high
- First start has significant emissions compared to other non-first starts

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CARB Emission Testing - Example Time Plots 2

Speed (mph)

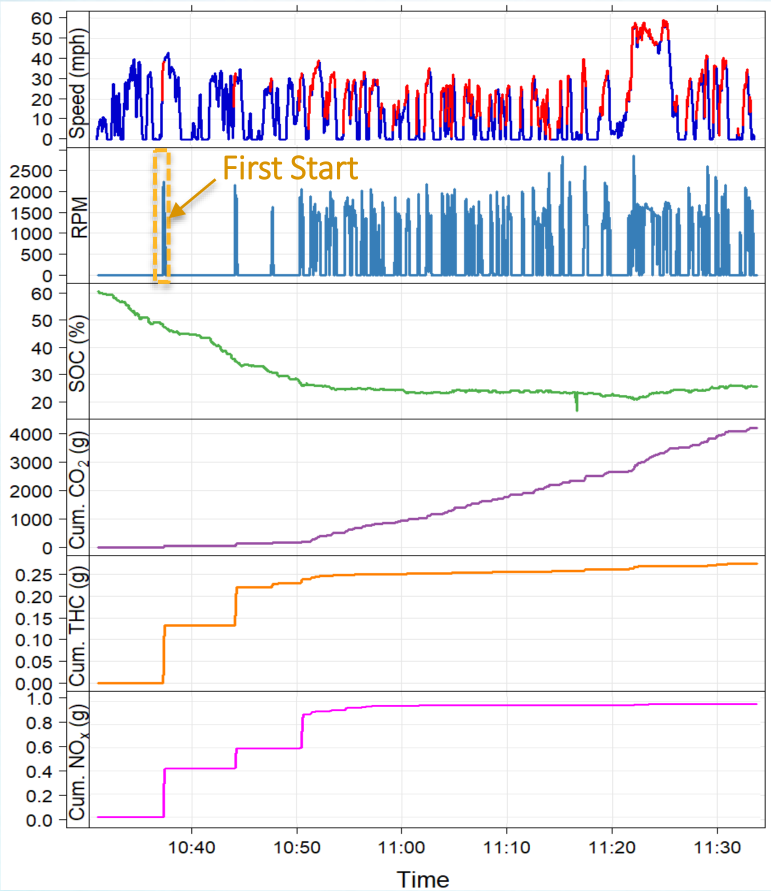
RPM

SOC (%)

Cum. CO_2 (g)

Cum. THC (g)

Cum. NO_x (g)



Red: engine on

Blue: engine off

- Vehicle 9 (2016 Mercedes C350e), DTLA
- Engine was turned on multiple times in charge-sustaining mode, especially when accelerating
- Significant emissions in 1st, 2nd, and 3rd starts, engine might not fully warmed up because of short duration

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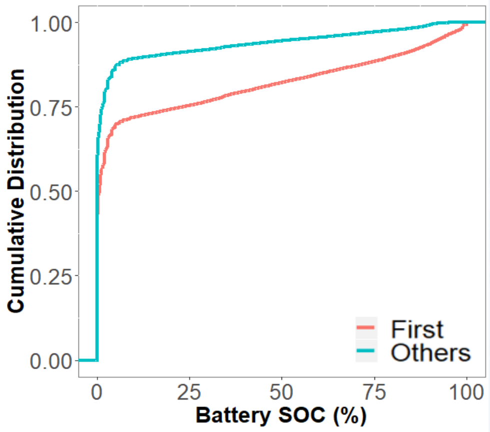
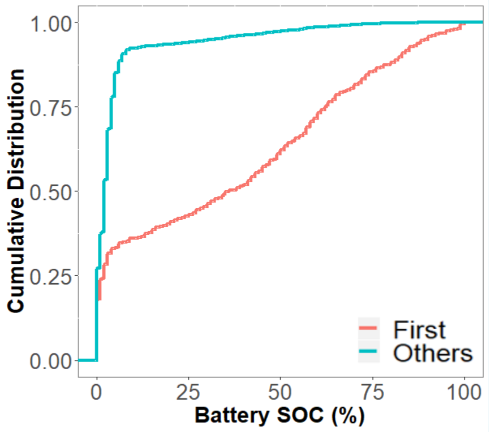
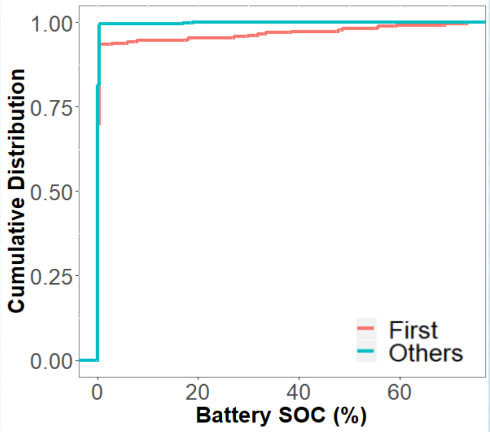
Cumulative Distribution of Battery SOC Level from UC Davis Activity Data



Results from All Test Vehicles



Example 2012 Prius Plug-in



Example 2016 Volt

- Different vehicles (example for Prius and Volt) have different starts strategies
- For example, Prius can start at any SOC level, but Volt mostly starts in CS mode

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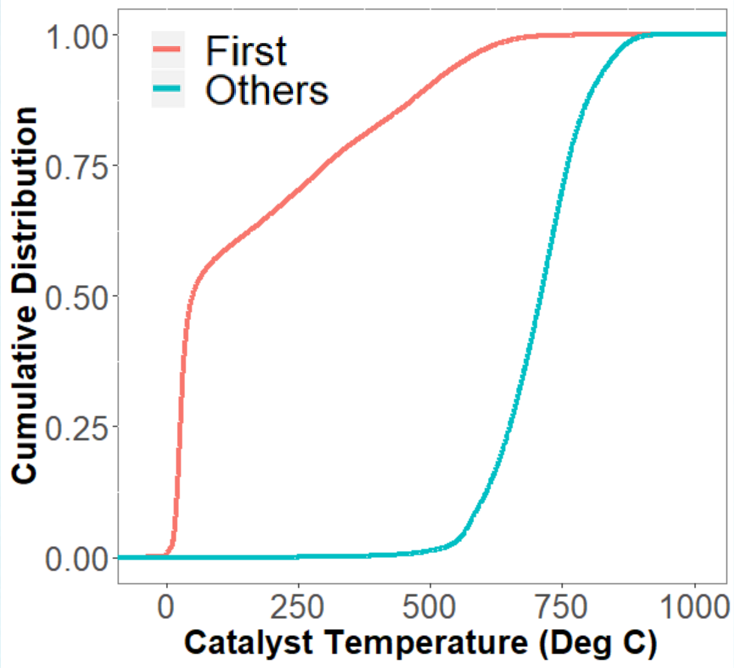
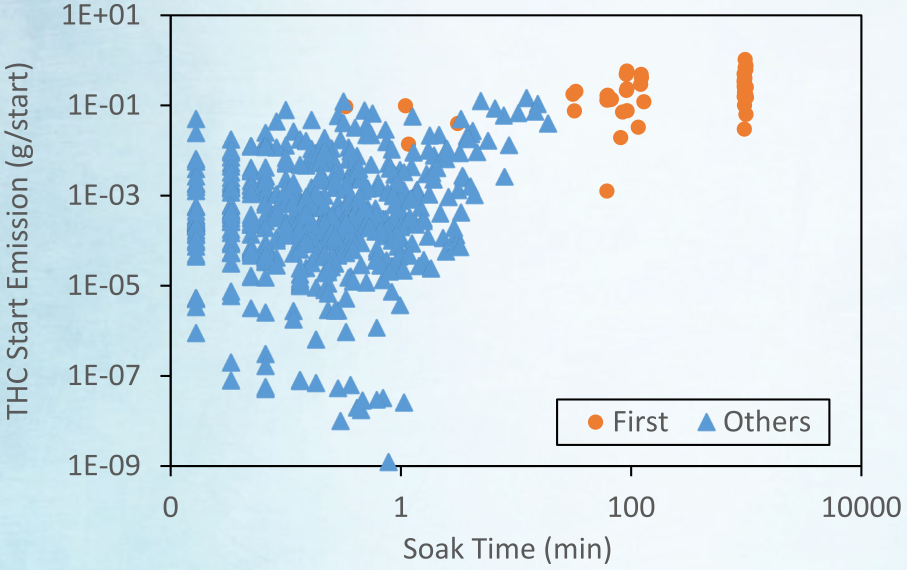
PHEV Starts Definition

