California Environmental Protection Agency

AIR RESOURCES BOARD

DRAFT
SUPPORTING INFORMATION FOR TECHNOLOGY ASSESSMENTS: TRUCK AND BUS SECTOR DESCRIPTION

April 2016

State of California
AIR RESOURCES BOARD

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LIST OF ACRONYMS

AB	Assembly Bill
ARB	Air Resources Board
ARBER	Air Resources Board's Equipment Registration
ATA	American Trucking Association
ATCM	Airborne Toxic Control Measure
ATRI	American Transportation Research Institute
BACT	Best Available Control Technology
BLS	Bureau of Labor Statistics
CCR	California Code of Regulations
CO_2	Carbon Dioxide
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Agency
GHG	Greenhouse Gases
GVWR	Gross Vehicle Weight Rating
HC	Hydrocarbons
HDVIP	Heavy-Duty Vehicle Inspection Program
IRP	International Registration Plan
Lbs.	Pounds
Mph	Miles per Hour
MY	Model Year
NAAQS	National Ambient Air Quality Standards
NOx	Oxides of Nitrogen
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturer
OTR	Over-the-Road
PAU	Public Agencies and Utilities
PM	Particulate Matter
PSIP	Periodic Smoke Inspection Program

ROG	Reactive Organic Gases
SCR	Selective Catalytic Reduction
TRU	Transportation Refrigeration Unit
VMT	Vehicle Miles Traveled

EXECUTIVE SUMMARY

This executive summary presents the Air Resources Board (ARB) staff's *Truck and Bus Sector Description*.

Heavy-duty trucks operate throughout California in numerous vocations and are an essential part of the state's economy. This report covers heavy-duty vehicles, which are defined here as vehicles over 8,500 pounds (lbs.) gross vehicle weight rating (GVWR), including garbage trucks, long-haul trucks, and much more. These trucks are significant sources of oxides of nitrogen (NOx), particulate matter (PM), and greenhouse gases (GHG) emissions. Thus, significant reductions in emissions from this heavy-duty truck sector must occur in order for California to meet its air quality goals.

1. What are the various categories of trucks and their characteristics?

Heavy-duty trucks have traditionally been grouped by weight class using various methodologies and groupings (as shown in Figure II-1), but this approach has failed to capture the whole picture of truck activity. To determine the applicability of alternative fuel technology (i.e. fuel cell, hybrid, and electric) to heavy-duty trucks, drive cycle is a critical factor. In this report, we adopt the CalHEAT categorization of heavy-duty trucks, in which trucks were grouped by similar use and driving patterns.

2. What is drive cycle and how does it differ for various trucks?

Drive cycle for heavy-duty trucks is a characterization of driving pattern, including vehicle miles traveled (VMT) per day, number of stops and starts, average driving speed, etc. Drive cycle is an essential element in determining the applicability and effectiveness of technologies such as hybridization, electrification, and other efficiency improvements. Heavy-duty trucks vary greatly in terms of drive cycle, from long-haul trucks (CalHEAT Over-the-Road) that have high VMT, high average speed and few stops, to urban vocational trucks (CalHEAT Urban) that have low VMT, low average speed and many stop and start events.

3. What portion of statewide emissions are heavy-duty trucks responsible for?

Heavy-duty trucks emit nearly 33 percent of NOx, 26 percent of PM 2.5, and 8 percent of GHG based on statewide emission sources. These vehicles represent significant sources of emissions, and reductions from these sources are necessary to meet California's air quality goals.

4. What are the trends in heavy-duty emissions?

Since the mid-2000s, as shown in Figure ES-1 and ES-2, NOx and PM emissions from heavy-duty trucks have steadily declined as a result of new engine standards and heavy-duty truck in-use regulations. In this same period, as shown in Figure ES-3, carbon dioxide (CO_2) emissions, on the other hand, have steadily increased due to the growth in truck population and VMT. Although NOx and PM emissions from heavy-duty trucks have steadily declined, in 2014, heavy-duty trucks were still the highest source of NOx emissions and the third highest source of diesel PM 2.5 emissions out of all statewide sources. Even in 2032, when all truck focused air quality regulations on the books will have been fully implemented (including the truck and bus regulation), heavy-duty trucks are expected to still be the second highest statewide source of NOx emissions and the fourth highest source of diesel PM 2.5 emissions.

Figure ES- 1: California NOx Emission Trend (Tons/Day) produced using the ARB EMFAC 2014 Database for Heavy-Duty Trucks Class 2b-8 (8,501+ lbs.)

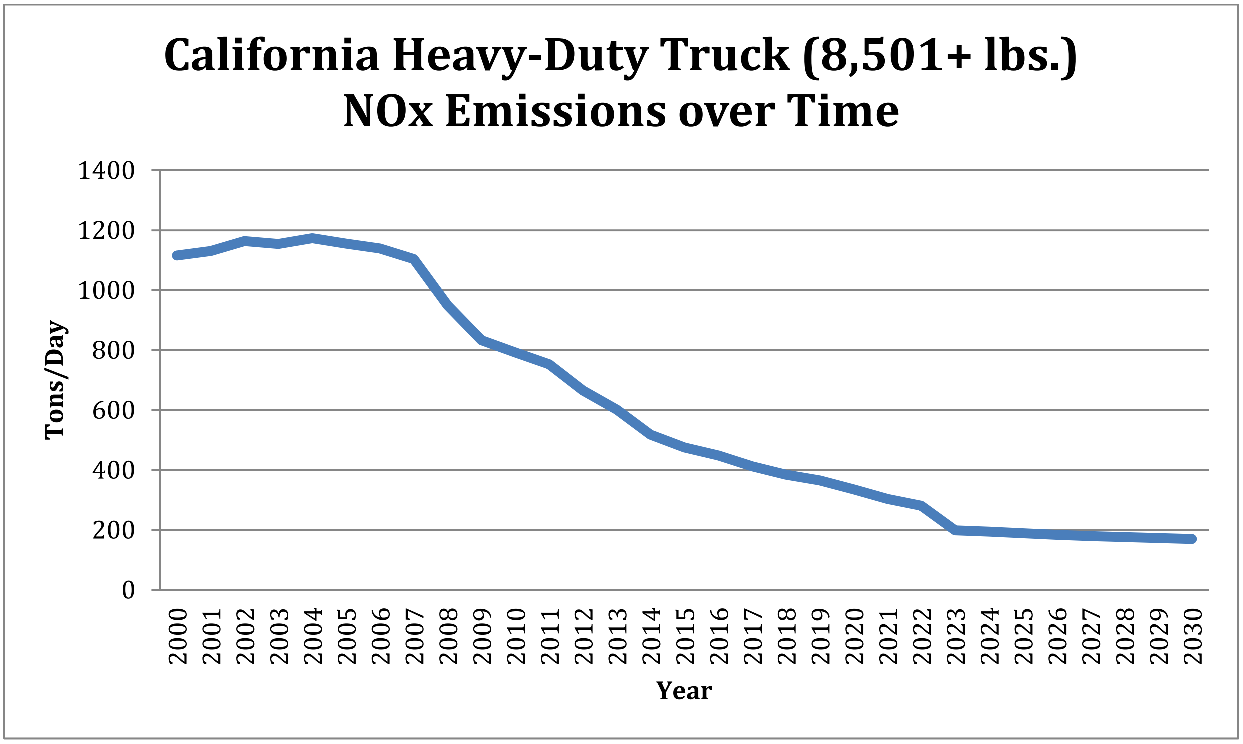


Figure ES- 2: California PM 2.5 Emission Trend (Tons/Day) produced using the ARB EMFAC 2014 Database for Heavy-Duty Trucks Class 2b-8 (8,501+ lbs.)

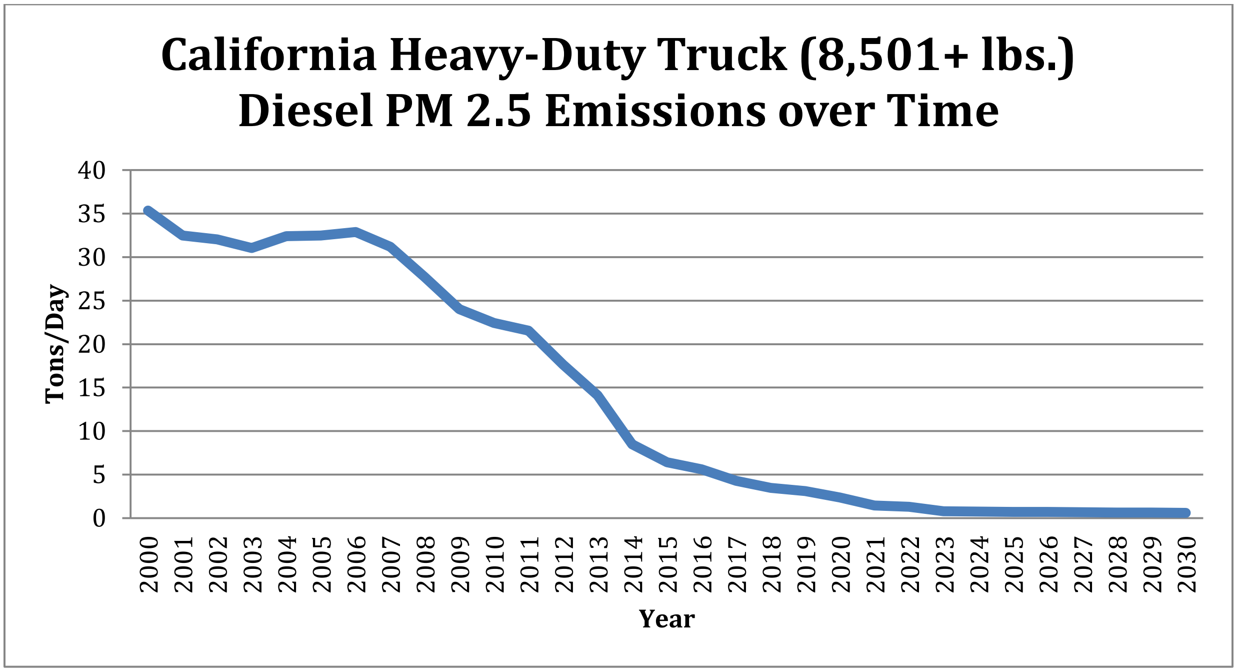
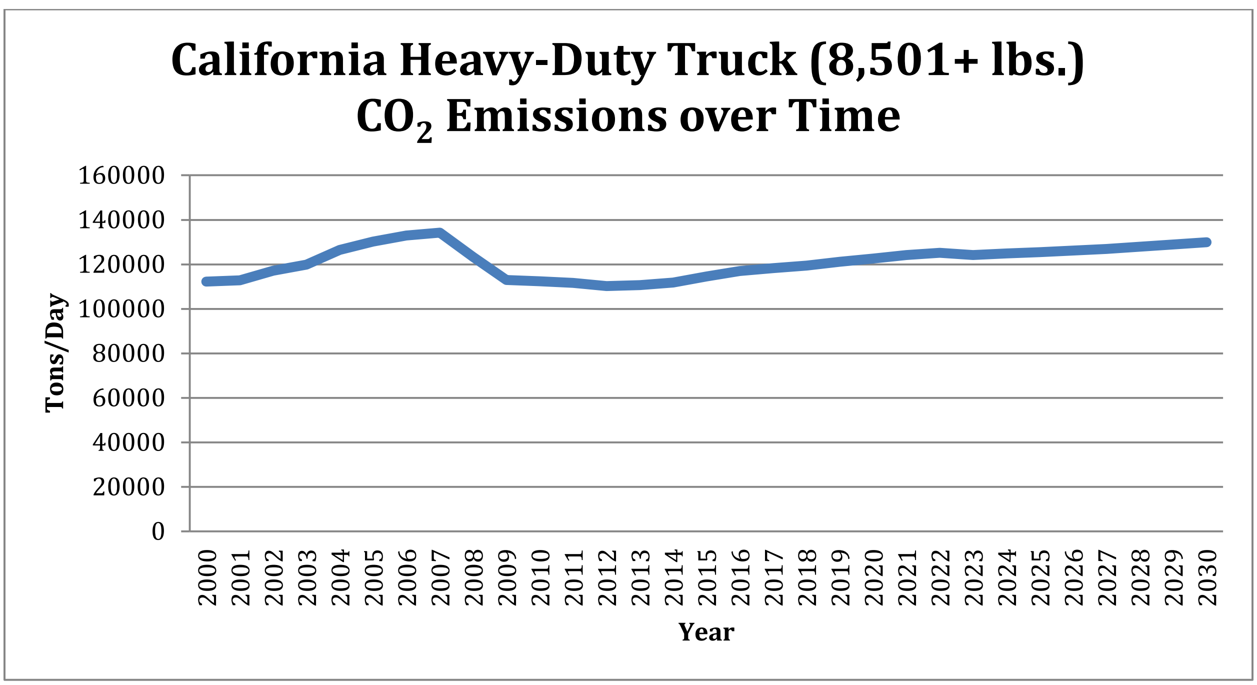


Figure ES- 3: California CO_2 Emission Trend (Tons/Day) produced using the ARB EMFAC 2014 Database for Heavy-Duty Trucks Class 2b-8 (8,501+ lbs.)[1]



[1] The projected CO_2 emissions include the Phase 1 GHG standards, which take effect with model year 2014 and decline through model year 2017, but do not include the proposed Phase 2 GHG standards, which are expected to increase in stringency through model year 2027.

5. How are heavy-duty trucks powered?

Heavy-duty trucks are predominately powered by gasoline or diesel fuel, with lighter vehicles (Class 2b and 3, 14,000 lbs. and under) mostly using gasoline and heavier vehicles using diesel as their dominant fuels. Alternative fuels such as fuel cells, electric, and hybrid technology have begun to be demonstrated or are in early commercialization for a variety of heavy-duty trucks.

6. What is the life span for heavy-duty trucks?

For the most part, heavy-duty trucks last more than 20 years, often times experiencing multiple lives as they are shifted from one use to another. For example, trucks may begin their lives as long-haul trucks and move to other applications such as regional transport as they age. Truck age varies by vocation; long-haul trucks tend to be younger trucks (average age of 4 to 5 years) while vocational and regional transport trucks were on average age of more than10 years (before in-use rules encouraged accelerated turnover).

7. How is heavy-duty truck manufacturing organized?

Heavy-duty truck manufacturing is highly dependent on the type and use of vehicles. Heavy-duty trucks can be manufactured by one vertically integrated manufacturer (i.e., the manufacturer produces the engine, chassis, and body) or by a non-vertically integrated manufacturing process (i.e., assembled from elements manufactured by a variety of suppliers).

Class 2b and 3 vans and pickups tend to be manufactured in whole by one manufacturer with the industry dominated by a few major vertically integrated manufacturers such as Chrysler, Ford, and General Motors.

Larger trucks such as class 4-8 trucks, on the other hand, are predominately manufactured by the assembly of elements from numerous manufacturers. In this segment, several manufacturers dominate the engine and chassis manufacturing. The main engine manufacturers are Cummins, Volvo Truck, and Detroit Diesel. Vocational truck chassis, for trucks such as utility trucks and delivery trucks, are manufactured by major manufacturers such as Ford and International, and then body manufacturers make the body of the truck depending on customer specifications. Major vocational truck body manufacturers such as Morgan Corp and Supreme Corp dominate the market for trucks that have general and wide applicability such as van type trucks, but specialty manufacturers fill the niche for special applications.

Similarly, Class 7-8 trailer manufacture is dominated by a few manufacturers (Wabash National, Utility Trailer, and Great Dane) who build traditional box type trailers. However, there are numerous smaller manufacturers that build specialty trailers.

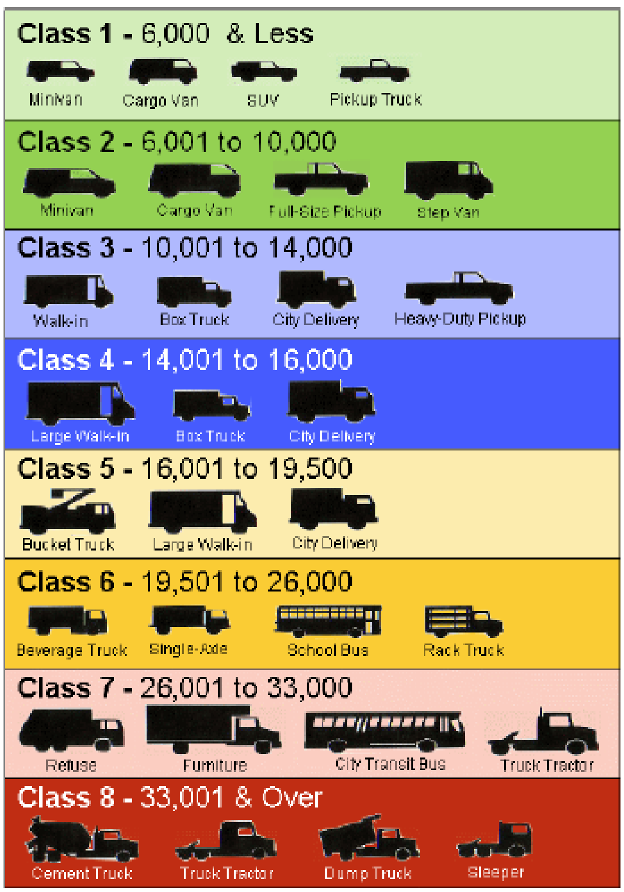
I. INTRODUCTION AND PURPOSE OF ASSESSMENT

The purpose of this report is to present an overview of the heavy-duty truck sector as well as its emissions trend, fleet characterization, and market information important for the development and application of new technologies to heavy-duty trucks. This report presents information about the different types of trucks (Chapter II), California trucking fleet dynamics and the economics of operating trucking fleets (Chapter III), emissions trends (Chapter IV), current emissions, population and vehicle miles traveled (VMT) for heavy-duty trucks (Chapter V), fuel sources and fleet characteristics (Chapter VI), and how heavy-duty truck manufacturing is structured among various companies (Chapter VII).

II. OVERVIEW OF HEAVY-DUTY TRUCK TYPES AND FUNCTIONS

Heavy-duty trucks perform various roles throughout the country from refuse collection to goods transport and much more. For the purpose of this report, heavy-duty trucks are considered to be trucks with a gross vehicle weight rating (GVWR) over 8,500 pounds (lbs.). Heavy-duty trucks are commonly classified according to their weight class. As shown in Figure II-1 below, weight class categories range from 2b to 8, which encompass a broad range of vehicles from heavy-duty pick-up trucks to long-haul trucks. In addition to the weight classification scheme in Figure II-1, heavy-duty trucks are also commonly grouped into light heavy, medium heavy, and heavy heavy-duty categories as shown in Table II-1, although as Table II-1 indicates, those terms are not used consistently. For the purpose of this report, we are defining all trucks over 8,500 lbs. GVWR as heavy-duty, and where the terms light heavy, medium heavy, and heavy heavy-duty are used we are providing the weight range.

Figure II- 1: Types of Trucks by Weight Class



(ORNL, 2000)

Table II- 1: Federal and Air Resources Board (ARB) Heavy-duty Truck Weight Classes

GVWR (pounds)	8,501-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,000+
Federal	Light heavy-duty				Medium heavy-duty		Heavy Heavy-duty
California (1995 and later model year)	Medium-duty		Light heavy-duty		Medium heavy-duty		Heavy Heavy-duty

(ARB, 2014b)

Trucks can also be classified by their drive patterns during their typical operation (i.e., drive cycle), including the number of stops per mile, average distance traveled during a day, speeds, and acceleration events per mile. Truck classifications by weight do not necessarily correlate to trucks' function or drive cycle in an effective manner for fully understanding how trucks operate and generate emissions. For example, Class 8 long-haul trucks have a drive cycle marked largely by highway driving, while class 8 refuse trucks have an urban drive cycle with many starts and stops. For this reason, it is necessary to adopt a classification system that groups vehicles with similar drive patterns and weights correlated to their vocations. In its California Truck Inventory and Impact Study, released in 2011, CalHEAT noted that when attempting to evaluate the impact of technology on the heavy-duty truck sector, the traditional weight classification was not sufficient; therefore, CalHEAT developed a classification system that groups vehicles of similar weight classifications along with similar drive cycle. Based on this approach, the six CalHEAT Truck Categories are: Class 7-8 Over-the-Road (OTR), Class 7-8 Short Haul/Regional, Class 3-8 Urban, Class 3-8 Rural/Intracity, Class 2b-3 Vans/Pickups, and Class 3-8 Work Site Support. These categories allow for the identification of vehicles having drive cycles (drive range, operating patterns, and function) most compatible with new technologies (CalHEAT, 2011). In addition to the CalHEAT categories, buses were isolated in this analysis as a separate category. It is necessary to analyze buses in their own category because of the unique drive cycles and technological opportunities that are applicable to these vehicles.

The emissions, population, and miles traveled for these six truck categories, and a bus category, are discussed in detail in Chapter V Section C.

III. ECONOMICS OF HEAVY-DUTY TRUCKING

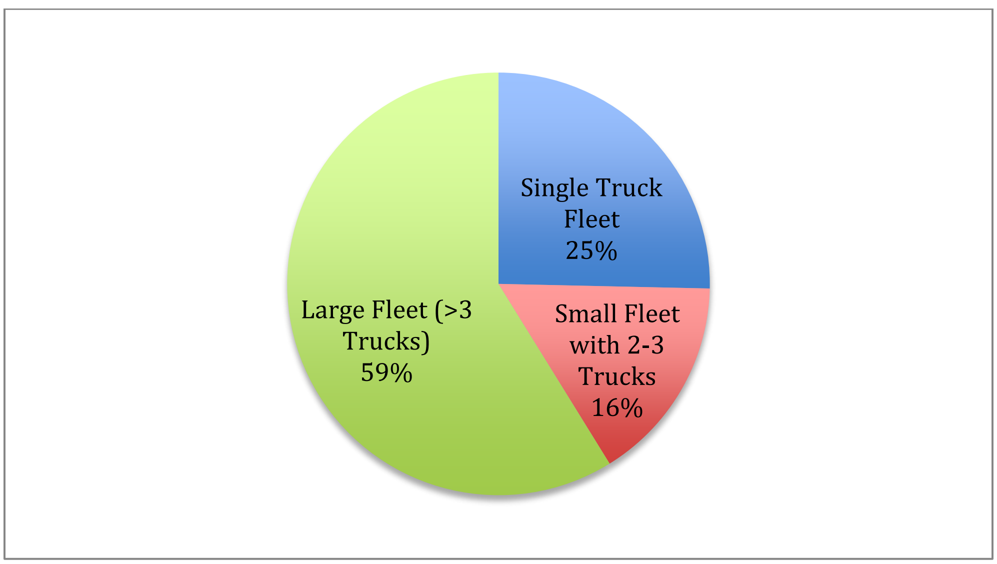
This chapter presents information about California trucking fleet dynamics and the economics of operating trucking fleets. Section A discusses the characteristics of fleets operating within California in terms of size and number of trucks. Section B discusses the costs of trucking operations in the context of tractor-trailer trucking and the challenges in terms of those costs in the current economic environment. Section C discusses the current state of trucking rates and its relation to intermodal shipping rates.

A. Characteristics of the Trucking Fleets in California

Heavy-duty trucks operate in a wide range of vocations throughout the state and are owned by small and large fleet operators, and by both in-state and out-of-state owners. Fleet composition is critical in gauging the ability of the trucking industry to adapt to new regulations and standards.

California has nearly 170,000 in-state owned and operated fleets. Of these 170,000 fleets, nearly 90 percent are characterized as small fleets (fleets owning 1-3 trucks) (ARB, 2008). Small fleets, as defined, own and operate approximately 41 percent of the overall light/heavy heavy-duty truck (GVWR 14,000+ lbs.) population. Owner-operators operate approximately 25 percent of all California light/heavy heavy-duty trucks (GVWR 14,000+ lbs.). These California fleet owned trucks have an average age of 8 or more years. (See Section VI-B for more information)

Figure III- 1: Heavy-Duty Truck (GVWR 14,000+ lbs.) Population by Fleet Size for California based Fleets[2]

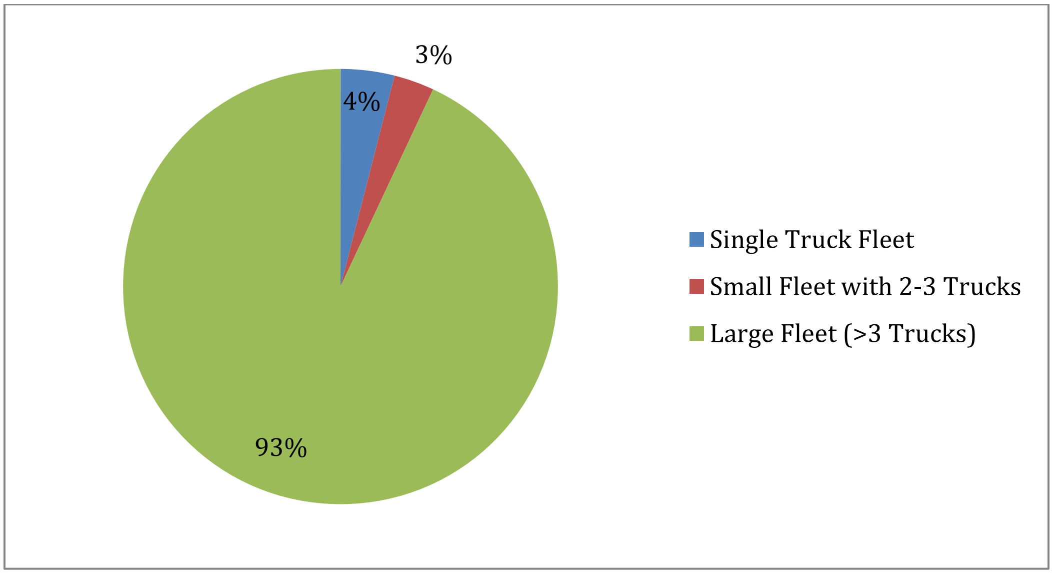


(ARB, 2014b)

[2] This chart includes trucks over 14,000 lbs. GVWR, which in California are called Light-Heavy, Medium-Heavy, and Heavy-Heavy-Duty trucks.

In addition to in-state trucks, there are significant populations of heavy-duty trucks that operate in California from other states. Of the on-road trucks operating in California, nearly 65 percent are from out of state. Unlike the distribution of trucks by fleet size for California-based fleets, out-of-state trucks operating in California are nearly all operated by large fleets (see Figure III-2). Trucks owned by out-of-state fleets also tend to be younger vehicles with an average age of 4-5 years old. (See Section VI-B for more information)

Figure III- 2: Heavy-Duty Truck (GVWR 14,000+ lbs.) Population by Fleet Size for Out-of-State Fleets[3]



(ARB, 2014b)

B. Cost of Trucking

The breakdown of the operational cost structure in the trucking industry is essential in order to understand the economics of trucking. The American Transportation Research Institute (ATRI) is a non-profit research organization that has studied transportation issues since 1954. In this capacity, the institute conducts a nationwide survey of the for-hire tractor-trailer trucking industry (i.e., fleets that carry freight for other businesses) using a standardized survey methodology to determine the operational costs of the trucking industry. ATRI also weights survey results to reflect average percentages of the major for-hire sectors (Truckload, Less-Than-Truckload, and Specialized). Although the data collected in this study are for the for-hire tractor-trailer trucking industry, the costs and trends presented in this study are comparable to those faced by private trucking fleets which transport their own goods via company owned trucks and trailers.

[3] This chart includes trucks over 14,000 lbs. GVWR, which in California are called Light-Heavy, Medium-Heavy, and Heavy-Heavy-Duty trucks.

The ATRI 2013 survey reflected national fleets ranging from those with very low revenue to those with high revenue, as shown in Table III-1. The largest portion of fleets had between $10 and $100 million annual revenue, and only a few surveyed fleets, 13 percent, had greater than $100 million annual revenue.

Table III- 1: Fleet Size by Annual Revenue in National ATRI Survey

Revenue	Percent
Less than $10 million/year	40%
$10-100 million/year	47%
Greater than $100 million/year	13%

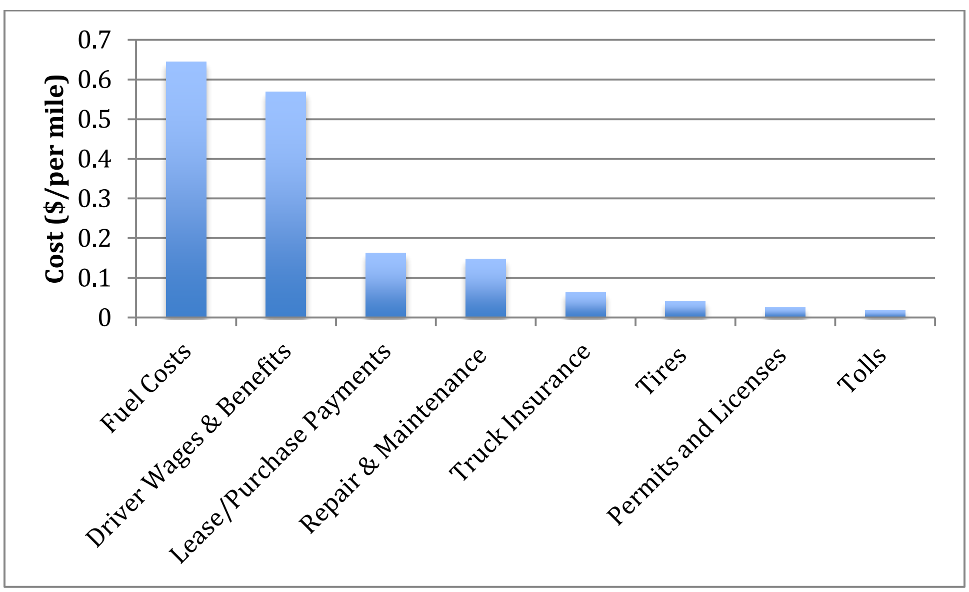
(ATRI, 2014)

a) Cost Elements for Tractor-Trailer Trucking

Heavy-duty trucking expenses include fuel costs, truck/trailer lease or purchase costs, repair and maintenance, insurance, permits and licenses, tires, tolls, and driver wages. These costs determine the ability of trucking fleets to operate in a profitable manner.

The ATRI survey collected information about the various costs impacting tractor-trailer trucking and found that the total average marginal cost per mile was $1.68 (ATRI, 2014). As shown in Figure III-3, fuel and driver wages and benefits are the major costs for the trucking industry, accounting for nearly 72 percent of the total cost per mile. Fuel is the biggest cost contributor to the trucking industry, and thus technologies that improve fuel economy can have a major impact on reducing the cost of operation and yield reasonable payback periods as a result.

Figure III- 3: Average Marginal Costs per Mile 2013 from ATRI Survey



(ATRI, 2014)

b) Major Challenges for Heavy-Duty Truck Fleets

Fuel

On-road diesel fuel costs were relatively stable from 2012-2013, around $4 a gallon, but in 2014 and 2015, fuel prices have fluctuated significantly and fallen to around $3 a gallon, based on the On-Highway Diesel Fuel Prices released by the U.S. Energy Information Administration. Diesel fuel continues to be a major cost for heavy-duty trucking and its rise and fall dramatically affects the profitability of the industry.

Driver Shortage

The trucking industry is facing a continued severe and growing shortage of qualified drivers. The American Trucking Association (ATA) estimated a nationwide shortage of 25,000 drivers at the end of 2013. The U.S. Bureau of Labor Statistics (BLS) estimates that employment of heavy-duty truck drivers will increase by 11 percent through 2020. The shortage of drivers is a result of high turnover, over 90 percent each year, (ATA 2015) primarily because wages have decreased on an inflation adjusted basis in the past decade, and various regulations have created additional challenges for drivers (New York Times, 2014). For example, new requirements for a national database that collects information about driver drug and alcohol test results are making it harder for drivers with substance abuse issues to jump from one truck company to another. Speed limiters which ensure trucks cannot travel faster than mandated speeds, and electronic hour loggers which will make it more difficult for drivers to cheat and drive more hours than permitted by law, also limit the hours and miles a single driver can cover. These factors combine to create conditions where more drivers will be needed to transport trucking freight and fewer drivers will be available in the hiring pool (Business Insider, 2014). The driver shortage issue has resulted in a shortage in supply of trucking freight capabilities and this will continue to be an issue.

C. Trucking Rates

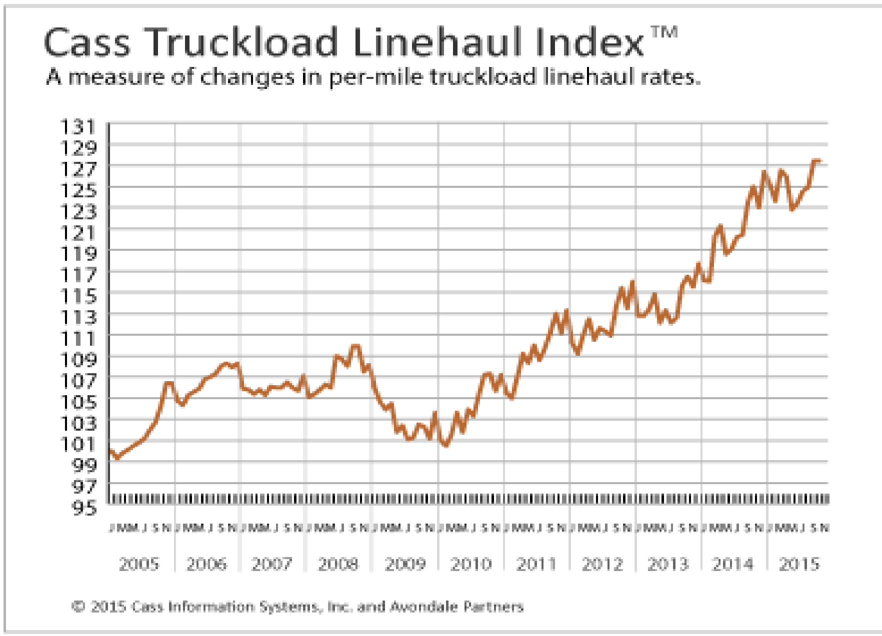
Trucking rates have continued to rise in recent years as a result of increased demand and constrained capacity. As fuel prices have decreased, the market has been shifting toward increased use of trucks over intermodal freight transportation (freight transported by multiple modes of transportation such as rail, ship, and/or trucking).

Trucking rates per-mile have grown steadily since 2014

Cass Information Systems, Inc. is the nation’s largest payer of freight bills and manages more than $16 billion in annual freight spending. Cass uses this information to compile data of transportation industry trends in the form of the Cass Truckload Linehaul Index. The Cass Truckload Linehaul Index is a nationwide measure of market fluctuations in per-mile truckload rates, independent of additional cost components such as fuels and accessories. The index measures fluctuations in per-mile truckload rates compared to the baseline. (Cass, 2015a)

As shown in Figure III-4, the Cass Linehaul Index has dramatically risen from 2010 through 2015 to an all-time high in March 2015, which is a result of increased demand and limits on trucking availability. This is in stark contrast to the dramatic decline in linehaul and intermodal rates in 2008-2009, which was a direct result of the recession (Wards Auto, 2009).

Figure III- 4: Cass Truckload Linehaul Index



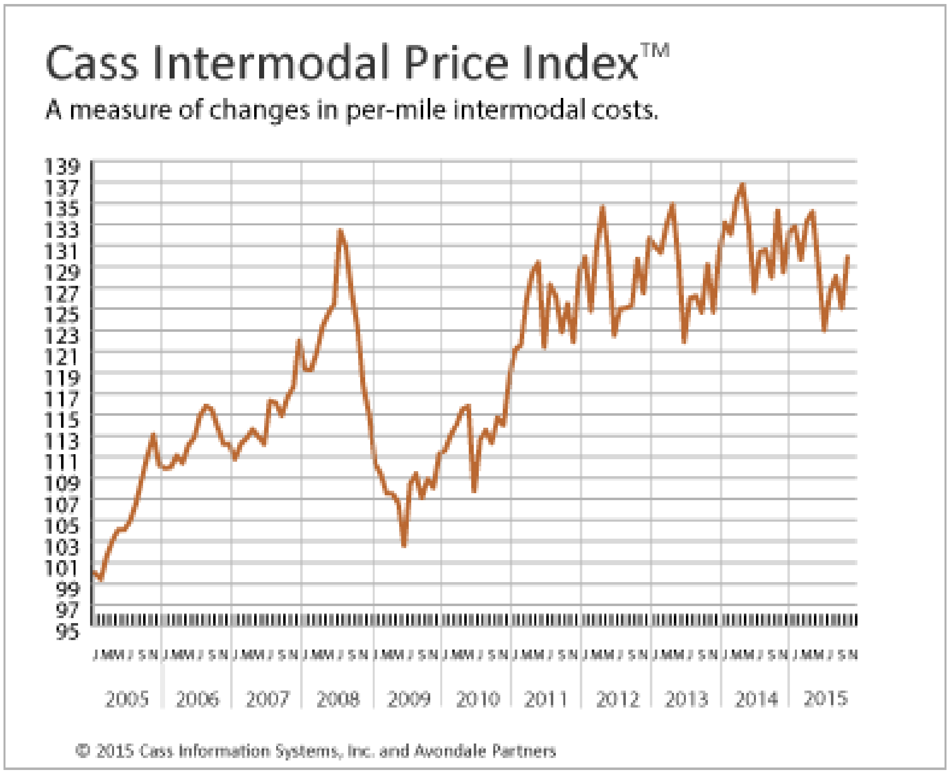
(Cass, 2015a)

a) Intermodal Shipping

Intermodal shipping involves the movement of goods by multiple modes of transportation, often including rail, ship, and truck. Since the use of rail and ship are transport means that are more energy efficient than over-the-road trucking, intermodal shipping is a more efficient means of transport than just trucking alone. Several economic factors play a part in the choice by mode of shipping. Often times, the most important factor is shipping rate, and shippers will choose intermodal over trucking or vice versa depending on rate considerations (NAS, 2010).

Diesel fuel prices play a significant role in determining whether domestic loads are taken via intermodal freight transport or over-the-road transport because of its effect on shipping rates. The Cass Intermodal Price Index measures the market fluctuations in U.S. domestic intermodal costs and shows fluctuations in shipping rates compared to a baseline (100). As shown in Figure III-5, the index shows that the market for intermodal shipping has fluctuated starting in the past several years, with some changes most likely due to falling diesel fuel prices. In periods of low diesel fuel prices, shipping will shift to over-the-road versus intermodal as trucking availability permits.

Figure III- 5: Cass Intermodal Price Index



(Cass, 2015b)

IV. EMISSIONS TRENDS AND THE RELATIONSHIP TO HEAVY-DUTY TRUCK REGULATIONS

This chapter presents the recent emissions trends and associated regulations for heavy-duty trucks. Specifically, Section A discusses the emission trends, Section B discusses the rules and regulations that have played a role in reducing emissions, and Section C discusses the need for further emission reductions in the future.

A. Emission Trends

Oxides of nitrogen (NOx) and particulate matter (PM) 2.5 emissions attributed to heavy-duty trucks have steadily declined since the mid-2000's and are expected to continue falling (see Figure IV-1 and IV-2 below). Emissions have dropped by more than 80 percent in less than 14 years, which is especially interesting given that the populations of trucks have grown throughout this period. NOx and diesel PM emissions are expected to continue to decrease significantly over the next 15 years. Emission reductions have been a direct result of the progressively more stringent new engine emission standards and the introduction of in-use regulations to curb heavy-duty emissions.

In contrast to NOx and PM 2.5 emissions trends, carbon dioxide (CO_2) emissions have steadily risen since 2000 due to the growth in truck population and VMT. As shown in Figure IV-3, CO_2 emissions steadily rose from 2000 to 2007 but significantly dropped from 2007 to 2009, which was mainly due to the decline in VMT during the recession. Starting 2012, with the improvement of the economy, leading to VMT growth, CO_2 emissions have increased gradually as a result. The Phase 1 Greenhouse Gas (GHG) standards for 2014 and newer model year (MY) heavy-duty engines and vehicles have played a significant role in curbing the CO_2 emissions from heavy-duty trucks; however, given the continued VMT growth and the Phase 1 GHG standards only for new engines and vehicles, the overall CO_2 emissions are projected to continually increase over time.

Figure IV- 1: California NOx Emission Trend (Tons/Day) produced using the ARB EMFAC 2014 Database for Heavy-Duty Trucks Class 2b-8 (8,501+ lbs.)

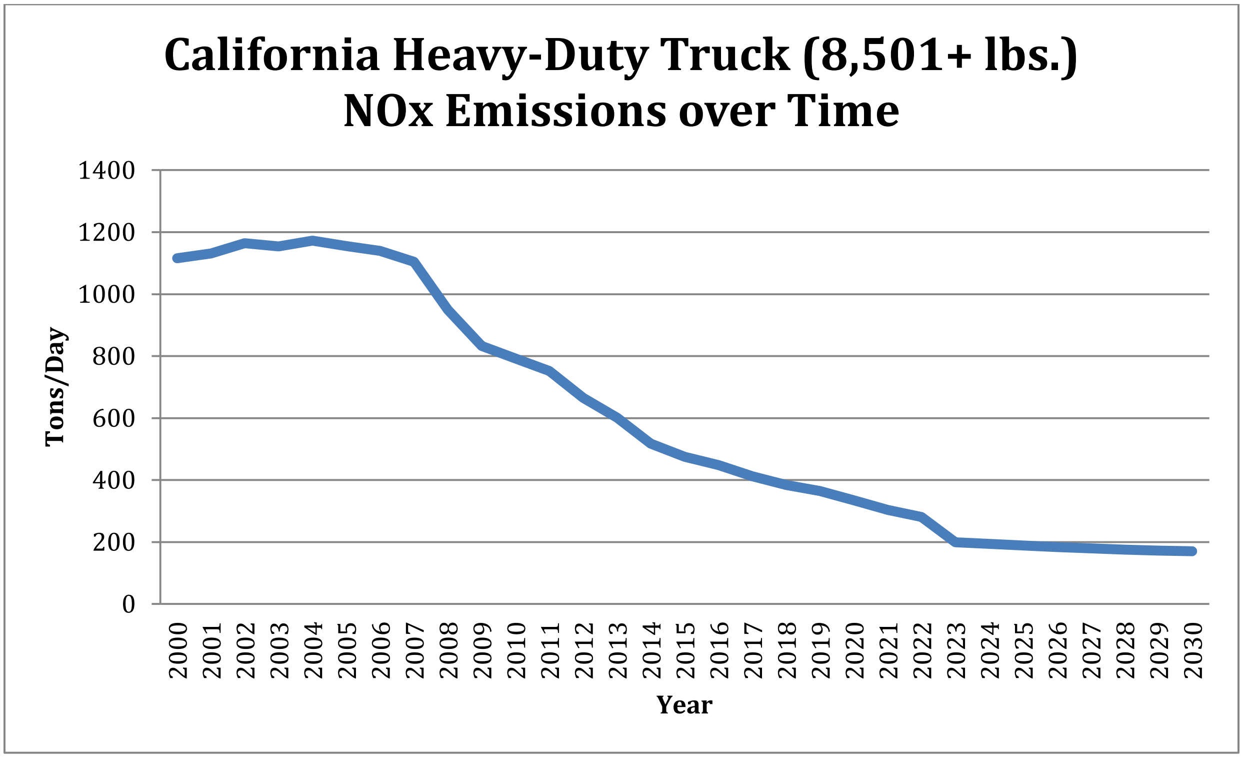


Figure IV- 2: California PM 2.5 Emission Trend (Tons/Day) produced using the ARB EMFAC 2014 Database for Heavy-Duty Trucks Class 2b-8 (8,501+ lbs.)

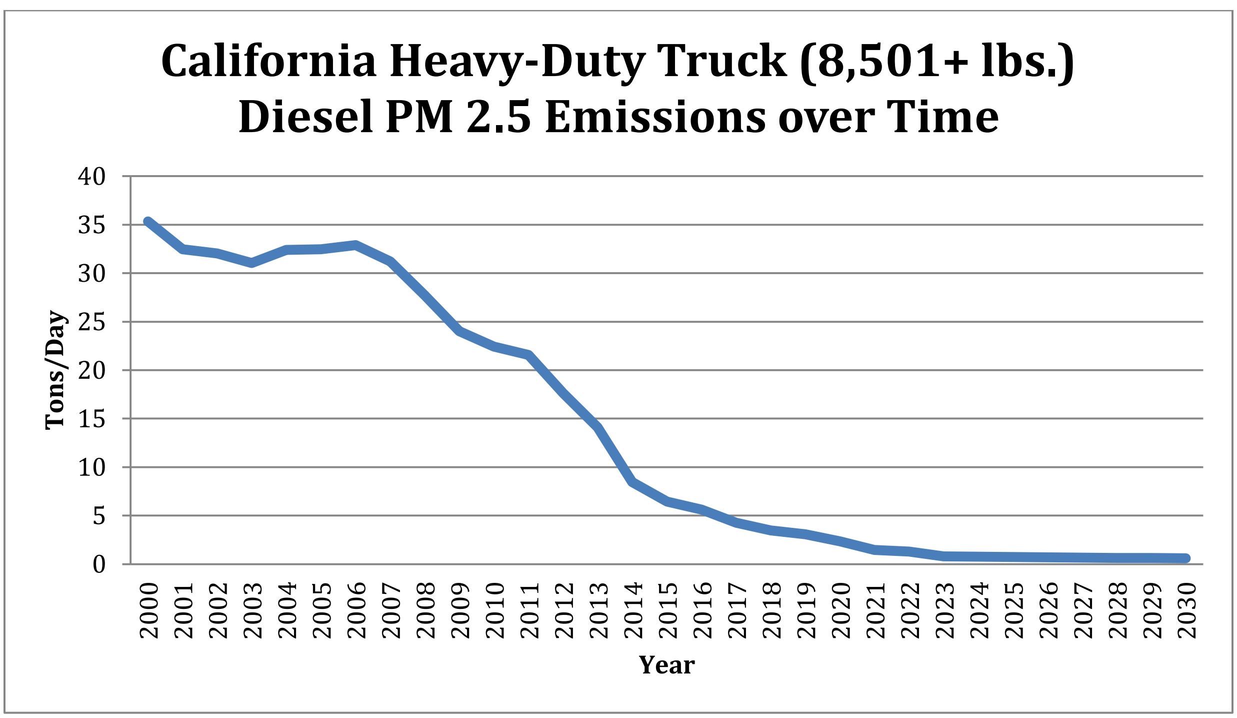
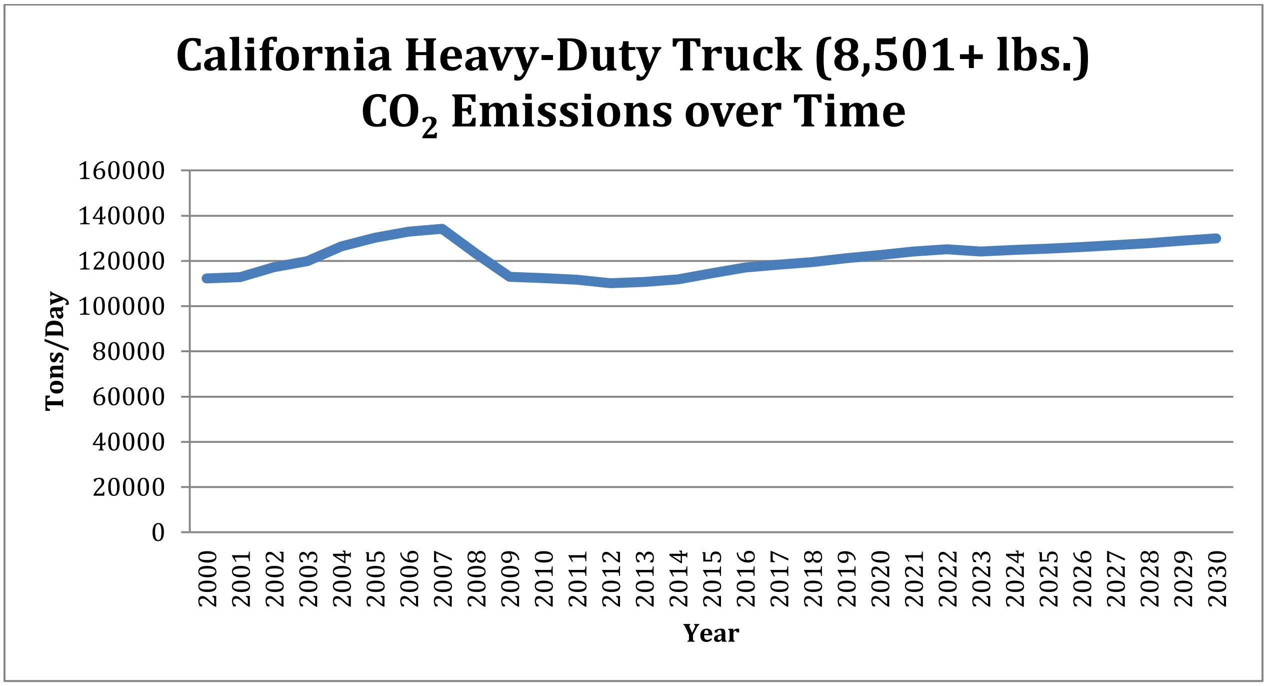


Figure IV- 3: California CO_2 Emission Trend (Tons/Day) produced using the ARB EMFAC 2014 Database for Heavy-Duty Trucks Class 2b-8 (8,501+ lbs.)[4]



B. ARB Rules and Regulations Targeting Heavy-Duty Truck Emissions

A significant reduction in criteria pollutants from heavy-duty trucks has occurred over the last three decades, as a result of the various regulations implemented by ARB and U.S. Environmental Protection Agency (EPA) with manufacturer and fleet efforts to comply. Below is a discussion of these regulations and standards, starting with a description of engine standards and concluding with a description of in-use regulations.

a) Heavy-Duty Engine Standards

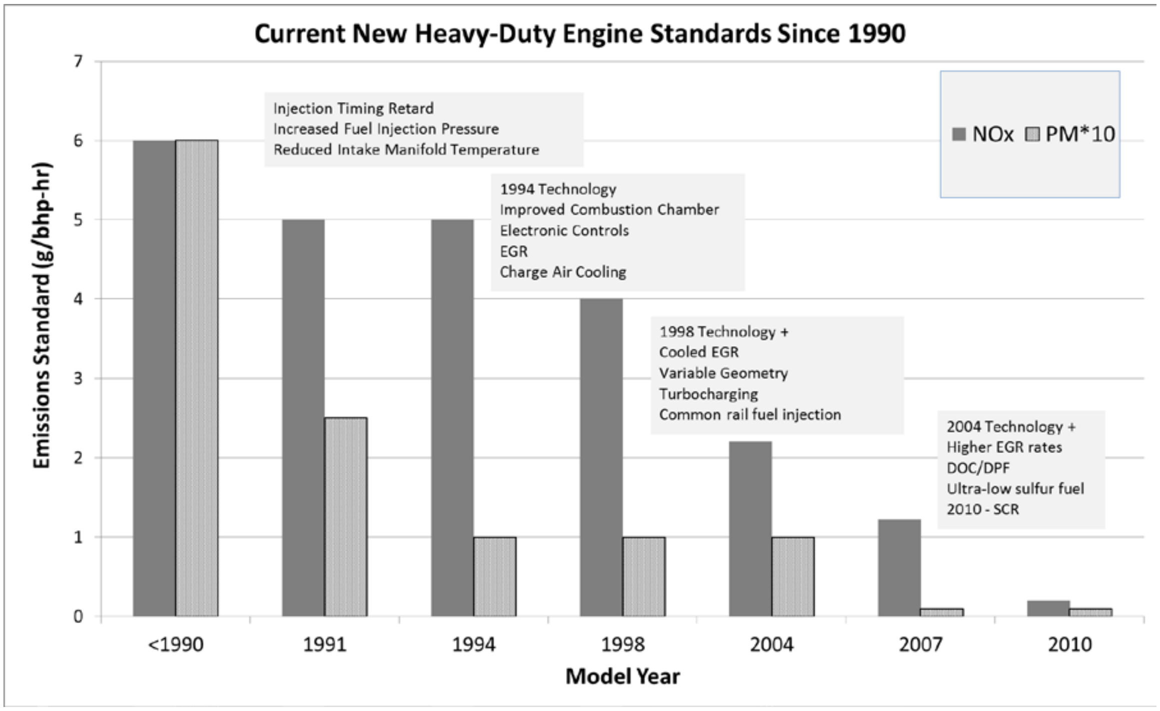
1. Heavy-Duty Engine Standards Since 1990

Heavy-duty engine standards have steadily declined since 1990, from 6 g/bhp-hr down to 0.20 g/bhp-hr for NOx, as shown in Figure IV-4. New engine standards have steadily increased in stringency beginning in the 1970s with smoke control standards and evolving to a focus on NOx and more stringent controls on other criteria pollutants such as hydrocarbons (HC) and PM emissions. Early engine standards were met by the introduction of better designed combustion chambers, improved mixture formation, high injection pressure, etc. Recently, the increased engine standard stringency has

[4] The projected CO_2 emissions include the Phase 1 GHG standards, which take effect with model year 2014 and decline through model year 2017, but do not include the proposed Phase 2 GHG standards, which are expected to increase in stringency through model year 2027.

required the introduction of exhaust aftertreatment controls such as diesel PM filters (DPF) and selective catalytic reduction (SCR) technology.

Figure IV- 4: Current New Heavy-Duty Engine Standards Since 1990



*EGR - Exhaust Gas Recirculation, DOC - Diesel Oxidation Catalyst, DPF- Diesel Particulate Filter

2. Phase 1 GHG Standards for Heavy-Duty Trucks

In 2014, ARB adopted the Phase 1 GHG standards, harmonizing with the U.S. EPA Phase 1 standards for new trucks and engines, which were adopted nationally in 2011. The Phase 1 standards establish limits on GHG emissions from new heavy-duty trucks and engines. They establish CO_2 standards for new compression and spark ignition engines, as well as vehicle standards for Class 2b through Class 8 vehicles. Compliance requirements began with MY 2014 with stringency levels increasing through MY 2018. The rule organizes truck compliance into three groupings, which includes a) heavy-duty pickups and vans, b) vocational vehicles, and c) combination tractors, but does not include trailers. The rule requires new truck manufacturers to certify trucks to emission standards, which apply not only to the engine but also to the full vehicle. The regulation will result in CO_2 emissions reduction and improved fuel economy. (More information is available at: http://www.arb.ca.gov/msprog/onroad/phaselghg/phaselghg.htm and in the *Draft Technology Assessment: Engine/Powerplant and Drivetrain Optimization and Vehicle Efficiency*)

b) Heavy-Duty In-Use Rules

ARB has implemented many regulations to curb emissions from in-use heavy-duty trucks operating in California. Table IV-1 below lists and briefly summarizes the major in-use regulations chronologically by implementation timeline. The regulations are described further below in the text in the same order as they appear in the table.

Table IV- 1: Summary of In-Use Heavy-Duty Regulations

Regulation	***Requirement***	***Pollutant***	***Implementation Schedule***	***Applicability***
Truck and Bus In-Use Regulation	Requires installation of PM filters or phase-out of older vehicles	PM and NOx	Began in 2012 and will be fully implemented by 2023	Nearly all diesel fueled trucks and buses with a GVWR over 14,000 lbs.
Drayage Truck Regulation	Drayage truck owners are required to register their trucks and are required to meet emissions standards	PM and NOx	Began in 2009 and will be fully implemented by 2023	On-road diesel-fueled, alternative diesel-fueled and dual-fueled heavy-duty drayage trucks operated at California ports and intermodal rail yard facilities
Tractor-Trailer Greenhouse Gas (GHG) Rule	The tractors and trailers subject to this regulation must use U.S. Environmental Protection Agency SmartWay^{SM} certified tractors and trailers, or retrofit their existing fleet with SmartWay verified technologies	GHG	Began in 2010 and will be fully implemented by the end of 2020	53-ft or longer box-type trailers, including dry-van and refrigerated-van trailers that operate on California highways
Transport Refrigeration Units (TRUs) ATCM	Requires TRUs operating in California to be registered and to meet in-use performance standards	PM	Registration began in 2009. In-use performance standards began in 2008 and must be met by the end of the 7th year after the engine model year	Apply to both TRUs and TRU generator sets

Regulation	***Requirement***	***Pollutant***	***Implementation Schedule***	***Applicability***
Fleet Rule for Public Agencies and Utilities	Requires application of BACT to applicable vehicles	PM	Began in 2007 and was fully implemented in 2012	Vehicles with GVWR 14,000 lbs. or higher with a model year of 1960 or newer owned by public agencies or utilities
Fleet Rule for Transit Agencies	Requires transit fleets to reduce PM and NOx emissions by achieving fleet targets for these emissions	PM and NOx	Began in 2007 and was fully implemented in 2010	On-road vehicles operated by a public transit agency, less than 35' in length and 33,000 lbs. GVWR but greater than 8,500 lbs. GVWR, powered by heavy-duty engines fueled by diesel or alternative fuel
Solid Waste Collection Vehicle Rule	Requires solid waste collection vehicles to apply Best Available Control Technology (BACT) for reducing diesel PM	PM	Began in 2004 and was fully implemented in 2010	Solid waste collection vehicles or those diesel-fueled trucks over 14,000 lbs. GVWR with MY engines from 1960-2006
Commercial Vehicle Idling Regulation	Prohibits idling of vehicle more than 5 minutes unless vehicle is certified to clean-idle standards	PM and NOx	Began 2005 and is ongoing	Diesel-fueled motor vehicles with a GVWR greater than 10,000 lbs.
Heavy-Duty Vehicle Inspection Program (HDVIP)	Requires roadside inspections of vehicles/engines for tampering, excessive smoke emissions, and emission control labels.	PM and NOx	Began in 1991 and is ongoing	All heavy-duty diesel-powered vehicles greater than 6,000 lbs. GWVR operating in California. Vehicles registered in other states and countries may be tested.
Periodic Smoke Inspection Program (PSIP)	PSIP requires California-based fleets to perform annual smoke and tamper inspections. ARB staff may randomly audit	PM and NOx	Began in 1998 (Implemented on a voluntary basis prior to 1998) and is ongoing	All California-based fleets of two or more heavy-duty vehicles greater than 14,000 lbs.

Regulation	Requirement	Pollutant	Implementation Schedule	Applicability
	fleets' maintenance/inspection records, and test representative sample vehicles.			GVWR (except for 1998 and older vehicles, GVWR is over 6,000 lbs.)

1. Truck and Bus In-Use Regulation

The California Truck and Bus In-Use regulation requires upgrades to in-use trucks and buses over 14,000 lbs. GVWR operating in California. Specifically, the regulation requires these trucks and buses to be upgraded to reduce criteria emissions (i.e., PM and NOx emissions). The regulation will require newer trucks to meet PM filter requirements and older trucks to be replaced or repowered. The goal of the regulation is to have nearly all trucks and buses operating in California with 2010 MY engines or equivalent emission outputs via upgrades.