Cumulative Distribution of Catalyst Temperature by first or other starts from all UC Davis activity



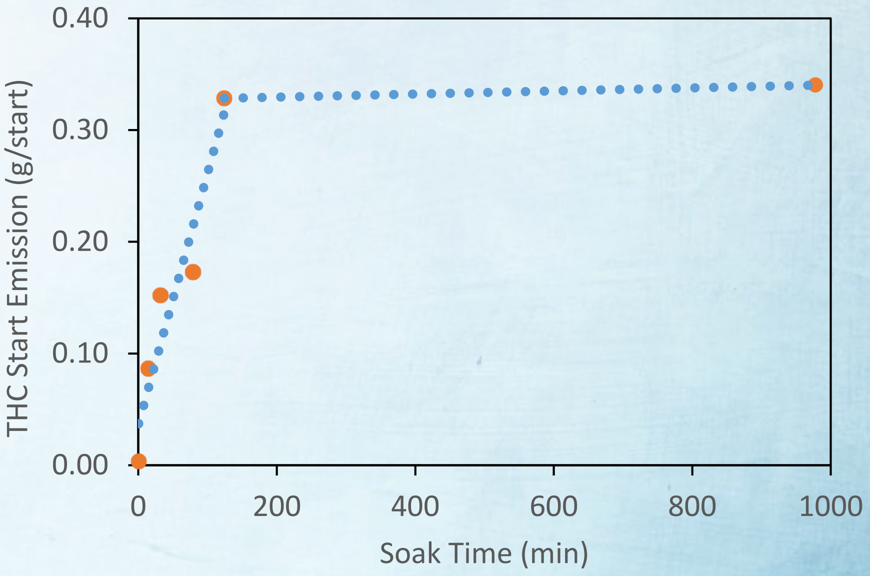
- Engine is considered to be ON (start) if RPM ≥ 100
- The start duration vary by make/model, and depends on speed, acceleration, power demand, and SOC level.
- A duration limit of 5 to 300 secs was set for start emissions
- Non-first starts occur with catalyst warmed up (above 425 deg C)

THC Start Emissions with Soak Time Relationship



Log-Log Scale

Note: only data with road grade within ±2% are included; Vehicle 8 data was excluded because it was certified under LEV2 ULEV



- Bin start emissions soak time into different bins minutes
- Apply piecewise linear regression (break point = 120 min, $R^2 = 0.90$)

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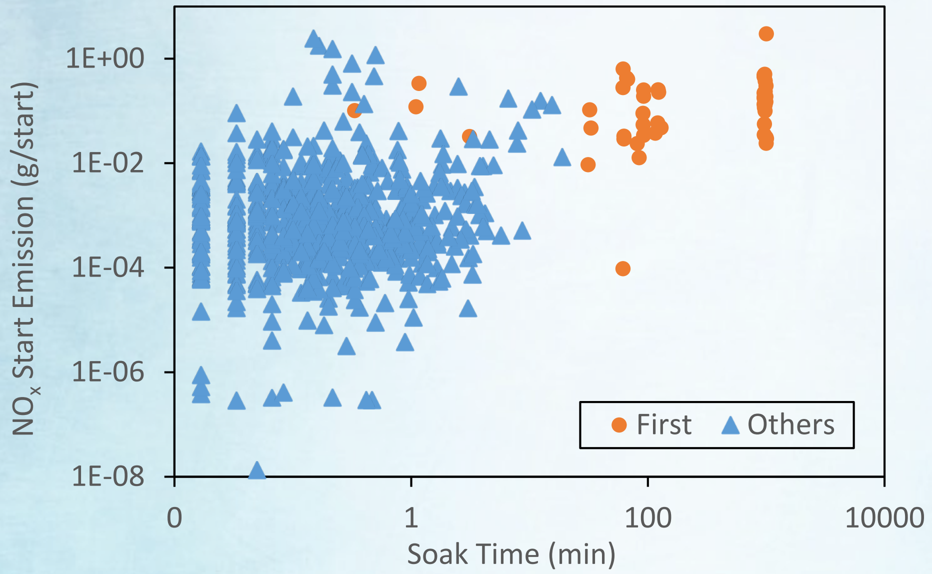
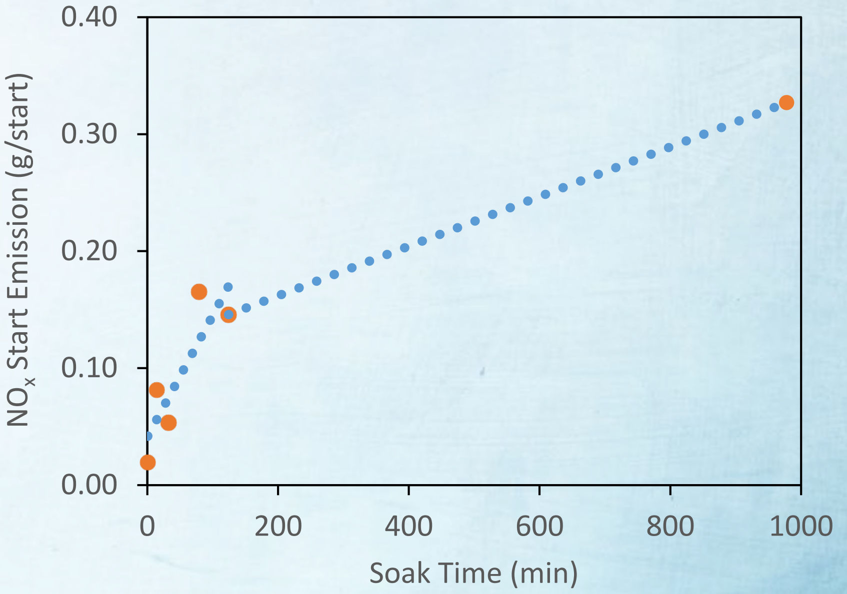
NO_x Start Emissions with Soak Time Relationship



Log-Log Scale



Note: only data with road grade within ±2% are included; Vehicle 8 data was excluded because it was certified under LEV2 ULEV

- Bin start emissions soak time into different bins minutes
- Apply piecewise linear regression (break point = 120 min, R^2 = 0.90)