The regulation applies to all privately and federally owned diesel fueled trucks and buses with a GVWR greater than 14,000 lbs. There are flexibilities within the regulation that apply to low use vehicles and small fleets. For example, the regulation grants compliance extensions for individual trucks within a fleet that meet the regulatory definitions of a low mileage work truck, low use, agricultural vehicle, or trucks that are operated in certain areas with cleaner air.

The Truck and Bus regulation, the largest in-use rule affecting heavy-duty trucks, is expected to achieve large reductions in PM and NOx emissions and impacts almost one million trucks operating annually in California. In 2023, this in-use rule is expected to result in a 39 and 37 percent reduction in diesel PM and NOx emissions, respectively, compared to the baseline (without the regulation) (ARB, 2014b). (More information is available at: http://www.arb.ca.gov/msprog/onrdiesel/onrdiesel.htm)

2. Drayage Truck Regulation

The Drayage Truck Regulation primarily applies to trucks operating in California's ports and intermodal rail yards with the goal of reducing PM and NOx emissions. Drayage trucks are classified as on-road diesel-fueled heavy-duty class 7 or class 8 vehicles (GVWR of 26,000 lbs. or greater) transporting cargo going to or coming from California's ports and intermodal rail yards. The main emission reduction of this regulation comes from the requirement that trucks meet targeted emission standards by certain dates. The regulation will essentially remove older polluting vehicles from these applications and introduce newer and cleaner trucks. (More information is available at: http://www.arb.ca.gov/msprog/onroad/porttruck/porttruck.htm)

3. Tractor-Trailer GHG Rule

The Tractor-Trailer GHG Rule is intended to utilize existing fuel-efficient technologies to reduce GHG emissions from heavy-duty tractor-trailers. The rule mandates the use of aerodynamic technologies verified by the U.S. EPA SmartWay program. The primary technologies utilized to comply include low rolling resistance tires and aerodynamic devices such as trailer skirts. The rule primarily applies to 53-foot or longer box-type trailers including dry-van and refrigerated trailers. These trailers are required to be equipped with aerodynamic technologies. (More information is available at: http://www.arb.ca.gov/msprog/truckstop/trailers/trailers.htm)

4. Transport Refrigeration Units (TRU) Airborne Toxic Control Measure (ATCM)

TRUs are refrigeration units used in the transport of perishable goods and are powered by relatively small (9 to 36 horsepower) diesel engines. The TRU ATCM requires that in-use TRU and TRU generator set engines operating in California must meet in-use performance standards for diesel PM by the end of the seventh year after the engine model year (PM standards vary by horsepower range). TRUs that are based in California must register with ARB's Equipment Registration (ARBER) system. (More information is available at: http://www.arb.ca.gov/diesel/tru/tru.htm)

5. Fleet Rule for Public Agencies and Utilities

The fleet rule for public agencies and utilities applied to fleets of heavy-duty trucks operated by those agencies defined under the Public agencies and utilities (PAU), Title 13, California Code of Regulations (CCR), Sections 2020, 2022, and 2022.1. The regulation required these agencies or utilities that own, lease, or operate on-road diesel-fueled heavy-duty vehicles with MY 1960 or newer heavy-duty engines certified above the 0.01 g/bhp-hr PM emission standard (i.e., engines not equipped with an original equipment manufacturer (OEM) PM filter) and greater than 14,000 lbs. GWVR, to apply Best Available Control Technology (BACT) based on a phase-in schedule that is now complete. (More information is available at: http://www.arb.ca.gov/msprog/publicfleets/publicfleets.htm)

6. Fleet Rule for Transit Agencies

The fleet rule for transit agencies, which is now fully implemented, required reductions in fleet emissions of PM and NOx from transit fleet vehicles; it also established demonstration and purchase requirements of zero emission technologies for large transit agencies. The rule applied to on-road vehicles operated by a public transit agency, less than 35 feet in length and between 8,500 and 33,000 lbs. GVWR, and powered by diesel or alternative fueled heavy-duty engines (excluding gasoline vehicles). (More information is available at: http://www.arb.ca.gov/msprog/bus/bus.htm)

7. Solid Waste Collection Vehicle Rule

The Solid Waste Collection Vehicle rule applied to owners of solid waste collection vehicles or those diesel-fueled trucks over 14,000 lbs. GVWR with MY engines from 1960 to 2006 used to collect residential and commercial solid waste. The rule required these owners to clean up their solid waste collection vehicles by using the BACT for reducing diesel PM. (More information is available at: http://www.arb.ca.gov/msprog/swcv/swcv.htm)

8. Commercial Vehicle Idling ATCM

The Commercial Vehicle Idling Regulation prohibits idling for more than 5 minutes, and applies to every heavy-duty diesel vehicle with a GVWR of 10,000 lbs. or heavier. The regulation allows for some exceptions including trucks that have engines that meet the optional-low-NOx idling emission standard. The goal of this regulation is to reduce PM, NOx, and HC. (More information is available at: http://www.arb.ca.gov/regact/idling/idling.htm)

9. Heavy-Duty Vehicle Inspection Program (HDVIP) and the Periodic Smoke Inspection Program (PSIP)

The HDVIP was approved by the Board in 1990 in response to Senate Bill 1997 (Presley; Chapter 1544, Statutes of 1988). With the original program implementation starting in 1991, the current program allows for any truck or bus over 6,000 lbs. GVWR operating in California to be inspected for tampering, excessive smoke emissions, and engine certification label compliance. Inspections are performed by ARB inspection teams at California Highway Patrol weigh stations, fleet facilities, randomly selected roadside locations, and border crossings. Owner of trucks and buses found in violation are subject to penalties starting at $300 per violation.

The PSIP, approved by the Board in 1992 in response to Senate Bill 2330 (Killea; Chapter 1453, Statutes of 1990), serves as a companion program to HDVIP to ensure that all of California's trucks and buses over 6,000 lbs. GVWR are properly maintained, tamper-free, and do not emit excessive smoke. All owners of California-based fleets of two or more heavy-duty vehicles over 14,000 lbs. GVWR (over 6,000 lbs. GVWR for 1998 and older vehicles) are required to perform annual smoke opacity and tampering inspections. A fleet owner that neglects to perform the annual smoke opacity inspection on applicable vehicles is subject to a penalty of $500 per vehicle per year.

For both programs, ARB staff is currently evaluating the need for reduced exhaust opacity limits for trucks equipped with DPFs. (More information on both the HDVIP and PSIP is available at: http://www.arb.ca.gov/enf/hdvip/hdvip.htm)

C. Future Need for Emission Reductions

While significant progress has been made in terms of achieving reductions in NOx, reactive organic gases (ROG), and direct PM 2.5 emissions, California still faces great challenges to reduce ozone in the South Coast Air Basin and PM 2.5 in the San Joaquin Valley. U.S. EPA has classified both areas as extreme nonattainment areas for the 2008 8-hour federal ozone standard; nearly 34.6 million people in the state, 91 percent of the population, live in these areas (Figure IV-5 and IV-6). In order for California to attain the National Ambient Air Quality Standards (NAAQS) for PM and ozone, there will need to be significant further reductions in emissions, especially from heavy-duty trucks (ARB, 2014b).

Furthermore, under the California Global Warming Solutions Act of 2006, Assembly Bill (AB) 32, California has a goal of reducing GHG emissions by 80 percent from 1990 levels by 2050 (ARB, 2014b). Governor Brown recently announced the interim goal of reducing GHG emissions by 40 percent from 1990 levels by 2030 (Governor's Executive Order B-30-15). To meet the GHG goals, GHG emissions from all sources including heavy-duty trucks need to be reduced as much as possible.

Figure IV- 5: 8-Hour Ozone Nonattainment Areas (2008 Standard) U.S. EPA

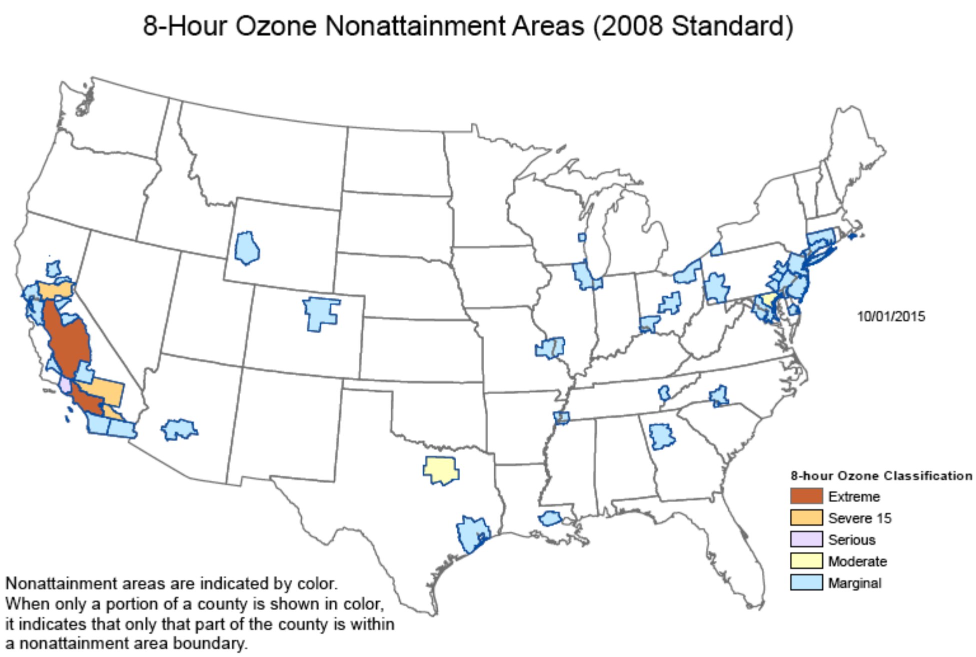
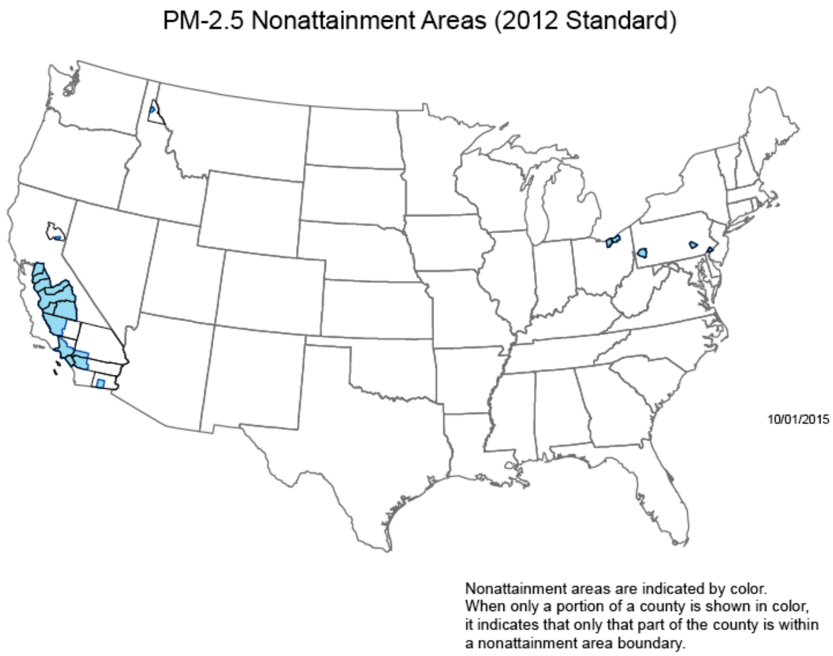


Figure IV- 6: PM 2.5 Nonattainment Areas (2012 Standard) U.S. EPA



V. CURRENT EMISSIONS, POPULATION, AND VEHICLE MILES TRAVELED (VMT) FOR HEAVY-DUTY TRUCKS

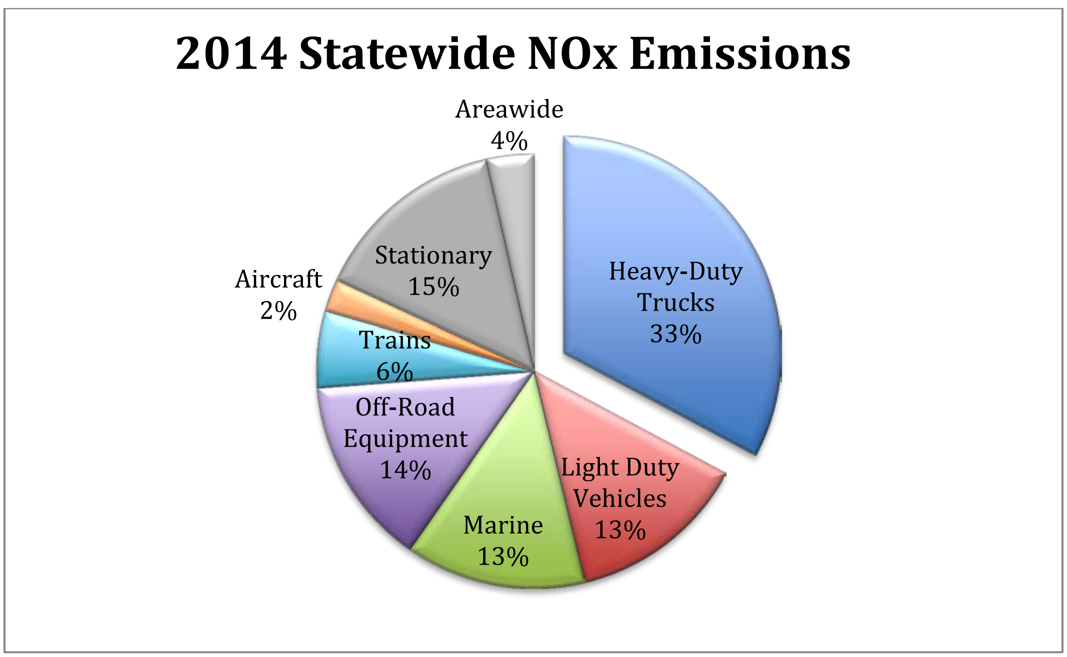
This chapter presents emissions, population, and VMT inventory for heavy-duty trucks. Section A discusses the emissions inventory data and looks at heavy-duty trucks in the context of statewide emissions sources and the distributions of emissions based on CalHEAT truck categories. Section B discusses population and VMT distributions of heavy-duty trucks based on CalHEAT truck categories. Section C presents a detailed breakdown of truck emissions, population, and VMT data by CalHEAT category. Section D discusses detailed drive cycle information for heavy-duty trucks and its relationship to the CalHEAT categories based on analysis of data from the National Renewable Energy Laboratory (NREL) Fleet DNA database.

A. Emissions Inventory

1. Statewide Emission Sources

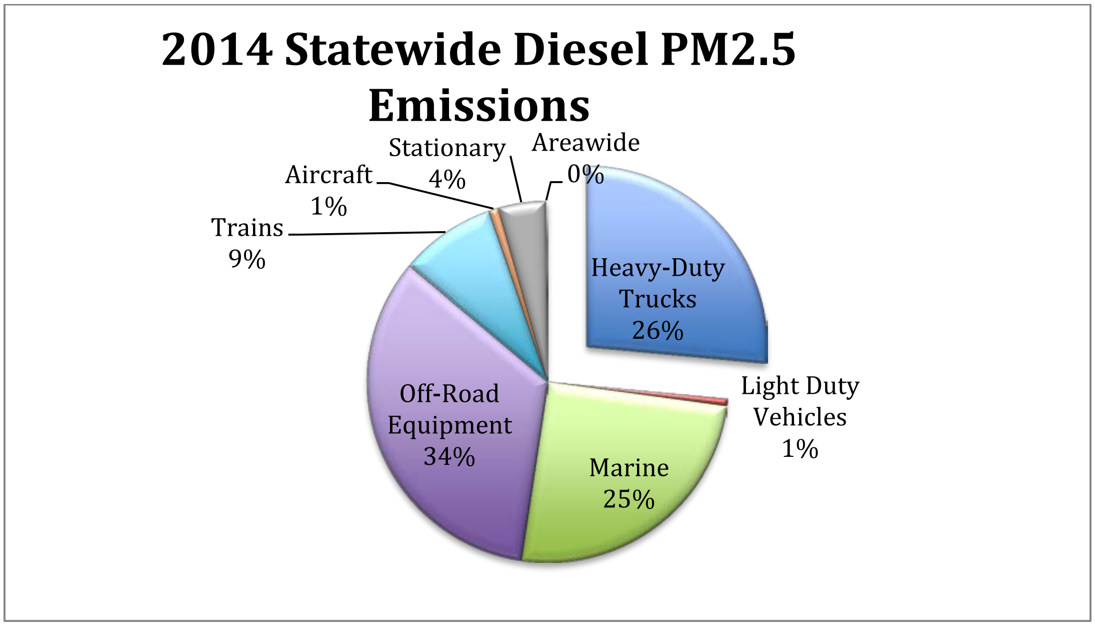
Heavy-duty trucks represent significant sources of emissions in California and nationwide. In California, heavy-duty trucks represent nearly 33 percent of all NOx emissions (Figure V-1) and 26 percent of diesel PM 2.5 emissions (Figure V-2). Heavy-duty trucks emit about 8 percent of the total statewide GHG emissions and represent approximately 21 percent of GHG emission from all transportation sources (see Figures V-3 and V-4).

Figure V- 1: Statewide NOx Emissions by Source in 2014



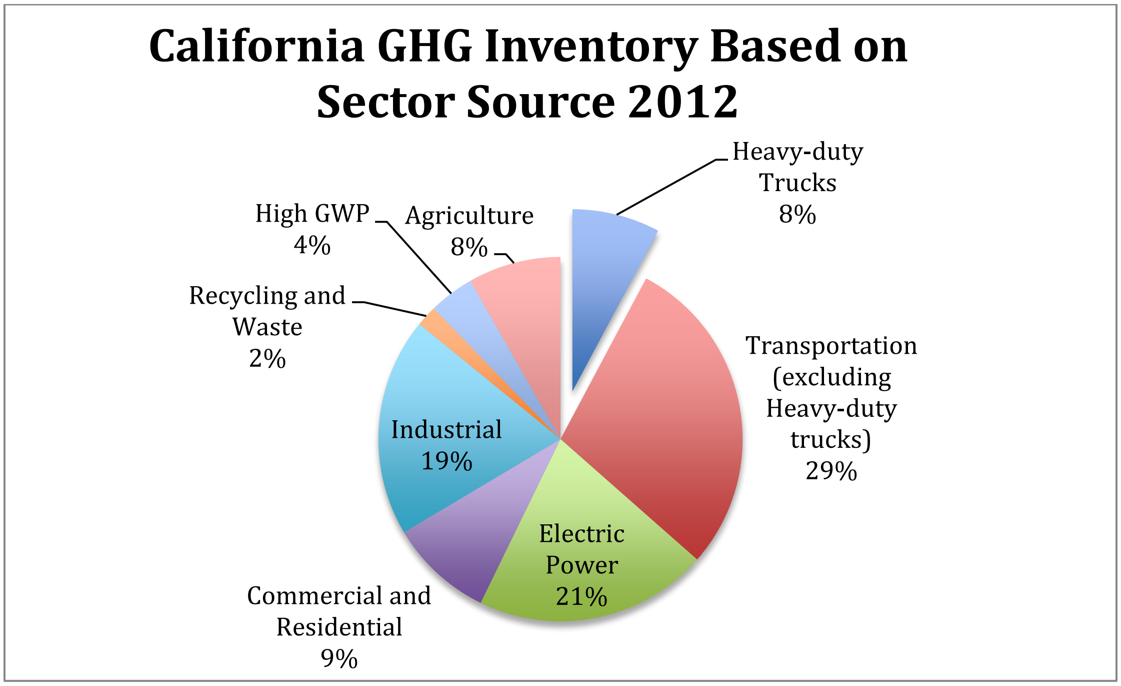
*Heavy-Duty Trucks classified as 8,501+ lbs. GVWR

Figure V- 2: Statewide Diesel PM 2.5 Emissions by Source in 2014



*Heavy-Duty Trucks classified as 8,501+ lbs. GVWR

Figure V- 3: Statewide GHG Emissions California GHG Inventory by Source



Using ARB's California GHG Inventory for 2000-2012-by Category as Defined in the 2008 Scoping Plan[5] with Heavy-Duty trucks classified as 8,501+ lbs. GVWR (ARB, 2014a)

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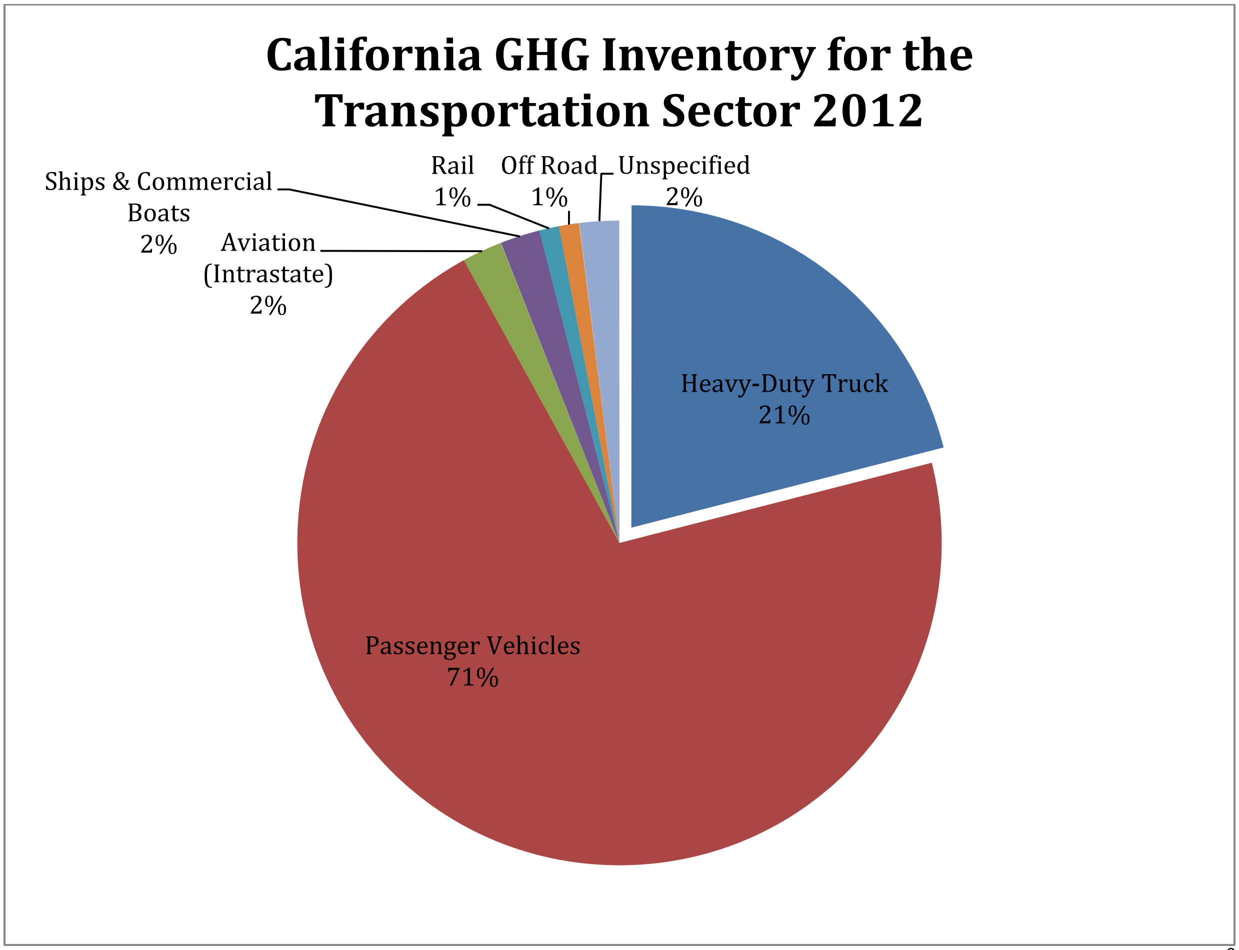
[5] On-Road Distillate (Diesel) vehicles, which include heavy-duty diesel trucks as well as lighter diesel vehicles, were responsible for about 5 percent of GHG emissions, (Figure 4-Statewide Greenhouse Gas (GHG) Emissions).

Figure V- 4: California GHG Inventory for the Transportation by Source

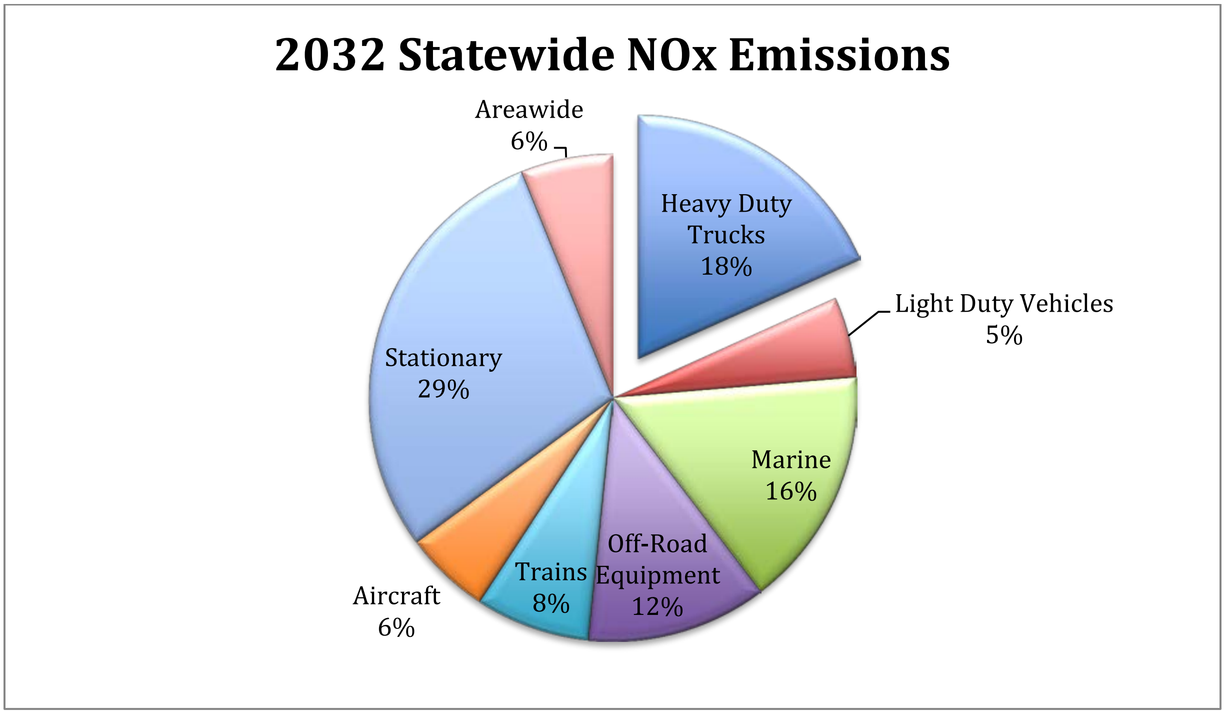


Using ARB's California GHG Inventory for 2000-2012-by Category as Defined in the 2008 Scoping Plan[6] with Heavy-Duty trucks classified as 8,501+ lbs. (ARB, 2014a)

Compared to today's levels, by 2032 heavy-duty trucks are projected to be a smaller relative contributor of NOx and diesel PM 2.5 emissions, although still significant. Figure V-5 and V-6 show relative contributions of various statewide sources of NOx and diesel PM 2.5 emissions, respectively, in 2032. It is projected that heavy-duty trucks will represent only 5 percent of diesel PM 2.5 emissions (down from 26 percent in 2014) and 18 percent of NOx emissions (down from 33 percent in 2014). This trend is a result of the full implementation of the various control measures including the in-use rules and engine standards (See Section IV).

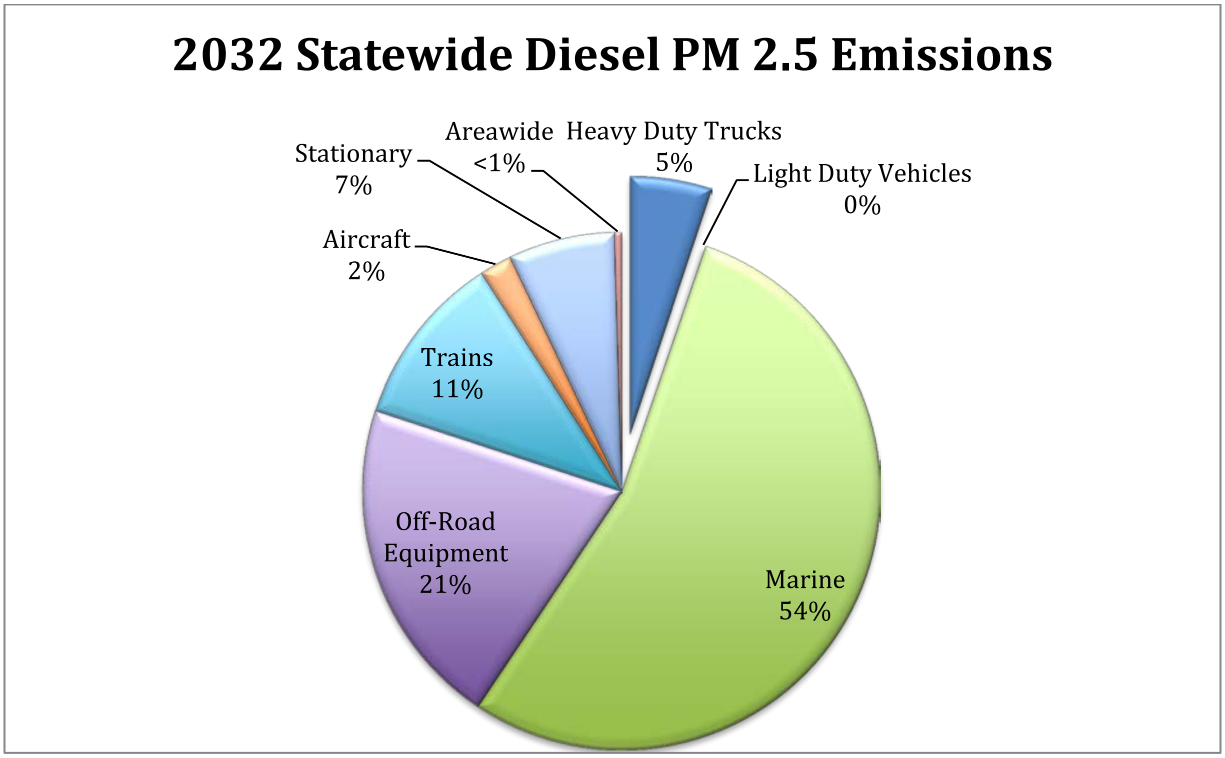
[6] On-Road Distillate (Diesel) vehicles, which include heavy-duty diesel trucks as well as lighter diesel vehicles, were responsible for about 5 percent of GHG emissions, (Figure 4-Statewide Greenhouse Gas (GHG) Emissions).