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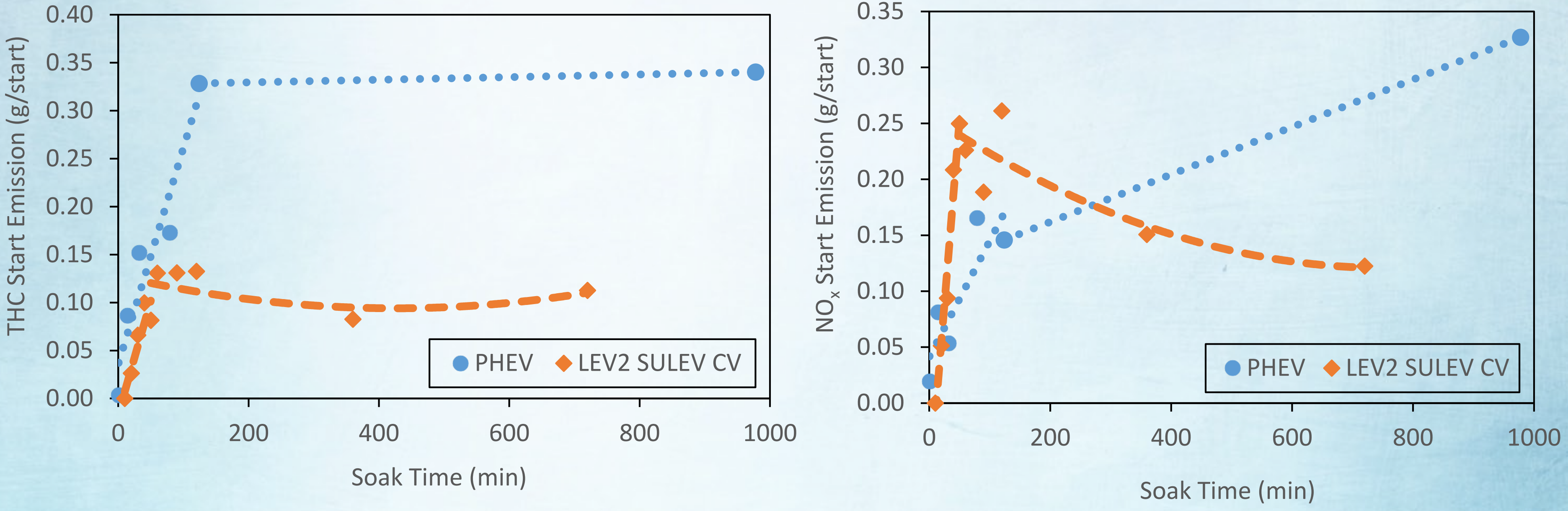
Comparison of PHEV Start Emissions with LEV2 SULEV in EMFAC2017



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MOVES Vehicle Specific Power (VSP) Modal Model Approach

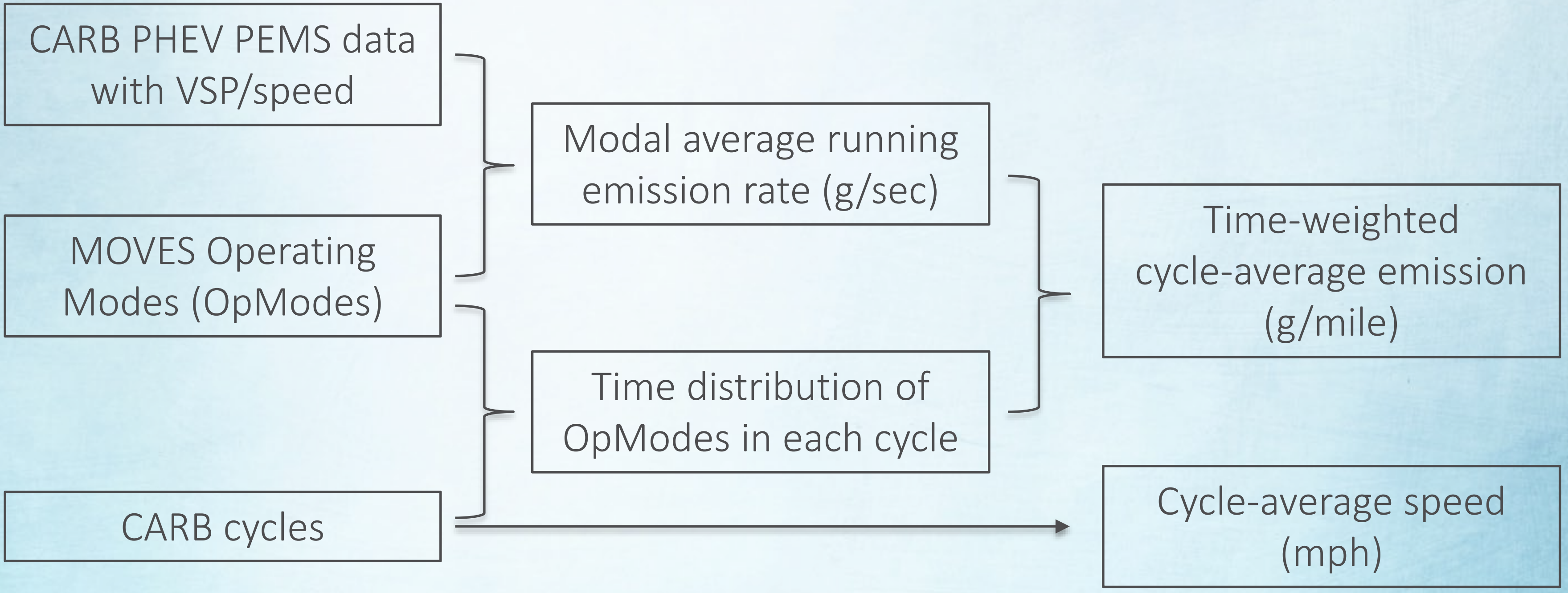
MOVES
Motor Vehicle Emission Simulator

- US EPA MOVES emission rates are based on "operating modes" (bins) that account for different patterns of acceleration, cruising, and deceleration, as well as average speed
- MOVES defines 23 operating modes for running exhaust emissions: combination of speed and VSP
- CARB used MOVES approach to analyze sec-by-sec emissions data from PHEVs to determine the running exhaust emissions as a function of cycle average speed

VSP(kw/ton)	Speed (mph)			
	0	0-25	25-50	>50
> 30		Bin 16	Bin 30	Bin 40
30				
27			Bin 29	Bin 39
24				
21			Bin 28	Bin 38
18				
15			Bin 27	Bin 37
12				
9		Bin 15	Bin 25	Bin 35
6		Bin 14	Bin 24	
3		Bin 13	Bin 23	Bin 33
0	Bin 1 (Idling), Bin 0 (Braking)	Bin 12	Bin 22	
<0		Bin 11	Bin 21	

CARB

EMFAC202x Approach for Estimating PHEV Running Exhaust Emissions Using MOVES Modal Model Bins



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Selected CARB Test Cycles

Cycle	Cycle Name	Average Speed (mph)
Unified Cycle Phase 2	UCP2	27
Arterial	MAC1	7
Arterial	MAC2	22
Arterial	MAC3	39
Arterial	MAC4	54
Freeway	MFC1	17
Freeway	MFC2	25
Freeway	MFC3	32
Freeway	MFC4	45
Freeway	MFC5	55
Freeway	MFC6	64
Freeway	MFC7	71
Unified Correction Cycle	UCC5	2
Unified Correction Cycle	UCC10	8
Unified Correction Cycle	UCC15	13
Unified Correction Cycle	UCC20	18

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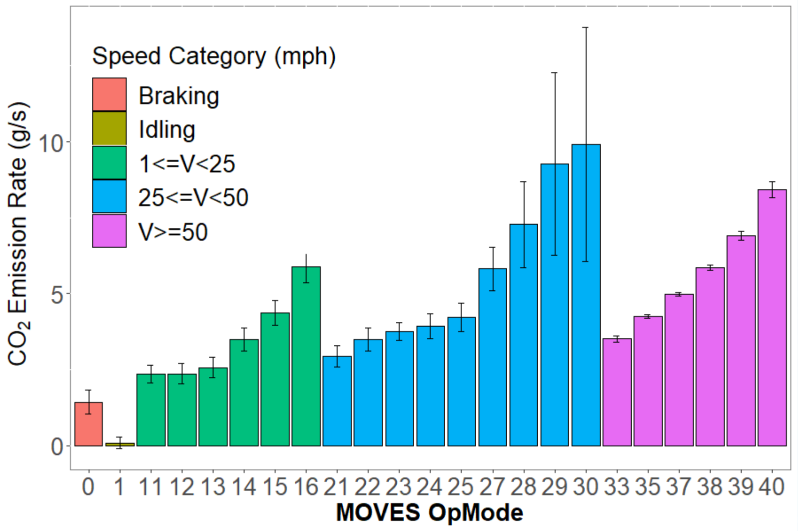
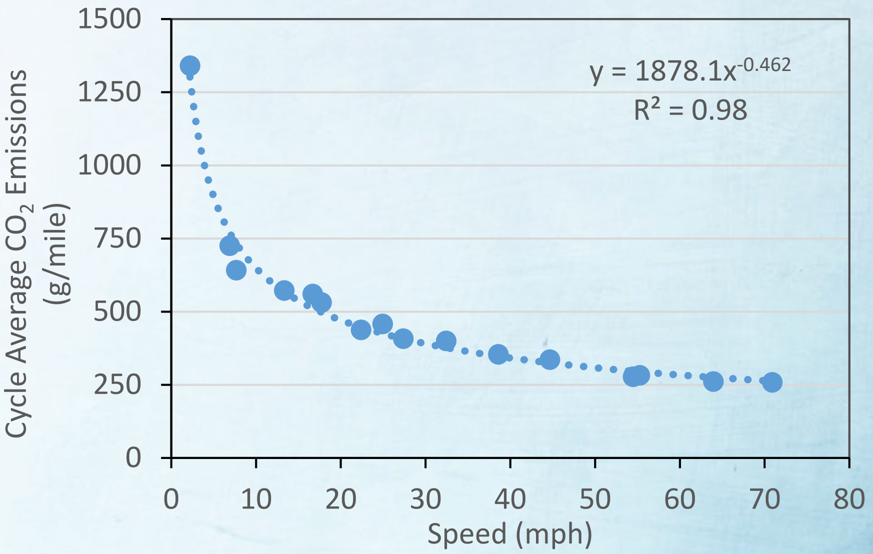
Preliminary CO_2 Running Exhaust Emissions Results

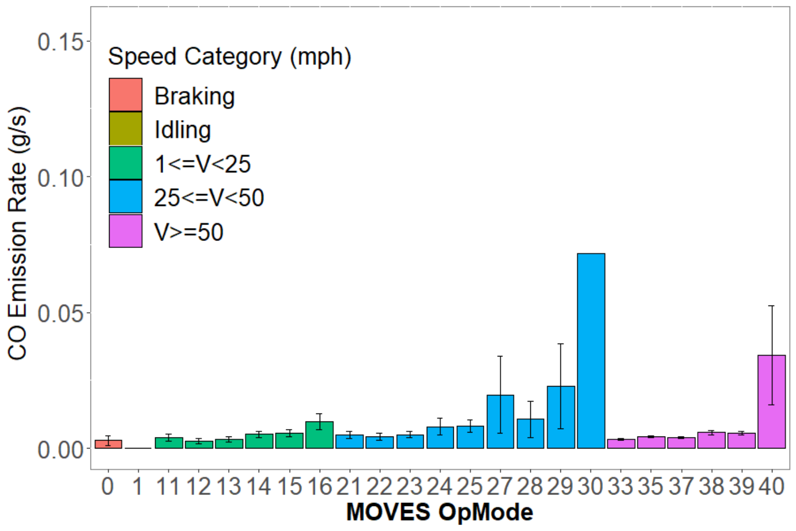


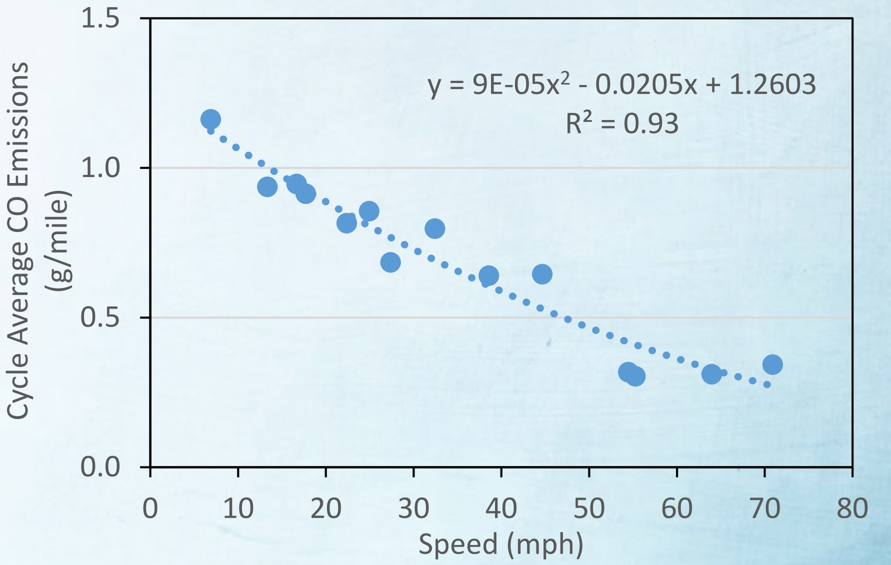


Note: only data with road grade within ±2% are included;
Vehicle 8 data was excluded because it was certified under LEV2 ULEV

CARB

Preliminary CO Running Exhaust Emissions Results





Note: only data with road grade within ±2% are included;
Vehicle 8 data was excluded because it was certified under LEV2 ULEV

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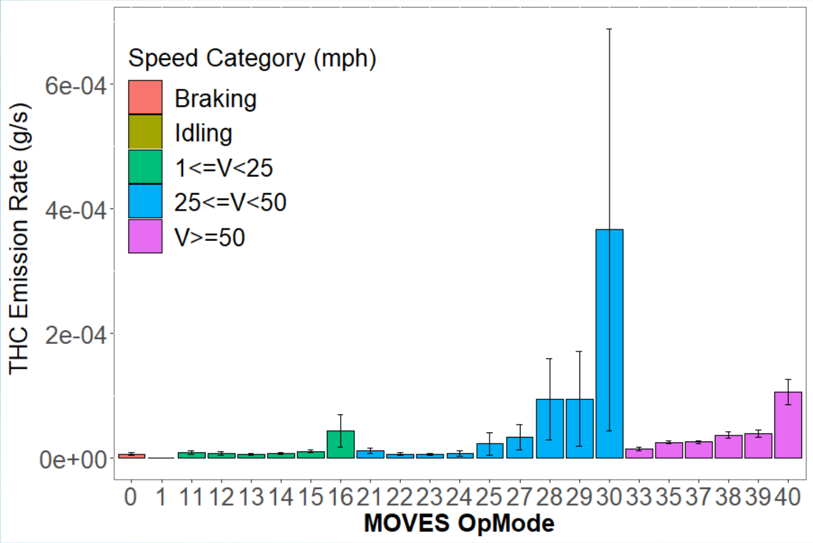
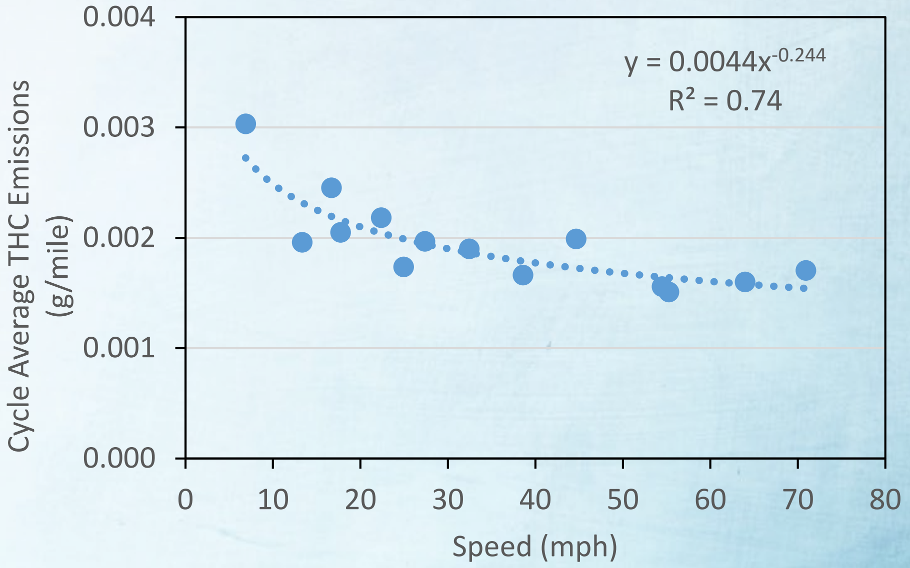
Preliminary THC Running Exhaust Emissions Results