Figure V- 5: Statewide NOx Emissions by Source in 2032



*Heavy-Duty Trucks classified as 8,501+ lbs.

Figure V- 6: Statewide Diesel PM 2.5 Emissions by Source in 2032



*Heavy-Duty Trucks classified as 8,501+ lbs.

2. Heavy-duty Truck Emissions by CalHEAT Classifications

The contribution of each CalHEAT truck category to NOx, PM 2.5, and CO_2 emissions is shown in Figures V-7, V-8, and V-9, respectively. (Appendix I details the source and groupings that were used to analyze the emissions data.) As shown in Figures V-7 to V-9, Over-the-road (OTR) (long-haul) trucks are responsible for the largest portion of statewide emissions, including 38 percent of NOx, 34 percent of PM 2.5, and 42 percent of CO_2. Vans/pickups are the second largest category with 20 percent of NOx, 8 percent of PM 2.5, and 21 percent of CO_2. Rural/intracity regional is the third largest contributor, with 11 percent of NOx, 24 percent of PM 2.5, and 11 percent of CO_2.

Figure V- 7: Contribution to California NOx Emissions based on CalHEAT Classifications (GVWR 8,501+ lbs.) in 2014, Annual Volumes (EMFAC 2014)

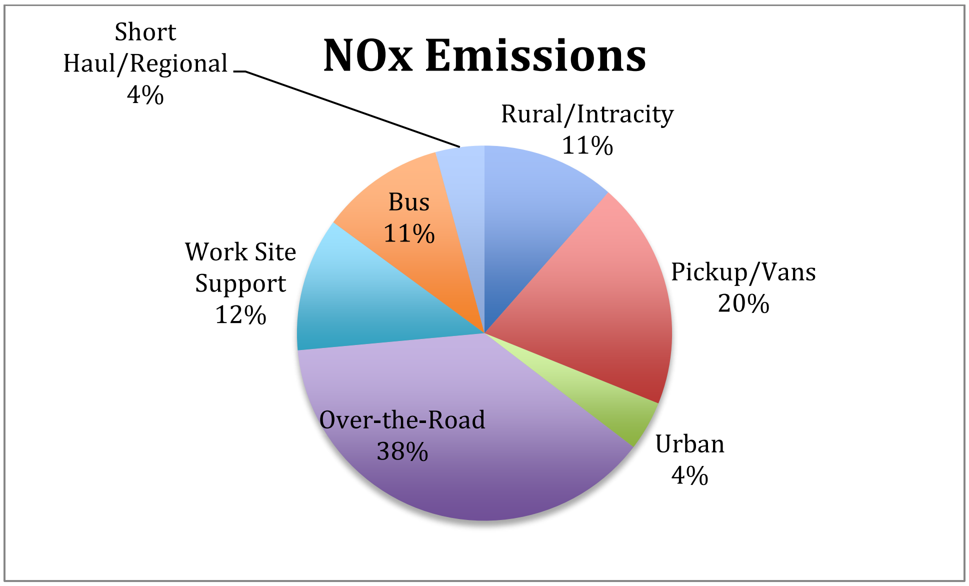


Figure V- 8: Contribution to California PM 2.5 Emissions based on CalHEAT Classifications (GVWR 8,501+ lbs.) in 2014, Annual Volumes (EMFAC 2014)

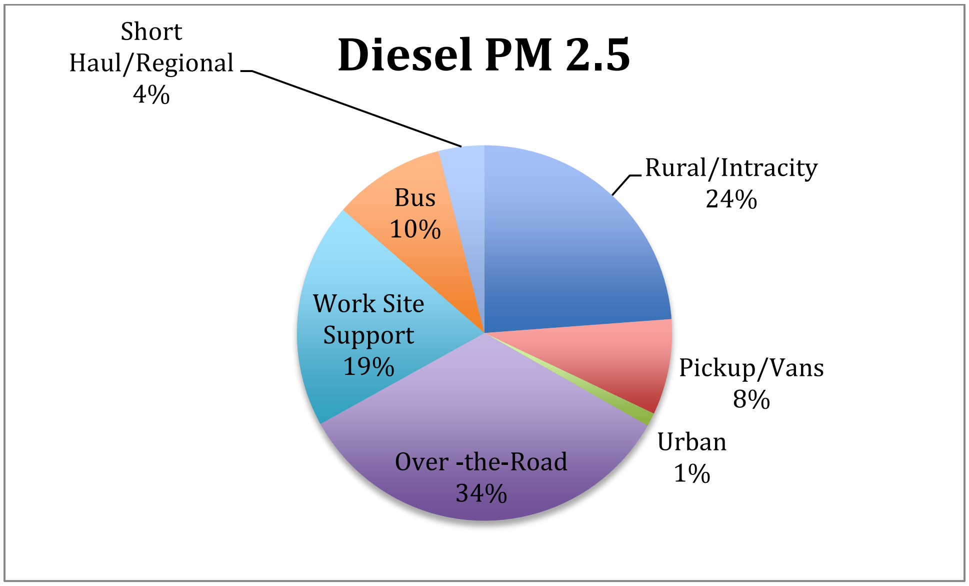
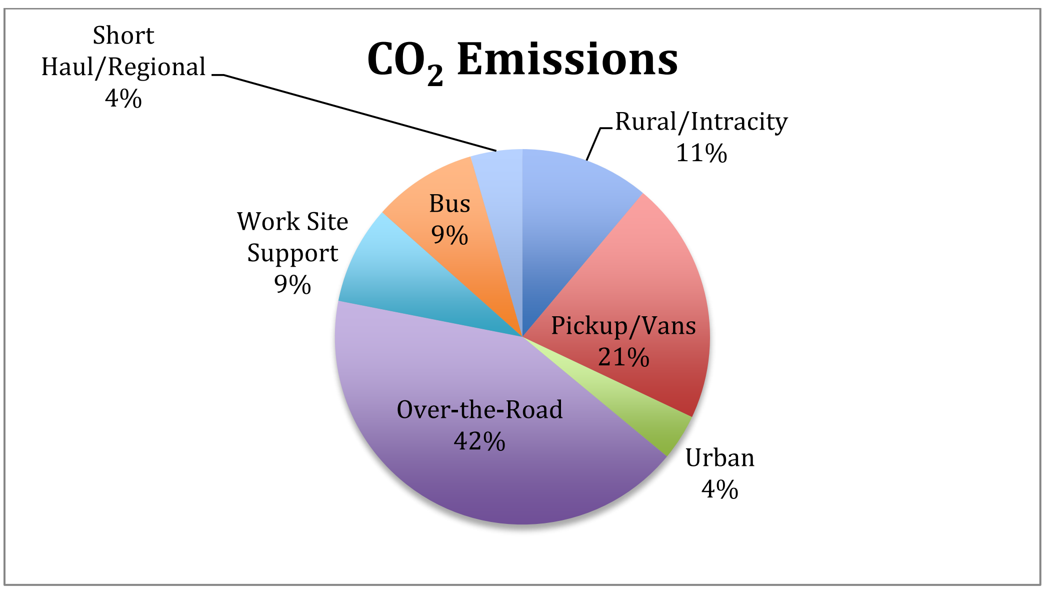


Figure V- 9: Contribution to California CO_2 Emissions based on CalHEAT Classifications (GVWR 8,501+ lbs.) in 2014, Annual Volumes (EMFAC 2014)

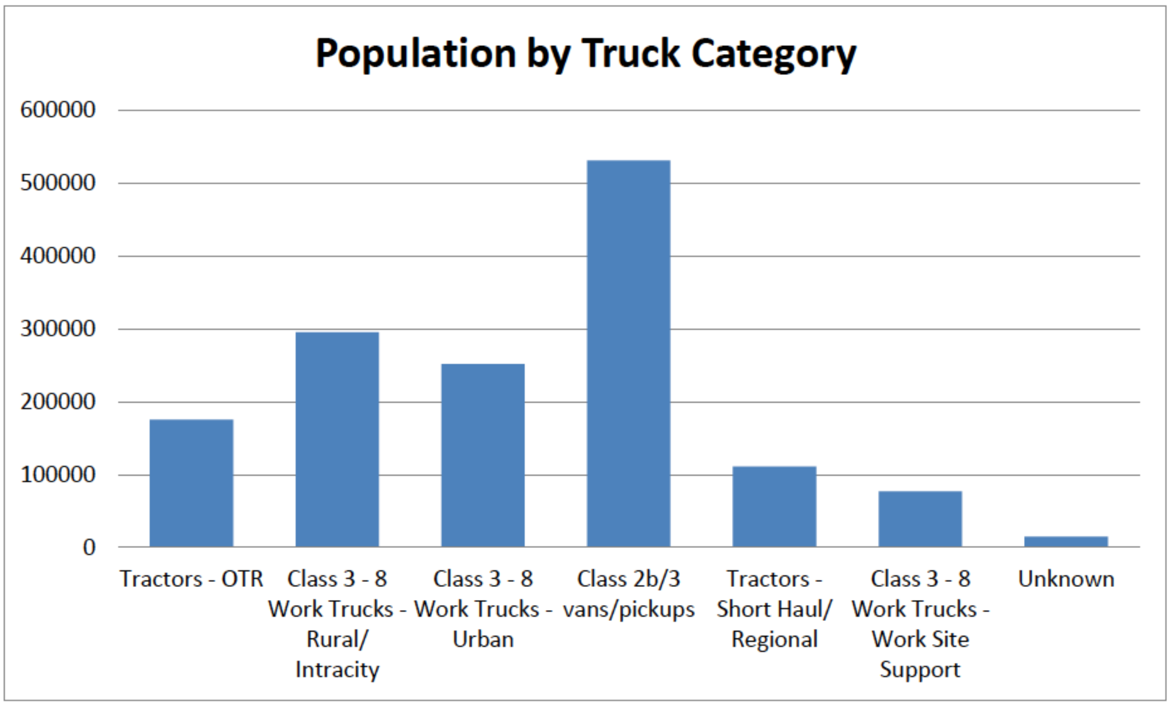


B. Population of California Heavy-duty Trucks and VMT

1. Population Data

In the CalHEAT California Truck Inventory and Impact Study from 2011, CalHEAT found that the class 2b-8 commercial heavy-duty truck population in California was nearly 1.5 million based on California registration figures and the R. L. Polk & Co database. They further analyzed the population and produced the chart shown in Figure V-10, categorizing the population by CalHEAT category.

Figure V- 10: California Truck Population by CalHEAT Category[7]



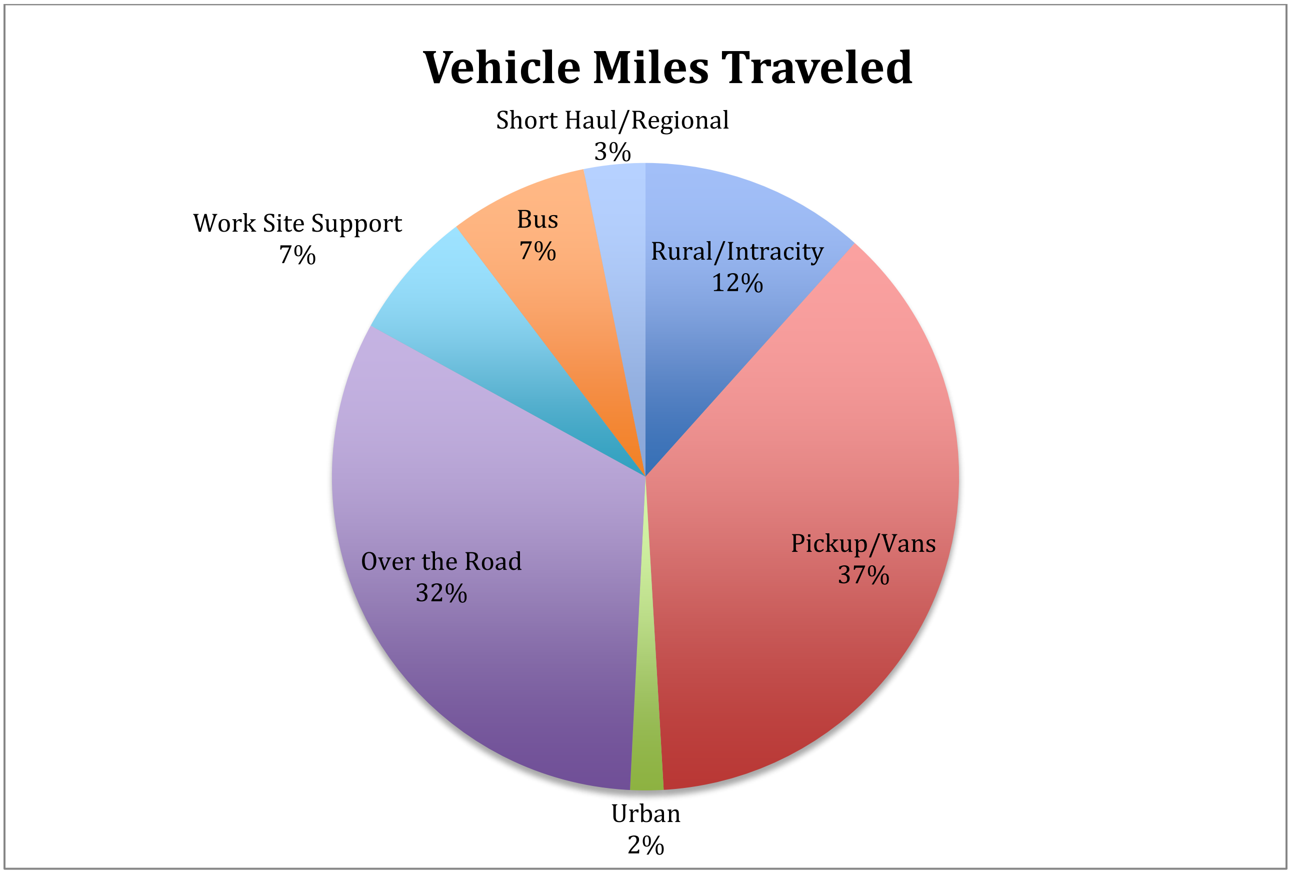
(CalHEAT, 2011)

2. VMT based on EMFAC 2014

Using the EMFAC 2014 database to analyze annual total VMT for trucks based on classification for calendar year 2014, vans/pickups have the highest VMT contribution of any of the CalHEAT categories. This is directly attributable to their large population within the state. OTR trucks had the second highest annual VMT, even though their population is approximately less than a 1/3 of vans/pickups (Figure V-11).

[7] Includes California-registered trucks only.

Figure V- 11: Vehicle Miles Traveled (VMT) by Heavy-Duty Trucks (GVWR 8,501+ lbs.) based on CalHEAT Classifications in 2014, Annual Values (EMFAC 2014)



C. <u>Breakdown of Truck Emissions, Population, and VMT Data for Heavy-Duty Truck Classifications</u>

As illustrated in Figures V-7 through V-9 above, OTR trucks are responsible for the majority of NOx, PM 2.5, and CO_2 emissions generated by heavy-duty trucks. OTR trucks are responsible for 32 percent of the total VMT of all heavy-duty trucks. The emission contribution of OTR trucks is notable, especially since their population is only around 10 percent of the total number of heavy-duty trucks. The other truck categories' emissions contributions are more commensurate with their populations.

Table V-1 summarizes CalHEAT estimates for annual VMT for an average truck in each of the CalHEAT classifications, each of which is discussed further below.

Table V- 1: CalHEAT Average Annual VMT for Truck Categories

Vehicle Category	Annual Average VMT (Single Truck)
Tractors-OTR	85,000
Tractors-Short Haul/Regional	55,000
Class 3-8 Work-Urban	25,000
Class 3-8 Work-Rural/Intracity	35,000
Class 3-8 Work-Work Site	13,000
Class 2b/3 Vans/Pickups	21,000
Unknown	8,192

(CalHEAT, 2011)

1. Vans and Pickups

The vans and pickups category is primarily composed of vehicles such as cargo vans and heavy-duty pickup trucks which weigh between 8,501-14,000 lbs. They have the largest population size of any other heavy-duty truck category. In contrast to the population size, vans and pickups have a relative low overall VMT per truck (21,000 miles per year). Despite the relatively low per truck VMT, due to the large number of vehicles in this category, vans and pickups contribute heavily to NOx and CO_2 emissions. They account for nearly 20 percent of the total NOx emissions and 21 percent of the total CO_2 emissions of all heavy-duty trucks. Their contribution to PM 2.5 emissions is relatively low, only 8 percent of the total diesel PM 2.5 emissions from all heavy-duty (8,501+ lbs.) trucks.

2. Rural/Intracity Trucks

Rural/Intracity trucks are primarily composed of trucks that carry cargo, freight, and delivery collection in the class 3-8 weight class, including many box trucks as shown in the photo at the right. These vehicles have relatively low average VMT (35,000 miles per year) and average speeds. In addition, their drive cycle is marked by significant amounts of start and stop activity. These vehicles account for significant percentages of NOx (11 percent), CO_2 (11 percent), and diesel PM 2.5 (24 percent) from all heavy-duty trucks.

3. Urban Trucks

The urban truck category is composed of similar vehicles as the rural/intracity category, but they primarily operate in a more urban environment (i.e., at lower speed and with shorter trips). These vehicles have low average VMT (25,000 miles annually, which is less than half of the VMT for short haul/regional trucks, and less than a third of the VMT for OTR trucks) and low average speeds. In addition, their drive cycle is marked by significant amounts of start and stop activity. On an emissions basis, these vehicles contribute a small percentage of NOx (4 percent), CO_2 (4 percent), and diesel PM 2.5 (1 percent) to the statewide emissions inventory from all heavy-duty (8,501+ lbs.) trucks.

4. Work Site Support Trucks

Work site support trucks are primarily utility type vehicles in the weight class of 3-8 that support utility and construction type applications. These vehicles have low average VMT (13,000 miles per year, which is just over half the annual VMT of urban trucks) and low average speed. Work site support trucks typically spend a significant amount of time at idle and in power take-off mode. These vehicles are the smallest category in terms of total population. Work site support trucks account for 12 percent of NOx, 19 percent of diesel PM 2.5, and 9 percent of CO_2 emissions from all heavy-duty trucks.

5. Over-the-Road Trucks

OTR trucks are class 7-8 tractor-trailer trucks that primarily transport cargo long distances and thus have the highest annual VMT of any CalHEAT category, on average about 85,000 miles/year. These vehicles spend most of their time at highway speeds and tend to be newer vehicles. After the first few years of operation, these trucks typically change vocations; they change from OTR trucks to short haul/regional trucks. OTR trucks comprise about 10 percent of the population but nearly 50 percent of the VMT attributed to heavy-duty vehicles. As a result, the emissions contribution from OTR trucks is significant, accounting for 42 percent of CO_2, 34 percent of diesel PM 2.5, and 38 percent of NOx emissions from all heavy-duty trucks statewide.

Due to their emissions contribution, OTR trucks are the most important truck category to control. As discussed in further detail in the other Truck Technical Assessment reports; due to their long routes without much idling or starting and stopping, and without frequent returns to a central base, they are the most challenging truck application for adopting alternative fuels and advanced technologies such as natural gas and battery electric systems.

6. Short Haul/Regional Trucks

Short haul/regional trucks are composed of class 7-8 tractor-trailers that transport cargo typically from city to city. These trucks are usually classified as drayage trucks, day cabs, former long-haul trucks that are used in regional routes, and other Class 7 and 8 trucks with smaller engines. Short haul/regional trucks have lower VMT (~55,000 miles per year) than OTR trucks but higher VMT than other CalHEAT categories, and experience a mix of highway and urban driving. These trucks are responsible for 4 percent of statewide CO_2, diesel PM 2.5, and NOx emissions from all heavy-duty (8,501+ lbs.) trucks.

7. Buses

Buses are comprised of transit, motor homes, motor coaches, and school buses that transport individuals in urban and regional operation. Depending on their transport routes, annual VMT can vary around 20,000 miles. These vehicles represent a significant source of emissions, accounting for 9 percent of CO_2, 10 percent of diesel PM 2.5, and 11 percent of NOx from all heavy-duty trucks.

D. <u>Drive Cycles for Heavy-Duty Truck Types</u>

Drive Cycle Characterization using NREL Fleet DNA

1. NREL Fleet DNA Database

NREL's mission is to encourage advanced vehicle development and support development of technologies that reduce fuel consumption and emissions. Within this role, NREL maintains a database created by NREL and Oak Ridge National Laboratory that contains medium- and heavy-duty commercial fleet transportation data. Although the database has only recently been developed (since 2008), it contains data from thousands of trucks and gives a glimpse at the daily life and drive cycle of these vehicles.

2. Truck Types

NREL has identified 8 truck categories: Delivery Vans, Delivery Trucks, School Buses, Transit Buses, Bucket Trucks, Service Vans, Tractors, and Refuse Trucks. Table V-2 shows how these categories compare to the CalHEAT categories.

Table V- 2: Fleet DNA Categories equivalence to CalHEAT plus Bus Categorization

Fleet DNA Category	CalHEAT Category
Delivery Vans	Class 3-8 Work-Urban, Class 3-8 Work-Rural/Intracity
Delivery Trucks	Class 3-8 Work-Urban, Class 3-8 Work-Rural/Intracity
School Buses	Buses
Transit Buses	Buses
Bucket Trucks	Class 3-8 Work-Work Site
Service Vans	Class 3-8 Work-Work Site
Tractors	Class 7-8 Over the Road, Class 7-8 Short Haul/Regional
Refuse Trucks	Class 3-8 Work-Urban, Class 3-8 Work-Rural/Intracity

3. NREL Fleet DNA Truck Categories and Drive Cycles

Table V-3 includes a breakdown of each of the truck categories maintained by NREL in the Fleet DNA database and the magnitude of data in the database for each category. The duty cycle data in the Fleet DNA database supports the observations about drive cycles made by CalHEAT in reference to their categories of heavy-duty trucks (see Table V-4). Appendix II contains charts produced by NREL further summarizing the drive cycle data in the database.

Table V- 3: Fleet DNA Categories and Description of Data Sets as of February 2016

Fleet DNA Category	Weight Class	Number of Trucks Logged	Number of Days Logged
Delivery Vans	Class 3-6	94	974
Delivery Trucks	Class 8	36	553
School Buses	Class 6	204	857
Transit Buses	Class 7 and 8	19	472
Bucket Trucks	Class 3 and 7	20	283
Service Vans	Class 2 and 3	4	29
Tractors	Class 7 and 8	70	1150
Refuse Trucks	Class 8	39	387

As shown in Table V-4, tractors (which would fall in the CalHEAT category of Class 7-8 Short Haul/Regional Trucks and Class 7-8 Over-the-Road Trucks) were recorded to have the highest average driving speed (32 miles per hour (mph)) as they were used to deliver goods over long distances, which typically requires travelling on freeway and at high speed for the majority of their operating time (48 percent of total distance traveled at speed of 50 mph or greater); as a result, tractors also had the least acceleration events per mile (6.1) and the least number of stops per mile (1.1). Due to their frequent stops and urban driving environment, transit buses, delivery trucks and refuse trucks also had the lowest average driving speed (about 20 mph). Delivery trucks and refuse trucks are categorized in the CalHEAT scheme as Class 3-8 work-urban, which have drive cycles with significant amounts of start and stop activity. This drive cycle behavior is also reflected in the collected data. As shown, these trucks had the highest number of acceleration events and stops per mile (11.9 and 5.6, respectively). School buses are typically used to transport students locally, thus travelling at low speed on most part of their routes. As shown, school buses spent only 8 percent of their total distance at speed of 50 mph or greater. Bucket trucks spent almost 60 percent of their operation time at idle, which is consistent with what one would expect for a typical work site support truck. (NREL, 2014)

Table V- 4: Fleet DNA Categories and Drive Cycle Information

Fleet DNA Category	Max Speed (mph)	Average Driving Speed[8] (mph)	Median Speed (mph)	Average Daily Distance Traveled (miles)	Idle Time (%)	% of Total Distance Traveled at 50 mph+	Acceleration Events per mile	Number of Stops per mile
Delivery Vans	80	24	21	57	51	27	9.2	2.8
Delivery Trucks	58	20	14	73	53	18	11.9	5.6
School Buses	79	24	23	61	24	8	6.6	1.4
Transit Buses	74	21	20	108	45	13	8.0	2.0
Bucket Trucks	75	26	26	27	59	16	6.4	1.5
Service Vans	78	26	26	33	43	11	6.4	1.8
Tractors	76	32	34	96	44	48	6.1	1.1
Refuse Trucks	58	19	15	73	53	18	11.9	5.6

[8] No idling time included

VI. HEAVY-DUTY TRUCK FUEL SOURCES AND FLEET CHARACTERISTICS

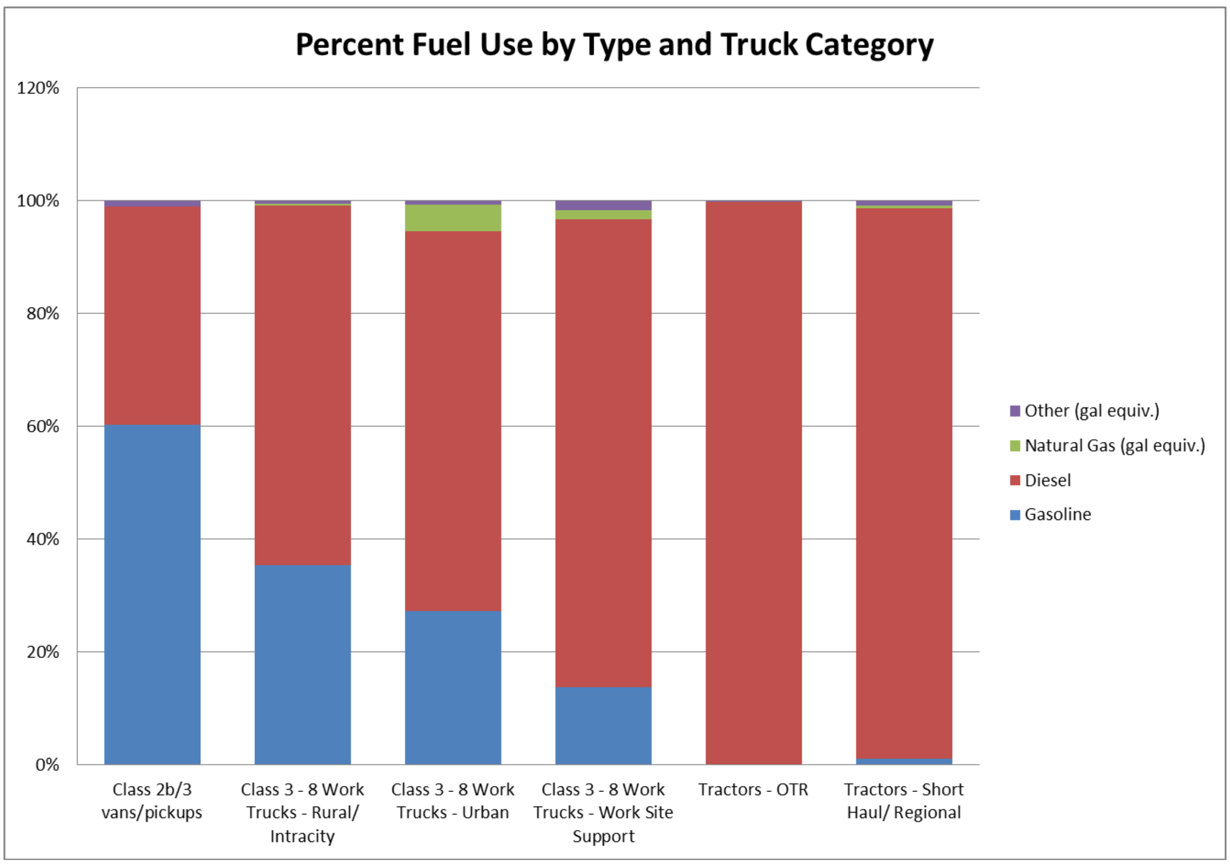
This chapter presents information on how heavy-duty trucks are fueled and characteristics of truck fleets. Specifically, Section A discusses fuel sources, Section B discusses fleet age and truck lifetime, and Section C discusses trailer age.