Note: only data with road grade within ±2% are included;
Vehicle 8 data was excluded because it was certified under LEV2 ULEV

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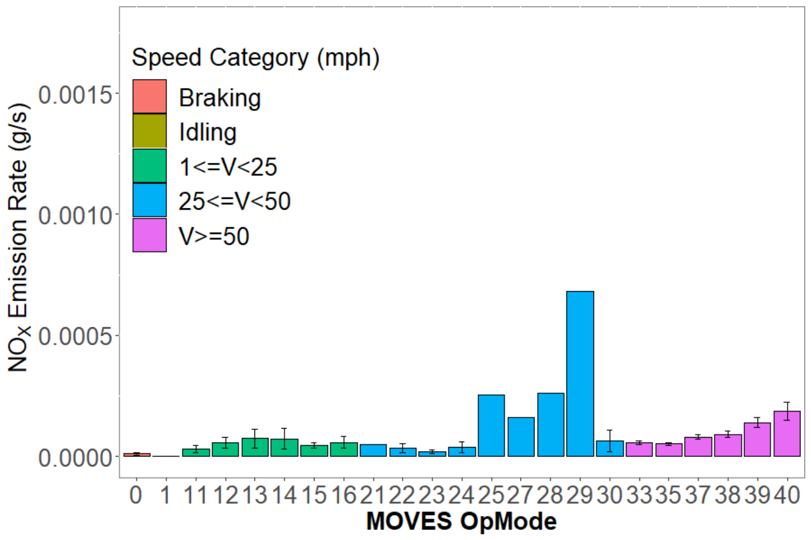
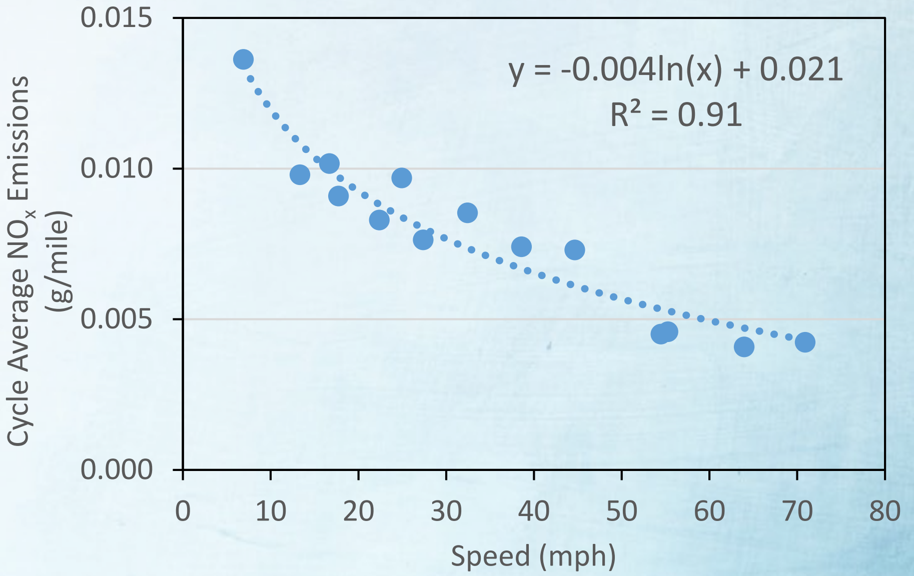
Preliminary NO_x Running Exhaust Emissions Results





Note: only data with road grade within ±2% are included;
Vehicle 8 data was excluded because it was certified under LEV2 ULEV

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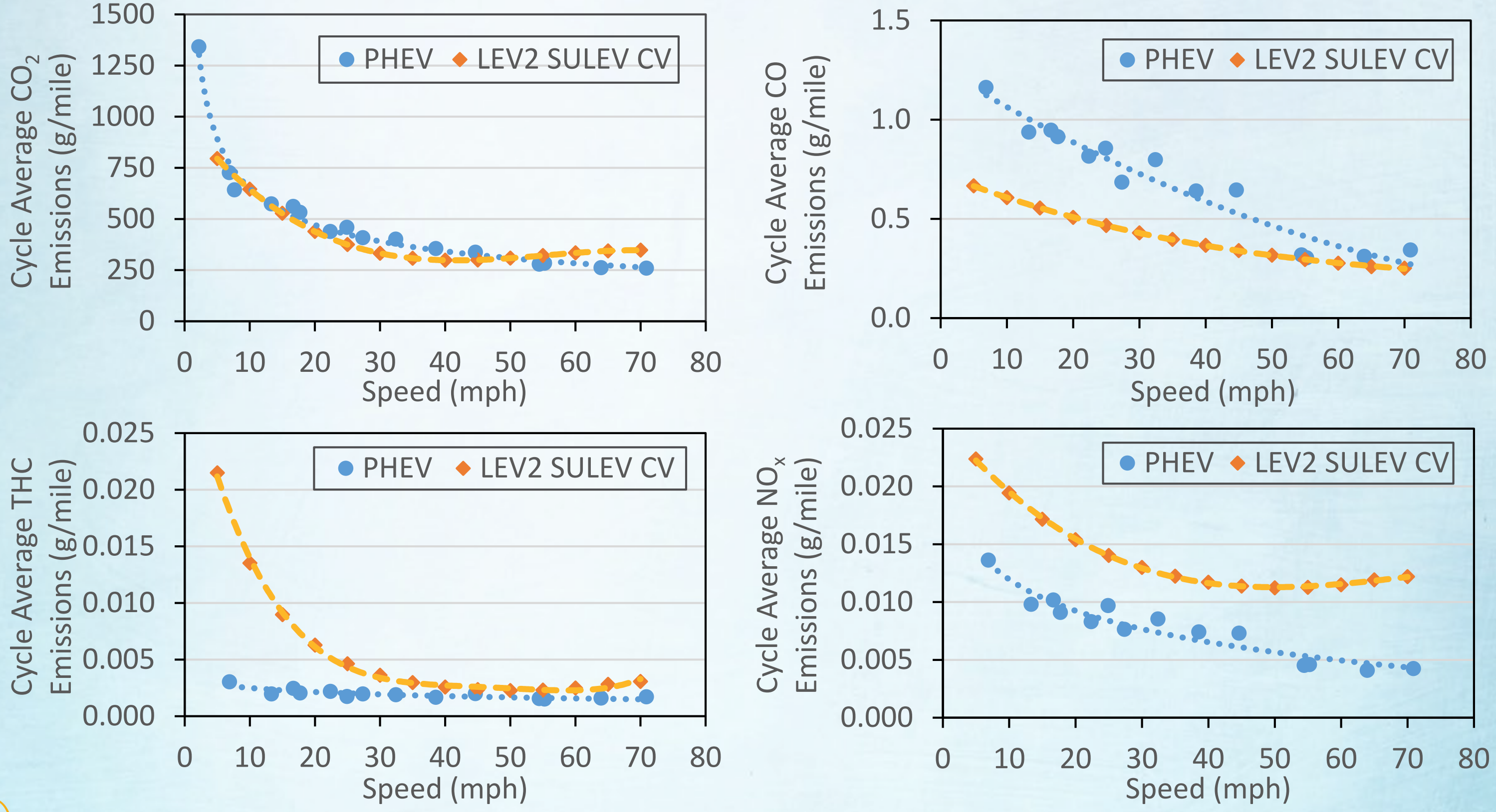
Comparison of PHEV Running Exhaust Emissions with LEV2 SULEV in EMFAC2017