A. Heavy-Duty Trucks Fuel Source

1. Conventional Fuels

Conventional fuels such as gasoline and diesel are the dominant fuel choice for nearly all heavy-duty trucks today. The use of fuel is highly dependent on the application and weight class of the truck. Diesel fuel predominates in trucks of heavier weight classes, and gasoline is the fuel of choice for lighter trucks (See Figure VI-1).

Figure VI- 1: California Truck Inventory and Impact Study



(CalHEAT, 2011)

2. Alternative Fuels

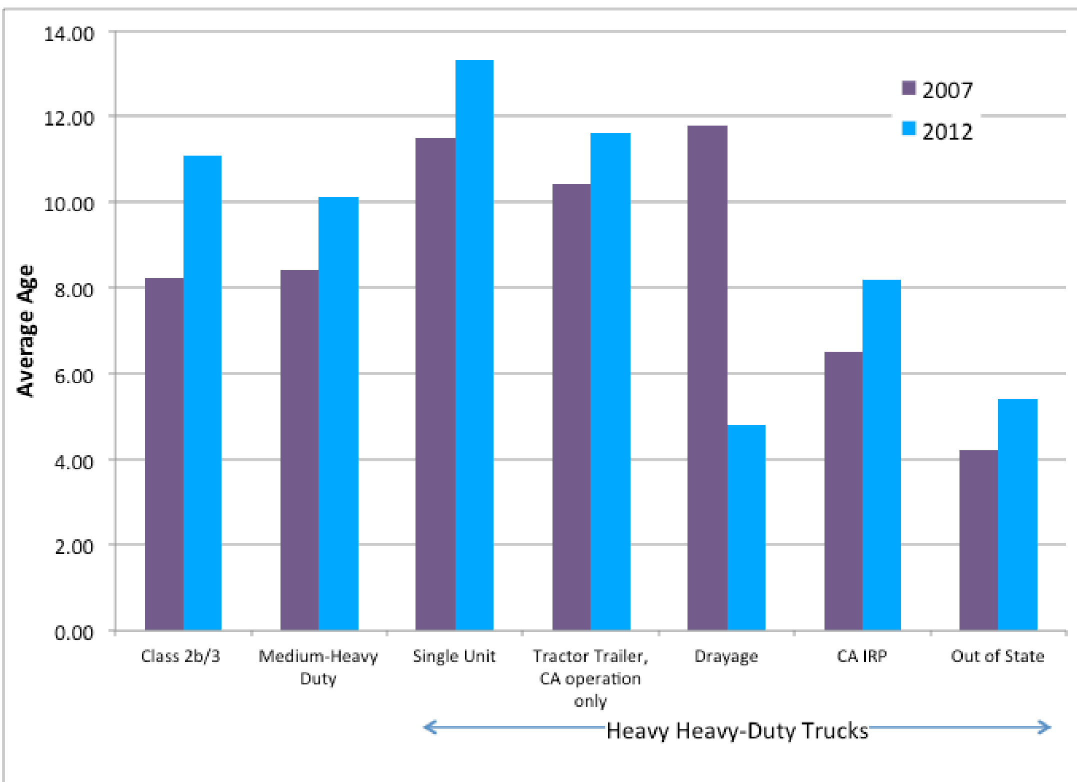
Currently, heavy-duty trucks are predominately fueled by conventional fuels, but significant progress has been made in the development of alternative fuels. Hybrids and battery electric technology have been demonstrated and are in the early commercial stage for a variety of vocations including drayage, waste, and bus applications. Fuel cell technology is also currently being developed and demonstrated in several applications. The development and broad application of these technologies are important to achieve critical reductions in emissions and attainment of California's air quality standards.

B. <u>Characterization of California's Heavy-Duty Truck Fleet in terms of Age and Life</u>

Heavy-duty trucks operate for relatively long periods of time, commonly for 20 or more years. In addition, it is not uncommon for these vehicles to accumulate over a million miles. Furthermore, trucks often have multiple lifetimes. For example, Class 8 long-haul trucks are often used for the first years of life accumulating significant VMT from long-haul applications and later in life used for regional transport (CalHEAT, 2011). Larger fleets (fleets with 51or more trucks) tend to have younger trucks, and smaller fleets (fleets with less than 6 trucks) tend to have older trucks (ICCT, 2009).

Figure VI-2 presents the average age of heavy-duty California trucks in various categories, for calendar year 2007 and 2012.

Figure VI- 2: Average Age by Truck Classification for California Heavy-Duty Trucks (GVWR 8,501+ lbs.) in calendar year 2007 and 2012



*Medium Heavy-Duty (GVWR 19,501-26,000 lbs.) and Heavy Heavy-Duty Trucks (33,000+ lbs.). DMV registration data are only available up to 2012.

Tractor-Trailers operating only in California more closely fit into the CalHEAT Short Haul/Regional category and, consistent with this category, tend to be slightly older than long-haul trucks (i.e., international registration plan (IRP) and Out of State trucks) with an average age of 10 to 12 years old. As expected, out-of-state trucks, which operate in long-haul applications, best fit into the CalHEAT OTR category, which is a younger truck with an average age of 4 to 5 years old. Medium Heavy-Duty and Single Unit truck categories best fit into the CalHEAT categories of Urban, Rural/Intracity, and Work Site Support. These categories of trucks tend to be older on average with an age of 8 to12 years.

Drayage trucks are classified as on-road diesel-fueled heavy-duty class 7 or class 8 vehicles (GVWR of 26,000 lbs. or greater) transporting cargo to or coming from California's ports and intermodal rail yards. This category correlates with the CalHEAT Class 7-8 Short Haul/Regional truck category. In 2007, the average age of drayage trucks was nearly 12 years old. By 2012, due to the implementation of the drayage rule, the category's average age dropped to under 5 years old.

C. Trailer Age

Unlike heavy-duty truck tractors, companies often use multiple trailers with a single tractor and, as a result, accumulate significantly less miles per trailer than per tractor. Thus, trailers acquire less miles than tractors and, as a result, operate longer than heavy-duty trucks. Trailers have an effective life of 30 or more years with an annual turnover rate of trailers half that of heavy-duty tractors (ICCT, 2013).

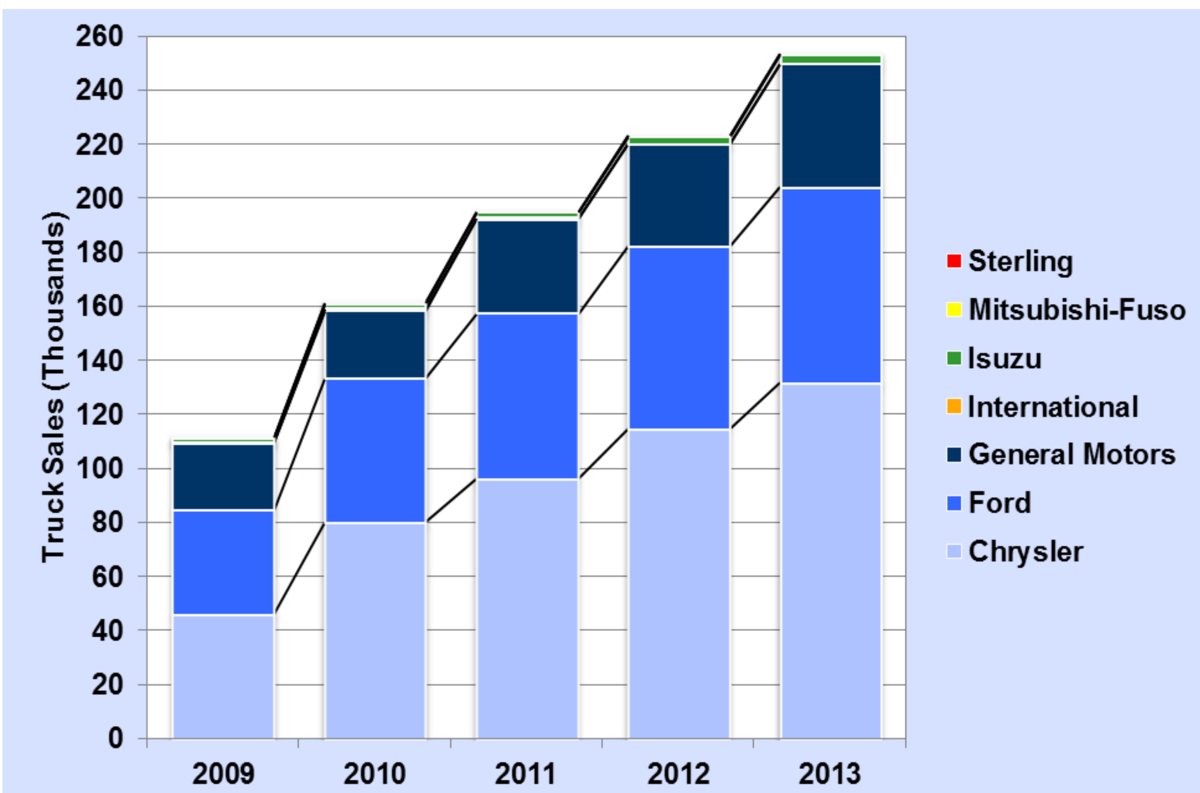
VII. HEAVY-DUTY TRUCK MANUFACTURING AND SALES

Heavy-duty trucks can be manufactured by one vertically integrated manufacturer (i.e., the manufacturer that produces the engine, chassis, and body) or assembled from elements manufactured by a variety of suppliers. The typical manufacturing structure varies by type and use and is summarized below for each class of heavy-duty truck. Section A presents manufacturing and sales information for Class 3 vehicles. Section B presents manufacturing and sales information for Class 4-8 vocational trucks. Section C presents manufacturing and sales information for Class 7-8 tractor trucks. Section D presents manufacturing and sales information for Class 7-8 trailers.

A. Class 3

Class 3 heavy-duty trucks and vans are mostly manufactured by manufacturers of the entire vehicle in a vertically integrated process. This market is dominated by many of the same manufacturers of lighter duty trucks and vans including Chrysler, Ford, and General Motors. The following chart shows the market share and leading manufacturers of Class 3 vehicles from 2009 through 2013. In California, new trucks operating in California are nearly all purchased in state (based on analysis of California DMV registration data for 2012).

Figure VII- 1: Class 3 Manufacturers by Nationwide Truck Sales Volume



(ORNL, 2014)

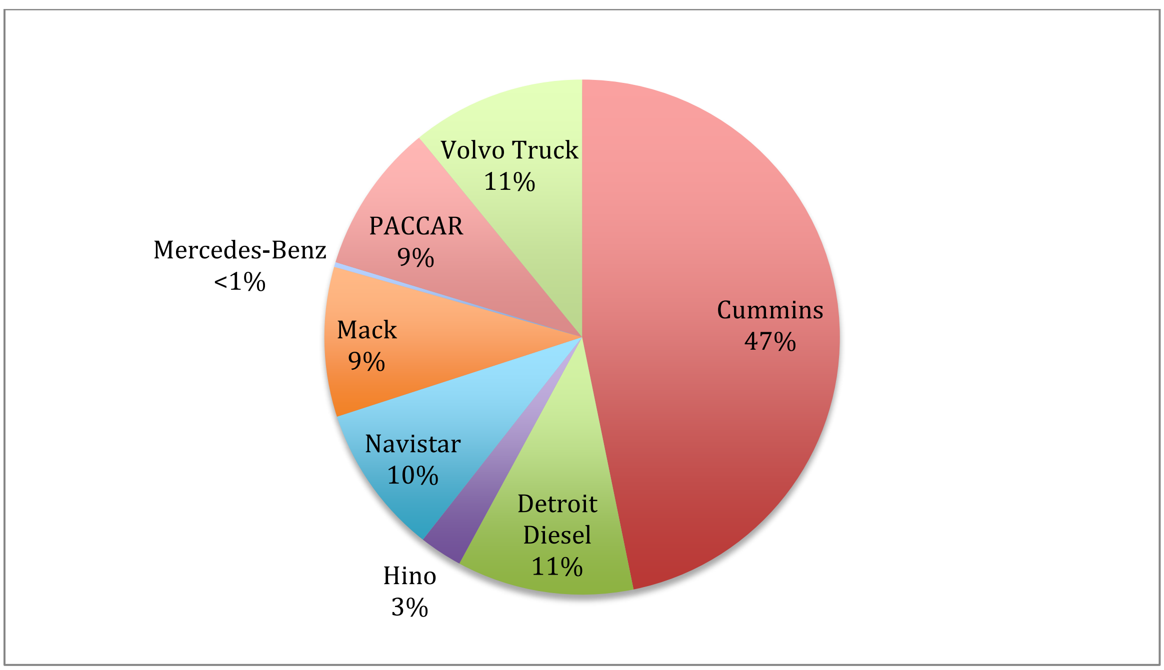
B. Class 4-8 Vocational Trucks

Class 4-8 trucks mainly function in vocational applications from urban delivery, work-site trucks, to numerous other fields. Unlike Class 3 vehicles, the majority of these trucks are manufactured in segments and not manufactured in a vertically integrated process. Although the majority of Class 4-8 vocational trucks are manufactured via non-vertically integrated manufacturing, several manufacturers such as Hino, Navistar, Ford, and GM produce the powertrain and chassis in a vertically integrated process. The major elements of these vehicles are the chassis, powertrain, and body. These elements are manufactured by a variety of companies and assembled based on the specifications of the end user.

Powertrain Manufacturing

The powertrain consists of the engine and transmission. The powertrain can be manufactured by one company or assembled from parts made by different manufacturers. Two of the major manufacturers of the transmission element of the powertrain for vocational vehicles are Allison and Eaton transmissions. Heavy-duty engine manufacturing is dominated by a variety of makers, with Cummins, the top manufacturer, responsible for nearly half the market. Figure VII-2 below depicts the leading manufacturers for class 4-8 engines.

Figure VII- 2: Class 4-8 Engine Manufacturers by Nationwide Market Share in 2013

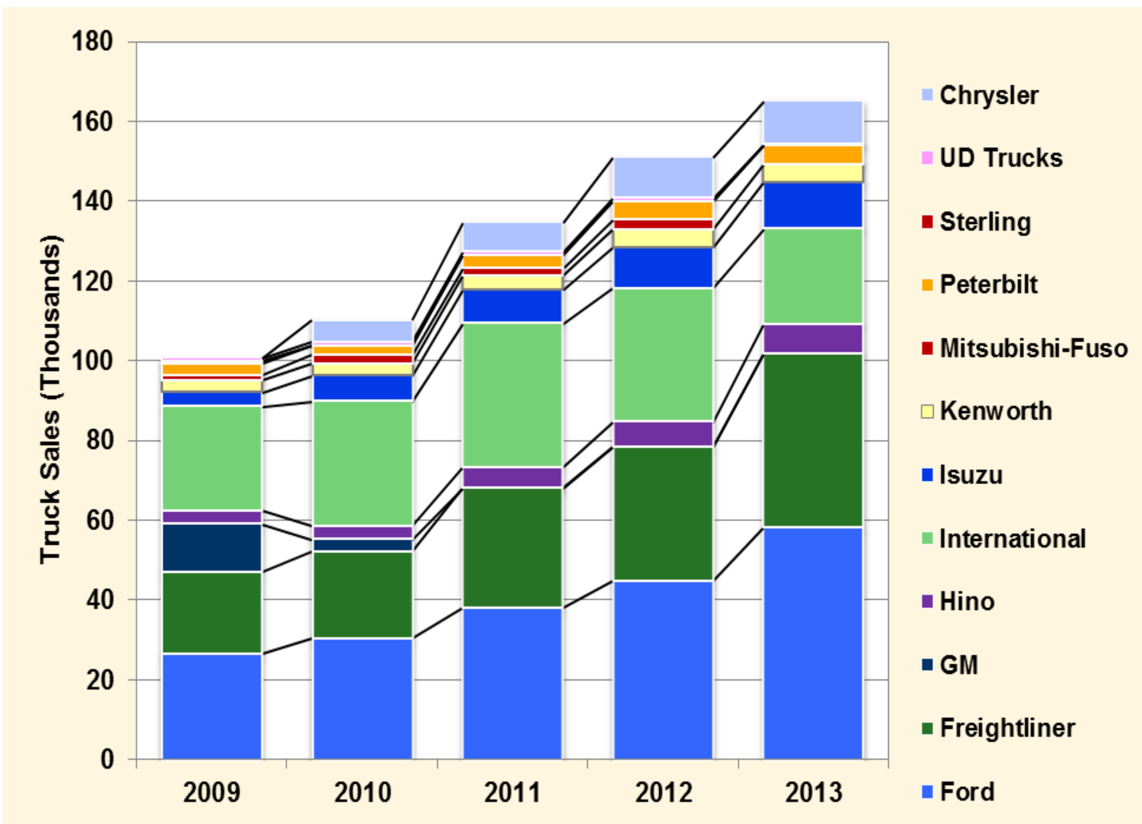


(ORNL, 2014)

Chassis Manufacturing

The truck chassis includes the powertrain and the driving frame (i.e., suspension and axles), but not the actual body of the truck. The chassis or truck manufacturers can either assemble elements from different manufacturers or manufacture these pieces completely within their own facilities. Figure VII-3 shows the major truck manufacturers for Class 4-7 vehicles. The top manufacturers are Ford, Freightliner, and International. In California, nearly all new Class 4-7 vehicles operating within the state are purchased within the state. Approximately 10,600 new Class 4-7 trucks were sold in California in 2012, representing about 13 percent of nationwide Class 4-7 sales (based on analysis of California DMV registration data and Wards Auto Sales Data for 2012).

Figure VII- 3: National Class 4-7 Truck Manufacturers by Nationwide Market Share 2009-2013



(ORNL, 2014)

Vocational Truck Body Manufacturing

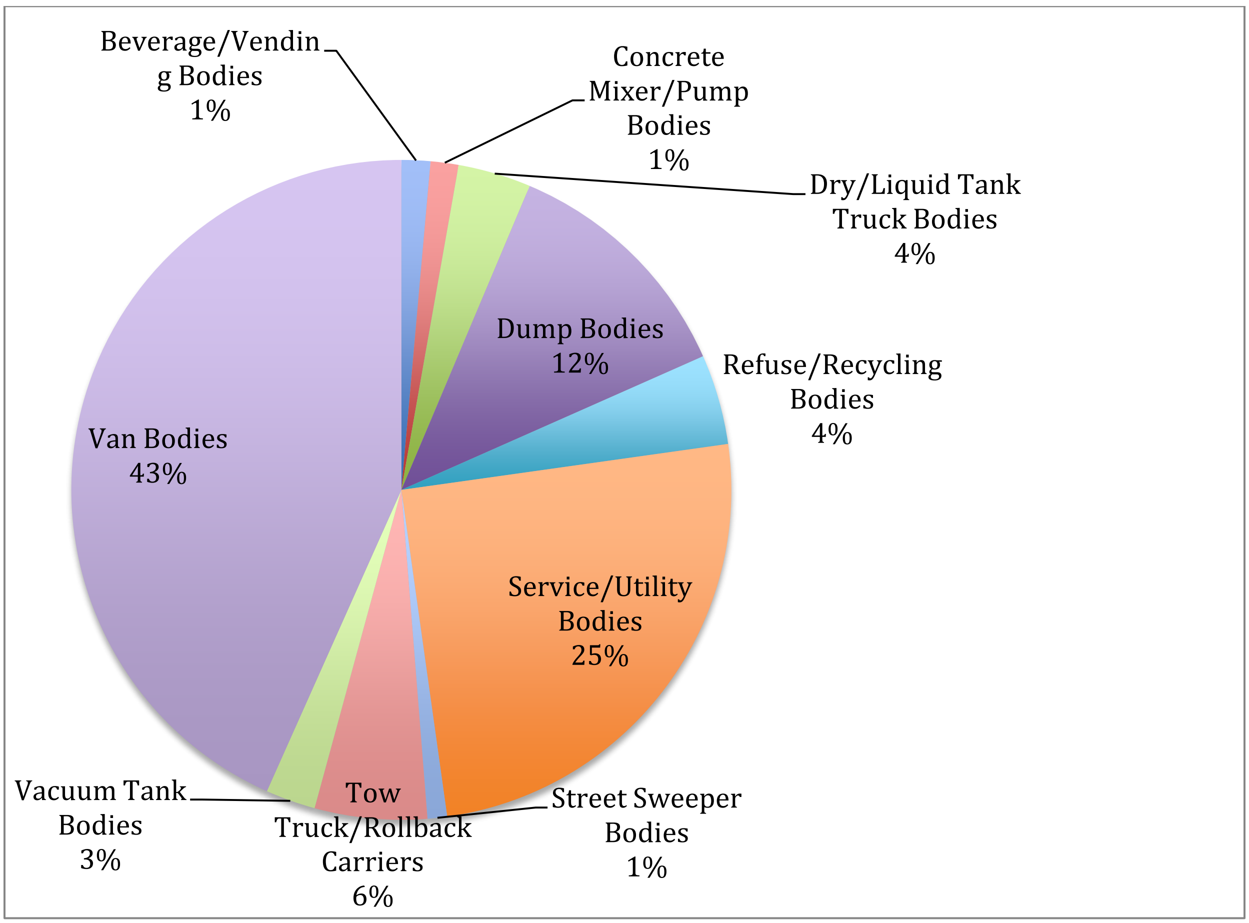
The vocational truck body is manufactured using a class 3-8 truck chassis and a custom built body that is specific to a customer's request and needs. Thus, the number and types of vocational bodies are varied and numerous. Truck Body Manufacturing in North America by Specialty Transportation is a market research study looking at vocational truck body manufacturing. The study classifies the wide range of vocational truck body types into 10 specific categories: Beverage and Vending, Concrete Mixers and Pumps, Dry and Liquid Tank, Dump, Refuse and Recycling, Service and Utility, Street Sweepers, Tow Trucks and Rollback Carriers, Vacuum Tank, and Van type trucks. Van bodies (like the one shown in Figure VII-4), which are mainly used to deliver cargo, are the predominant body type. As shown in Figure VII-7, service/utility bodies (like the one shown in Figure VII-5) and dump bodies (like the one shown in Figure VII-6) are the next two most numerous body types (ST, 2012).

Figure VII- 4: Example of a Van Body

Figure VII- 5: Example of a Utility Body

Figure VII- 6: Example of a Dump Body

Figure VII- 7: Truck Body Type by Market Share 2011



(ST, 2012)

There are over 280 individual manufacturers engaged in the production of truck bodies in North America. The industry is highly disjointed with small manufacturers competing with large national manufacturers. Truck Body Manufacturing in North America by Specialty Transportation reports that 84 percent of all manufacturers produce less than 1000 units annually, with 74 percent manufacturing less than 500 units annually (ST, 2012). The leading manufacturers in the industry mainly produce van bodies, the most common body type.

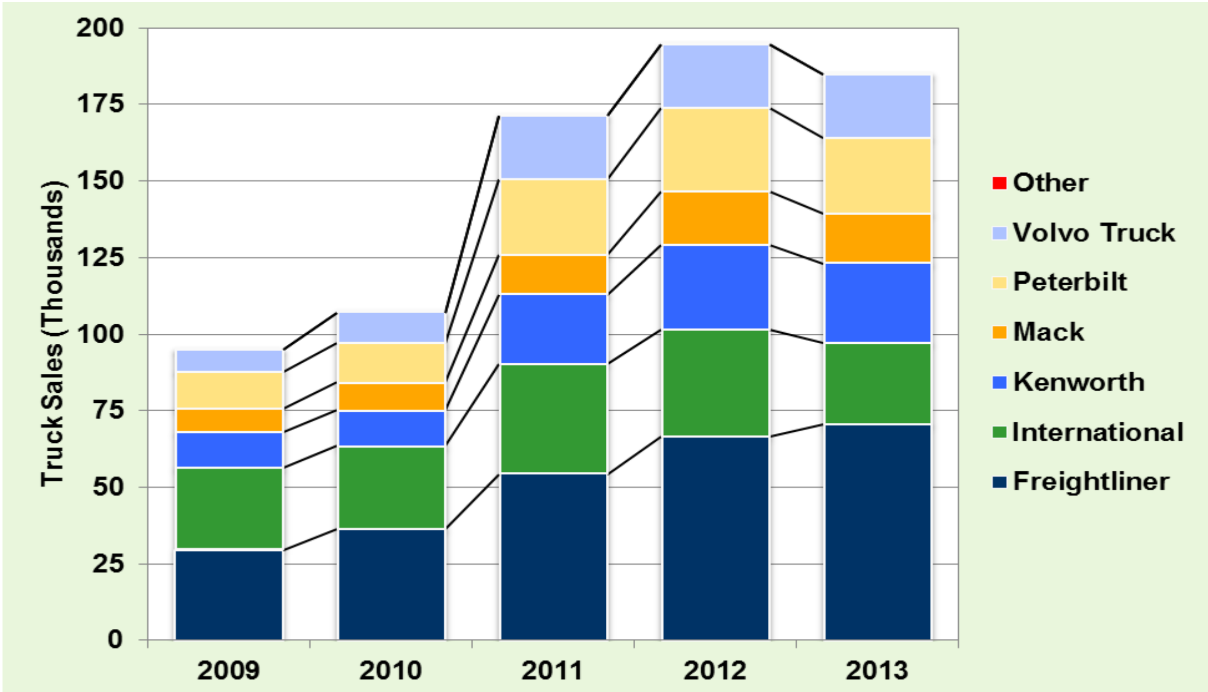
C. Class 7-8 Tractor Trucks

Class 7-8 tractor truck manufacturing, like class 4-8 vocational truck manufacturing, is currently conducted in a fragmented fashion with different manufacturers producing different elements of the truck including the engine, powertrain, transmission, etc..

In 2013, five manufacturers - Daimler Trucks (Freightliner), Kenworth, Peterbilt, Navistar (International), and Volvo Trucks produced over 90 percent of the newly manufactured class 8 vehicles sold (see Figure VII-8). Of the total Class 8 new vehicle sales listed in Figure VII-8, only 5 to 7 percent occurred in California (based on analysis of California DMV registration data and Wards Auto Sales Data for 2012).

Class 7-8 tractor engine manufacturing is also dominated by a small group of manufacturers. As shown in Table VII-1, in 2013, Daimler Trucks, Volvo, Cummins, Navistar, Mack, and PACCAR manufactured more than 90 percent of Class 7-8 tractor engines.

Figure VII- 8: Nationwide Class 8 Truck Sales by Manufacturer 2009-2013



(ORNL, 2014)

Table VII- 1: Nationwide Diesel Engine Suppliers by Manufacturer in 2013

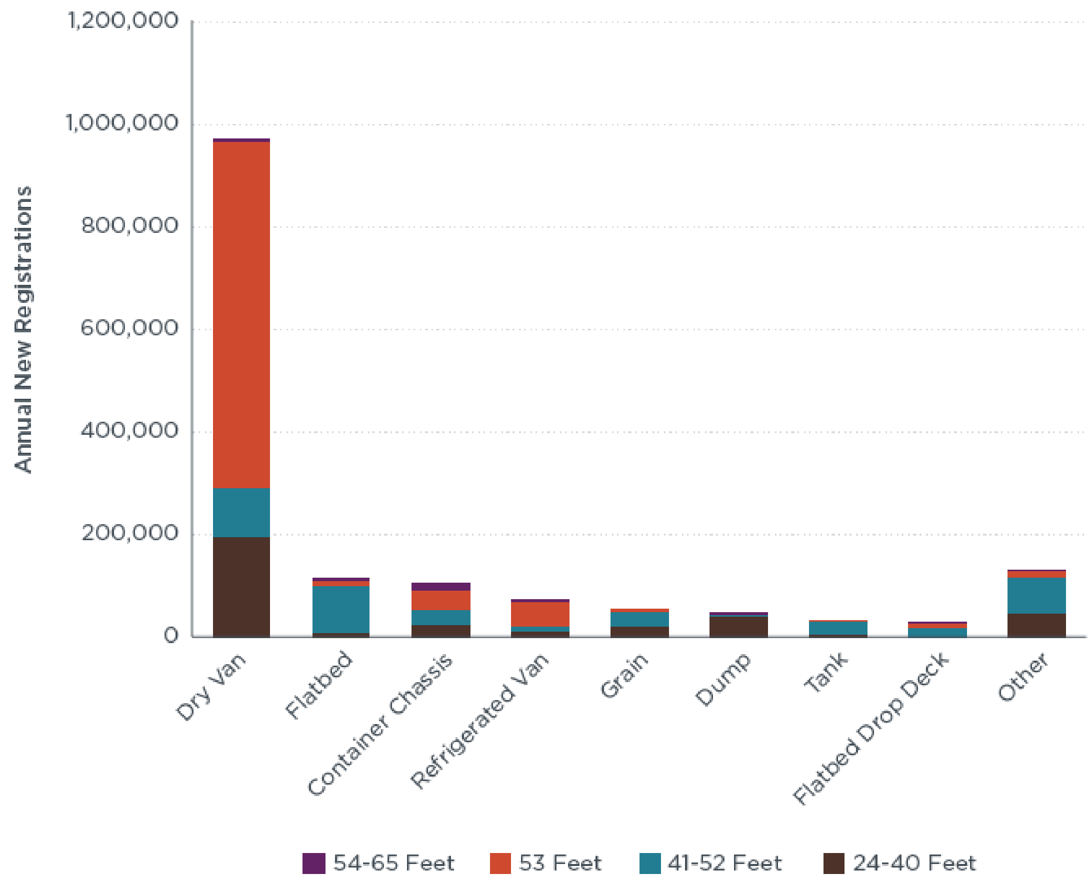
Make	Engine Manufacturer	Share
Freightliner	**Cummins**	**62.3%**
	Detroit Diesel	37.0%
	Mercedes Benz	0.7%
	Total	**100.0%**
Hino	Hino	100.00%
International	Cummins	7.2%
	Navistar	92.8%
	Total	**100.0%**
Kenworth	Cummins	66.0%
	PACCAR	34.0%
	Total	**100.0%**
Mack	Cummins	6.0%
	Mack	94.0%
	Total	**100.0%**
Peterbilt	Cummins	65.2%
	PACCAR	34.8%
	Total	**100.0%**
Volvo	Cummins	13.6%
	Volvo	86.4%
	Total	**100.0%**
Western Star	Cummins	21.2%
	Detroit Diesel	78.8%
	Total	**100.0%**
Other	Cummins	100.0%

(ORNL, 2014)

D. Class 7-8 Trailer

Class 7-8 trailers must support a variety of freight applications from dry freight to liquids and much more. In 2011, there were approximately 176,000 new trailer registrations in the nation (ICCT, 2013). Trailers are not purchased in a 1 to 1 ratio with tractors by trucking fleets; instead, typically multiple trailers are purchased per tractor. For the period of 2007-2012, the ratio of new trailer registrations to new tractor registration varied from 1.17 to 2.18 (ICCT, 2013). Industry estimates that there are 3 trailers per tractor operating in the market place. Similar to vocational class 4-8 truck bodies, trailers vary in uses and types; Figure VII-9 shows the major trailer types and number of new annual registrations for each type.

Figure VII- 9: Average Annual US New Commercial Trailer Registrations by Type and Size 2003-2011



(ICCT, 2013)

Dry vans dominate the new trailer registrations representing nearly 70 percent of new trailers. In the report Trailer Technologies for Increased Heavy-Duty Vehicle Efficiency by ICCT, the group observed that the dominance of dry vans results in two markets for trailers: dry vans and specialty trailers. The top 10 producers of trailers account for 78 percent of all new trailers manufactured with the top manufacturer, Wabash National, alone accounting for 20 percent of the market. Tale VII-2 below illustrates the major manufacturers and their market share.

Table VII- 2: Trailer Manufacturers by Market Share

Trailer Manufacturer	Average Annual New Registrations	Market Share	Main Products
Wabash National	23,303	20.2%	van, refrigerated van, flatbed, tank
Utility Trailer	20,615	17.9%	van, refrigerated van, flatbed
Great Dane	19,268	16.7%	van, container chassis, flatbed
Hyundai	7,153	6.2%	container chassis
Stoughton Trailers	4,621	4.0%	van
Timpte	4,141	3.6%	grain
CIMC USA	4,014	3.5%	container chassis, refrigerated van
Vanguard National	3,527	3.1%	van, container chassis
Wilson Trailer	1,563	1.4%	grain, flatbed, drop-deck flatbed
Transcraft Corporation	1,455	1.3%	flatbed, drop-deck flatbed
Remaining Manufacturers	17,553	22.1%	-

(ICCT, 2013)

VIII. REFERENCES

(ARB, 2008) California Air Resources Board, "Staff Report: Initial Statement of Reasons for Proposed Rulemaking – Proposed Regulation for In-Use On-Road Diesel Vehicles," October 2008.

(ARB, 2014a) California Air Resources Board California, "2014 Edition - Greenhouse Gas Inventory for 2000-2012," May 2014.

(ARB 2014b) California Air Resources Board, "Staff Report: Initial Statement of Reasons for Proposed Regulation for Proposed Amendments to the Truck and Bus Regulation," March 2014.

(ATA, 2015) American Trucking Association, Press Release: Truckload Turnover Remained High in Fourth Quarter, April 1, 2015, <http://www.trucking.org/article.aspx?uid=ee5468d9-0b00-4e01-9f9b-42d970b1510c>, accessed on October 2015.

(ATRI, 2014) W. Ford Torrey, IV and Dan Murray, "An Analysis of the Operational Costs of Trucking : 2014 Update," American Transportation Research Institute, September 2014.

(Business Insider, 2014) Mamta Badkar, "There's a Huge Shortage of Truck Drivers in America — Here's Why the Problem Is Only Getting Worse," *Business Insider*, August 4, 2014, <http://www.businessinsider.com/americas-truck-driver-shortage-2014-7>, accessed on May 2015.

(CalHEAT, 2011) Geoff Jennings and Tom Brotherton, "California Truck Inventory and Impact Study," CalHEAT: Truck Research Center, November 30, 2011.

(Cass, 2015a) Cass Information Systems Inc., "Cass Truckload Linehaul Index," October 2015, <http://www.cassinfo.com/Transportation-Expense-Management/Supply-Chain-Analysis/Transportation-Indexes/Truckload-Linehaul-Index.aspx>, accessed on December 2015.

(Cass, 2015b) Cass Information Systems Inc., "Cass Intermodal price Index," October 2015, <http://www.cassinfo.com/Transportation-Expense-Management/Supply-Chain-Analysis/Transportation-Indexes/Intermodal-Price-Index.aspx>, accessed on December 2015.

(ICCT, 2009) The International Council on Clean Transportation, "Heavy-Duty Market Analysis-Vehicles characteristics & Fuel Use Manufacture Market Shares," June 2009.

(ICCT, 2013) Ben Sharpe, Nigel Clark, and Dana Lowell, “Trailer technologies for increased Heavy-Duty Vehicles efficiency,” The International Council on Clean Transportation, July 3, 2013.

(NAS, 2010) The National Academies of Sciences, “Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles,” Washington, D.C., National Research Council, The National Academies Press, 2010.

(New York Times, 2014) Neil Erwin, “The Trucking Industry Needs More Drivers. Maybe It Needs to Pay More,” *The New York Times*, August 9, 2014.

(ORNL, 2000) Oak Ridge National Laboratory, Center for Transportation Analysis, Oak Ridge, TN. Weight category definitions from 49CFR565.6 (2000).

(ORNL, 2014) Oak Ridge National Laboratory, “Vehicle Technologies Market Report: Ward’s Automotive Group, Motor Vehicle Facts and Figures,” 2014.

(ST, 2012) SpecialtyTransportation.net, “Truck Body Manufacturing in North America,”<http://specialtytransportation.net/>.

(NREL, 2014) Walkowicz, K., Kelly, K., Duran, A., Burton, E., “Fleet DNA Project Data,” National Renewable Energy Laboratory, 2014.   <http://www.nrel.gov/fleetdna>.

(Wards Auto, 2009) Kilcarr S., “2008 Worst of Times for U.S. Trucking Industry,” *Wards Auto*, March 23, 2009, <http://wardsauto.com/news-amp-analysis/2008-worst-times-us-trucking-industry>, accessed on May 2015.

APPENDICES

APPENDIX I
EMFAC 2014 Heavy-Duty Truck Categories versus CalHEAT Categories

The following are a breakdown of EMFAC 2014 Heavy-duty Truck Categories into CalHEAT categories for the purposes of analyzing emissions.

Weight Classifications to EMFAC 2014

Federal Classification		EMFAC2014	
Class	GVWR	Class	GVWR
Class 2b	8,501 - 10,000	LHDT1	8,501 - 10,000
Class 3	10,001 - 14,000	LHDT2	10,001 - 14,000
Class 4	14,001 - 16,000	T6 Small	14,001 - 26,000
Class 5	16,001 - 19,500		
Class 6	19,501 - 26,000		
Class 7	26,001 - 33,000	T6 Heavy	26,001 - 33,000
Class 8	33,001 - above	T7	33,001 - above

CalHeat Categories to EMFAC Categories

CalHeat Category | EMFAC Category

Rural/Intracity	T6 INSTATE CONSTRUCTION SMALL
	T6 INSTATE CONCRTRUCTION HEAVY
	Urban
	T6 INSTATE SMALL
	T6TS

Pickup/Vans	LHD1
	LHD2

Urban	
	T7 PUBLIC
	T7 SWCV

OVER THE ROAD	T6 CAIRP SMALL
	T6 CAIRP HEAVY
	T6 OOS SMALL

	T6 INSTATE HEAVY
	T6 OOS SMALL
	T6 OOS HEAVY
	T7 CAIRP
	T7 CAIRP CONSTRUCTION
	T7 NNOOS
	T7NOOS
	T7 SINGLE
	T7 TRACTOR
	T7IS

WORK SITE SUPPORT	T6 UTILITY
	PTO
	T7 UTILITY

BUS	All Other Bus
	UBUS
	SBUS
	OBUS
	MH
	MOTOR COACH

SHORT HAUL/REGIONAL	T6 AG
	T7 AG
	T7 OTHER PORT
	T7 POAK
	T7 POLA
	T7 SINGLE CONSTRUCTION
	T7 TRACTOR CONSTRUCTION

Operating Days for Vehicle Classes:

LHD1	327
LHD1	327
LHD2	327
LHD2	327
MH	327

MH	327
Motor Coach	292
OBUS	327
PTO	312
SBUS	327
SBUS	327
T6 Ag	312
T6 Public	312
T6 CAIRP heavy	312
T6 CAIRP small	312
T6 OOS heavy	312
T6 OOS small	312
T6 instate construction heavy	312
T6 instate construction small	312
T6 instate heavy	312
T6 instate small	312
T6 utility	312
T6TS	327
T7 Ag	312
T7 CAIRP	312
T7 CAIRP construction	312
T7 NNOOS	312
T7 NOOS	312
T7 other port	312
T7 POAK	312
T7 POLA	312
T7 Public	312
T7 Single	312
T7 single construction	312
T7 SWCV	312
T7 tractor	312
T7 tractor construction	312
T7 utility	312
T7IS	327
UBUS	327
UBUS	327
All Other Buses	292

APPENDIX II

NREL Fleet DNA Data: Distribution of Daily Stops per Mile, Operating Distance, Maximum and Average Driving Speed for a Variety of Truck Types

The following are detailed charts created by NREL characterizing data from trucks in a variety of truck types.

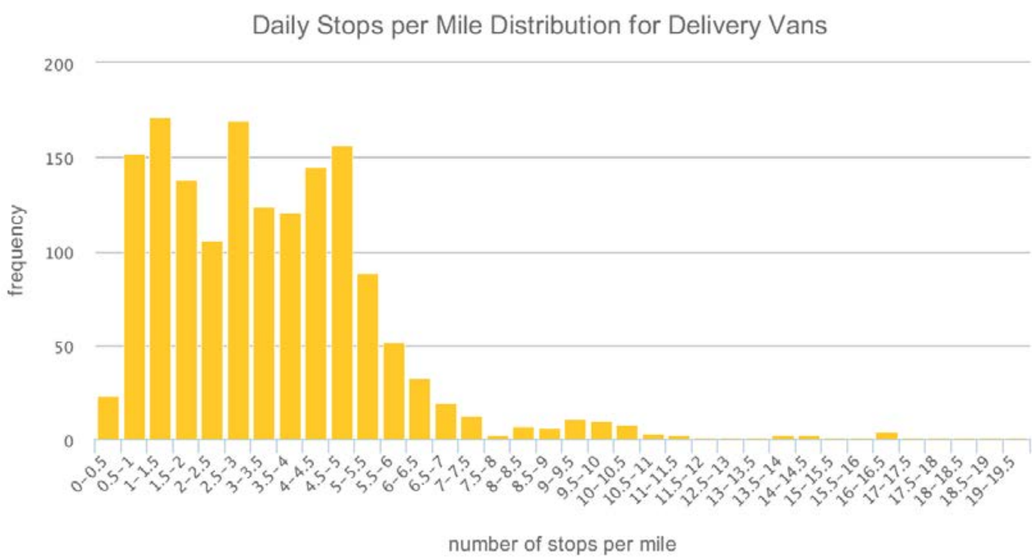
Summary Table

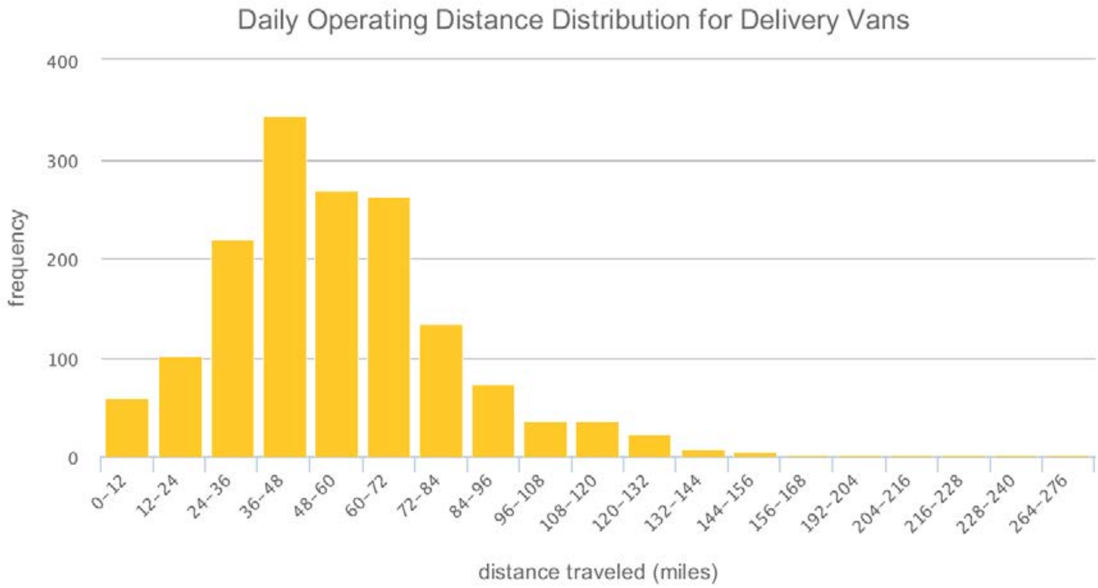
Type of Truck	Max Speed	Average Driving Speed (mph)	Median Speed (mph)	Idle Time	% of Distance Traveled above 50 mph	Average Distance Traveled (daily)	Acceleration events per mile	Stops per mile
Bucket Truck	74.63	26.09	26.75	58.82%	15.82%	26.86	6.42	1.48
Delivery Vans	80.67	23.57	20.92	50.94%	26.64%	57.02	9.2	2.84
Delivery Trucks	58.03	19.36	14.65	52.62%	72.78%	72.78	11.92	5.64
Tractors	76.75	32.28	33.85	43.73%	47.69%	96.08	6.08	1.07
School Buses	79.24	23.79	23.27	24.37%	8.10%	60.58	6.56	1.43
Transit Buses	73.65	20.89	19.86	44.88%	13.37%	108	7.99	2.04
Service Vans	77.58	25.98	26.56	42.99%	10.95%	32.8	6.38	1.79
Refuse Trucks	58.03	19.36	14.65	52.62%	18.32%	72.78	11.92	5.64

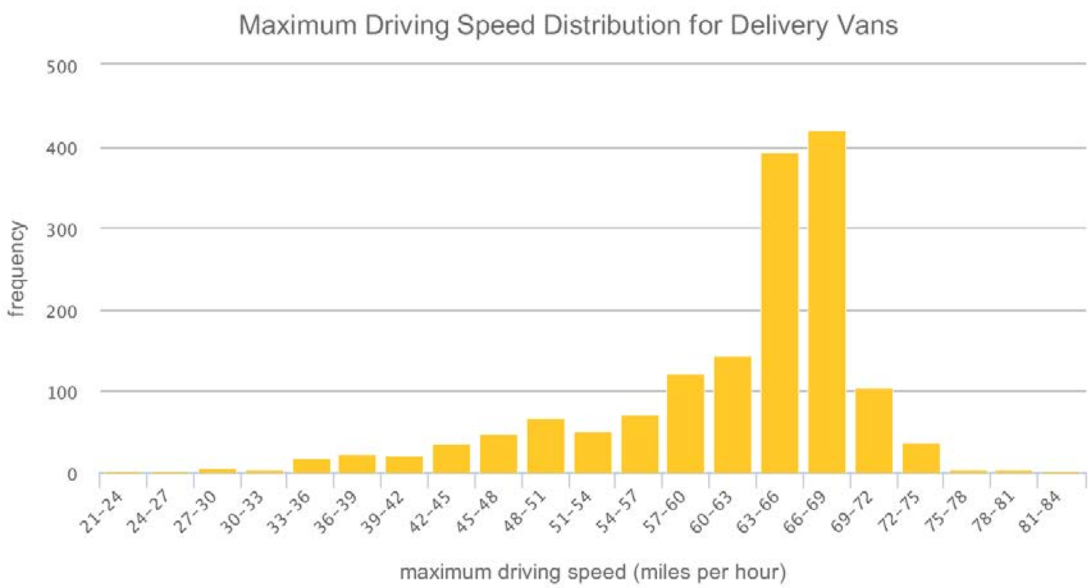
<u>Delivery Vans</u>

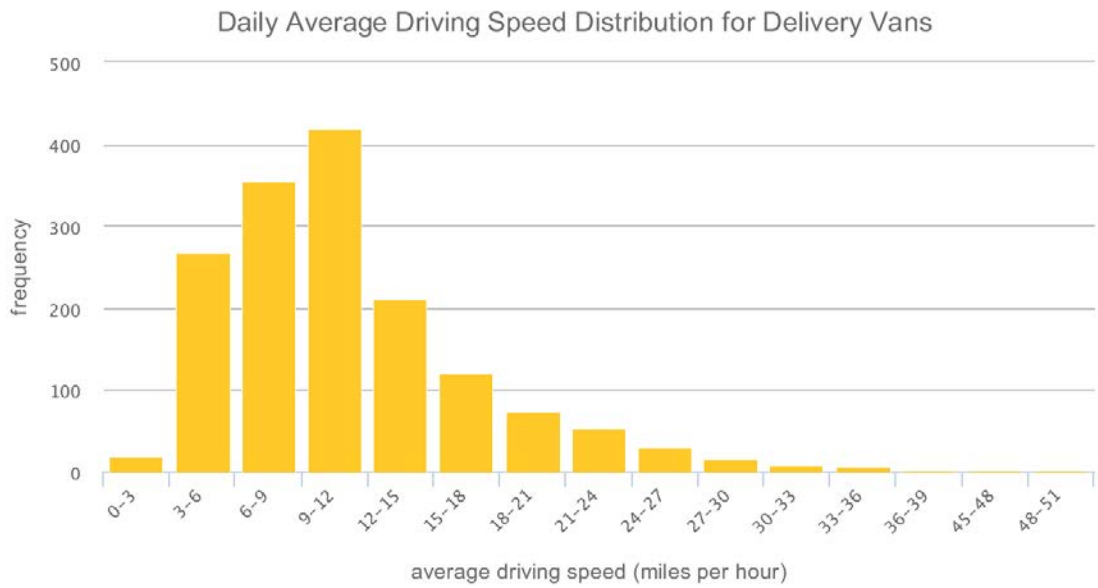
Source Data: Fleet DNA had 974 operating days from 94 delivery vans:

Graphs depicting Drive Cycle for Delivery Vans (NREL, 2014)




Daily Operating Distance Distribution for Delivery Vans
400
300
200
100
0
frequency
0-12
12-24
24-36
36-48
48-60
60-72
72-84
84-96
96-108
108-120
120-132
132-144
144-156
156-168
192-204
204-216
216-228
228-240
264-276
distance traveled (miles)

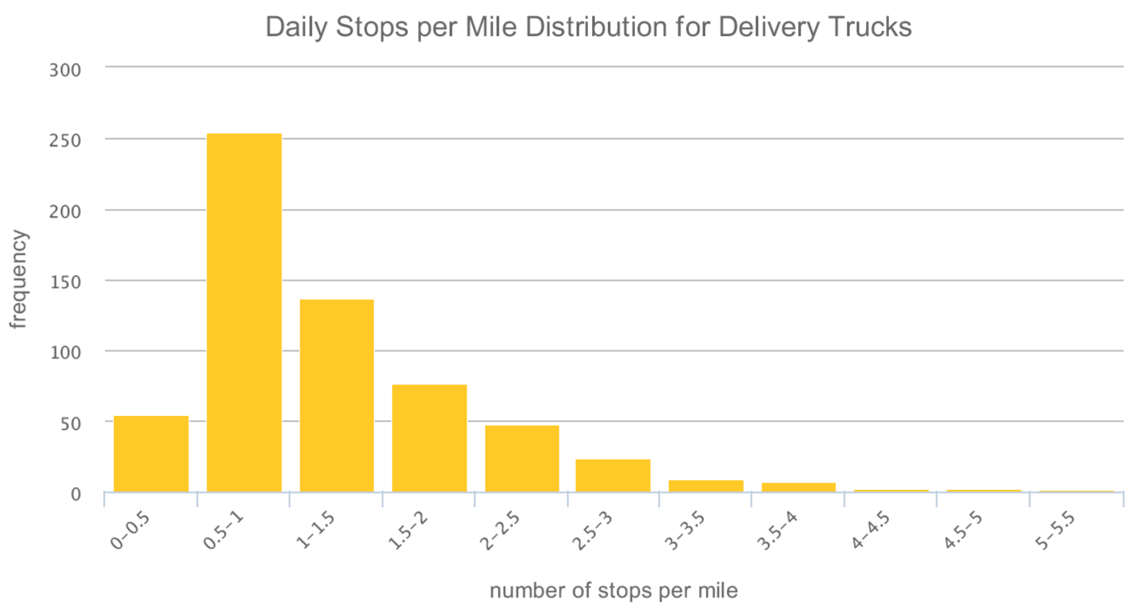

Maximum Driving Speed Distribution for Delivery Vans
500
400
300
200
100
0
frequency
21-24
24-27
27-30
30-33
33-36
36-39
39-42
42-45
45-48
48-51
51-54
54-57
57-60
60-63
63-66
66-69
69-72
72-75
75-78
78-81
81-84
maximum driving speed (miles per hour)

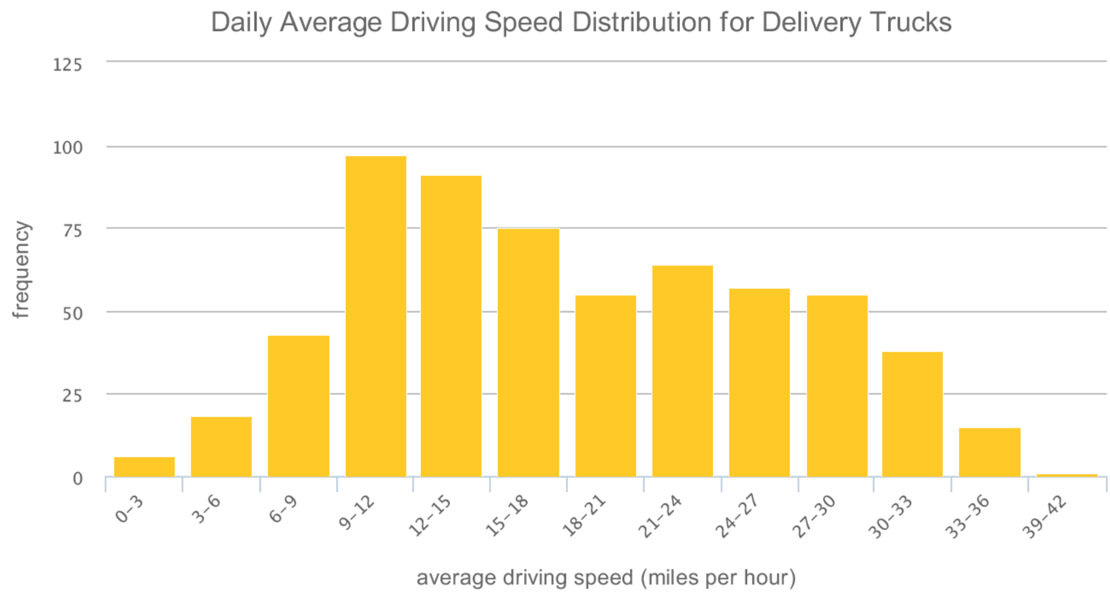


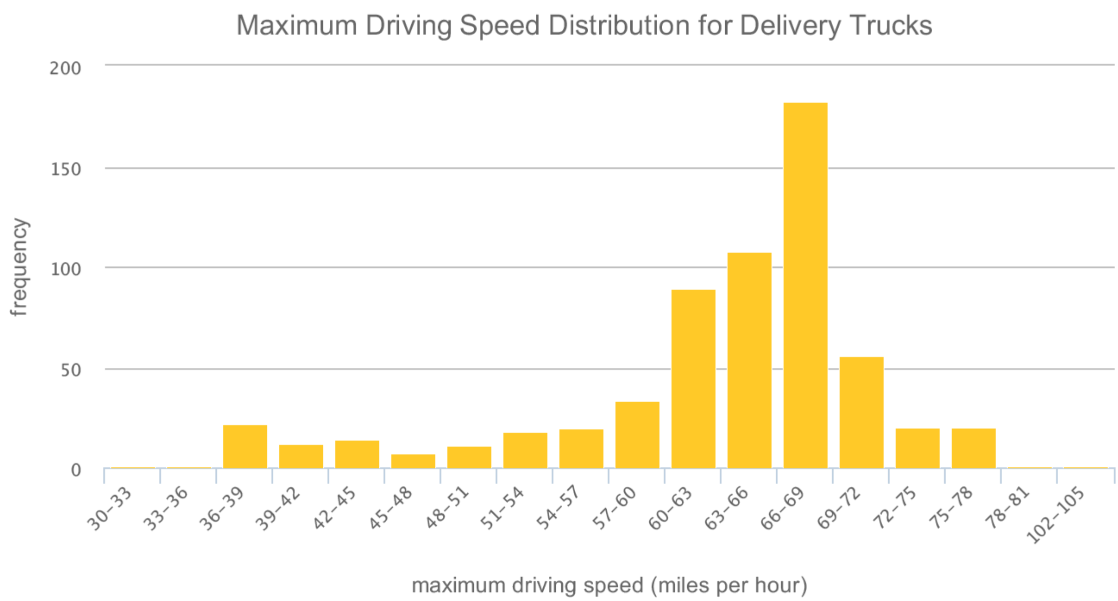
<u>Delivery Trucks</u>

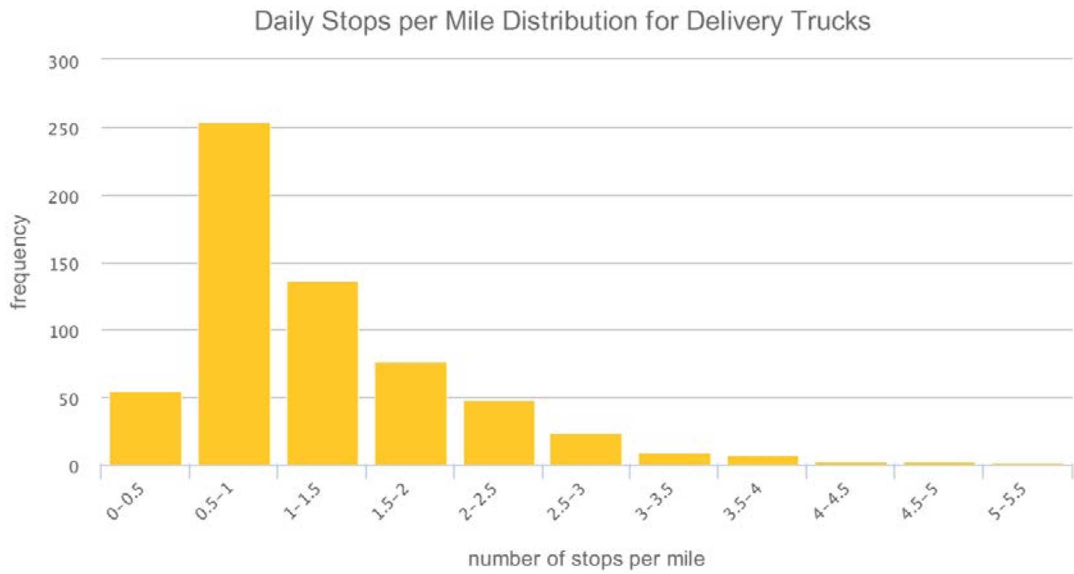
Source Data: Fleet DNA had 553 operating days from 36 delivery trucks

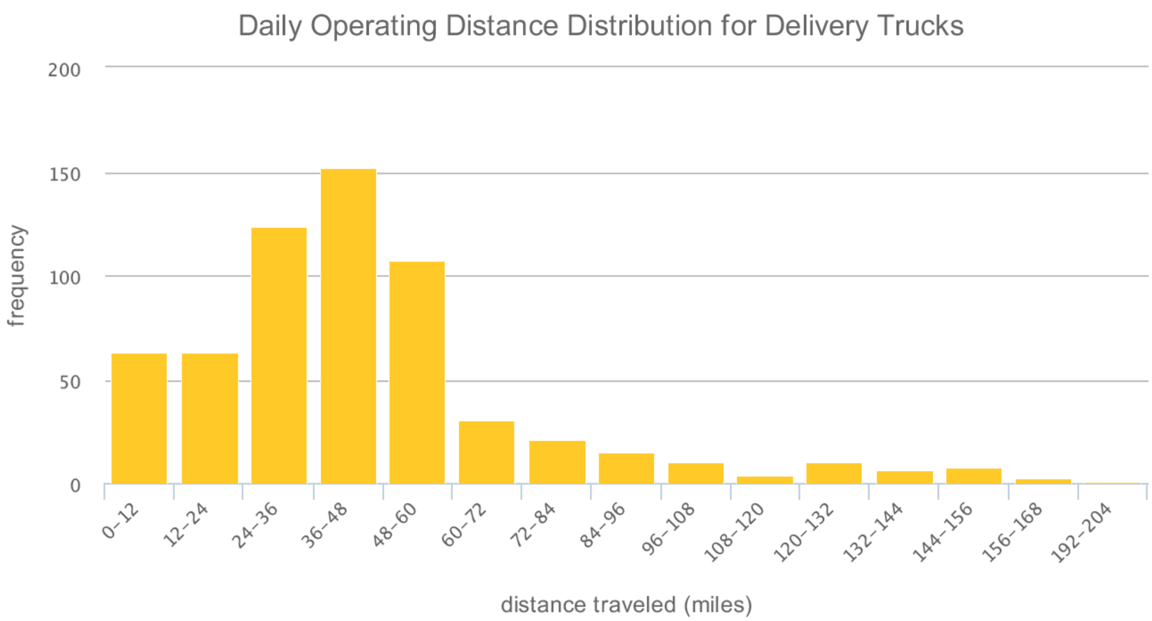
Graphs depicting Drive Cycle for Delivery Trucks (NREL, 2014)

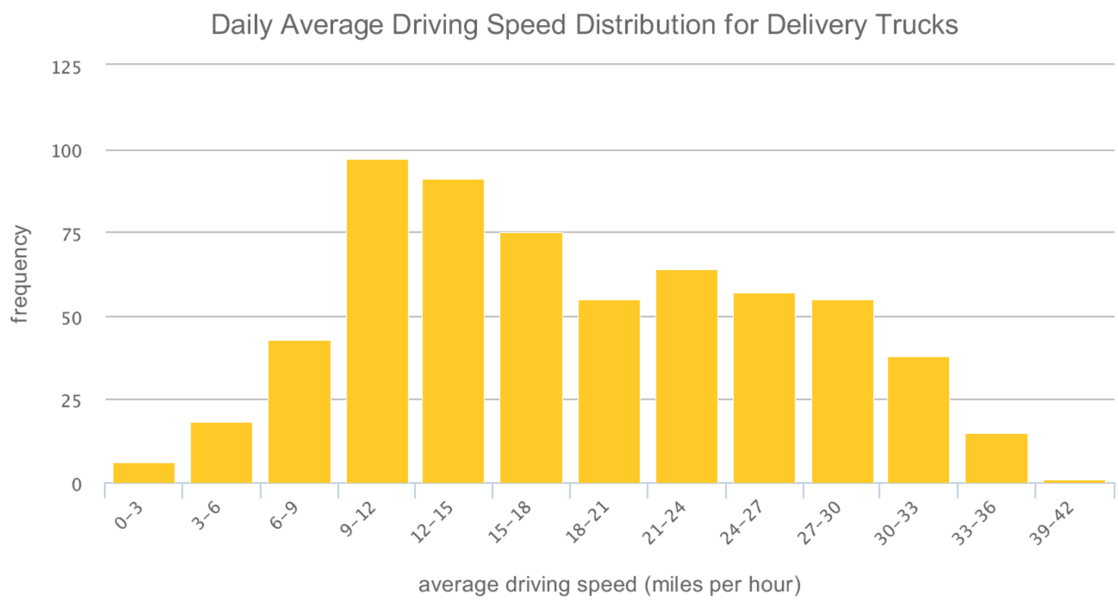



Daily Average Driving Speed Distribution for Delivery Trucks
125
100
75
50
25
0
frequency
0–3
3–6
6–9
9–12
12–15
15–18
18–21
21–24
24–27
27–30
30–33
33–36
39–42
average driving speed (miles per hour)


Maximum Driving Speed Distribution for Delivery Trucks
200
150
100
50
0
frequency
30–33
33–36
36–39
39–42
42–45
45–48
48–51
51–54
54–57
57–60
60–63
63–66
66–69
69–72
72–75
75–78
78–81
102–105
maximum driving speed (miles per hour)


Daily Stops per Mile Distribution for Delivery Trucks
300
250
200
150
100
50
0
frequency
0-0.5
0.5-1
1-1.5
1.5-2
2-2.5
2.5-3
3-3.5
3.5-4
4-4.5
4.5-5
5-5.5
number of stops per mile

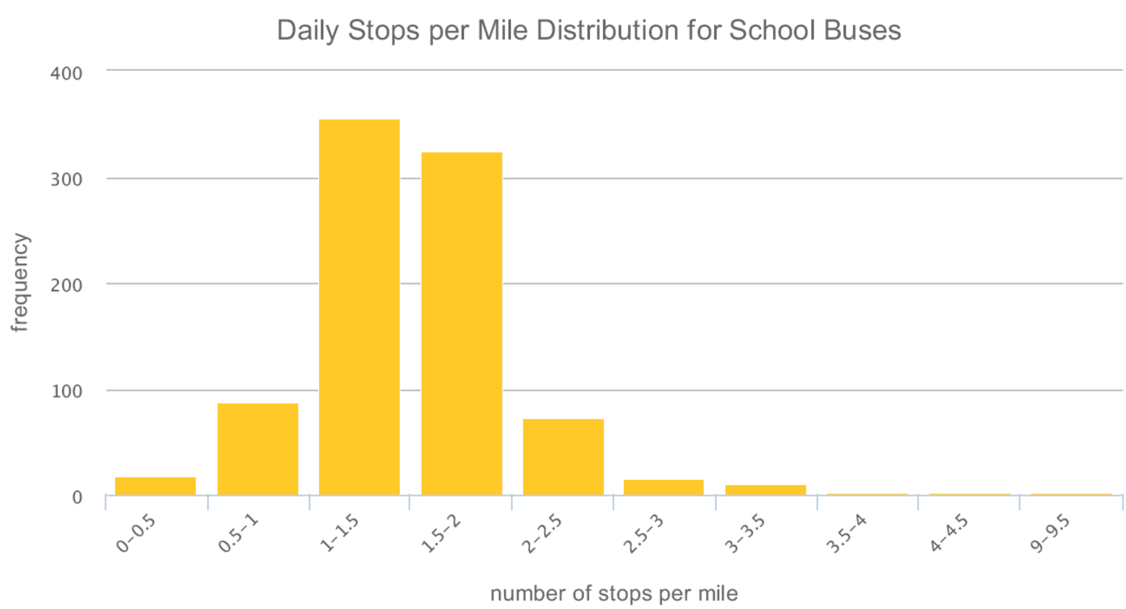

Daily Operating Distance Distribution for Delivery Trucks
200
150
100
50
0
frequency
0-12
12-24
24-36
36-48
48-60
60-72
72-84
84-96
96-108
108-120
120-132
132-144
144-156
156-168
192-204
distance traveled (miles)

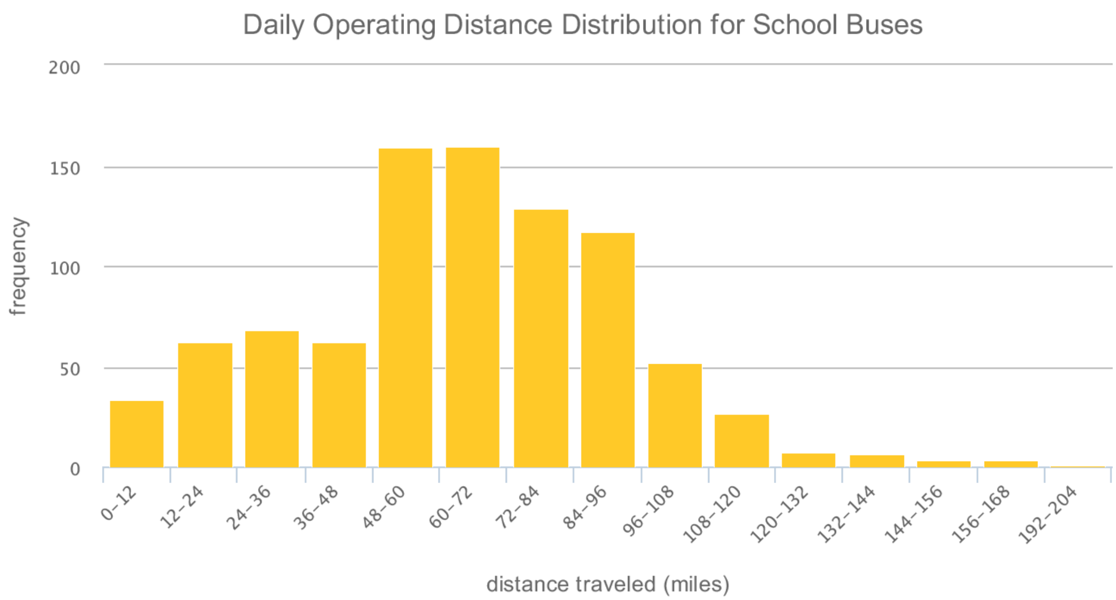


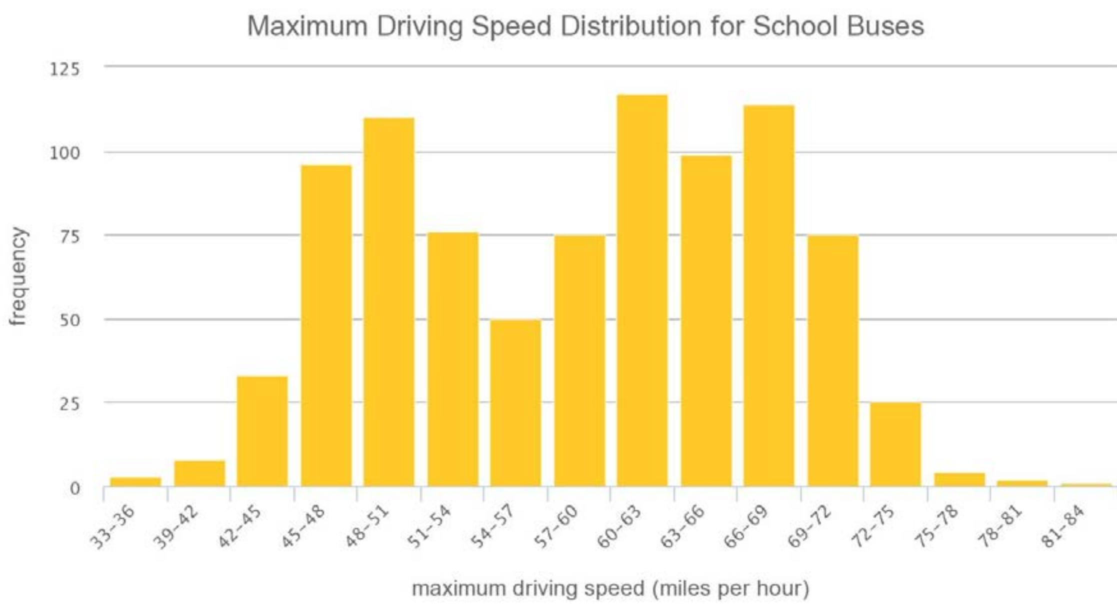
<u>School Buses</u>

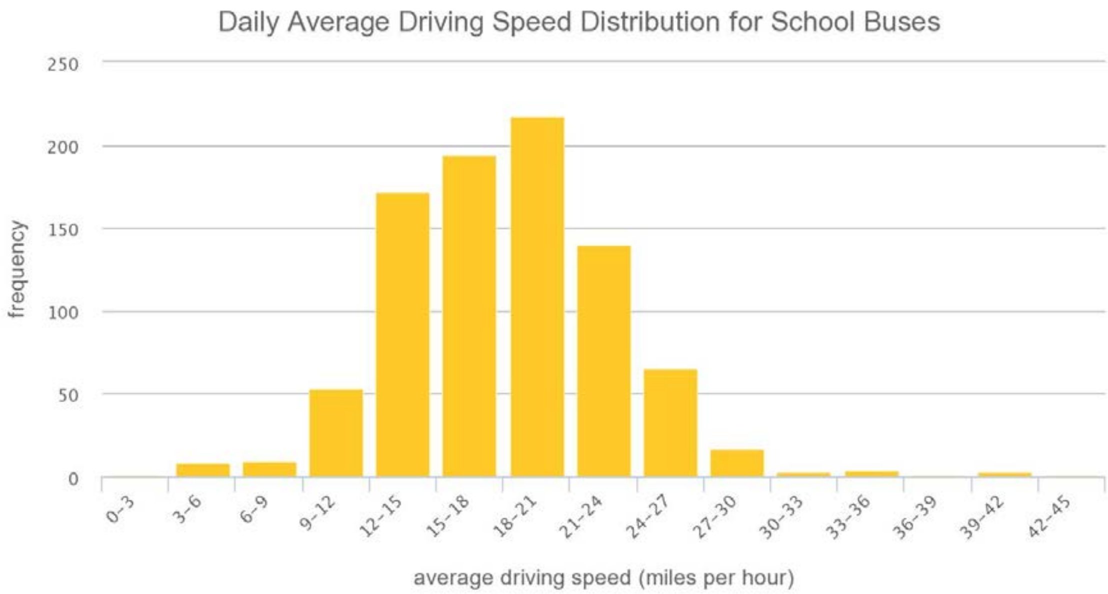
Source Data: Fleet DNA had 857 operating days from 204 school buses

Graphs depicting Drive Cycle for School Buses (NREL, 2014)




Daily Operating Distance Distribution for School Buses
200
150
100
50
0
frequency
0–12
12–24
24–36
36–48
48–60
60–72
72–84
84–96
96–108
108–120
120–132
132–144
144–156
156–168
192–204
distance traveled (miles)

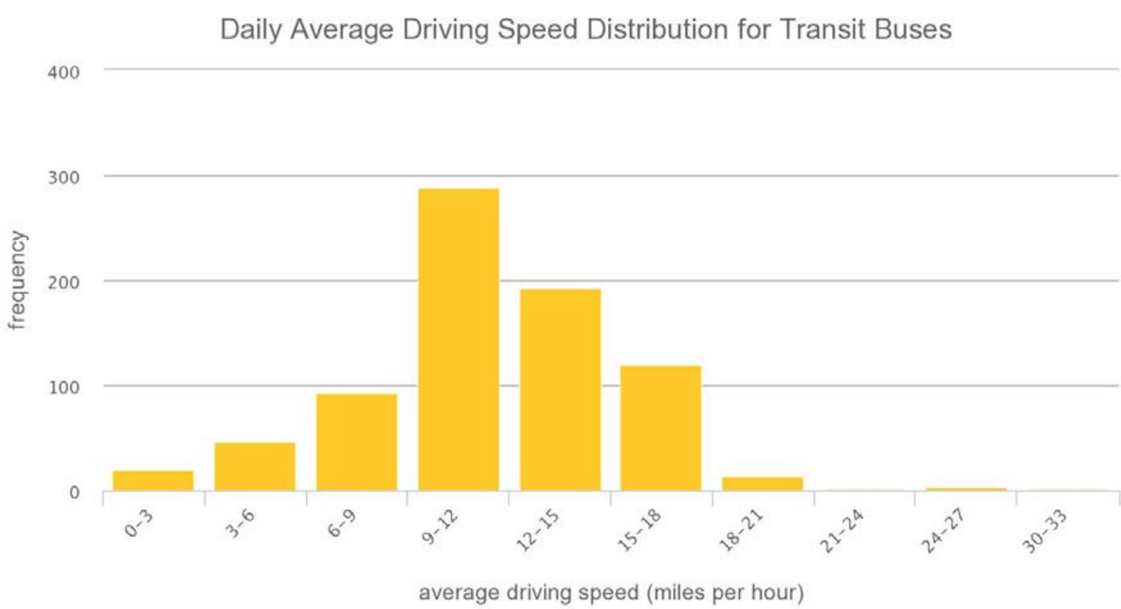

Maximum Driving Speed Distribution for School Buses
125
100
75
50
25
0
frequency
33–36
39–42
42–45
45–48
48–51
51–54
54–57
57–60
60–63
63–66
66–69
69–72
72–75
75–78
78–81
81–84
maximum driving speed (miles per hour)

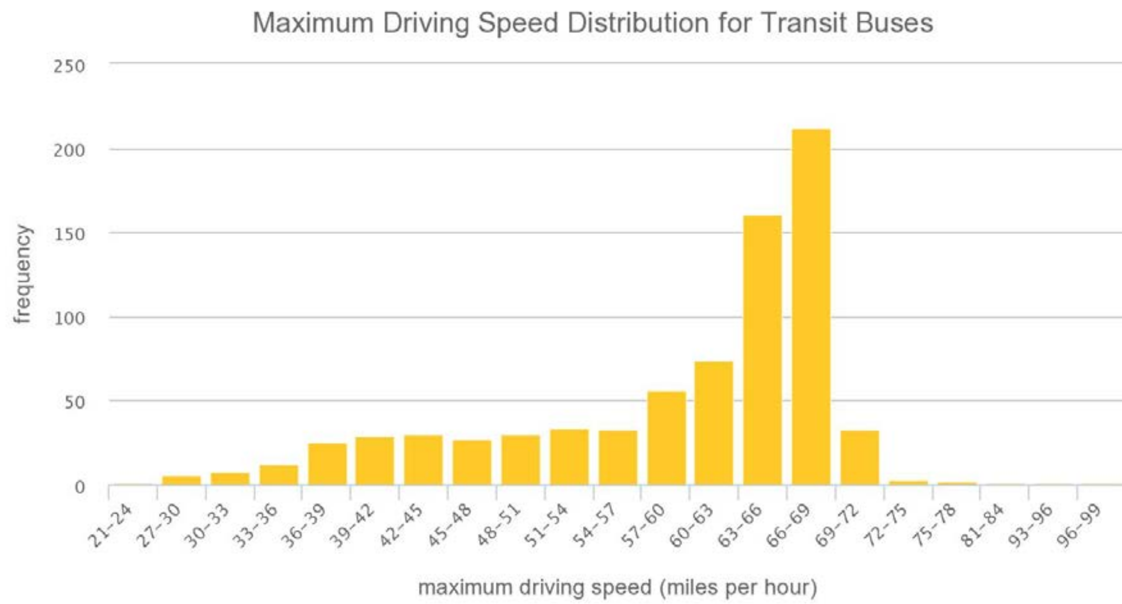


<u>Transit Buses</u>

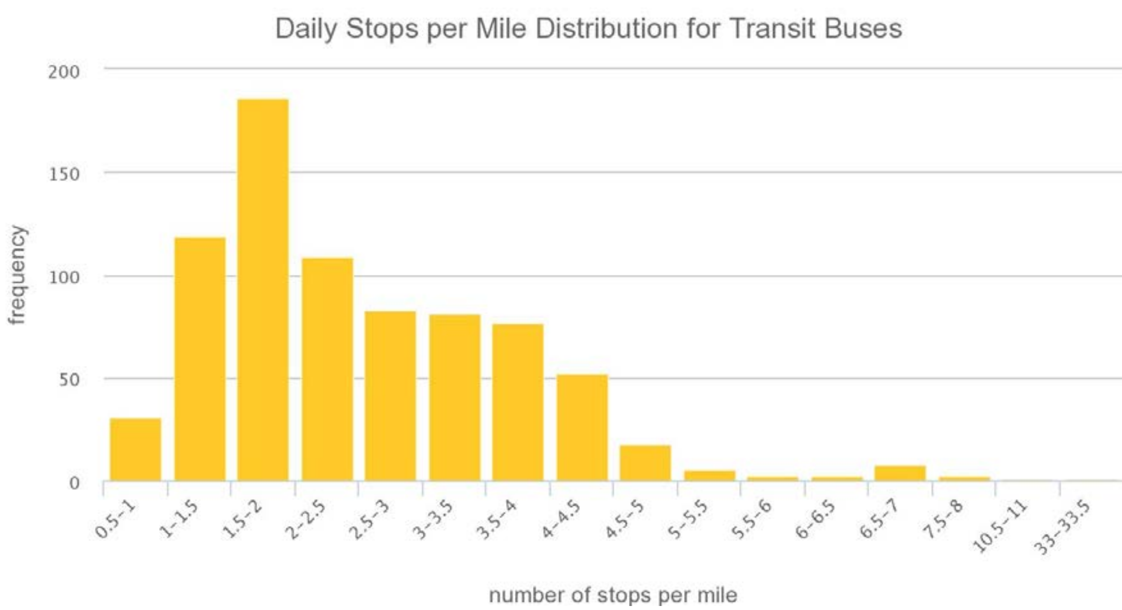
Source Data: Fleet DNA had 472 operating days from 19 transit buses

Graphs depicting Drive Cycle for Transit Buses (NREL, 2014)

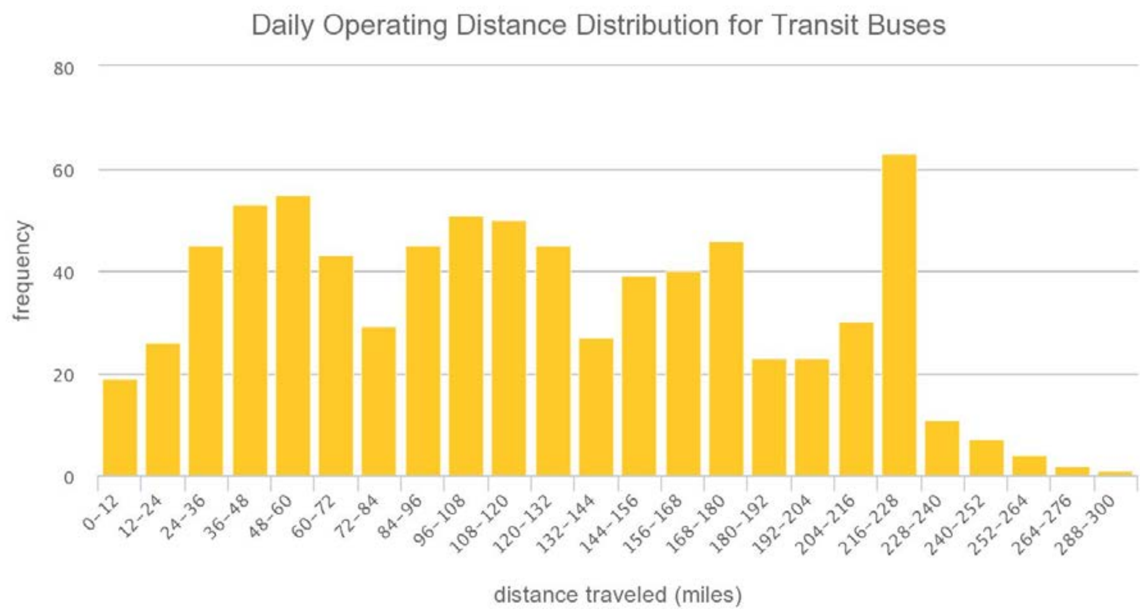




Maximum Driving Speed Distribution for Transit Buses
250
200
150
100
50
0
frequency
21-24
27-30
30-33
33-36
36-39
39-42
42-45
45-48
48-51
51-54
54-57
57-60
60-63
63-66
66-69
69-72
72-75
75-78
81-84
93-96
96-99
maximum driving speed (miles per hour)



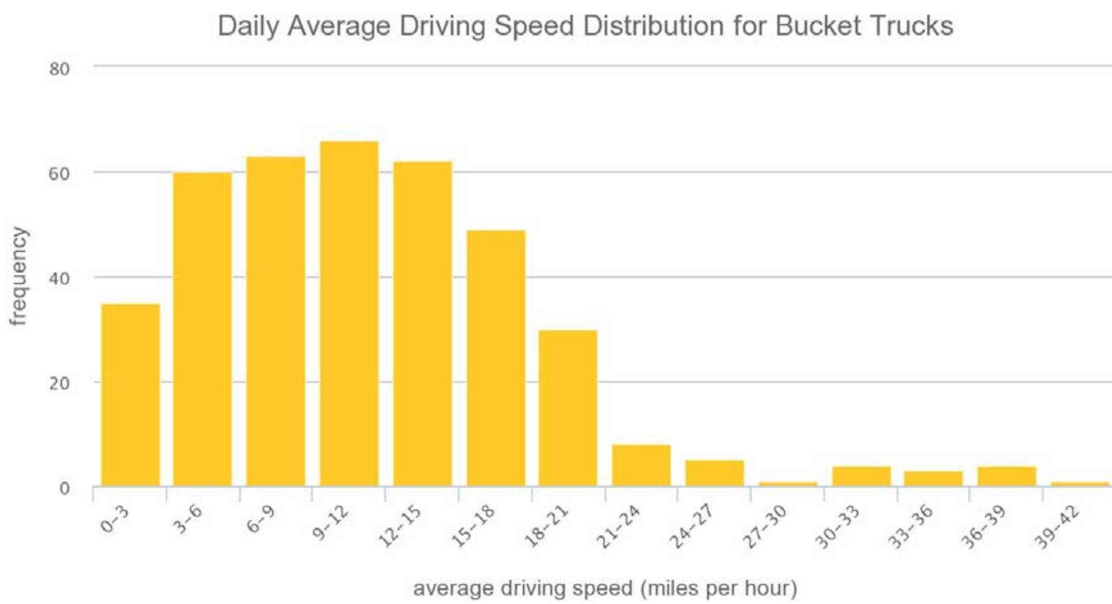
Daily Stops per Mile Distribution for Transit Buses
200
150
100
50
0
frequency
0.5-1
1-1.5
1.5-2
2-2.5
2.5-3
3-3.5
3.5-4
4-4.5
4.5-5
5-5.5
5.5-6
6-6.5
6.5-7
7.5-8
10.5-11
33-33.5
number of stops per mile

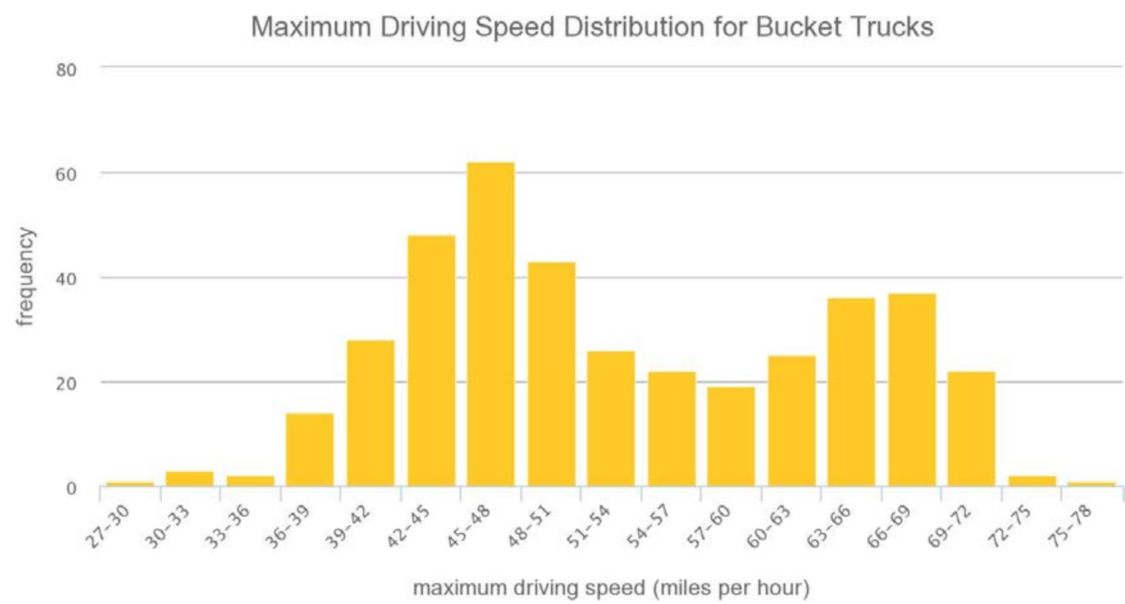


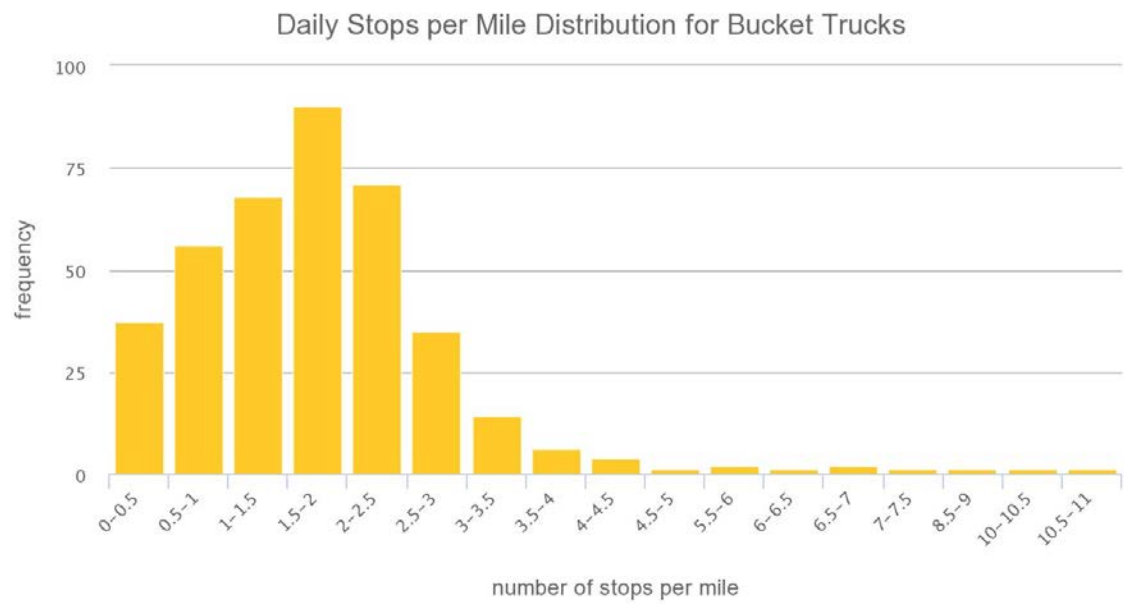
<u>Bucket Trucks</u>

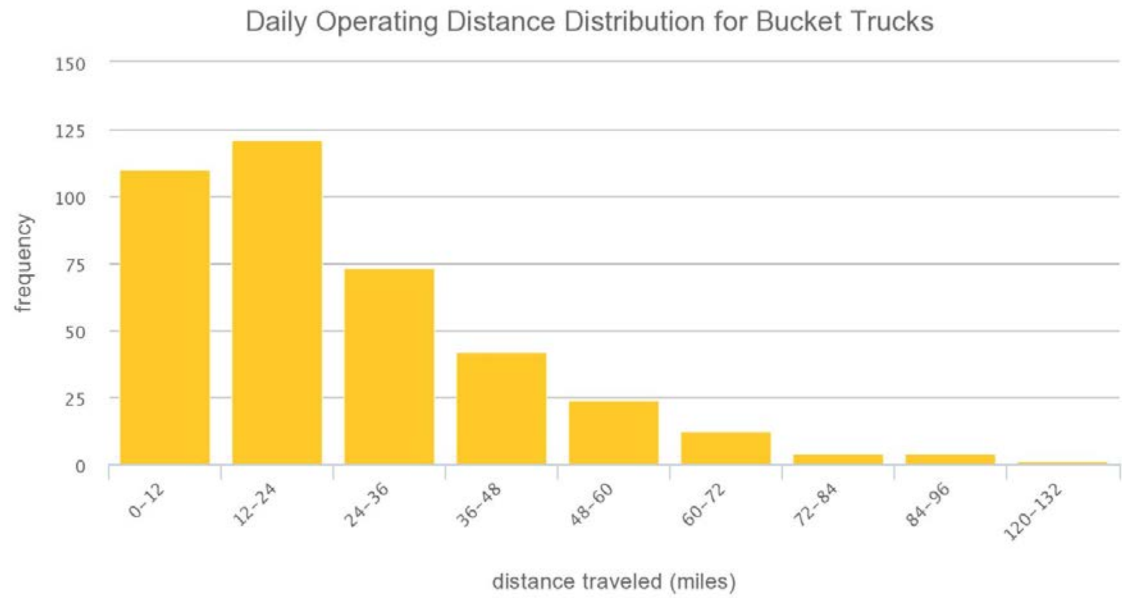
Source Data: Fleet DNA had 283 operating days from 20 bucket trucks

Graphs depicting Drive Cycle for Bucket Trucks (NREL, 2014)




Maximum Driving Speed Distribution for Bucket Trucks
80
60
40
20
0
frequency
27–30
30–33
33–36
36–39
39–42
42–45
45–48
48–51
51–54
54–57
57–60
60–63
63–66
66–69
69–72
72–75
75–78
maximum driving speed (miles per hour)

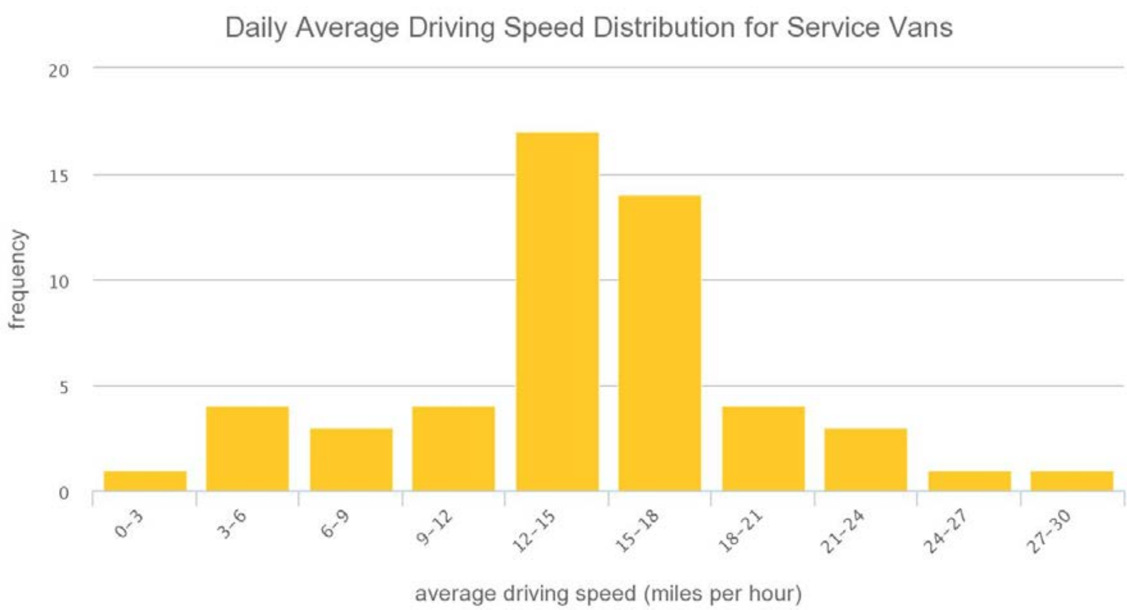

Daily Stops per Mile Distribution for Bucket Trucks
100
75
50
25
0
frequency
0–0.5
0.5–1
1–1.5
1.5–2
2–2.5
2.5–3
3–3.5
3.5–4
4–4.5
4.5–5
5.5–6
6–6.5
6.5–7
7–7.5
8.5–9
10–10.5
10.5–11
number of stops per mile

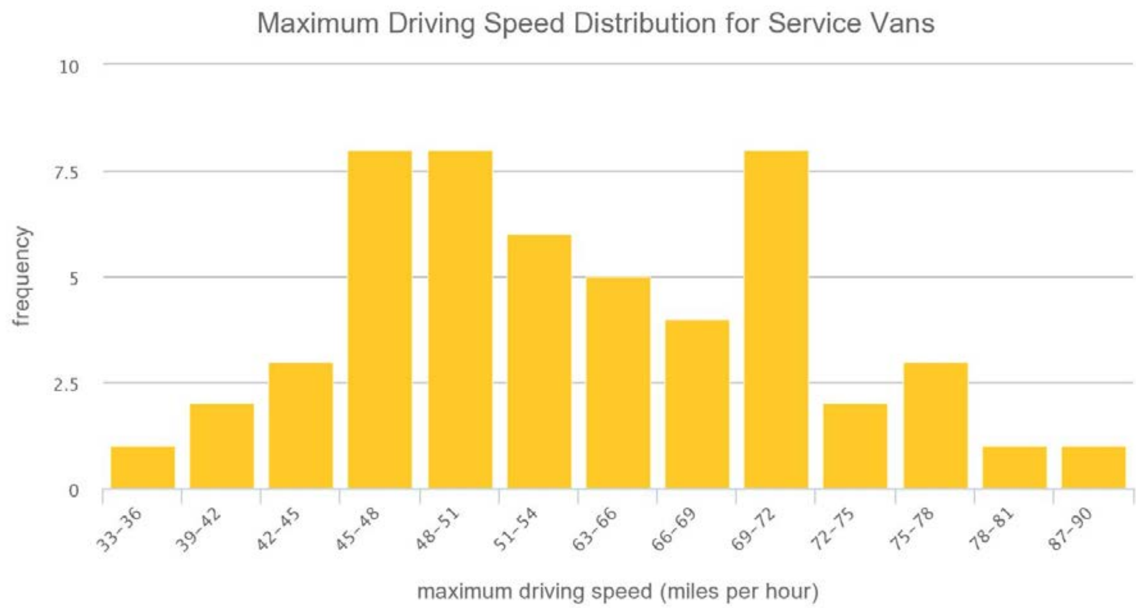


Service Vans

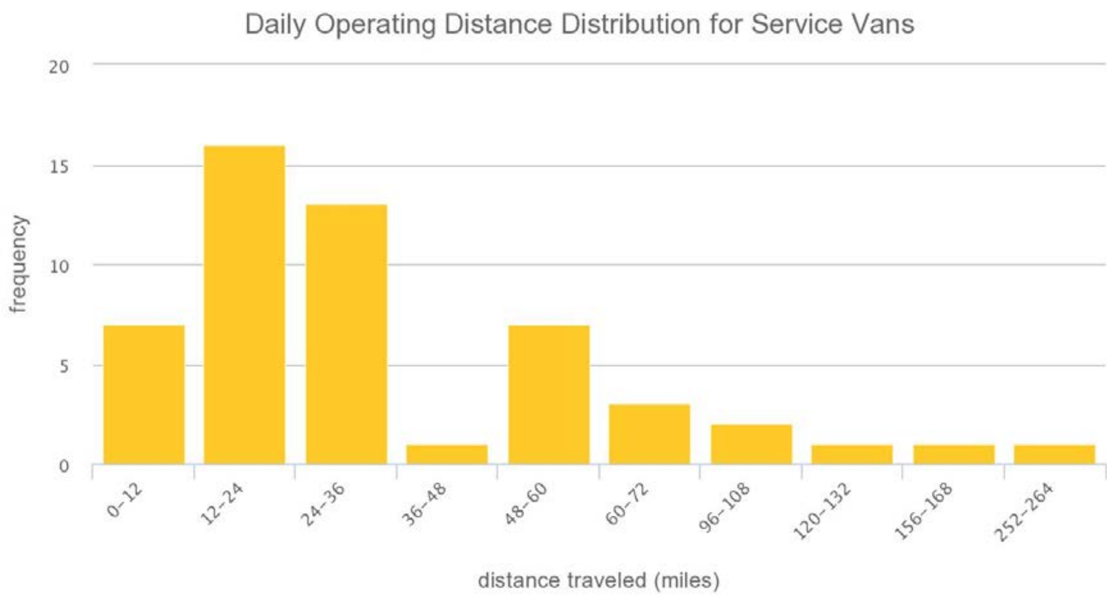
Source Data: Fleet DNA had 29 operating days from 4 bucket trucks

Graphs depicting Drive Cycle for Service Vans (NREL, 2014)




Maximum Driving Speed Distribution for Service Vans
10
7.5
5
2.5
0
frequency
33–36
39–42
42–45
45–48
48–51
51–54
63–66
66–69
69–72
72–75
75–78
78–81
87–90
maximum driving speed (miles per hour)

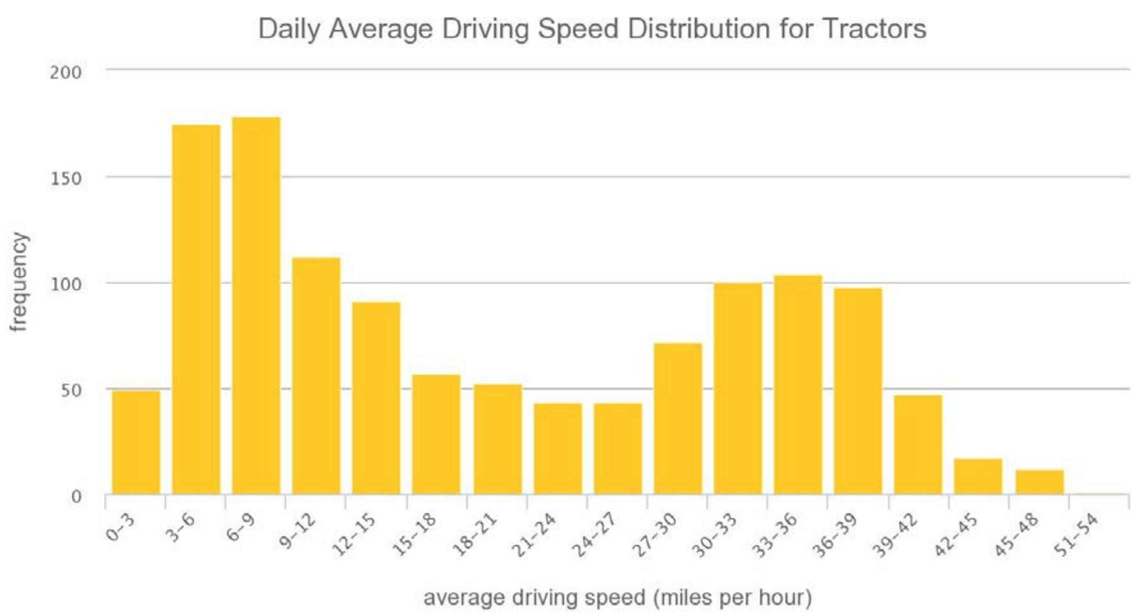

Daily Stops per Mile Distribution for Service Vans
20
15
10
5
0
frequency
0–0.5
0.5–1
1–1.5
1.5–2
2–2.5
2.5–3
3–3.5
4.5–5
number of stops per mile

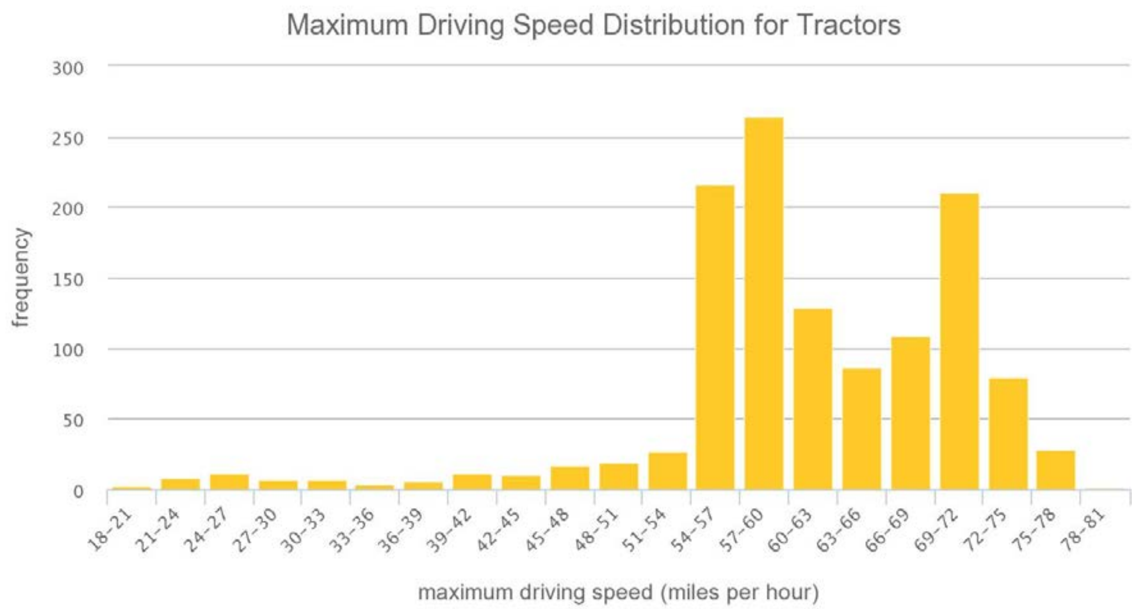


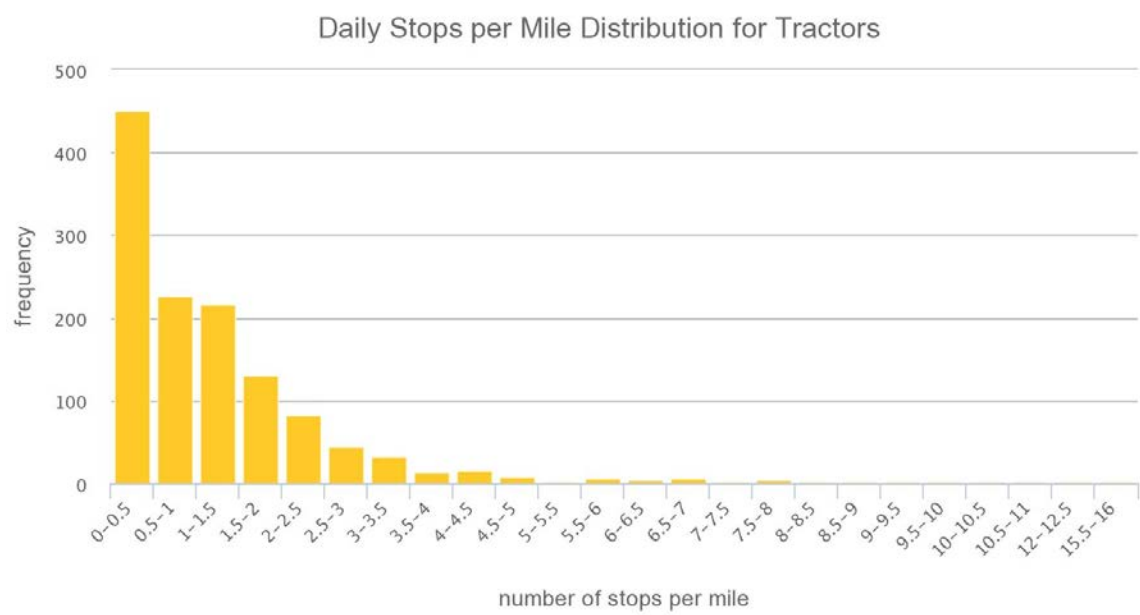
<u>Tractors</u>

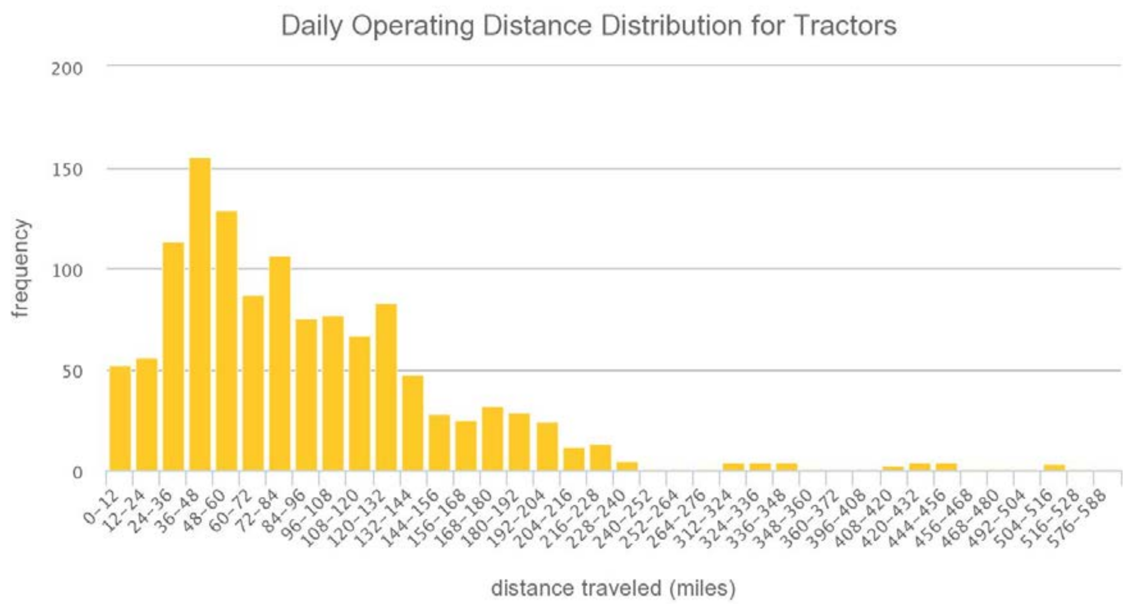
Source Data: Fleet DNA had 1,150 operating days from 70 tractors

Graphs depicting Drive Cycle for Tractors (NREL, 2014)




Maximum Driving Speed Distribution for Tractors
frequency
300
250
200
150
100
50
0
18–21
21–24
24–27
27–30
30–33
33–36
36–39
39–42
42–45
45–48
48–51
51–54
54–57
57–60
60–63
63–66
66–69
69–72
72–75
75–78
78–81
maximum driving speed (miles per hour)

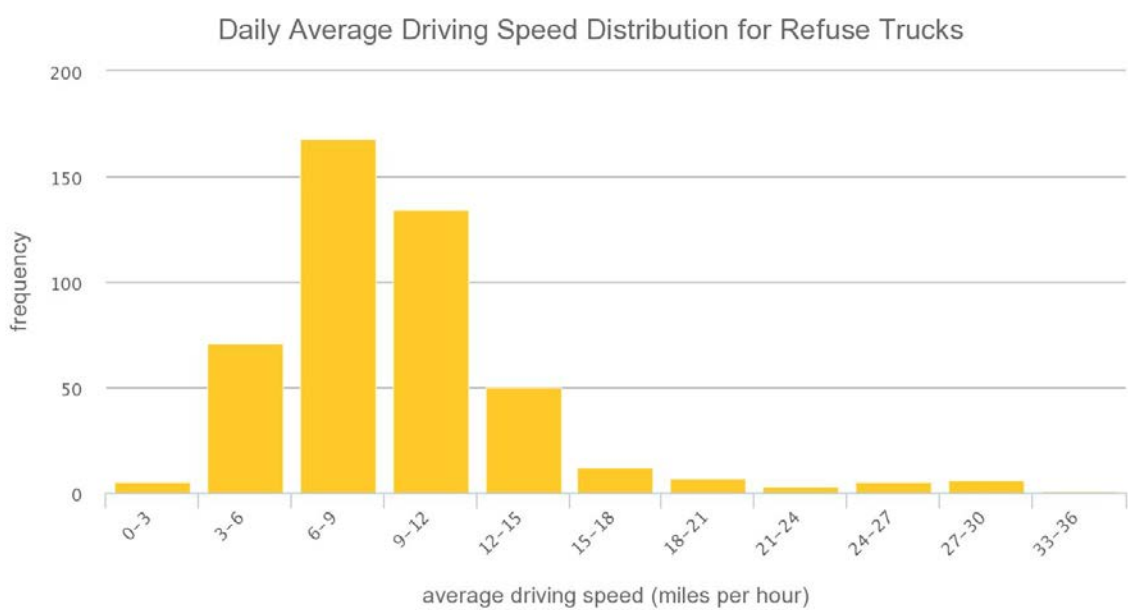

Daily Stops per Mile Distribution for Tractors
frequency
500
400
300
200
100
0
0–0.5
0.5–1
1–1.5
1.5–2
2–2.5
2.5–3
3–3.5
3.5–4
4–4.5
4.5–5
5–5.5
5.5–6
6–6.5
6.5–7
7–7.5
7.5–8
8–8.5
8.5–9
9–9.5
9.5–10
10–10.5
10.5–11
12–12.5
15.5–16
number of stops per mile

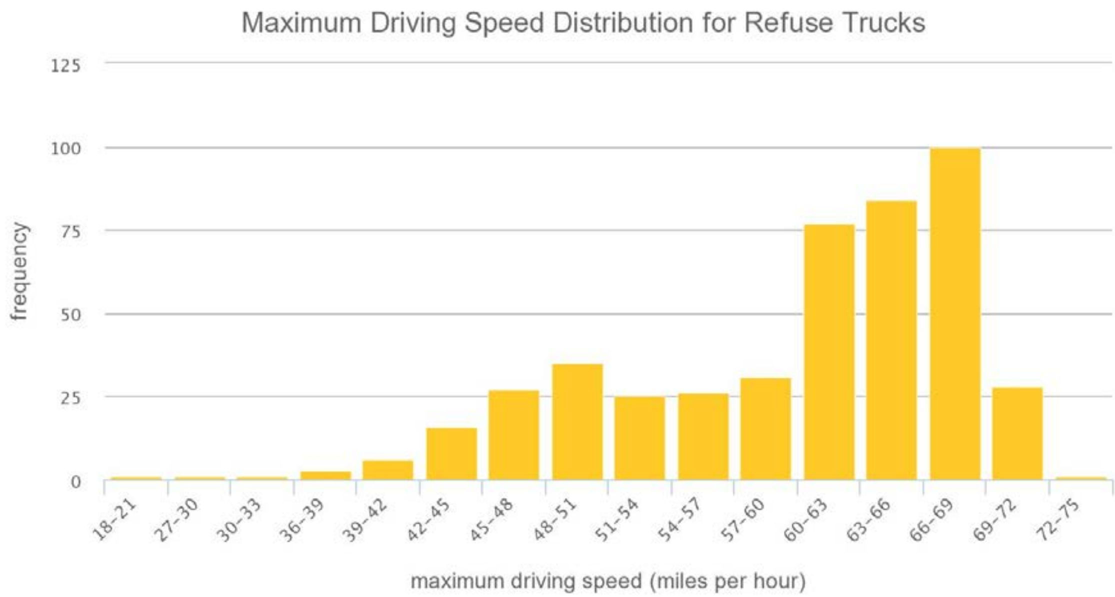


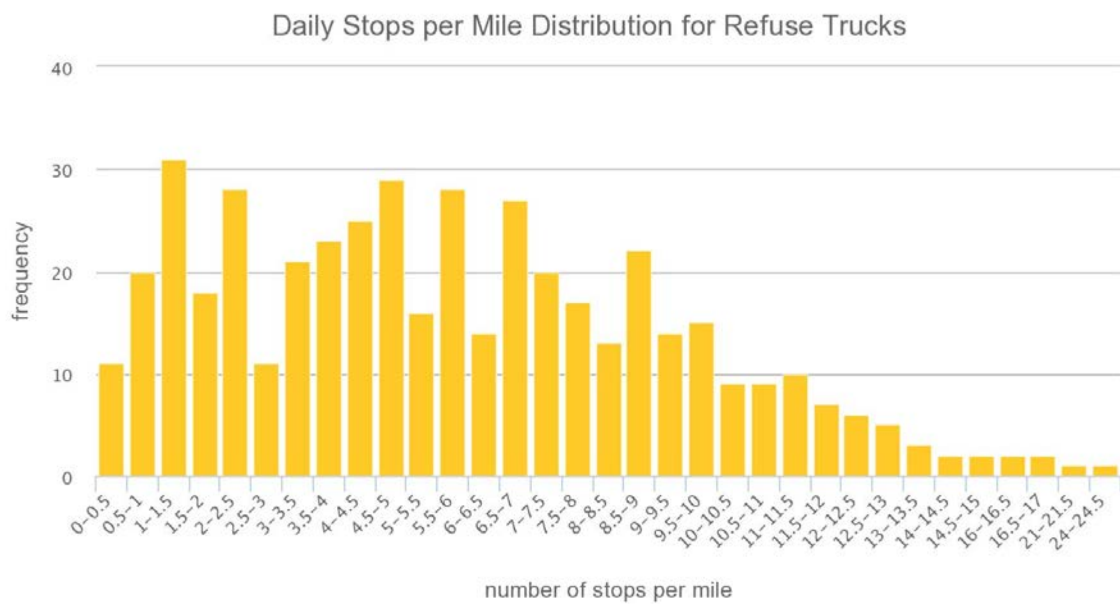
<u>Refuse Trucks</u>

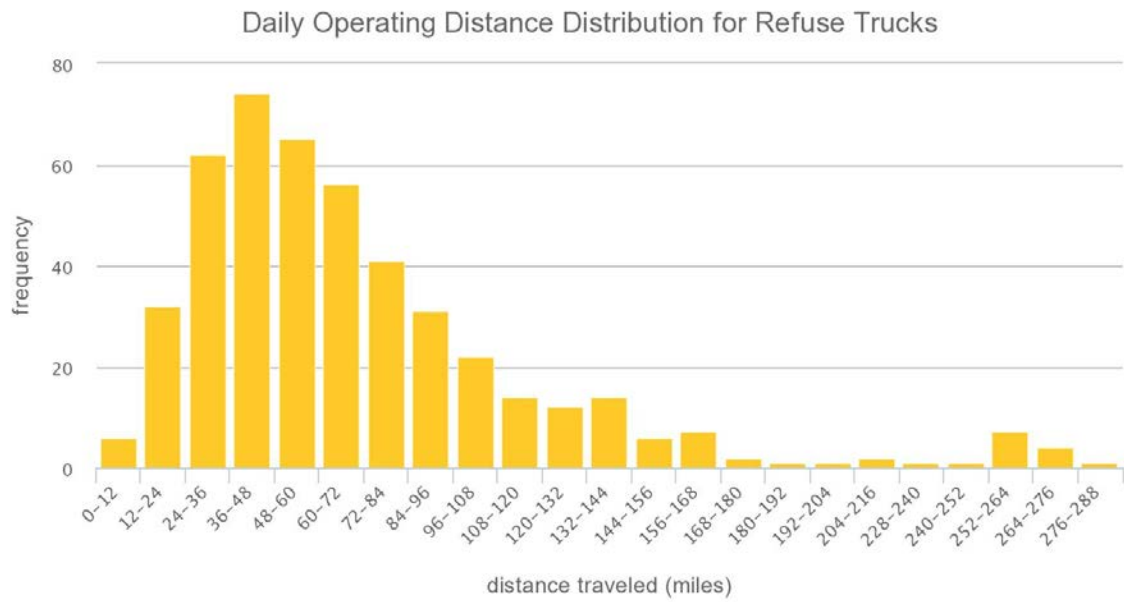
Source Data: Fleet DNA had 387 operating days from 39 refuse trucks

Graphs depicting Drive Cycle for Refuse Trucks (NREL, 2014)




Maximum Driving Speed Distribution for Refuse Trucks
125
100
75
50
25
0
frequency
18–21
27–30
30–33
36–39
39–42
42–45
45–48
48–51
51–54
54–57
57–60
60–63
63–66
66–69
69–72
72–75
maximum driving speed (miles per hour)


Daily Stops per Mile Distribution for Refuse Trucks
40
30
20
10
0
frequency
0–0.5
0.5–1
1–1.5
1.5–2
2–2.5
2.5–3
3–3.5
3.5–4
4–4.5
4.5–5
5–5.5
5.5–6
6–6.5
6.5–7
7–7.5
7.5–8
8–8.5
8.5–9
9–9.5
9.5–10
10–10.5
10.5–11
11–11.5
11.5–12
12–12.5
12.5–13
13–13.5
14–14.5
14.5–15
16–16.5
16.5–17
21–21.5
24–24.5
number of stops per mile


Daily Operating Distance Distribution for Refuse Trucks
frequency
80
60
40
20
0
0-12
12-24
24-36
36-48
48-60
60-72
72-84
84-96
96-108
108-120
120-132
132-144
144-156
156-168
168-180
180-192
192-204
204-216
228-240
240-252
252-264
264-276
276-288
distance traveled (miles)