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Next Steps

- Two more PHEV PEMS testing data to be added in the analysis
- Incorporate complete activity dataset collected through extramural contract
- Implement PHEV module in EMFAC202x
- Assess the impact of this update on the overall emissions inventory

Light-Duty Vehicles

Energy Module

Introduction

- Electric Vehicle (EV) operational efficiency as a function of drive-cycle characteristics previously not modeled in EMFAC
  - Battery Electric Vehicle (BEV)
    - Auxiliary battery provides electricity to power electric motor
  - Plug-In Hybrid Electric Vehicle (PHEV)
    - Electric motor supplemented by gasoline-fueled internal combustion engine (ICE)

The Driven – Electric Vehicle Insiders

Background

- No prior information on EV operational efficiency as a function of speed
- Real-world consumer trip data provided by manufacturers
  - Several OEMs provided trip by trip data for six different PHEVs and three different BEVs
  - Data collected via telematics, advanced OBD technologies, and consumer cellphones via mobile apps (*for approx. ~50,000 vehicles*)
- BEV trip type:
  - Pure electricity powered trip (*eTrip*) → electric Vehicle Miles Traveled (*eVMT*)
- PHEV trip types:
  - Pure electricity powered trip (eTrip) → eVMT
  - Charge sustained trip (*CS Trip*), battery is fully depleted at the beginning of the trip, consumed gasoline energy only → conventional VMT (*cVMT*)
  - Energy from both grid electricity and gasoline consumed → *ICE Blend Trip* → eVMT and cVMT

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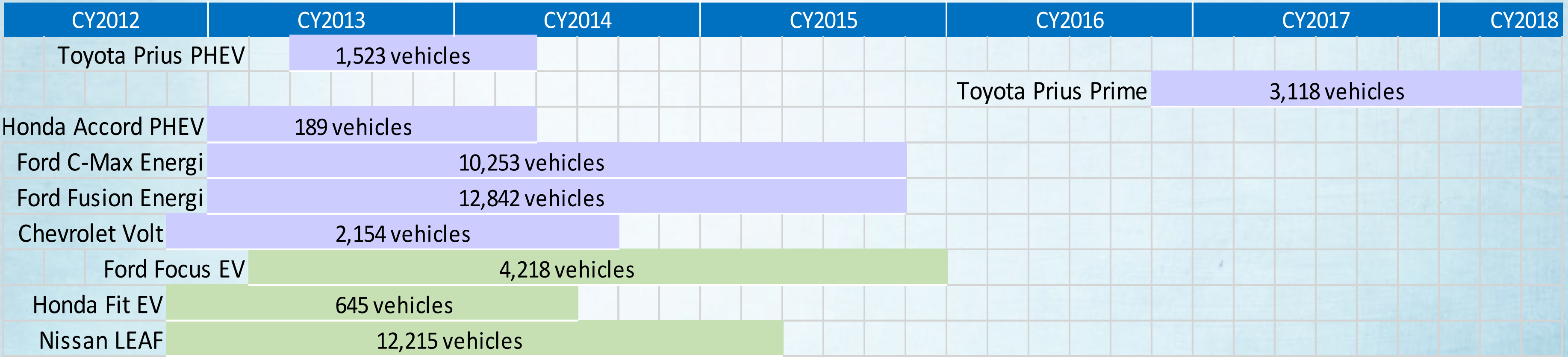
30,000 PHEVs and 17,000 BEVs



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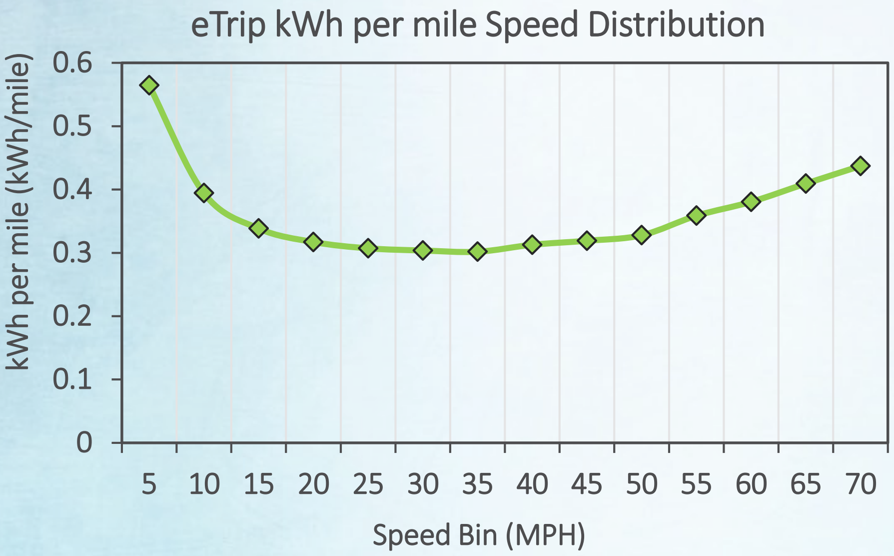
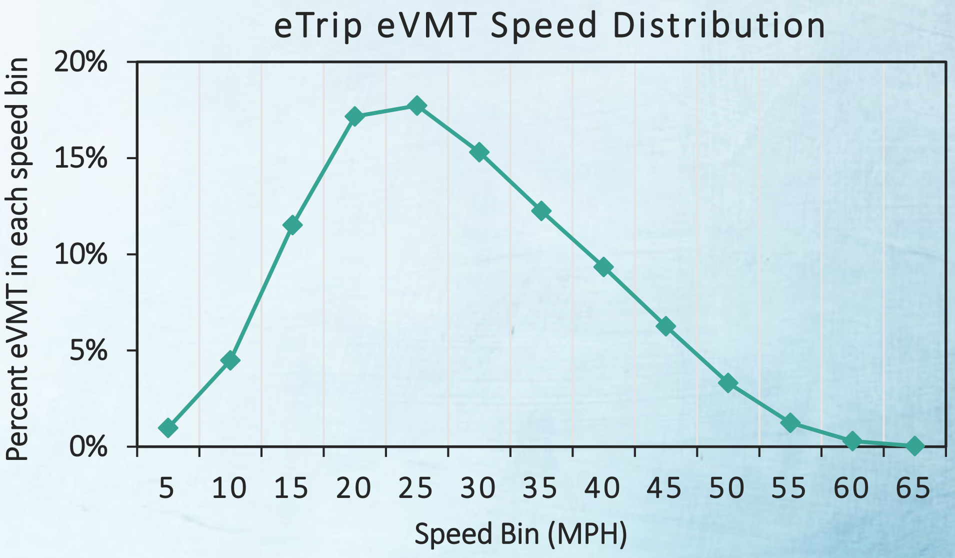
Analysis Methodology

- For each EV trip, find average grid kWh per mile (or equivalent ICE gallons per mile) by speed bin
  - Grid kWh per mile accounts for *~20%* energy loss during charging from power grid
- Differentiated energy consumption based on trip type
  - BEV and PHEV eTrips → Find grid kWh per mile and eVMT Speed Distributions
  - PHEV CS Trips → Find gallons per mile and cVMT Speed Distributions
- Data is sales weighted using CA fleet population

Make/Model	Type of Electric Vehicle
Nissan Leaf	BEV
Honda Fit	BEV
Ford Focus Electric	BEV
Ford C-Max Energy	PHEV
Ford Fusion Energy	PHEV
GM Chevrolet Volt	PHEV
Honda Accord	PHEV
Toyota Prius	PHEV
Toyota Prius Prime	PHEV

EV eTRIP Results





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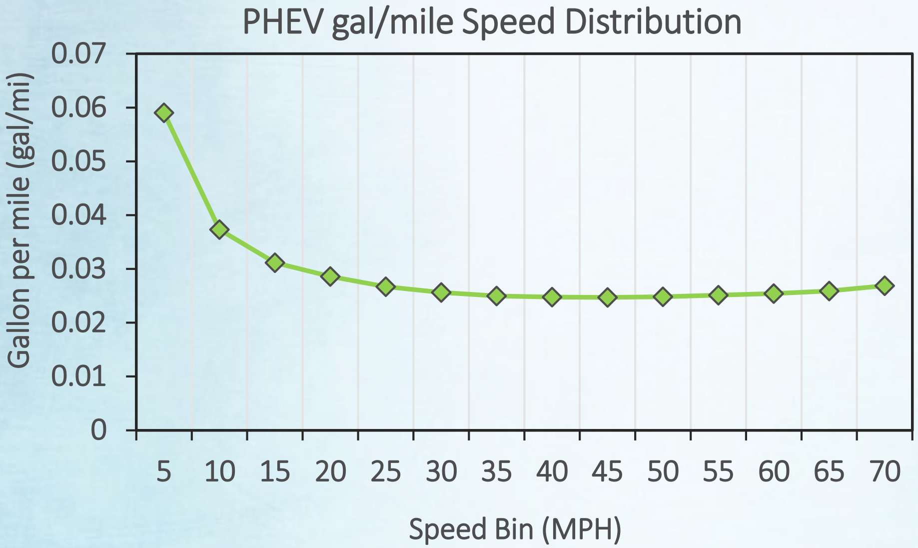
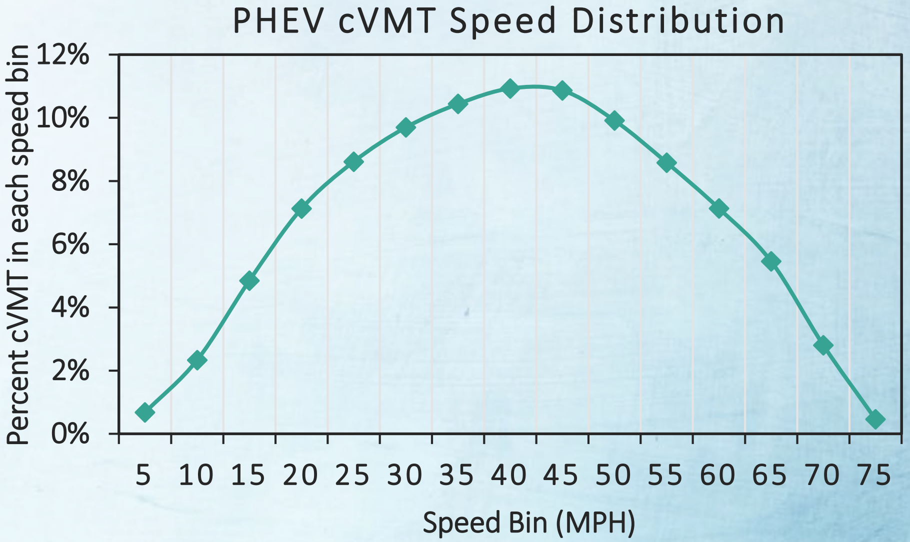
PHEV CS Trip Results





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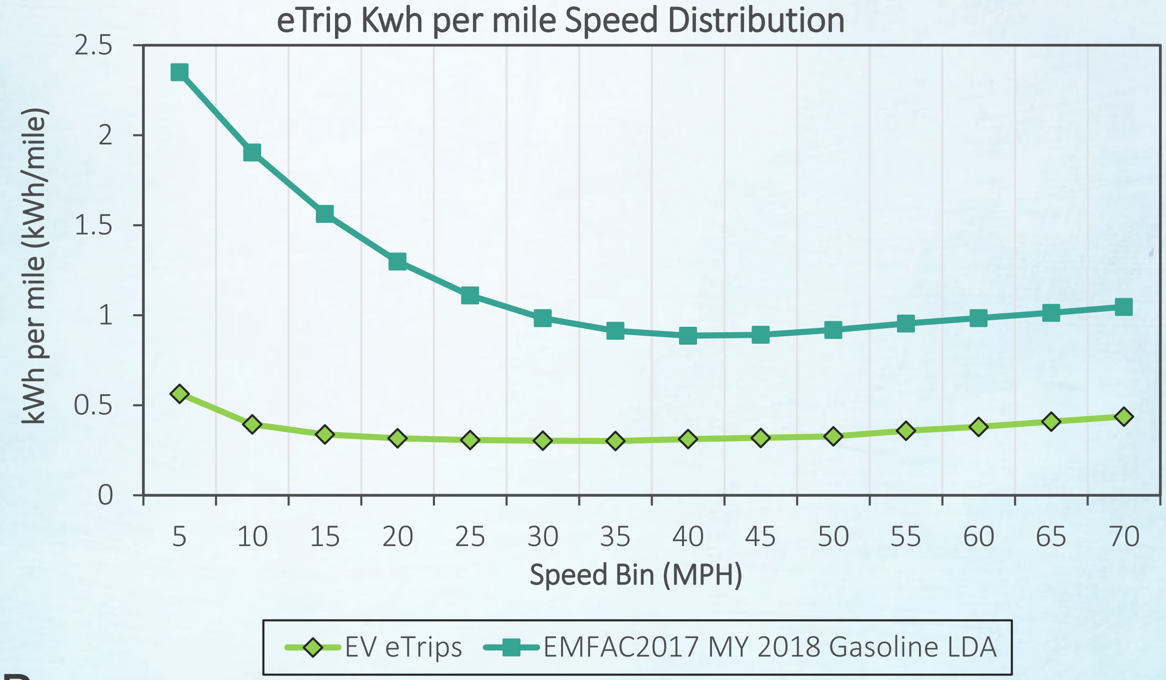
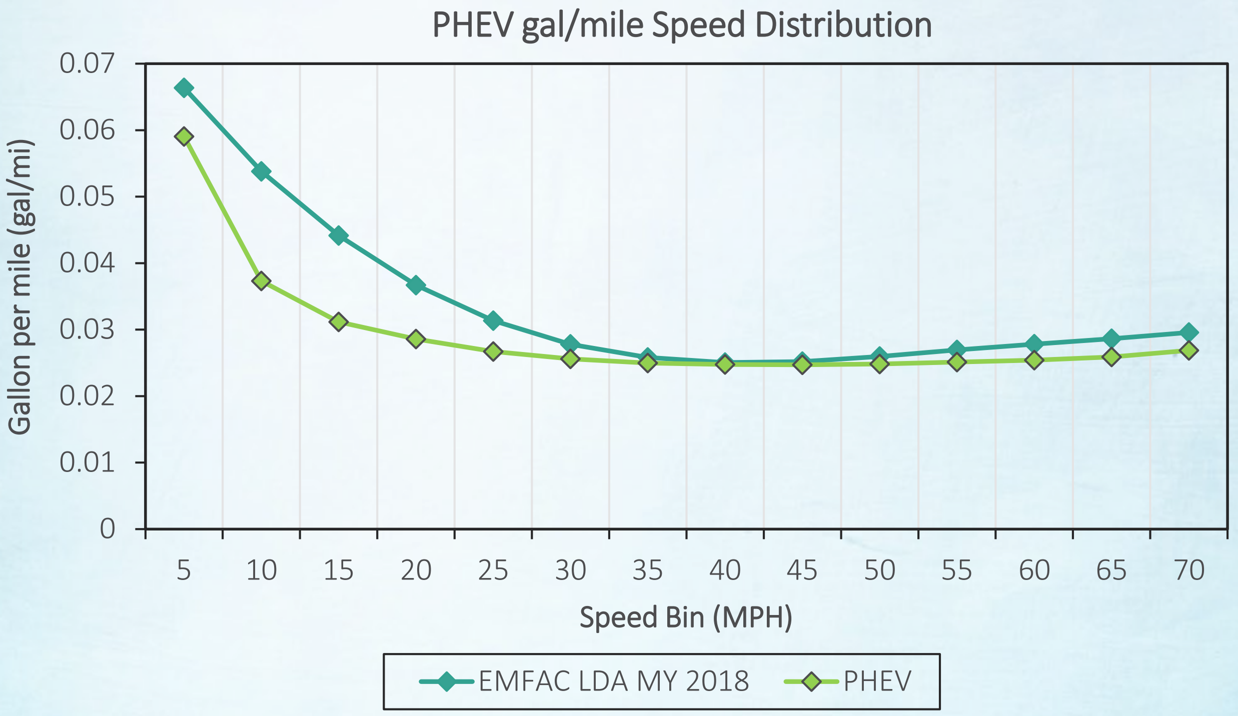
Preliminary Draft

BEV and PHEV in EV Mode vs. Conventional

- Conventional LDA kWh per mile found using EMFAC2017 CO_2 emission rates and U.S. EPA GHG Mandatory Reporting Regulation heat content in BTU per gallon of gasoline
- EVs operate approximately 3 times more efficient than conventional LDA



PHEV in ICE Mode vs. Conventional



EMFAC Implementation

- EVs (PHEVs + BEVs) pure electric trips → eVMT
  - Use eVMT as a function of speed to find energy consumption from the electrical grid:

$$\text{eVMT} \times \sum f_{\text{eVMT}}(\text{speed}) \times \text{kWh/mile (speed)} = \text{kWh energy consumption}$$

Conclusions

- During electric trips, EVs operate **three times more efficient** than conventional passenger cars
- PHEVs efficiency in ICE mode is similar but still better at lower speeds than conventional passenger cars
- Significant energy conservation may be achieved by driving EVs, rather than conventional passenger cars, especially at lower speeds
- This analysis will create the ability to estimate EV electricity consumption as a function of speed, and help improve PHEV gasoline consumption modeling in EMFAC202x

Heavy-Duty Vehicles

Freight Forecasting

Current HDV VMT Forecasting Method in EMFAC

- The underlying assumption in EMFAC to forecast heavy duty VMT is:

> *"VMT follows the same trend as fuel use, assuming no significant change in fuel efficiency,"*

  - Up until 2014, fleet average fuel efficiency for diesel have not changed significantly
- Historical diesel fuel use is modeled with socio-economic variables
  - Disposable personal income & unemployment rate
- For drayage trucks at ports and railyards, EMFAC uses growth factors consistent with container growth in CARB's Ocean Going Vessel model
  - Based on Freight Analysis Framework (FAF)

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Reasons to Update HDV VMT Forecasting with Freight Projections

- Create consistent forecasting method across inventory sectors
  - HDV, Ocean Going Vessels (OGV), Cargo Handling Equipment (CHE), Class I rail are all driven by growth in freight movement
  - OGV and CHE primarily use Freight Analysis Framework (FAF) projections, along with other freight forecasts
- Allow forecasts by truck class at regional level
  - Current method uses a statewide uniform growth rate
- Explore future scenarios related to mode shifts, oil price, infrastructure capacity, congestion, etc.

Existing Freight Forecasting Resources

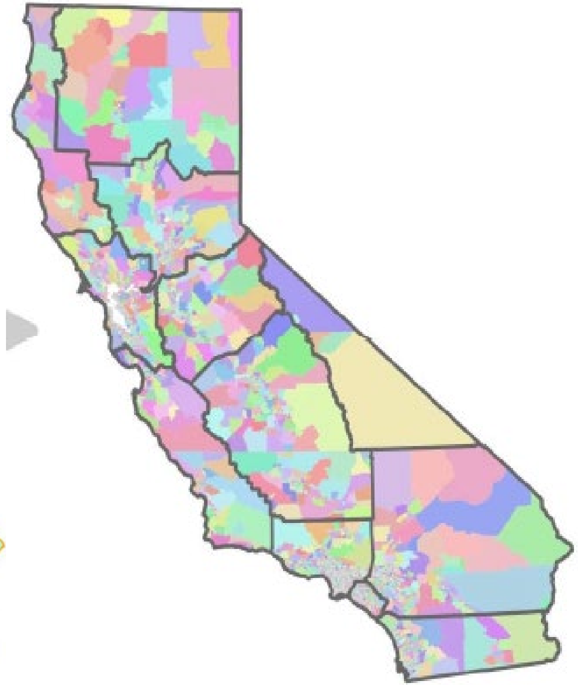
- Freight Analysis Framework (FAF) by FHWA
  - 5 zones in California, 2012-2045
  - Modes: long-haul trucks, rail, water, air, pipeline, multi-modes; no mode-shift module
  - Outputs: commodity flow (tonnage, value, ton-miles) by transportation mode
- California Statewide Freight Forecasting Model (CSFFM) by Caltrans
  - Based on FAF, 97 zones in California
  - Modes: 4 truck classes, rail, water, pipeline, multi-modes; has mode-shift module
  - Outputs similar to FAF, at a finer scale
  - Currently being integrated with California Statewide Travel Demand Model (CSTDM)
- SCAG Regional Travel Demand Model
  - Over 4000 zones in Southern California, 2012-2040
  - 3 truck classes

Freight Zones

FAF 5 zones

CSFFM 97 zones

CSTDM sub-area zones



Proposed Freight-based Forecasting Approach

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Next Steps

- Communicate with state and local transportation planning agencies (Caltrans, MPOs) about growth methodology
- Development of a freight forecasting document – released before or along with EMFAC202x
- Longer term: development of a freight analysis tool that allows assessment of future scenarios related to mode shifts, infrastructure capacity, congestion, etc.

Next Steps for EMFAC Development

- Send us your comments and feedback by November 1, 2019 on the analysis presented at the first public workshop of EMFAC202x
- Continue data collection and analysis
- Evaluate the updated emission rates and activity using real world data (e.g., remote sensing, roadside data collection, etc.)
- Alpha Testing – A preliminary version of the model will be released to CARB designated testers
- Beta Testing – A revised version of the model reflecting feedback will be released
- Future Workshops – Spring & Summer 2020
- Finalize and release model – Late 2020/Early 2021

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Detailed EMFAC202x Schedule – Workshops/Model Release

- User Needs Discussion — March 2019
- First Public Workshop — **Fall 2019 (Today)**
- Second Public Workshop — Spring 2020
- Alpha Release and Testing — Summer 2020
- Third Public Workshop — Fall 2020
- Beta Release and Testing — Fall 2020
- Official Public Release — Late 2020/Early 2021

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Questions and Comments

For questions and comments please contact us at:

EMFAC@arb.ca.gov

You can also visit our website at:

https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory