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Carbon Neutrality Study 1:Driving California’s Transportation Emissions to Zero

Authors
Brown, Austin L.
Fleming, Kelly L.
Lipman, Timothy
et al.

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- Office of Planning and Research

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Carbon Neutrality Study 1: Driving California's Transportation Emissions to Zero

Austin L. Brown[1], Kelly L. Fleming[1], Timothy Lipman[2], Lew Fulton[1], Jean Daniel Saphores[4], Gil Tal[1], Colin Murphy[1], Susan Shaheen[2], Bernadette Austin[1], Juan Carlos Garcia Sanchez[1], Elliot Martin[2], Marshall Miller[1], Michael Hyland[4], Susan Handy[1], Mark A. Delucchi[1,2], Daniel Coffee [3], JR DeShazo[3]

[1]UC Davis, [2]UC Berkeley, [3]UCLA, [4]UC Irvine

October 2020

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Glossary

AB	Assembly Bill
AFV	alternative fuel vehicle
APTA	American Public Transportation Association
AQIP	Air Quality Improvement Program
AQMD	Air Quality Management District
AHSC	Affordable Housing and Sustainable Communities
ATP	Active Transportation Program
AV	automated vehicles
BART	Bay Area Rapid Transit
BAU	business as usual
BD	biodiesel
BEV	battery electric vehicle
BLS	Bureau of Labor Statistics
CAFE	Corporate Average Fuel Economy
CalSTA	California State Transportation Agency
CARB	California Air Resources Board
CAV	clean air vehicle
CEC	California Energy Commission
CHTS	California Household Travel Survey
CO	carbon monoxide
CO2	carbon dioxide
CPUC	California Public Utilities Commission
CSTDM	California Statewide Travel Demand Model
CVA	Clean Vehicle Assistance
CVRP	Clean Vehicle Rebate Program
DACs	disadvantaged communities
DGE	diesel gallon-equivalent
DMV	Department of Motor Vehicles
DOE	US Department of Energy
DOT	US Department of Transportation
E10	10% ethanol
EIA	Energy Information Administration
EJ	environmental justice
EMFAC	EMission FACtor
EPA	Environmental Protection Agency

EVSE	electric vehicle supply equipment
FCEV	fuel cell electric vehicle
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GDP	gross domestic product
GGE	gasoline gallon-equivalent
GHG	greenhouse gas
GVWR	gross vehicle weight rating
HDV	heavy-duty vehicle
HOT	high-occupancy toll
HOV	high-occupancy vehicle
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program
ICE	internal combustion engine
ICEV	internal combustion engine vehicle
LCFS	Low Carbon Fuel Standard
LDV	light-duty vehicle
LNG	liquefied natural gas
LOS	level of service
MDV	medium-duty vehicle
MPO	Metropolitan Planning Organization
MSRC	Mobile Source Air Pollution Reduction Review Committee
MV	motor vehicle
MJ	Megajoule
NG	natural gas
NHTS	National Household Travel Survey
NOx	nitrogen oxides
OEHHA	Office of Environmental Health Hazard Assessment
OPR	Governor’s Office of Planning and Research
P2P	person-to-person
PEV	plug-in electric vehicle
PFCEV	plug-in fuel cell electric vehicle
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
PMT	person miles traveled
RD	renewable diesel
RFS	Renewable Fuel Standard
RNG	renewable natural gas

SAFE	Safer Affordable Fuel Efficiency
SAV	shared automated vehicle
SB	Senate Bill
SCS	Sustainable Communities Strategy
SO2	sulfur dioxide
SUV	sport utility vehicles
TCO	total cost of ownership
TNC	transportation network company
TTM	Transportation Transitions Model
VMT	vehicle miles traveled
VOC	volatile organic compound
VOMS	vehicles operated in maximum service
ZEB	zero-emission bus
ZEV	zero emission vehicle

Executive Summary

Executive Summary

The purpose of this study overall is to explore the policy pathways to achieve a zero carbon transportation system in California by 2045. The purpose of this synthesis report is to describe the existing state of knowledge and policy related to energy use and greenhouse gas (GHG) emissions in the transportation sector, especially in California. It is an interim product of the larger study, which will use this report as the baseline and policy context sections. The report comprises four sections. Section 1 provides an overview of the major components of transportation systems and how those components interact. Section 2 explores key underlying concepts in transportation, including equity, health, employment, and environmental justice (EJ). Section 3 discusses California's current transportation-policy landscape. Section 4 analyzes projected social, environmental, and economic outcomes of transportation under a "business as usual (BAU)" scenario—i.e., a scenario with no significant transportation-policy changes.

Some key takeaways of this report are:

- Transportation emits more GHGs than any other sector, and is a significant contributor to air pollution.
- Transportation is an essential component of the economy, both as a source of employment and as a system that supports all economic sectors.
- The current transportation system contributes to multiple negative EJ outcomes, including unequal access to transportation services, unbalanced ability of communities to influence transportation policies and decisions, and a much higher pollution burden on communities of color. These injustices are perpetuated as these communities also lack equitable access to quality jobs, critical services, and goods.
- Many options based on available technology exist for decarbonizing transportation. These include:
    - Options for decarbonizing light-duty vehicles (LDVs), including through plug-in electric and fuel-cell personal vehicles.
    - Options for decarbonizing heavy-duty vehicle (HDV) options, including through electric and fuel-cell HDVs.
    - Factors that reduce vehicle miles traveled (VMT) while improving accessibility and choice.
    - Lower-carbon fuels that can replace petroleum fuels (gasoline, diesel, and jet fuel).
- Each of these options faces a specific set of barriers to widespread adoption.
- California has a significant suite of policies, many administered by the California Air Resources Board to address these barriers and reduce emissions in the transportation sector, including at least one major policy in each of the subsectors examined in this report.
- It is important for each of these policies to consider the equity impacts, and California is increasingly designing transportation policy explicitly to help improve the equity of outcomes.
- Under a BAU scenario, California is extremely unlikely to meet emissions-reductions goals in the transportation sector. In particular, expected progress in electrification and lower-carbon fuels will likely be insufficient to offset growth in travel, absent significant policy changes.

Contents

1 Current State of the Transportation System

1.1 Transportation, the economy, and greenhouse gas emissions

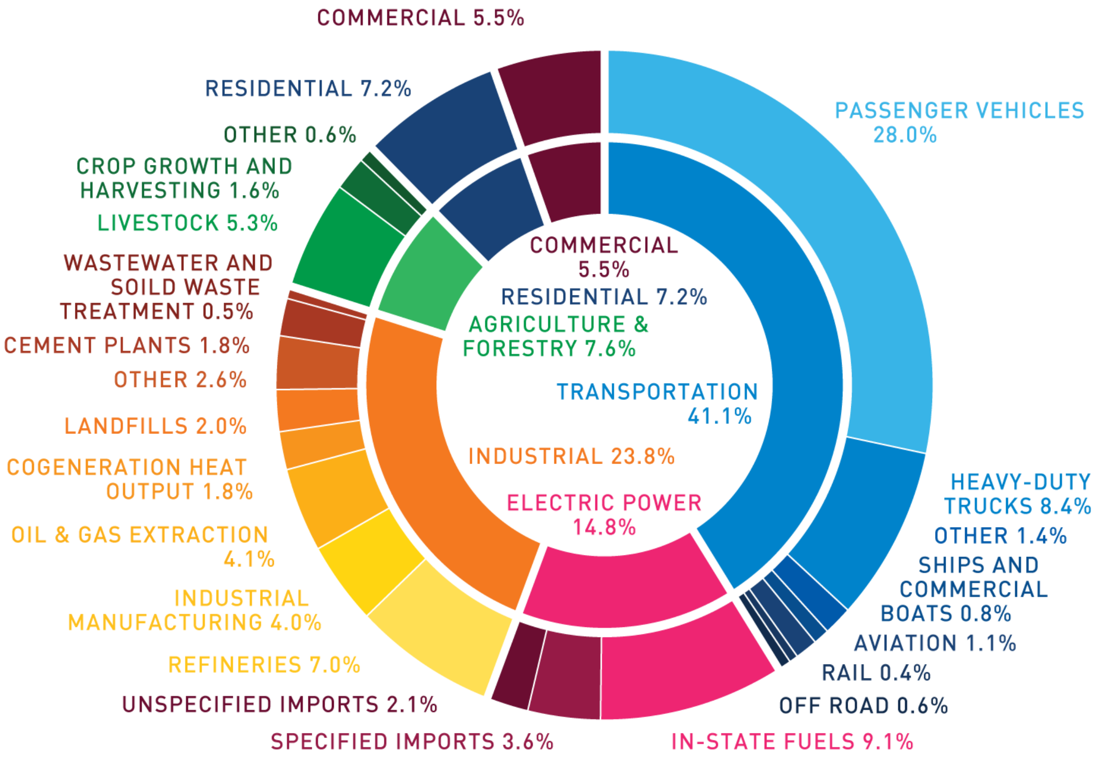
Transportation provides essential services, including access to jobs, health care, education, religious services, shopping, and much more. Affordable movement of goods through multiple modes is the lifeblood of the modern economy. Approximately 10% of U.S. Gross Domestic Product (GDP) is in transportation and transportation services, and no sector of the economy could exist in its current form without modern transportation. However, the current personal-vehicle-centric transportation system also contributes to many societal ills, including air pollution, climate change, road crashes, congestion, urban fragmentation, and unsustainable urban design, which are exacerbated for low-income and disadvantaged communities. Decades of vehicle-focused land use planning make cars a necessity for many communities and heavy-duty trucking as the primary method for goods movement and delivery, continuing the pattern of vehicle dependence. The overarching goal of sustainable transportation policy is to reduce these negative impacts while also improving transportation services and accessibility.

1.1.1 Energy use and emissions

The transportation sector is the largest emitter of GHGs in the United States, and is also a major source of local air pollutants. In California, transportation makes up 41% of GHG emissions, mostly from tailpipe emissions from cars and trucks (Figure 1). When the production and refining of oil is considered, transportation's contribution to GHG emissions rises above 50%.

Figure 2. Greenhouse Gas Emissions by Source

CALIFORNIA, 2017



NEXT 10 CALIFORNIA GREEN INNOVATION INDEX. Data Source: California Air Resources Board, California Greenhouse Gas Inventory – by Sector and Activity. NEXT 10 / SF · CA · USA

Figure 1. Emissions by sector (CARB 2018)

Unlike emissions from the power sector and from buildings, California's transportation emissions have not been falling over time (Figure 2). Some modest improvement in fuel economy and increased use of lower-carbon fuels has been generally outweighed by significant increases in driving.

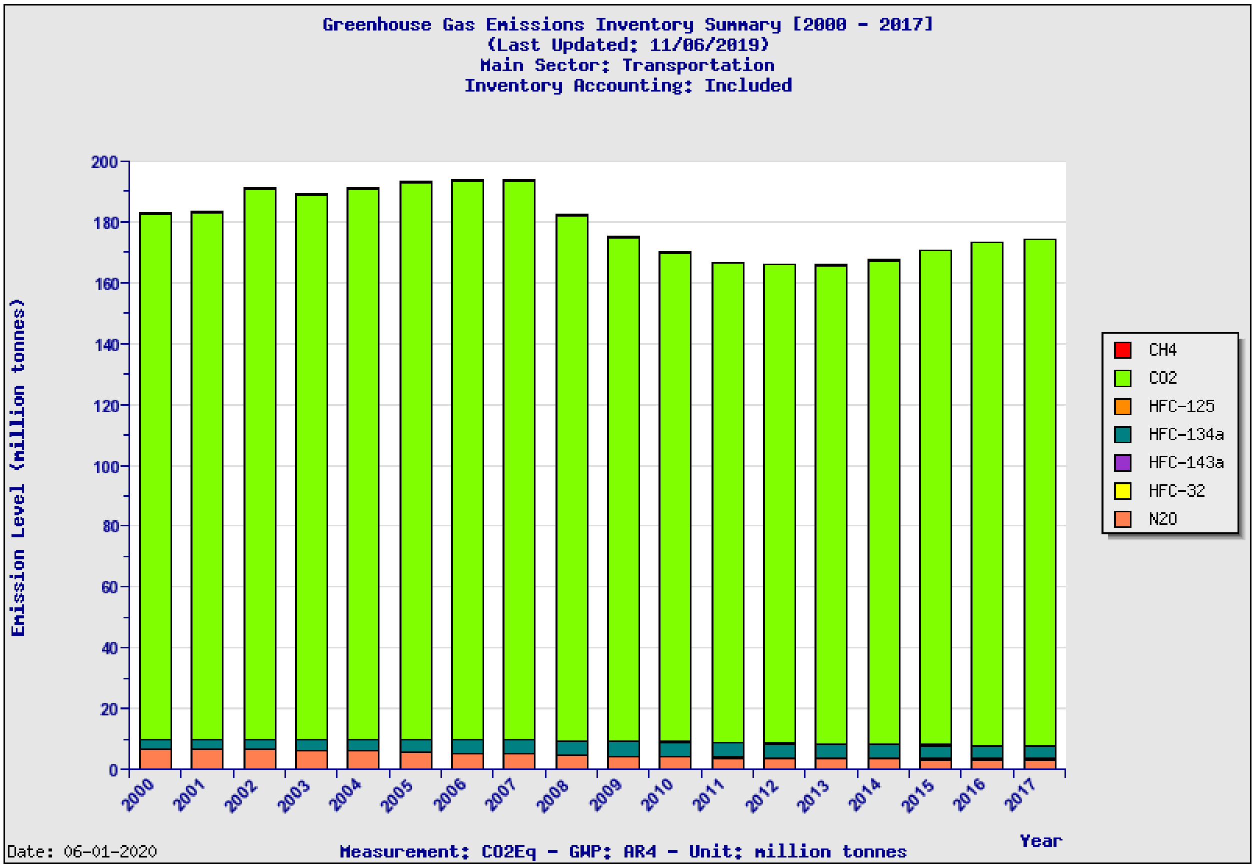


Figure 2. California Transportation Emissions over Time (CARB)

On-road vehicles, including LDVs (cars, sport utility vehicles [SUVs], etc.) as well as medium- and heavy-duty trucks, are responsible for the vast majority of transportation energy use and emissions in California (Figure 3). Aircraft and marine shipping emissions are significant, but often not included in state inventories. Other modes, including rail and transit, provide important transportation services but comprise a much smaller share of emissions.

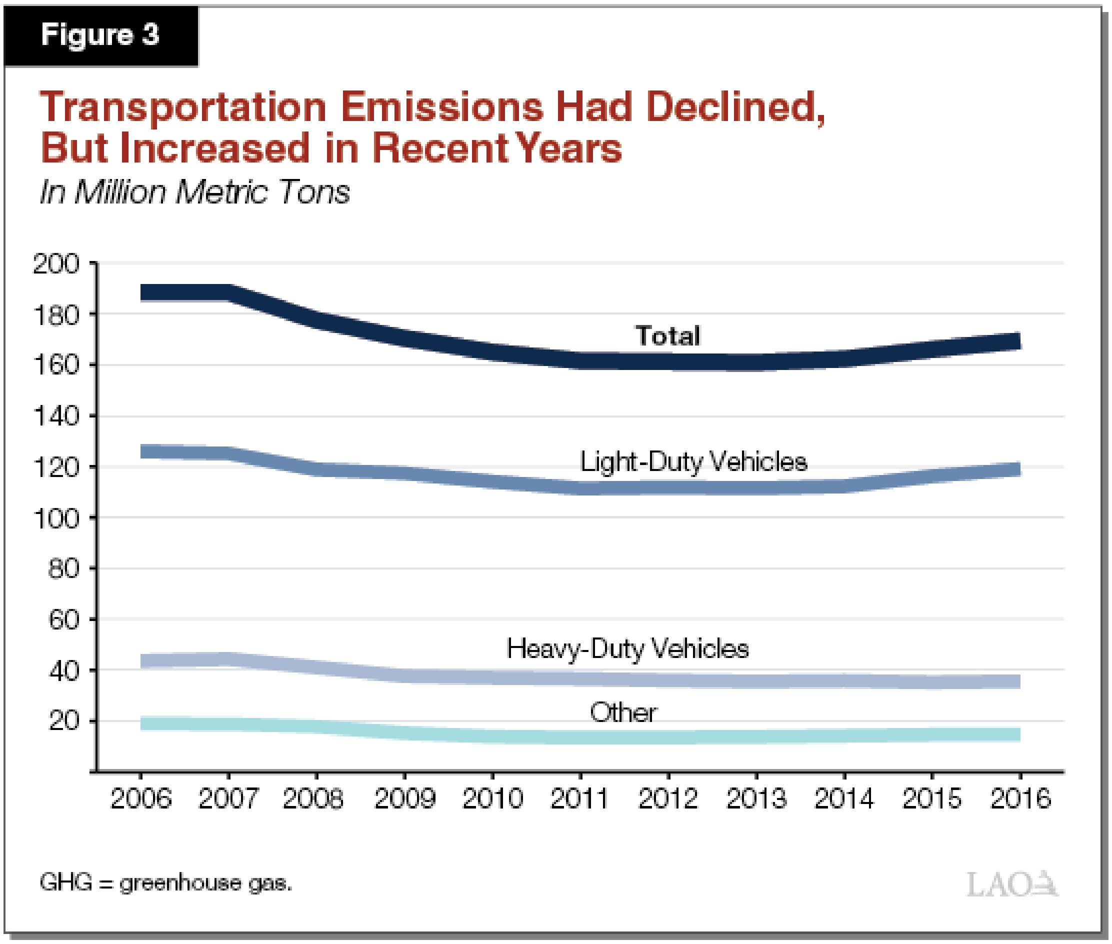


Figure 3. History of Emissions by Transportation Segment Source: Legislative Analyst's Office based on GHG Inventory data.

The overall recent history of emissions is therefore one of modest progress in efficiency and significant early growth in electric vehicle deployment, as well as increasing use of biofuels, swamped out by an increase in demand for driving. The automobile and the truck have remained the most common way to travel and move goods respectively as mode shift to cleaner modes has been limited. The Great Recession significantly contributed to a net decline in emissions from 2008-2012, and it is difficult to disaggregate the effect of structural changes in efficiency or travel demand from the effects of the recession and recovery.

1.1.2 Infrastructure

Transportation relies on a large and expensive network of interconnected infrastructure. Physical infrastructure is required for every kind of transportation, including walking, cycling, driving (personal vehicle, ridehailing, carshare), transit, freight, maritime, rail, air travel, off-road and agricultural. As discussed above, LDVs and passenger travel are responsible for most of California's GHG emissions from the transportation sector. LDVs and passenger travel also account for the largest sources for (through fuel taxes) and recipients of (for roads and highways) transportation-related funding from the state and federal government.

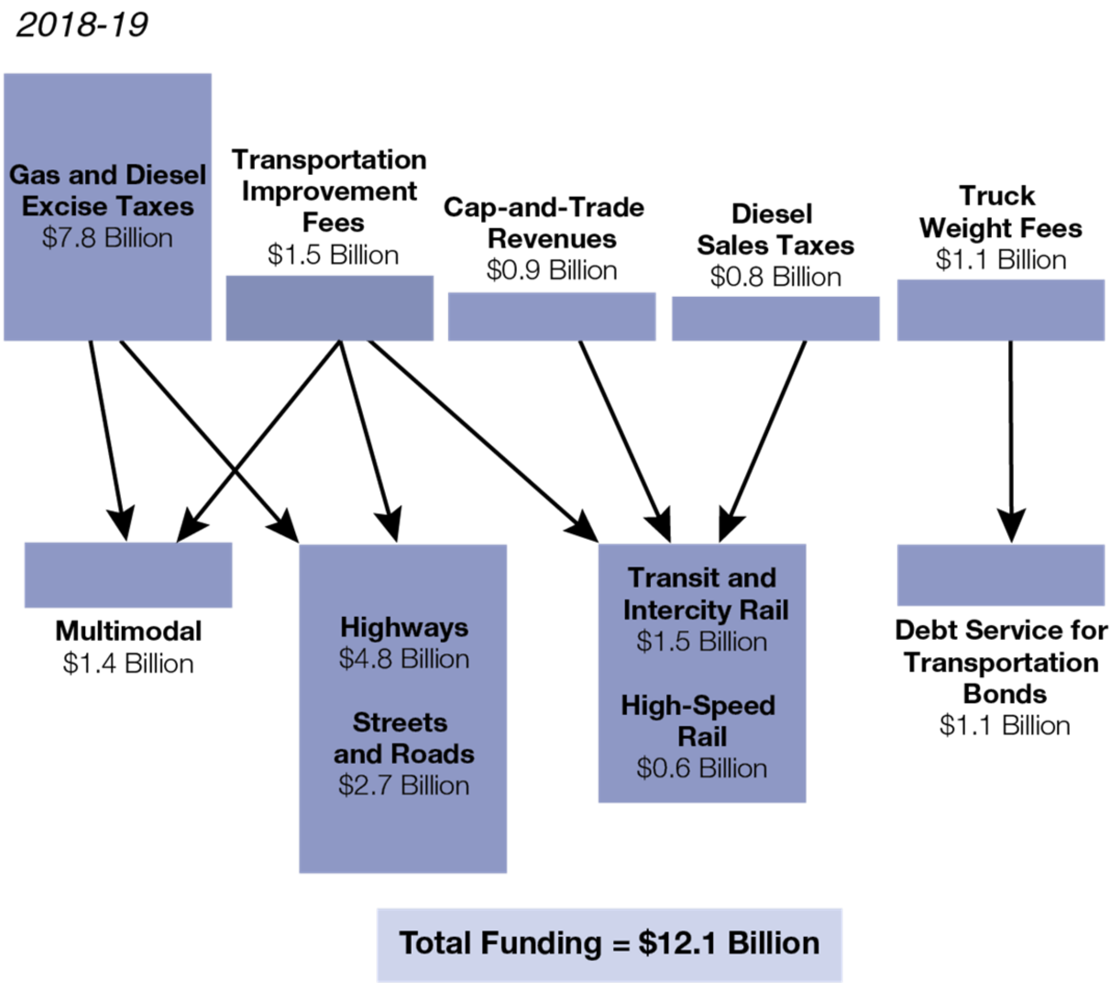


Figure 4. State Transportation Funding Flow. Figure adapted from Legislative Analyst's Office Report: California's Transportation System, page 46. (Legislative Analyst's Office 2018). Includes revenue from GGRF allocated for transportation. Multimodal includes multiple transit modes for one trip, such as bus and train.

Roads: California has 176,000 miles of public roadways, 59% of which are in urban areas [1]. Relatedly, most transportation expenditures in California include projects related to road construction, repair, and maintenance. Roadway expansion (adding more lane miles) accounted for 35% of transportation spending, which has been tied to an increase in VMT and GHG emissions through induced congestion [2]. An additional 35% of transportation spending was for road repair. Despite this, the condition of California roads has continued to worsen. Deteriorating road conditions has also been shown to increase in GHG emissions by reducing fuel economy and causing congestion and vehicle damage.

Freight rail: California has 4,800 miles of freight rail track owned, operated, and maintained by intermodal operators [3]. Freight rail is almost exclusively powered by diesel-electric locomotives, most of which are in line-haul, interstate operations and since 2007, consume Environmental Protection Agency (EPA) ultra-low sulfur (15 ppm) diesel fuel, per an agreement between the California Air Resources Board (CARB) and the two main interstate railroad companies operating in California, Union Pacific (UP) and Burlington Northern Santa Fe (BNSF). The 15 ppm sulfur standard was required for all interstate railroad operations in the U.S. in 2012. Where interstate trains refuel in California, they typically do so using

CARB diesel, which maintains the same 15 ppm sulfur limit as EPA diesel, but has stricter limits on aromatic content and which typically reduces PM and NOx emissions compared to EPA diesel. Intrastate rail operations in California are required to operate on CARB diesel.

Transit and Passenger Rail: Unlike freight rail, passenger rail is a recipient of significant public funding. California has three heavy-rail systems for urban area passenger transit (Bay Area Rapid Transit [BART], part of Los Angeles Metro Rail, and Caltrain serving the communities between San Francisco and San Jose). There are also several regional and commuter rail systems, including Metrolink in the Los Angeles region, SMART in the Northern Bay Area, Coaster serving San Diego, and some Amtrak routes with enhanced commuter service. Los Angeles, San Francisco, San Jose, Sacramento, and San Diego also have light rail systems. The state's first high-speed rail network is currently under construction through the High-Speed Rail Authority (HSRA). 4% of the state's transportation program budget is allocated to transit and intercity rail, and 5% is allocated to high-speed rail. Passenger trains are operated on freight rail tracks, which are all owned by private entities, as well as publicly owned right of way. The National Railroad Passenger Corporation (NRPC), now Amtrak, was created by Congress in 1960 to oversee the operation of intercity passenger trains that utilize privately owned tracks. California's Public Transportation Account totaled $1.29 billion in 2018. Most of this account ($1.04 billion in 2018) is allocated to cities and counties to maintain public transportation infrastructure and service. Some passenger rail in California, e.g. BART, is electrified and draws either from the California grid or through a power purchase agreement (PPA) with specified sources of electricity. Other systems, e.g. Caltrain, are powered by diesel-electric locomotives, burning CARB diesel, though there are efforts underway to switch to electrify the train corridor.

Bus service usually uses the same road infrastructure as cars and trucks. A new exception is bus rapid transit, which include new infrastructure such as dedicated lanes, stations where fare is paid off-board, and platform-level boarding. Los Angeles, San Diego, and several other regions have bus systems with some of these elements. Of these, only Los Angeles' system has been scored by the Institute for Transportation & Development Policy, which rates the systems as Bronze (meaning it has many but not all of the preferred elements).

Ports: California is home to eleven commercial maritime ports, and is the largest port network in the country. The three largest ports in California are Los Angeles, Long Beach, and Oakland. Ports are used for international trade of agricultural and other products, but are also used for passenger services, tourist attractions, and other retail [4]. Some ports have begun to electrify their ship fleets and ground transportation, a transition that requires installation of new electrical and charging infrastructure for all sources, including vessels, locomotives, trucks, and passenger vehicles [5].

Airports: Airports require a huge variety of infrastructure for ground transportation, baggage, shelter, retail, security, air traffic control, and fueling. The federal government provides $14 billion per year on average to U.S. airports for infrastructure projects, mostly through the Federal Aviation Administration's grant programs. The federal government also collects revenue from passenger fees and retail generated revenue [6]. Most major airports in California are seeking to electrify airside ground-support equitpment. California has 26 major commercial passenger airports as well as many private airports, and airports used in agricultural regions that are not publicly funded [7].

Petroleum: California's oil and gas industry has been a central part of its economy for over 150 years, though production and its economic importance has been declining steadily (study 2 explores this in more detail). California has developed a large refining industry in parallel with its oil extraction activities. California has two major refining centers, in and around the cities of Los Angeles and San Francisco, with a statewide aggregate capacity around 1.9 million barrels of oil per day. California's petroleum market is somewhat isolated from that of the rest of the United States. While California imports 57% of its crude oil from foreign sources (primarily Saudi Arabia, Ecuador, Iraq, and Colombia) and a further 12% from

Alaska [8], it imports very little finished fuel [9]. Pipeline connections to the rest of the continental United States are limited, with a few refined product pipelines distributing fuel from coastal refineries to markets in central California and Western Nevada. One significant pipeline connects the Los Angeles market with Phoenix, AZ. However, this pipeline generally conveys refined products from California Eastward rather than bringing products into the California market. The majority of petroleum trade through California occurs by ocean-going tanker or barge via petroleum terminals in San Francisco and Los Angeles.

Electricity: The electric grid has not traditionally been considered a component of transportation infrastructure, beyond some use of electricity for pipelines and commuter rail. As electric transportation becomes more widespread, the two sectors are becoming more linked. Relevant infrastructure includes generation, transmission, and especially the distribution and charging systems used to recharge electric vehicles. Electric utilities investment in charging infrastructure and grid upgrades to account for increased loads and demand management is critical for increasing the adoption of electric vehicles.

1.1.3 Transportation and the economy

Access to jobs requires high-quality safe, and accessible transportation services. In the many parts of the state where transit and cycling infrastructure is insufficient, this means owning a car, which creates equity issues. Indeed, access to a reliable vehicle is one of the strongest predictors of economic mobility for lower-income Californians [10]. Car access has ironically become especially important to Californians working in urban areas. Though it is generally easier to travel car-free within urban areas, very high housing costs and lack of multimodal infrastructure has made it impossible for many urban workers to have convenient and affordable access to jobs and other essential destinations by modes like walking, biking, and transit.

Movement of goods is also essential for the state economy. As of 2017, almost $1.5 trillion in shipments originated in California (over 10% of the value of total U.S. shipments)[10].

The rest of this section examines four key components of transportation in California. These are:

- Light-duty vehicles (LDVs): cars and light trucks (including pickups and SUVs). Most of these vehicles are personally owned and operated.
- Medium- and heavy-duty vehicles (MDVs and HDVs): generally defined as vehicles over 10,000 pounds, this subsector includes vehicles primarily used for the movement of goods.
- Vehicle miles traveled (VMT): the total miles travelled by all vehicles in the state, often used as a measure for demand. VMT is shaped by many factors and personal decisions, including land use, housing, mode choice, location of jobs and destinations, availability of biking and pedestrian infrastructure, and distribution of goods.
- Fuels: including all fuels that supply energy to transportation vehicles, such as gasoline, diesel, hydrogen and electricity.

1.2 Light-duty vehicles (LDVs)

1.2.1 Overview

With the introduction of a variety of new plug-in electric vehicles (PEVs)—including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)—in the last decade, the market share of PEVs in California has been increasing annually. These vehicles, together with light-duty fuel cell electric vehicles (FCEVs), are commonly referred to in California as zero emission vehicles (ZEVs). The following section explores the state of ZEVs in California in 2020. The analysis synthesizes a large variety of data sources, including dealer association sale records, Department of Motor Vehicles (DMV) records, state agency records, and data collected by the UC Davis PH&EV Research Center. The analysis discusses vehicles as well as charging infrastructure, focusing mostly on the plug-in light-duty segment.

1.2.2 California's light-duty vehicle fleet

In 2018, according to the California DMV there were approximately 30 million LDVs in California. Gasoline-powered and other conventional-fuel vehicles still constitute 98% of the fleet (Figure 5). In order to reduce GHG emissions from the transportation sector and achieve carbon neutrality by 2045, the LDV fleet that is currently heavily dependent on fossil fuels needs to be almost entirely replaced by BEVs, PHEVs, and FCEVs, using very low to zero carbon electricity and fuels.

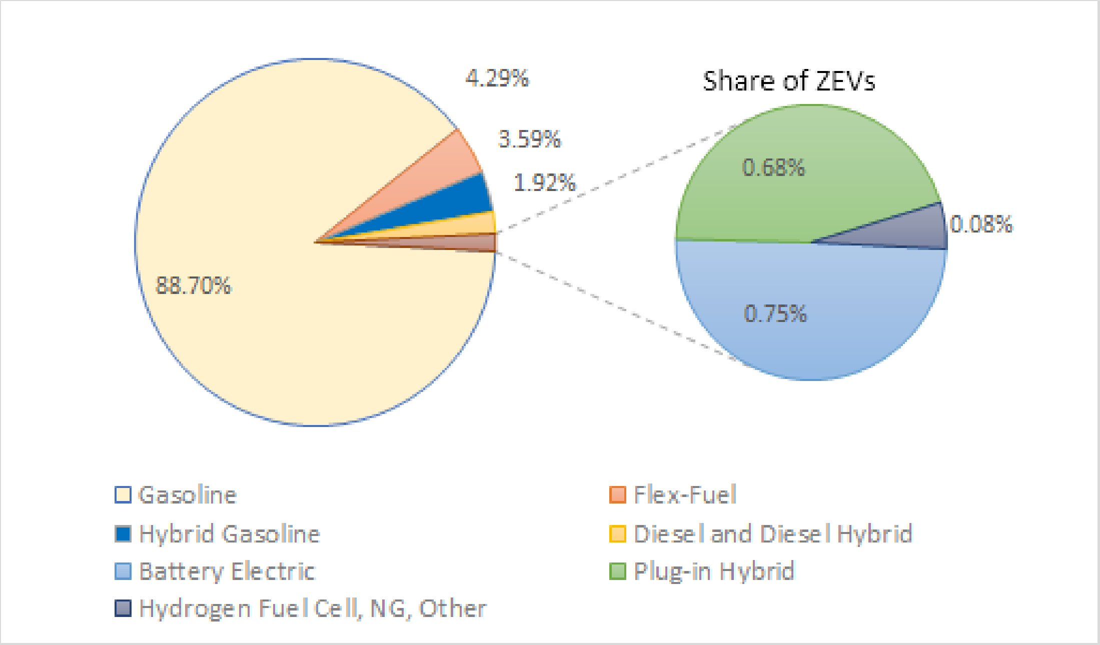


Figure 5. California LDV Fleet Composition (2018) by Fuel Type (CA Department of Motor Vehicles, published 2019)

Table 1. Total vehicle population by drivetrain type (2018)

Fuel Type	Count of Vehicles
Gasoline	26,685,840
Flex-Fuel[1]	1,290,066

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[1] The classification follows from DataOne Vindecoder definitions of fuel type.

Hybrid Gasoline	1,079,558
Diesel and Diesel Hybrid	577,819
Battery Electric	225,240
Plug-in Hybrid	204,002
Natural Gas	14,527
Hydrogen Fuel Cell	5,138
Other	4,926
Grand Total	30,087,116

The market share of BEVs and PHEVs (collectively known as PEVs) has been increasing over the past decade. Note that the share of hydrogen fuel cell vehicles (FCEVs) has been considerably lower than the share of BEVs and PHEVs, largely due to price, limited supply and limited public fueling infrastructure, few available models, and low consumer interest so far. According to the California DMV and data reported by the California New Car Dealers Association, the share of PEVs in total new vehicle sales/registration went up from 3% in 2014 to 8% in 2019 (Figure 6). The share of PEVs in the total LDV stock of California increased from 0.4% in 2014 to 1.43% in 2018.

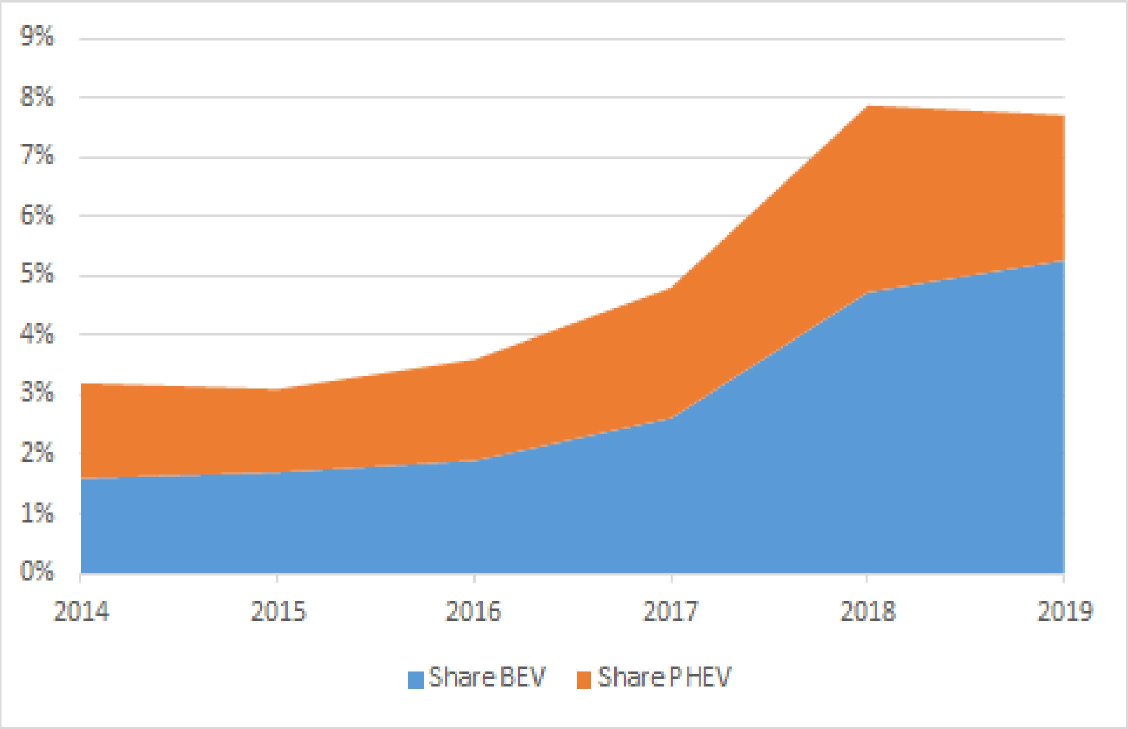

Figure 6. Share of BEVs and PHEVs in New Vehicle Registration (Source: California New Car Dealers Association)

The deployment of vehicles so far is not evenly distributed across income groups; areas with higher income populations and more total vehicles have a higher share of electric vehicles. (Figure 7)

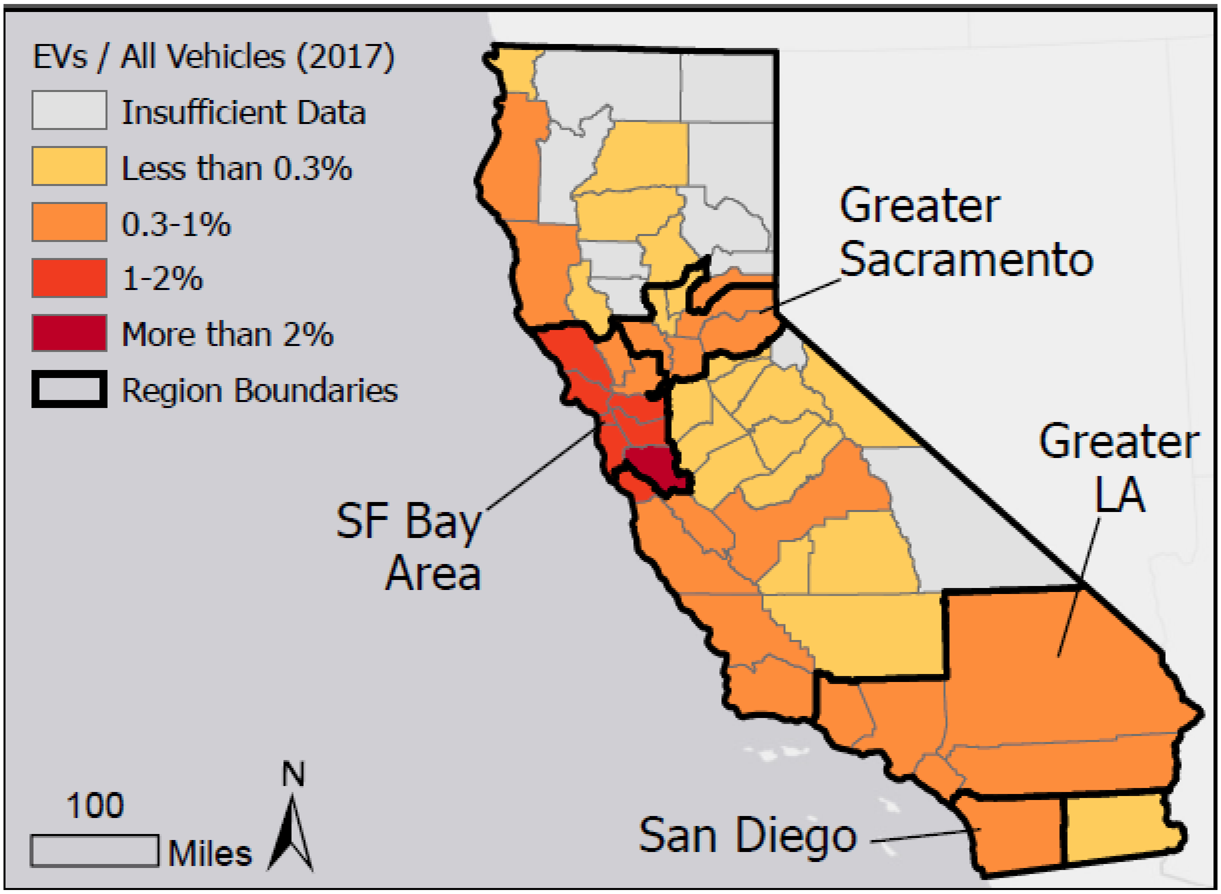

Figure 7. EVs as share of all vehicles

Over the years, federal and state governments, electric utilities, and a number of other stakeholders have provided support in the form of monetary and non-monetary incentives to accelerate EV purchases from qualifying manufacturers. For a limited number of first-time eligible EV buyers, rebates can go up to $7,000 towards the purchase or lease of a new PHEV, BEV, or FCEV, where the total includes increased rebate amounts for income-qualified applicants. It might be useful to note that CVRP rebates can be stacked incentives as well with qualifying PEV buyers receiving a rebate of $2000 under the Clean Vehicle Rebate Program (CVRP) for BEVs and $1000 for PHEVs. Past research has shown that every $1000 offered as a rebate or tax credit can increase average sales of PEVs by 2.6%. Incentive programs designed to encourage the adoption of PEVs have also been revised over the years to ensure equity through programs like the “Clean Cars 4 All” in California.

The share of BEVs compared to PHEVs has been increasing over the years (though as a caveat, this is based only on the vehicles receiving a vehicle rebate). In 2014, 56% of the CVRP applications were for BEVs and 43% were for PHEVs. In 2019, these numbers were 71% and 26%, respectively (Figure 8). One thing to note is that not all the BEV and PHEV models available in the market are eligible for the CVRP rebate. A PEV is not eligible for CVRP rebate if the base manufacturer suggested retail price (MSRP) of a PEV is more than $60,000, or the PHEV does not have at least 35 mile electric range, the eligible model is more than two years old, or the PEV does not meet the required tailpipe emission standards [11]. In general, though PHEVs have a major role to play as a transitional technology, it is necessary to have a higher share of BEVs with zero tailpipe emission in the LDV fleet to achieve carbon neutrality by 2045.

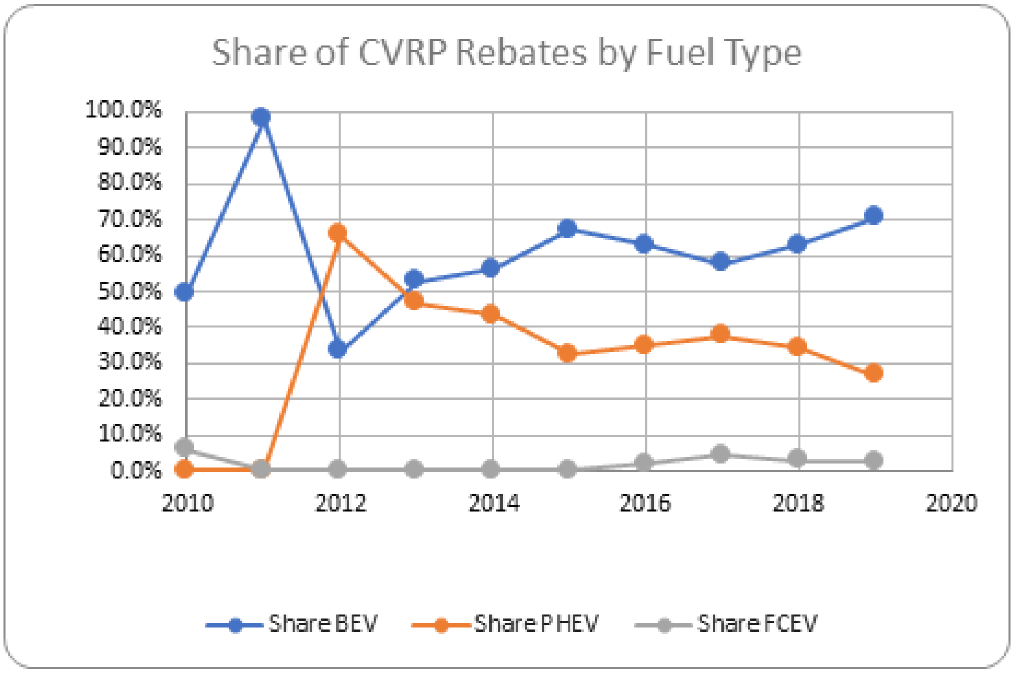

Figure 8. CVRP Applications by Fuel Type (2010-2019)[2]

When it comes to BEVs, a large share of the rebates in the past four years has gone to Tesla buyers while the share of Nissan Leaf rebates has dropped among first-time BEV adopters. In the case of PHEVs, adopters of the Chevrolet Volt, Toyota Prius Prime, and the PHEVs offered by Ford like the Fusion and the C-Max Energi have claimed the majority of CVRP rebates (Figure 9 and Figure 10)[3]. The shift from first generation BEVs such as the Nissan LEAF to longer range vehicles such as the Chevrolet Bolt and Tesla (Model S, Model 3, or Model X) and the higher share of longer range PHEVs in the LDV fleet may lead to a higher share of electric miles driven.

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[2] In 2011, the PHEV share of the CVRP rebates was zero even though the Chevrolet Volt was introduced concurrently with the Nissan LEAF because the former didn't meet the required super ultra-low emission vehicle tailpipe emission standards.

[3] The Ford Fusion and C-Max Energi are no longer eligible for the CVRP rebate.

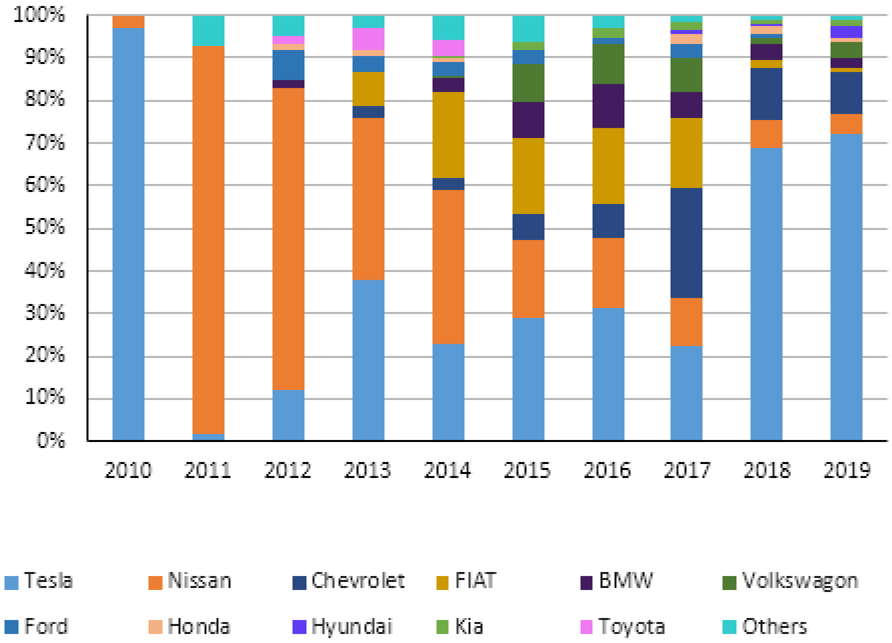

Figure 9. CVRP Applications by Vehicle Make (BEVs)

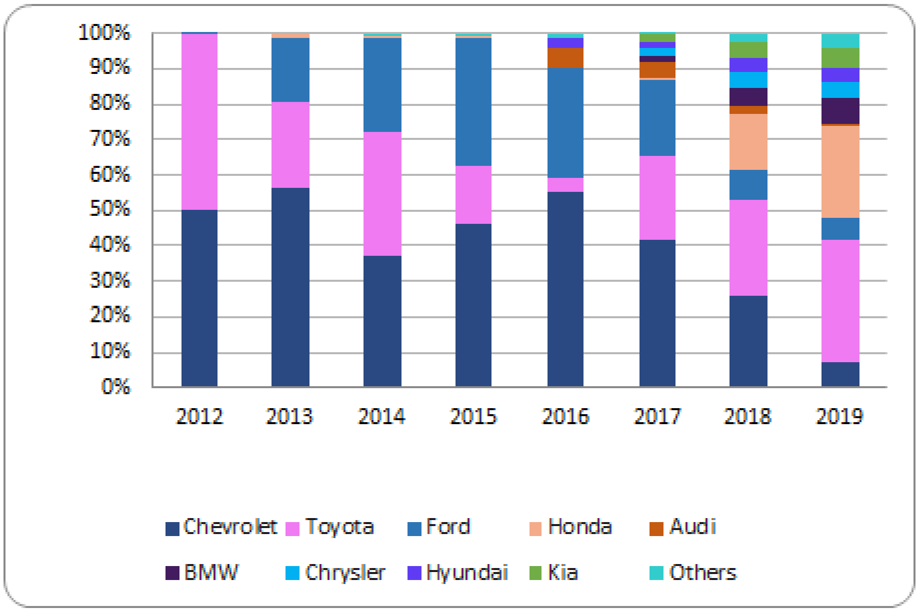

Figure 10. CVRP Applications by Vehicle Make (PHEVs)

In addition to the monetary and non-monetary incentives (e.g., High-Occupancy Vehicle (HOV) lane access) offered to PEV adopters, household socio demographics, access to charging infrastructure, and vehicle-buyer characteristics (e.g., environmental attitudes and social networks) play an important role in the decision to adopt PEVs .household The impact of incentives is also heavily impact by the public awareness of the PEV and incentives availability and by the supply of those vehicles [12].

One of the major barriers in PEV adoption is the high purchase price of these vehicles in comparison to a gasoline-powered vehicle in the same vehicle segment. In this scenario, used PEVs with a lower purchase price can play an important role in increasing the market penetration of PEVs. Though the market for used PEVs is still nascent, the numbers have been going up in the past few years. According to the California DMV vehicle registration data, between 2016 and 2017, the sales of used BEVs went up by 30%.[4] Considering both BEVs and PHEVs, the market for used PEVs increased by 15% (Figure 11). One can hypothesize that the recent increase in the number of PEV transactions in the secondary market is influenced by leased vehicles that have been returned after the lease period.

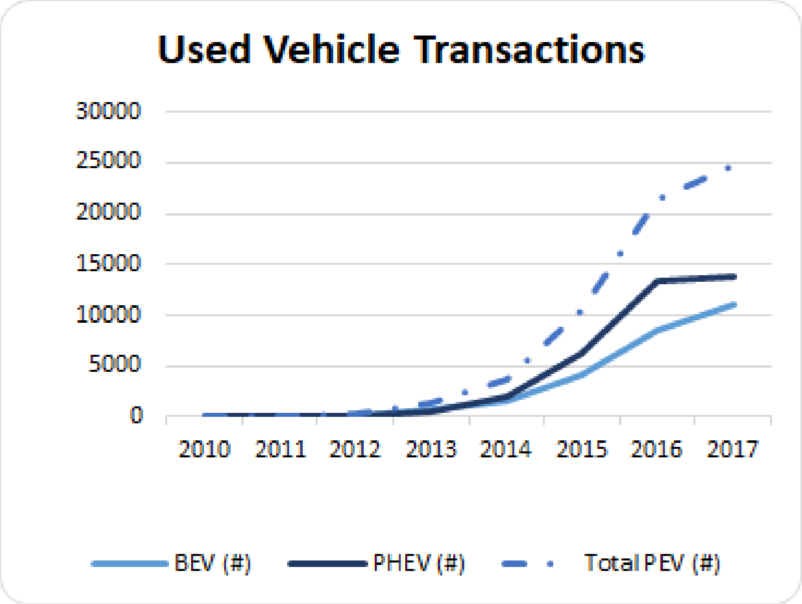

Figure 11. Used PEV transactions in California

In terms of spatial distribution, California DMV data indicates that distributions of the used PEV market is similar to the distribution of new PEV sales. In other words, factors mentioned above (like social network or neighborhood effect and access to charging infrastructure) that influence an individual's exposure to new technology also play an important role in the used PEV market. However, the market for used PEVs is less concentrated than for new PEVs. Analysis of the distribution of new and used PEVs was performed using the Lorenz curve and Gini coefficients, two standard economic measures of inequality. The Lorenz curve in Figure 12 shows the cumulative proportion of the California's PEVs on the vertical axis, with the cumulative proportion of all vehicles on the horizontal axis, and the Gini coefficient measures the area between the curves and the diagonal line labeled "equal distribution." If PEVs were evenly distributed throughout the state, the curves would follow the diagonal line, and the Gini coefficient would be 0. If PEVs were completely concentrated in a single area, the curve would be almost flat at 0% on the vertical axis, and the Gini coefficient would be 1. Analysis of the distribution of new and used PEVs in California as a proportion of all vehicles shows that while all electric vehicles are densely concentrated in a small number of zip codes in particularly dense areas, used PEVs are somewhat less concentrated than new PEVs (Figure 12). The Lorenz curve for used vehicles is closer to the line of equality than the curve

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[4] Only tracking in-state transactions. The DMV data does not allow us to identify whether an older vehicle (older model year) originally registered out of state is a used vehicle transaction or whether the household moved to California from a different state. We do not have access to DMV data for 2018 or later years.

for new vehicles, and the Gini coefficient for used vehicles (0.422) is somewhat lower (0.566). This suggests that used PEVs are playing a role in expanding access to electric vehicles into new areas.

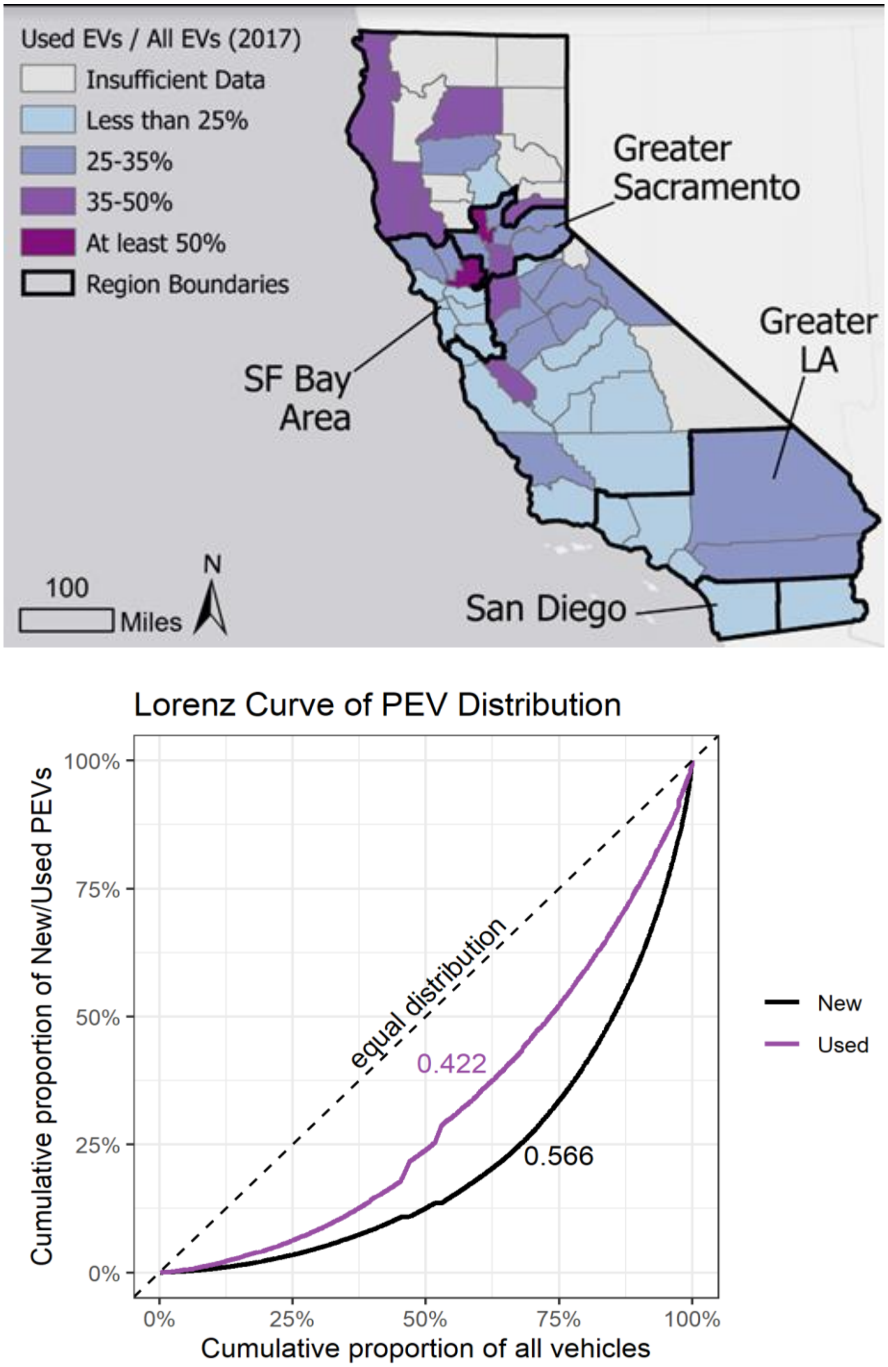


Figure 12. Spatial and Lorenz Distribution of Used and New PEVs in California

1.2.2.1 Vehicle Charging Infrastructure

Though a variety of alternative-fuel vehicles have been developed over the last decade, plug in-electric vehicles are being adopted most rapidly as an alternative to internal combustion engine (ICE) vehicles. In contrast to ICE vehicles, PEVs can be refueled (charged) anywhere if an electrical outlet is available. Currently, three types of chargers are commonly used by PEV drivers in the U.S.—Level 1 (L1), Level 2 (L2), and DC fast—each of which have different charging powers.

Charging an electric car can be as simple as plugging in your phone into home power. Almost 80% of the light duty vehicles in California used by detached houses dwellers and are more likely to be able to charge at home. For multi-unit dwellings overnight charging will require public infrastructure installations [13]. Charging can also be similar to refueling a gasoline car, where you start by using your credit card and then plugging in a large nozzle. (Figure 13) summarizes different charging types.

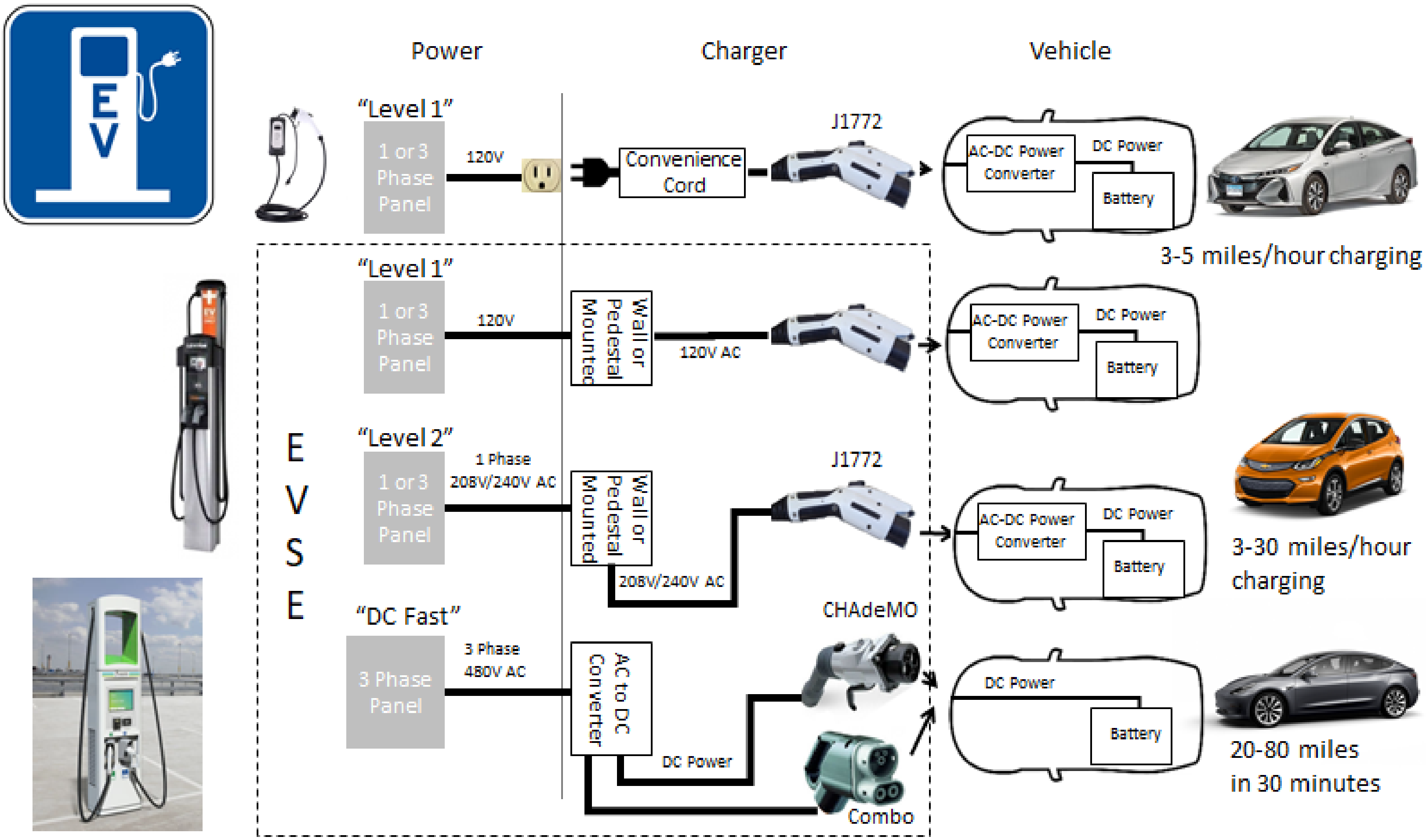


Figure 13. Charging options at Home and Electric Vehicle Supply Equipment (EVSE) Types

According to the UC Davis PH&EV Center survey that include a 7 days charging diary [14]. Home charging is the most common choice for PEVs. In many cases home charging relies on L1 convenience cords charging, thereby circumventing the need to install additional charging infrastructure. For longer daily trips or larger battery L2 EVSE chargers are more common. (Figure 14)

Charging while at work at designated workplace charging or at a public charger are the second-most common charging options, after home charging. Together, home and work charging cover more than 80% of total charging events. To estimate the number of chargers available in California, we combined data from two publicly available sources (Plugshare [15] and the alternative Fueling Station Locator [16]), removing duplicated locations that appear in both datasets and compare this against data from the PH&EV Center surveys on workplace charging locations of more than 15,000 PEV users in California (Table 2).

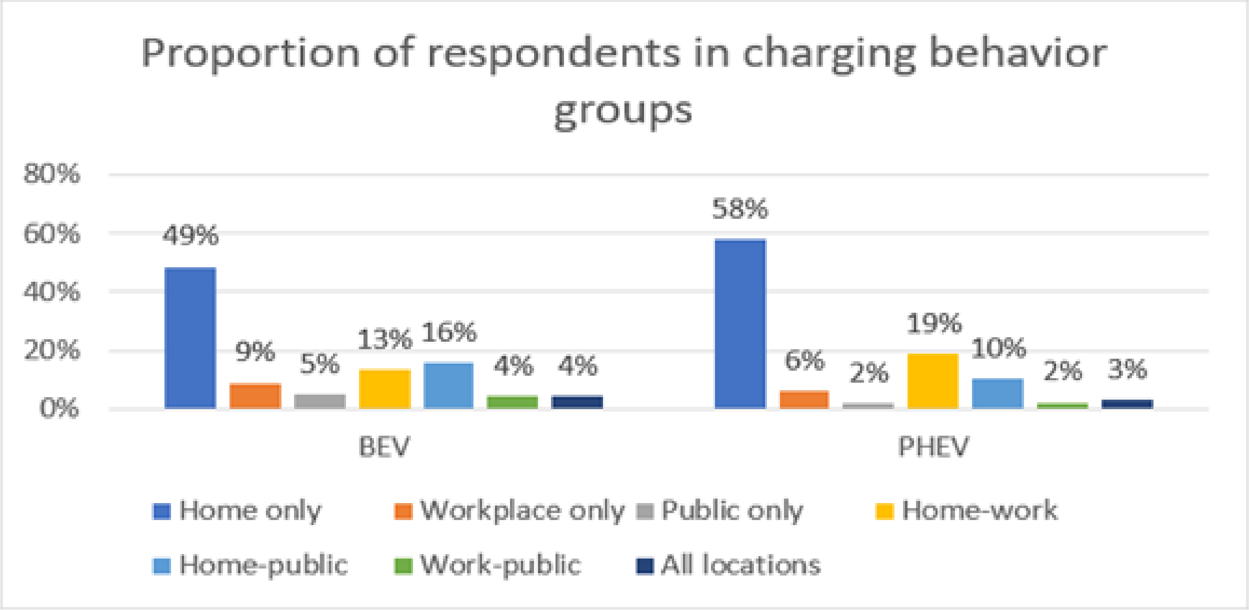


Figure 14. Charging Behavior of BEV and PHEV Users Who Responded to the Initial Survey (N=7,979)

Table 2. Number of chargers California 2020

Region	Workplace Chargers at least:	Public Level 2	Public DCFC
Greater Sacramento	600	1,600	500
San Francisco Bay Area	15,500	9,500	2,300
Greater Los Angeles	17,400	12,100	2,700
San Diego	2,300	2,200	500
Rest of California	1,600	2,800	1,400
Statewide Totals	37,600	28,200	7,400

The total number of workplace chargers available for commuters is higher than the total number of public chargers by more than 20%. Workplace chargers are more common in California's main metropolitan areas (Figure 15).

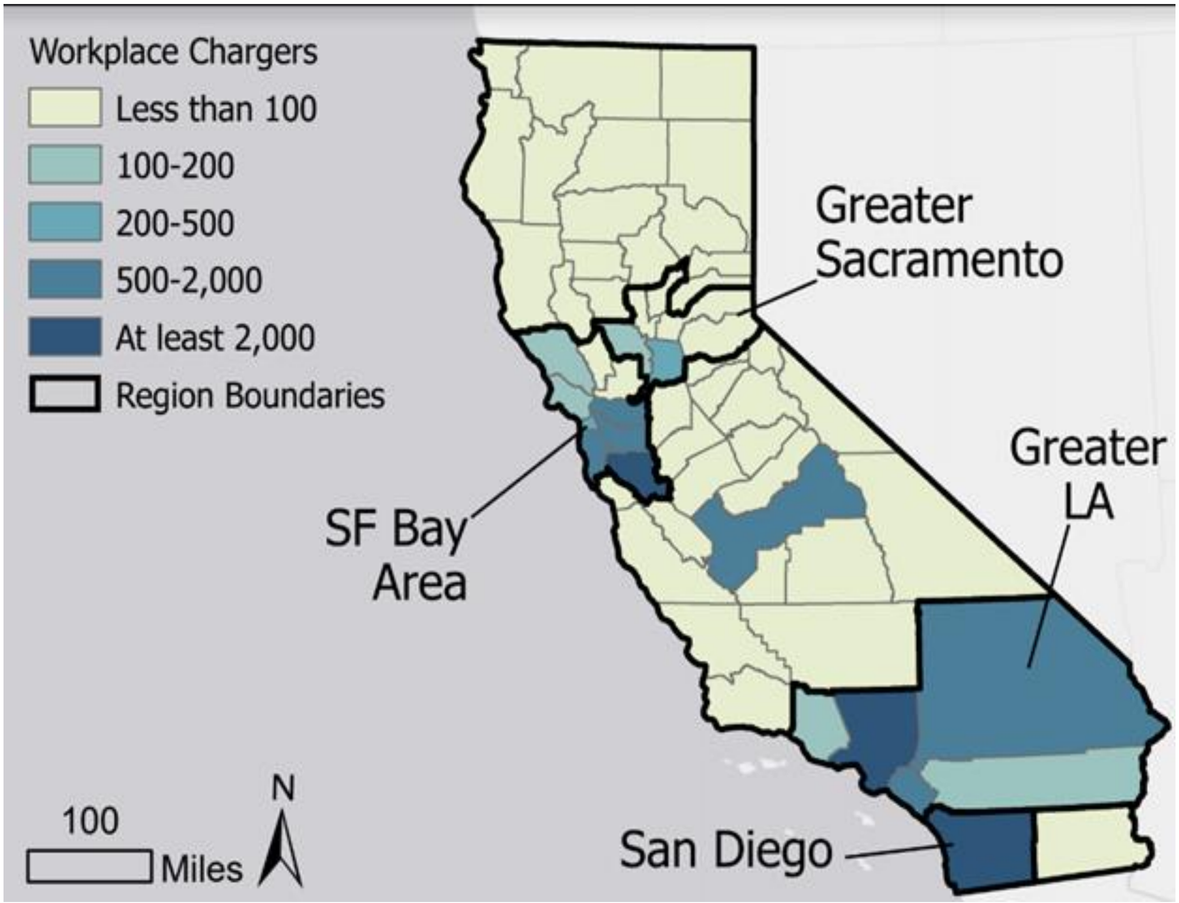


Figure 15. Fast charging distance from Home

DC fast chargers are mostly used for BEVs around home as a substitute for home and work charging, when more charging is needed and in a few cases for trips longer than the range of the vehicle.

A recent analysis by the PH&EV Center of about 200 vehicles over a year shows that most DC fast charger events happen within 40 miles from home. Only 7% of the Bolt (240 miles range) fast charging happens more than 100 miles from home and about 17% of the Tesla charging events happened on long trips away from home. (Figure 16).

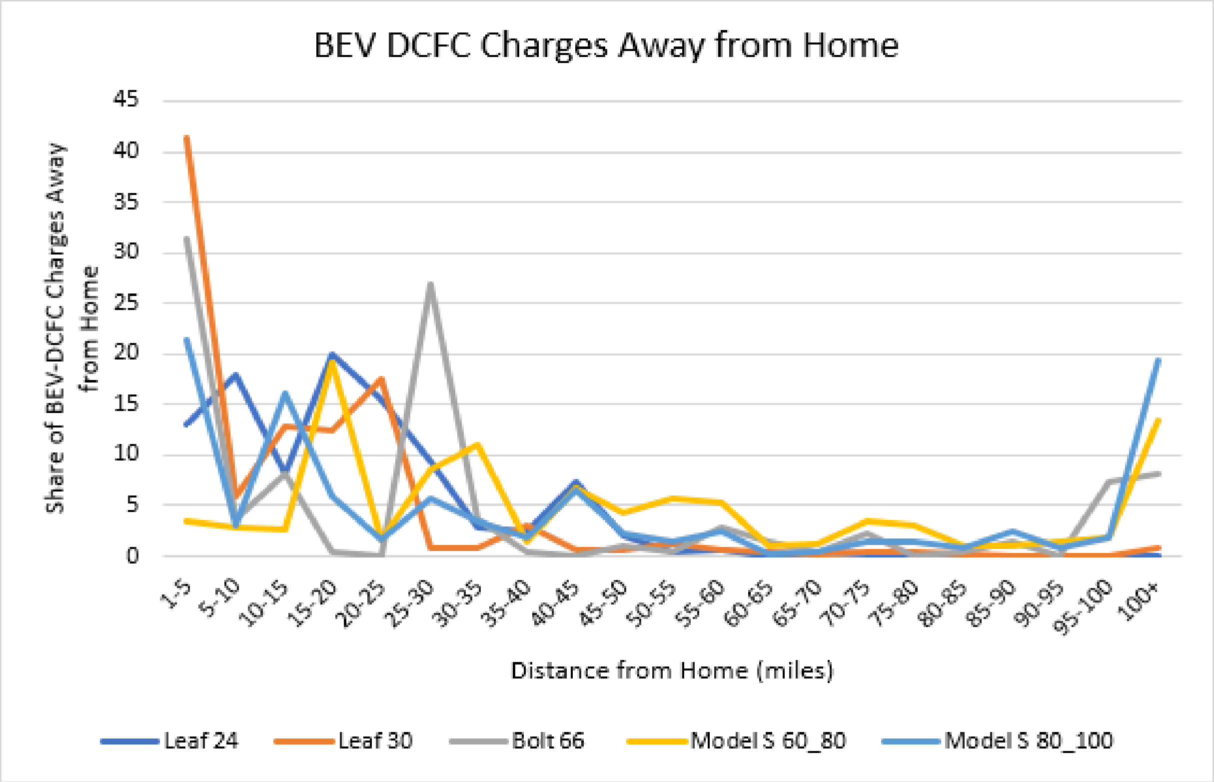
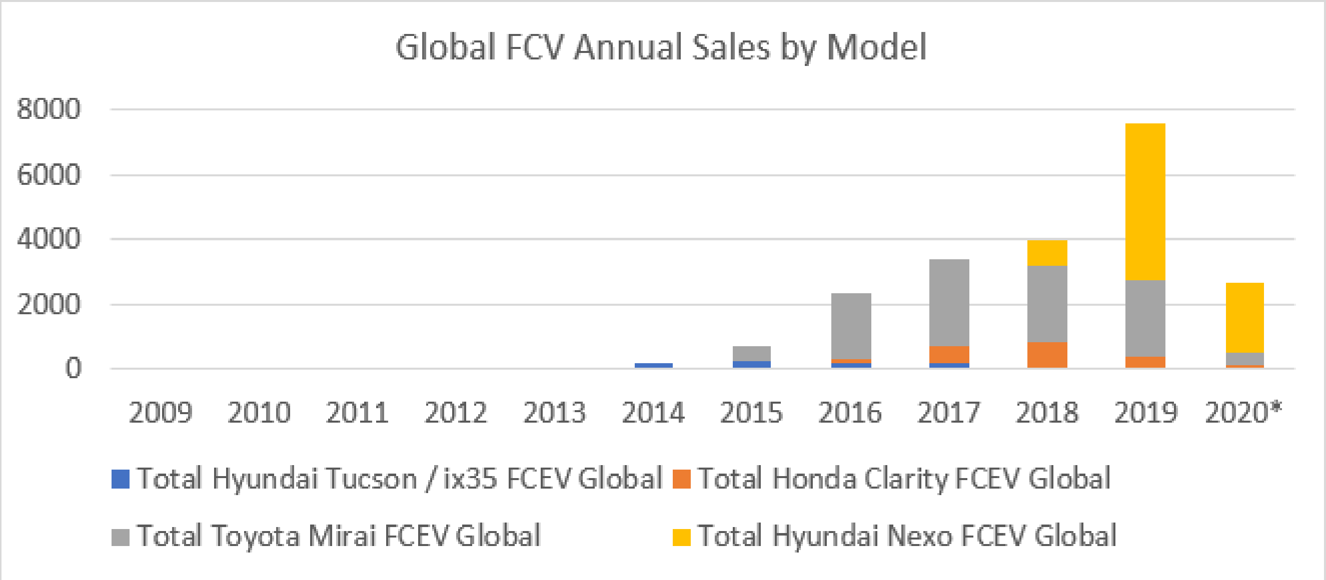


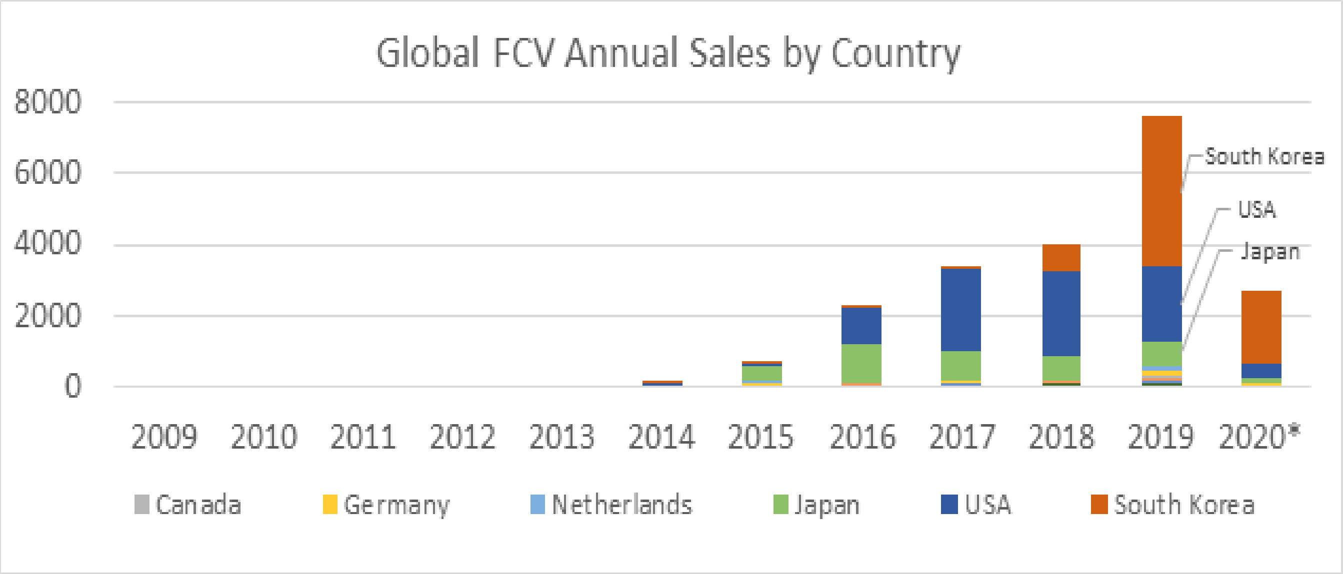
Figure 16. Fast charging frequency by distance from home

1.2.3 Fuel cell vehicles

Several automakers are promoting FCVs to consumers. These vehicles are often compared to BEVs. Both vehicle types have zero tailpipe emissions, can be fueled by renewable energy, and are driven by electric motors. Apart from purchase price, the key difference between these vehicles is their driving range and refueling style. When BEVs were first introduced into the market, most had driving ranges of 100 miles, though BEVs with almost 400 miles of range are now available. FCVs have driving ranges of more than 300 miles (and may be longer with larger hydrogen tanks) and can be refueled in less than 10 min at a hydrogen fueling station. Unlike PEVs, FCVs are still in earlier phase with very low volumes of production and in most cases lease only agreement that include free hydrogen. The following section explores the global market in which California is the largest player, though other markets such as South Korea will likely overtake the CA market in 2020 Our data does not separate between the USA and California market but because of lack of publicly available refueling infrastructure outside of California we assume that all privately used FCVs sold in the US are in California. Three original equipment manufacturers (OEMs) currently offer FCVs in California, with the Toyota Mirai being the most common (Figure 17). Sales of these vehicles began in 2014, with most vehicles leased for a period of three years. OEMs generally subsidize hydrogen fuel cost, which would otherwise be much higher than for PEVs and internal combustion engine vehicles (ICEVs).



Note: Sales data does not include limited production vehicles.



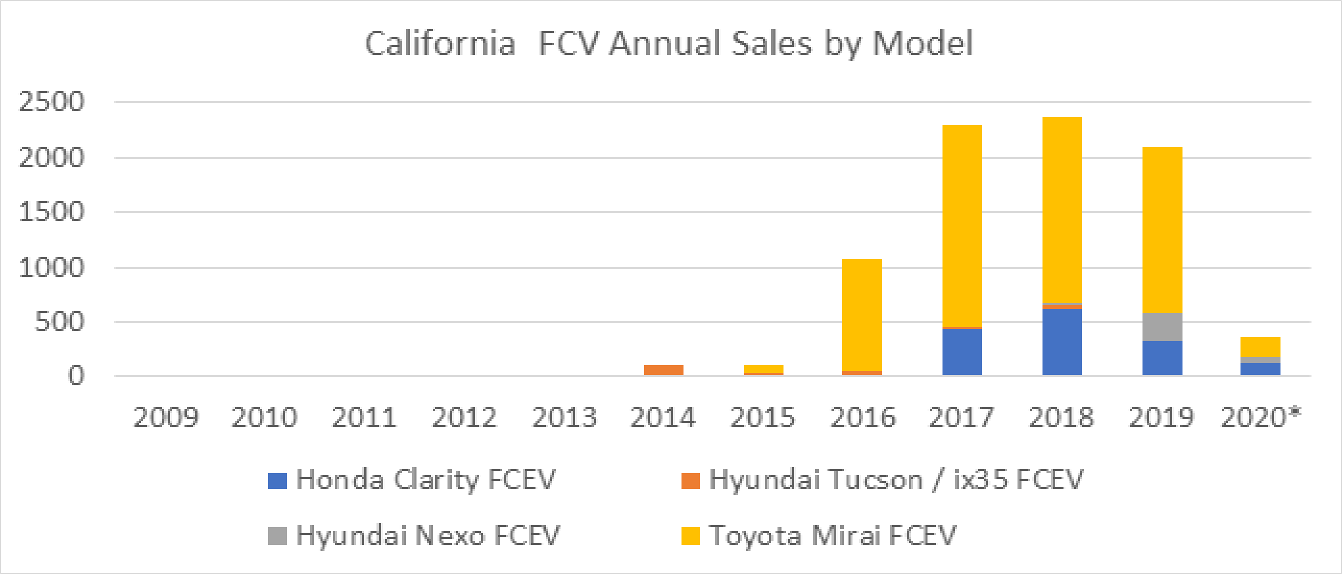


Figure 17. Fuel Cell Vehicle Sales by Model, Country, and Model for California

As of 2020 California currently has 43 active hydrogen-fueling stations, built through a combination of industry funds and capital and operating cost support from the California Energy Commission (CEC). These are predominantly located in the Los Angeles, San Francisco Bay, and Sacramento Bay areas as shown in (Figure 18) below.

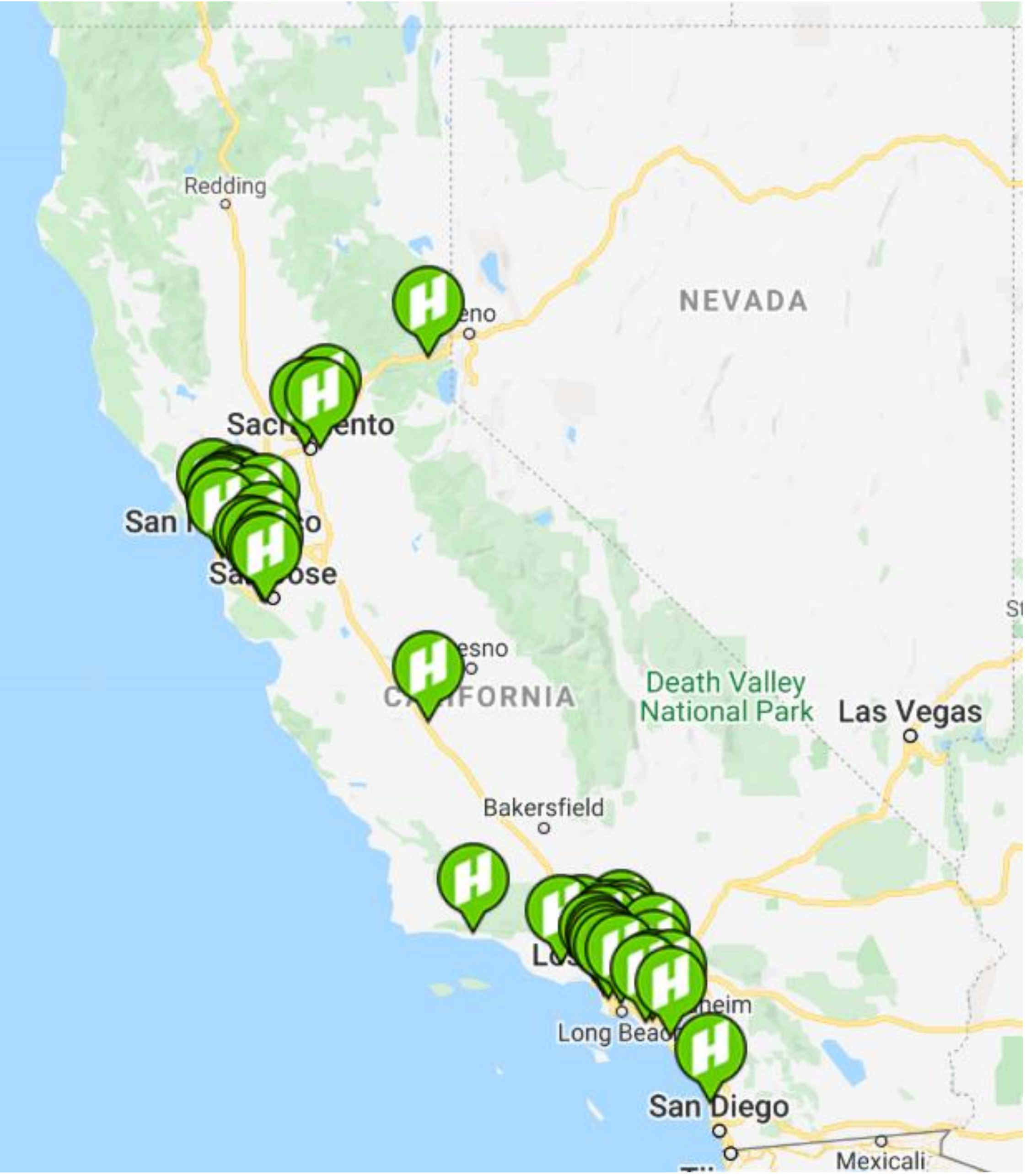


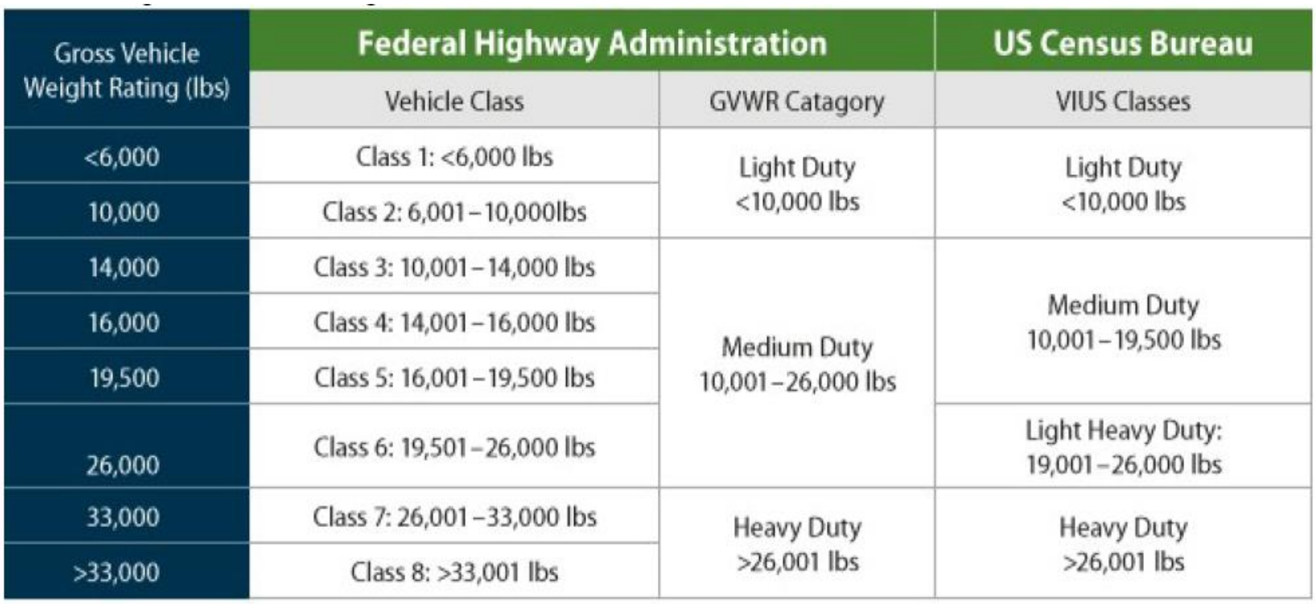
Figure 18. California Active Hydrogen Station Map. Source: https://cafcp.org/stationmap

1.3 Heavy-duty vehicles (HDVs)

1.3.1 Total number of HDVs

To characterize HDVs, we relied on the widely used eight vehicle classes defined by the Federal Highway Administration (FHWA) and the U.S. EPA. These classes are based on gross vehicle weight rating (GVWR), which represents the maximum weight of a vehicle (vehicle weight + fuel + passenger weight + cargo weight) as specified by its manufacturer. **Error! Not a valid bookmark self-reference.** summarizes FHWA weight classes and categories.

Table 3. FHWA weight classes (Source AFDC [17])



Gross Vehicle Weight Rating (lbs)	Federal Highway Administration		US Census Bureau
	Vehicle Class	GVWR Catagory	VIUS Classes
<6,000	Class 1: <6,000 lbs	Light Duty <10,000 lbs	Light Duty <10,000 lbs
10,000	Class 2: 6,001–10,000lbs		
14,000	Class 3: 10,001–14,000 lbs	Medium Duty 10,001–26,000 lbs	Medium Duty 10,001–19,500 lbs
16,000	Class 4: 14,001–16,000 lbs		
19,500	Class 5: 16,001–19,500 lbs		
26,000	Class 6: 19,501–26,000 lbs		Light Heavy Duty: 19,001–26,000 lbs
33,000	Class 7: 26,001–33,000 lbs	Heavy Duty >26,001 lbs	Heavy Duty >26,001 lbs
>33,000	Class 8: >33,001 lbs		

(Figure 19) displays the number of trucks in California for selected categories. Between 2011 and 2020, there was a steady increase in the number of long-haul (more than 200 miles from origin to destination) (+40.5%), short-haul (+58.1%), and heavy-duty vocational trucks (+37.5%). The number of heavy-duty pickups and vans also increased, but only by 10.5% (not shown because the number of heavy-duty pickups and vans is much higher than for other categories of trucks in California). This growth was partly due to the expansion of the logistics industry (~+67% in revenue for the US between 2010 and 2018; see [18]), the development of online shopping, and to a lesser extent to population growth in California (+7.2% between 2010 and 2019; see [19].

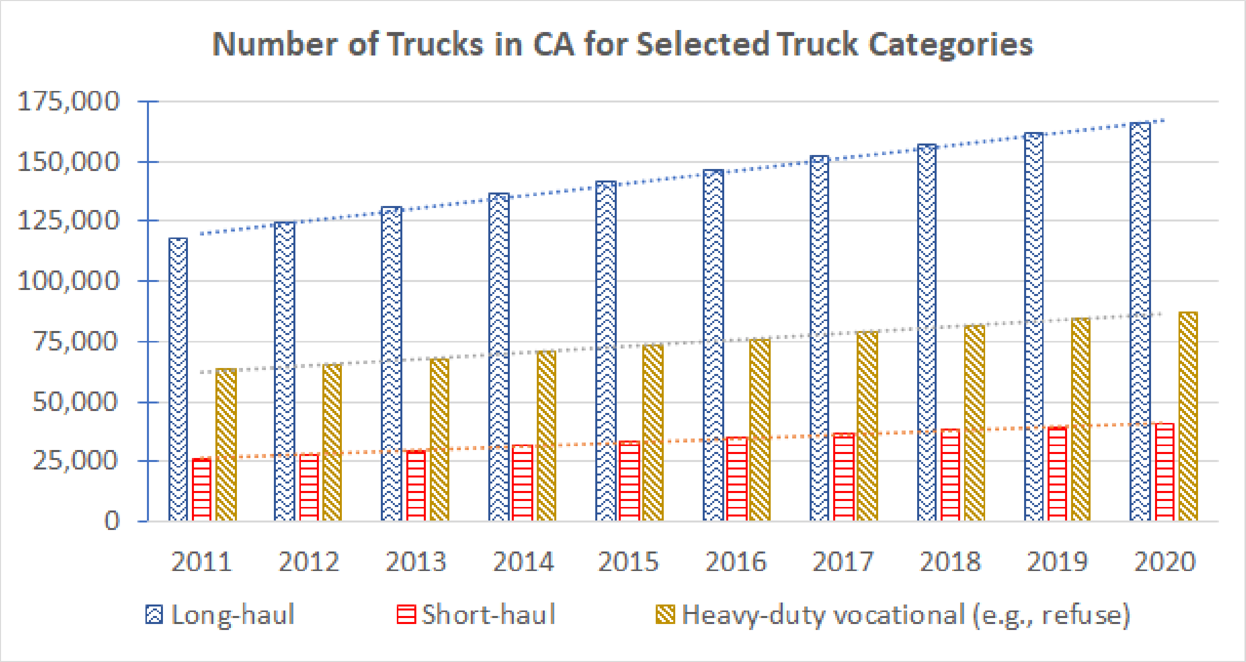


Figure 19. Number of California trucks in selected categories

1.3.2 Duty cycles and types of trucks

Currently, approximately 98% of Class 8 HDVs are powered by diesel ICEs, and the balance by natural gas (NG) engines [20].

Whereas LDVs typically serve to transport drivers, passengers, and occasionally small amounts of cargo from one location to another, HDVs tend to be specialized in sets of tasks, such as hauling goods over long distances, transporting containers from ports to distribution centers or railyards, transporting sand or gravel to cement plants, or collecting refuse from households and bringing it to landfills. This specialization decreases economies of scale attainable with LDVs and increases the cost of transitioning to alternative fuels.

(Figure 20) gives a picture of the change in the number of alternative-fuel trucks in California (based on EMission FACtor [EMFAC] 2017 [20]). A comparison with Figure 19 confirms that alternative fuel trucks are still only a very small percentage of trucks in California, although their numbers are growing (especially for hybrid and compressed NG trucks).

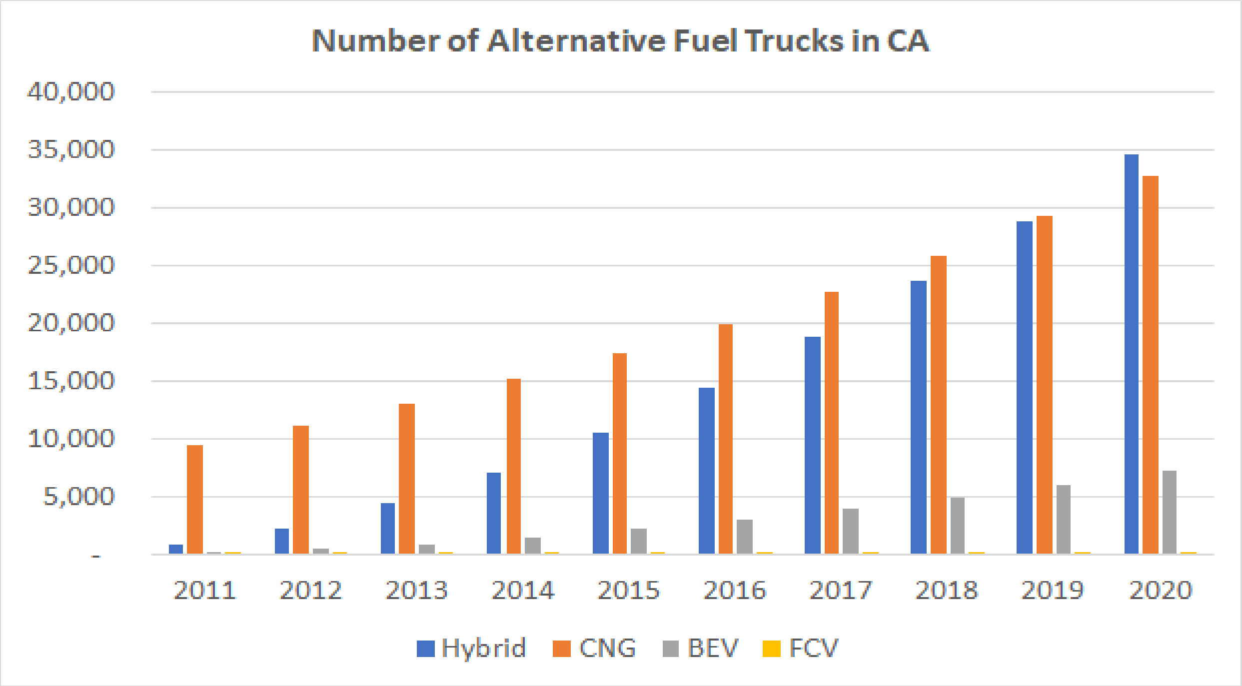


Figure 20. Number of Alternative Fuel Trucks in California

1.3.3 HDV VMT

According to the U.S. Department of Energy (DOE) [21], Class 8 HDVs drive the most miles per year per vehicle (Figure 21) and they are responsible for a disproportionate share of GHG emissions and local air pollution.

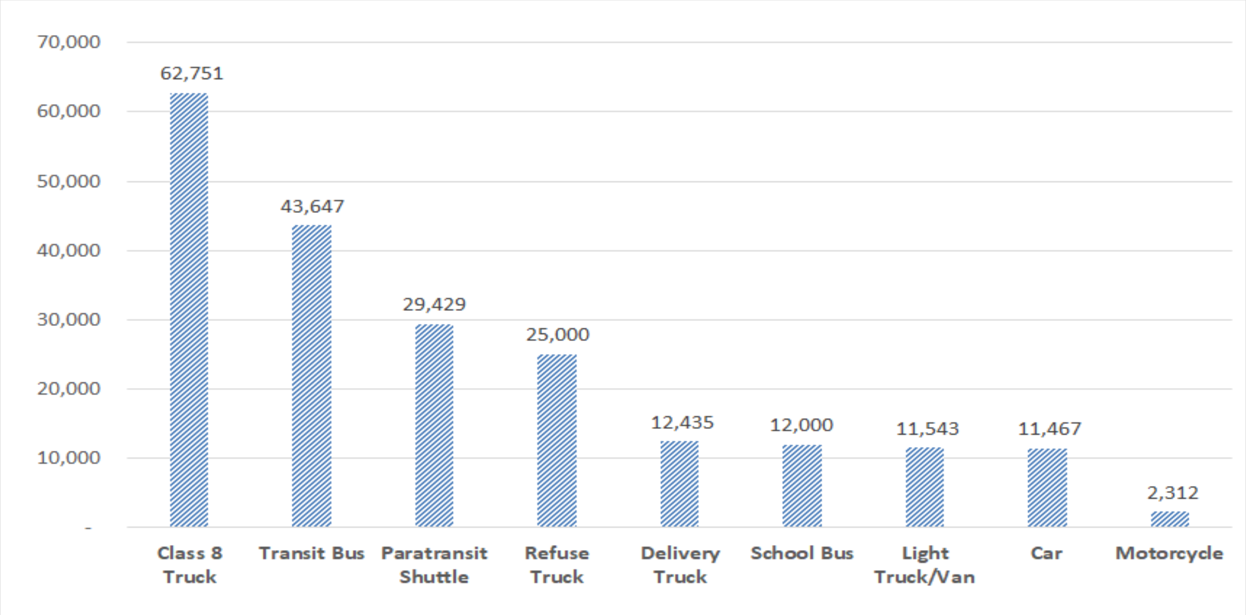


Figure 21. Average Annual Vehicle Miles Traveled per Vehicle by Major Vehicle Category

In the United States, VMT has increased over the long run with population and GDP, and has decreased at times with increased fuel prices [22]. Assuming that VMT growth will continue as business as usual (BAU), (Figure 22) shows how daily VMT in California (broken down between light duty and heavy duty vehicles) might have changed without the COVID-19 pandemic.

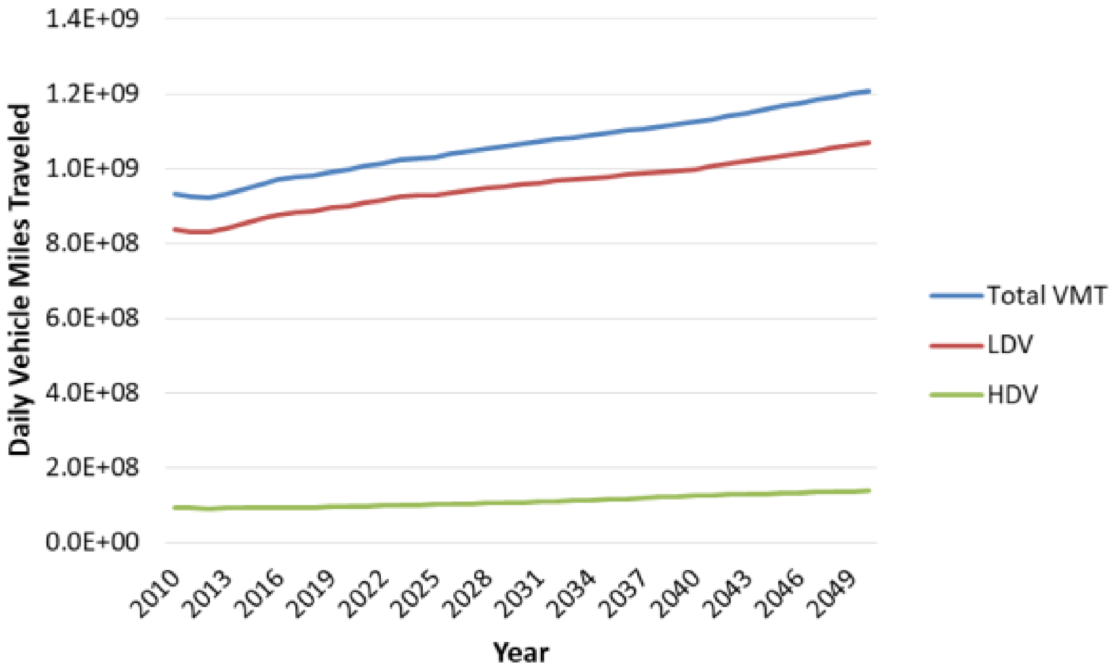


Figure 22. Daily VMT in California - ARB Baseline Projections

1.3.4 Alternative Fuel HDVs

Apart from HDVs powered by ICEs (ICE, 98% of which currently run on diesel fuel), several other powertrain technologies are likely to play a role in the future of HDVs: hybrid electric vehicle (HEV), PHEV, BEV, FCEV, and plug-in fuel cell electric vehicle (PFCEV) technologies.

HEVs add an electric motor and batteries to an ICE to improve energy efficiency. At low speeds, HEVs can run on their electric motor which is more efficient than their ICE and reduces GHG emissions. Moreover, when a HEV truck needs to brake, the electric motor can be run in reverse to slow the truck down, storing some energy in the battery and extending brake-pad life.

PHEVs are a variation on HEVs. The main differences are that they (1) can be recharged by an external electricity source when idle, and (2) have larger batteries, which extend their electric-only range.

Whereas HEVs and PHEVs have both an ICE and an electric motor, BEVs are powered only by electric motors and are equipped with larger batteries. BEVs are more efficient than similar vehicles with other types of powertrains, and they generate no air pollution or GHGs during their operation (the production of the electricity used to recharge their batteries may, however, generate both depending on the electric grid and when and where a BEV is charged). However, batteries are still relatively expensive and can add substantially to the weight of a vehicle therefore decreasing its useful load in certain applications. Charging time also remains an obstacle. Nevertheless, BEVs are under consideration for a number of vocations including buses, local delivery, drayage trucks, refuse trucks, and even long-haul trucks, including more than a dozen models currently available through the Heavy Vehicle Incentive Program.

An alternative technology to BEVs are FCEVs, which together can provide a broader zero-emission HDV strategy. In FCEVs, batteries are also included but with most power typically provided by a fuel cell system, which is an electrochemical device that converts the chemical energy of a fuel (typically hydrogen) and an oxidizing agent (typically oxygen) into electricity through a pair of redox reactions via proton exchange membranes. That electricity is sent to electric motors that propel the vehicle. Because hydrogen has a low volumetric density, it must be compressed and stored in a pressurized tank. To enhance their energy efficiency, FCEV HDVs, like battery-electric HDVs, will be equipped with regenerative braking. Like BEVs, FCEVs emit no air pollutants when they operate. We note that currently almost all of the hydrogen produced in the U.S. comes from the conversion of NG, which releases GHGs. California requires at least one-third of the hydrogen sold at fueling stations subsidized by the state to come from a renewable feedstock. Like ICE HDVs, FCEVs take little time to recharge. However, the lack of refueling infrastructure and vehicle weight are obstacles that still need to be overcome.

Finally, PFCEVs are an option that would borrow from FCEVs and PHEVs. They operate like PHEVs, but instead of an ICE, they are equipped with a fuel cell system like an FCEV. This makes PFCEVs more efficient than PHEVs as it removes the relative inefficiency of an ICE, but these vehicles are slightly more complex than FCEVs (although they offer more flexibility). These vehicles are not yet commercially available.

1.3.5 EV deployment

Zero-emission HDVs are an emerging market. Several automakers are already offering some vehicles for specific vocations, but the bulk of new offerings are yet to come. Table 4 shows some current and announced offerings by make and vehicle class.

Table 4. Examples of Heavy-Duty Zero-Emission Vehicles and Technical Specifications

Vehicle Make & Model	ZEV type	Vehicle type	Class	Battery size (kWh) H_2 capacity (kg)	Estimated fuel efficiency (kWh/mi or mi/kg)	Range
BYD	BEV	Bus	7, 8	324,500	>1.86, >1.97	156, 255
BYD	BEV	Day Cab	8	435	>2.47	124 (full-load) 167 (half-load)
BYD	BEV	Cab chassis / step van	6	221	>1.68	124 (full-load)-125
Cummins*	BEV	Truck	7	140	>1.33	100-300
Daimler / Mercedes*	BEV	Truck	7	240	>1.84	≤124
Einride*	BEV	Autonomous truck	8	200	1.6	124
Lightning Systems	BEV	Van	2B-3	43, 86	0.55	60, 120
Navistar eStar**	BEV	Van	3	80	0.74	99.4
Smith Newton**	BEV	Truck	6	80, 120	1.34	60, ≤150
Smith Newton**	BEV	Van	6	80	1.41	99.4

Tesla*	BEV	Truck	8	800 (est.)	<2	300, 500
Zenith Motors	BEV	Van	2B-3	51.8-74.5	>0.65	80-135
Proterra	BEV	Bus	7-8	220, 440	1.46-2.32	93-234
Phoenix Motorcars	BEV	Flatbed	4	105	>1.0	100
Nikola / Bosch*	FCEV	Truck	8	240 kWh, 9 kg	Not available	500-750
Toyota / Kenwood	FCEV	Truck	8	12 kWh, 40 kg	6 mi/kg	200, 300 (Gen 2)
Van Hool / UTC Power**	FCEV	Bus	8	53 kWh, 50 kg	4.79 mi/kg	240 (est.)
US Hybrid	FCEV	Step van	3	28 kWh, 9.78 kg	1.18-1.47 kWh/mi, 12.8 mi/kg	125

Notes.
1) Range assumes 95% discharge of battery capacity
2) *, ** denote respectively announced and on-road tested vehicles
Source: Forest, K. (2019).

Range assumes 95% discharge of battery capacity. *, ** respectively denote announced and on-road tested vehicles (Source: Forest, K., 2019).

The adoption of these vehicles over time depends on a number of factors, including purchase and operating costs, refueling infrastructure availability, reliability, and the relative costs of alternatives. We note that the evolution of purchase and operating costs depend on the pace of technological progress and adoption.

1.3.6 Fostering the adoption of alternative fuel HDVs

There are currently dozens of policies, programs, and funding opportunities in California and the US targeting emissions reductions from the HDV sector, many of which are trying to get vehicle owners to replace their diesel trucks with zero-emissions versions. A summary of the main programs is presented in Table 5. While programs range in scope and funding mechanisms (e.g., voucher, credits, loan), some of the more relevant programs for this project include the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program (HVIP), the Carl Moyer Memorial Air Quality Standards Attainment Program, and the Volkswagen Diesel Emissions Environmental Mitigation Trust. Most funding opportunities aim at reducing the high capital costs of low carbon/zero carbon vehicles and related infrastructure and accelerating their deployment. The Low Carbon Transit Operations Program (LCTOP) and the Transit and Intercity Rail Capital Program (TIRCP) fund clean transit, including electric buses.

While not a grant program, the federal Renewable Fuel Standard (RFS) and the California Low Carbon Fuel Standard (LCFS) programs provide credit-based incentives based on dispensed fuel amounts. This decreases the fuel costs for alternative fuel HDVs.

Although having many incentive programs is useful in principle, navigating funding programs and estimating their cost implications can be complex and may deter some truck owners, especially small owner-operators. A couple of tools are available to assist them in this process. The Funding Finder Tool from CALSTART provides a filterable list of available funding sources to support heavy-duty alternative fuel vehicle (AFV) adoption and infrastructure build-out [23]. The HVIP Total Cost of Ownership estimator calculates total cost of ownership (TCO) for program-eligible HDVs [24]. While helpful, these tools are limited in scope, and there remains a need for providing more comprehensive guidance to fleet operators.

The current reduction in fossil fuel prices has temporarily diminished the economic competitiveness of alternative fuels. In general HDV owners and operators focus on TCO [25]. In addition to the availability of various incentives that lower the purchase price of alternative fuel trucks, TCO also depends on fuel costs, maintenance costs, and reliability. The availability of refueling infrastructure is also important but depends on truck vocation. For example, public refueling infrastructure may not be very important for HDVs on fixed routes, such as urban buses or garbage trucks.

Table 5. Summary of HDV incentive programs

Program Name	**Agency / Organization**	**Program Description**
Carl Moyer Memorial Air Quality Standards Attainment Program (Carl Moyer Program)	CARB; All 35 Air Quality Management Districts (AQMDs)	Replacement, new purchase, repower, and retrofit trucks to reduce near-term air emissions; scrappage required. https://ww2.arb.ca.gov/our-work/programs/carl-moyer-memorial-air-quality-standards-attainment-program
Air Quality Improvement Program (AQIP); Low Carbon Transportation Program	CARB	Focuses on reducing criteria pollutants, diesel particulate emissions, and concurrent GHG emissions; Assembly Bill (AB) 32 Cap & Trade revenues applied to clean vehicle and equipment projects (mostly) for long-term GHG emissions reductions; https://ww2.arb.ca.gov/our-work/programs/low-carbon-transportation-investments-and-air-quality-improvement-program/low-1
Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program (HVIP)	CARB	Reduces up-front cost of cleaner, more efficient trucks and buses. HVIP works with dealers so the voucher incentive is applied directly at the time of purchase https://www.californiahvip.org/
Truck Loan Assistance Program	CARB	Focus is on near-term diesel emission reductions; funding so far has been for lower emission combustion vehicles. SB 1 allows only clean trucks to be registered with the California DMV. https://ww2.arb.ca.gov/our-work/programs/truck-loan-assistance-program
Low Carbon Fuel Standard (LCFS)	CARB	Credit-based incentive program aimed at reducing transportation fuel carbon intensity by 20% by 2030. https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard
Volkswagen Diesel Emissions Environmental Mitigation Trust	State Mitigation Trust and the Indian Tribe Mitigation Trust	Funding of five categories of projects (1) Freight and marine; 2) ZE transit, school, and shuttle buses; 3) ZE Class 8 freight and port drayage trucks; 4) LD ZE infrastructure, hydrogen; and 5) LD ZE infrastructure, electric) as approved by CARB.

Finally, although this section focuses on on-road vehicles, we note the availability of the Clean Off-Road Equipment Voucher Incentive Project, which is designed to accelerate the deployment of zero-emission off-road equipment by subsidizing its higher cost compared to conventional off-road equipment [26].

1.4 Vehicle miles traveled (VMT)

Reducing VMT in California from light, medium, and heavy-duty vehicles is a critical part of reducing transportation system GHG emissions. VMT is defined as miles of travel by all individual vehicles (light, medium, and heavy duty), excluding passenger and freight rail and off-road modes. Future trends in VMT in California can be influenced through various types of strategies and policies. These include land use policies, roadway and toll pricing, increased use of transit, policies to support tele-work, strategies to increase micromobility and “active transportation” (biking and walking), policies to regulate transportation network companies (TNCs) and constrain their VMT, and strategies addressing the VMT of freight and goods delivery.

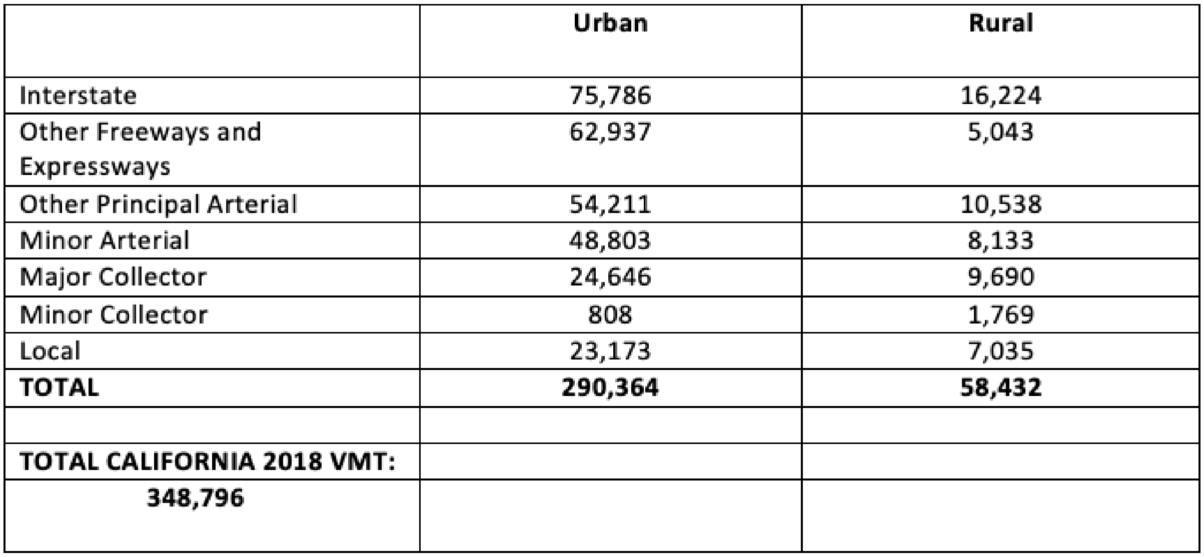
Currently, VMT is mostly examined and addressed at the metropolitan planning organization (MPO) level. SB375 requires MPOs to examine VMT and per capita GHG emissions targets as part of their planning process. Under current law, they must include sustainable communities strategies (SCS) plans to achieve CARB’s targets for their region as part of their long range plans. To do this they consider: 1) land use planning that considers the Regional Housing Needs Assessment and protection of sensitive resources; 2) analysis of transportation networks including highways, transit and local streets and roads; 3) transportation demand management strategies; and 4) transportation system management programs. The 18 MPOs in California have prepared these SCS plans, to be updated every 4-5 years with measurement of progress toward emission reduction, and updated policy and implementation plans.

The following sections describe various topics related to VMT and potential strategies for managing per capita VMT in California. These topics interact in complex ways, such as linkages between micromobility and active modes and the use of transit, land use and jobs/housing balance and mobility patterns, etc. Discussed first in this section are general VMT trends and VMT by travel mode. This is followed by discussion of shared mobility systems and VMT impacts, and then the rise of TNCs and impacts on VMT. Next, land use issues and strategies are discussed, followed by sections on transit systems, pricing strategies, and truck/freight VMT. A final section describes state tools that are useful for VMT analysis along with a new state strategy for assessing system performance based on VMT impacts rather than the level of service of the network.

1.4.1 Total VMT

First, according to the U.S. Department of Transportation (DOT), total California VMT in 2018 by all vehicle types was nearly 350 billion miles. This represents about 9% of all of the 3.26 trillion VMT in the U.S. in 2018. The next highest states are Texas with 282 billion VMT and Florida with 222 billion VMT. The majority (about 83%) of VMT in California came from urban regions, and the balance (17%) from rural areas. Table 6 provides a more granular breakdown of California VMT data.

Table 6. VMT by Functional Road Category in California - 2018 (millions)[5]



	Urban	**Rural**
Interstate	75,786	16,224
Other Freeways and Expressways	62,937	5,043
Other Principal Arterial	54,211	10,538
Minor Arterial	48,803	8,133
Major Collector	24,646	9,690
Minor Collector	808	1,769
Local	23,173	7,035
TOTAL	**290,364**	**58,432**
TOTAL CALIFORNIA 2018 VMT:		
348,796		

Source: U.S. DOT, 2018 [27]

As shown below (Figure 23), California's VMT has only increased slightly to about 8,700 miles per capita since dipping around 2009 during the financial crisis to about 8,500 miles per capita. By comparison, the U.S. national average has rebounded nearly to peak levels of about 10,000 miles per capita, having dipped to around 9,400 in 2009-10.

VMT analysis conducted by the Eno Center for Transportation as shown in Figure 23(a) compares the evolution of per capita VMT in some states that in 1981 had similar VMT to the national average. Figure 23(b) depicts VMT trends for a different group of four states that had somewhat higher or lower per capita VMT than the U.S. average in 1981. States such as Missouri, Mississippi, and West Virginia have generally much higher per capita VMT than California, whereas Washington VMT levels are about 6-7% lower per capita than in California (Figure 23). California had the 10th lowest and Washington had the 6th lowest per capita VMT of any state in 2017, and Mississippi had the 4th highest and Missouri the 7th highest amounts. VMT levels in Missouri have rebounded to higher than their previous peak, and in Mississippi they have rebounded by several hundred miles per capita but not to the level of the peak in around 2007, similar to West Virginia [28].

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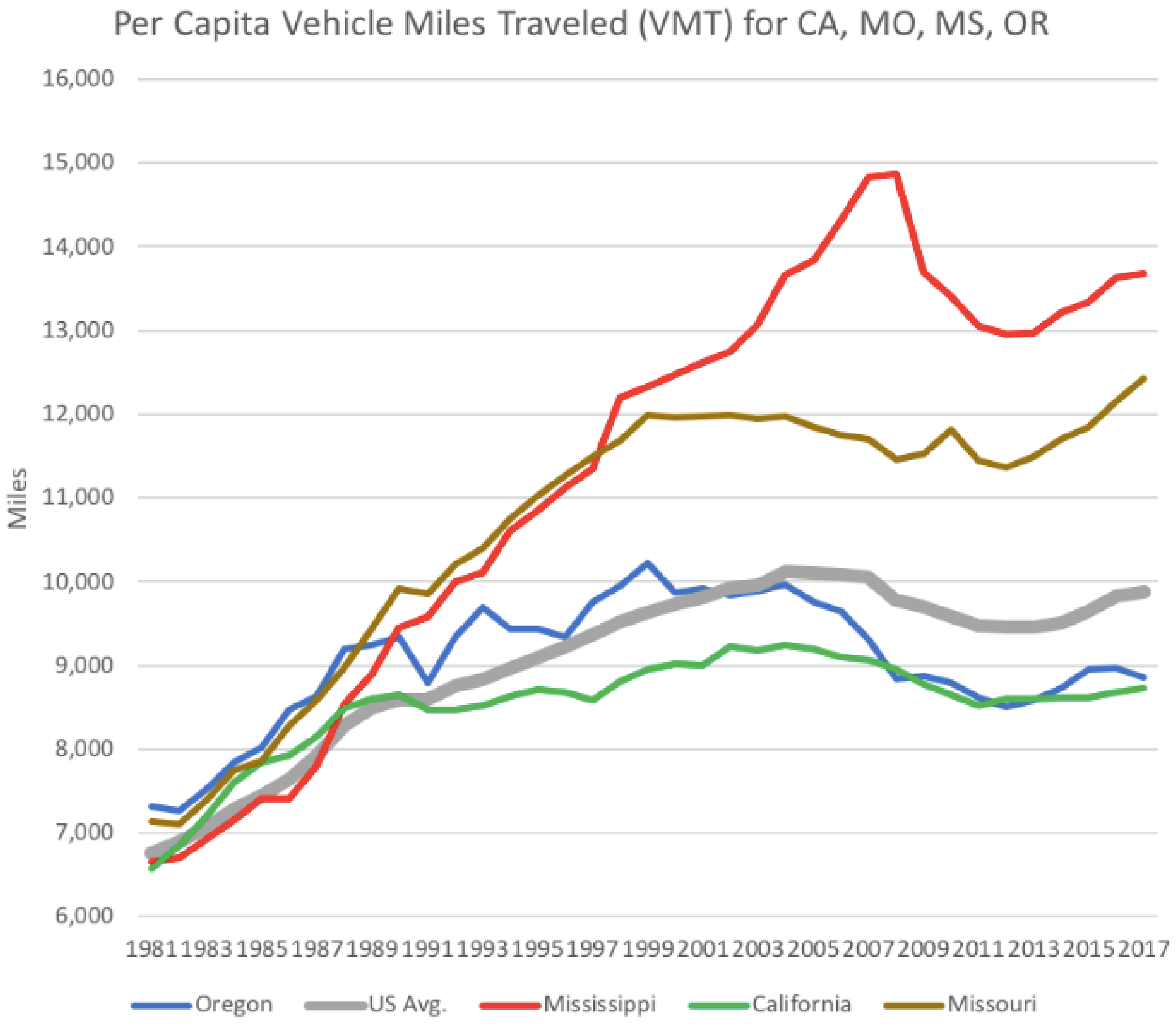
[5] Note: Arterials provide direct, relatively high speed service for longer trips and large traffic volumes. Collectors provide a bridge between arterials and local roads. Collectors link small towns to arterials as well as collect traffic from local roads. Local roads provide direct access to individual homes and farms. Arterials and Collectors are further differentiated into Major or Minor categories based on classification by local officials.


Per Capita Vehicle Miles Traveled (VMT) for CA, MO, MS, OR
Miles
16,000
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
1981
1983
1985
1987
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Missouri

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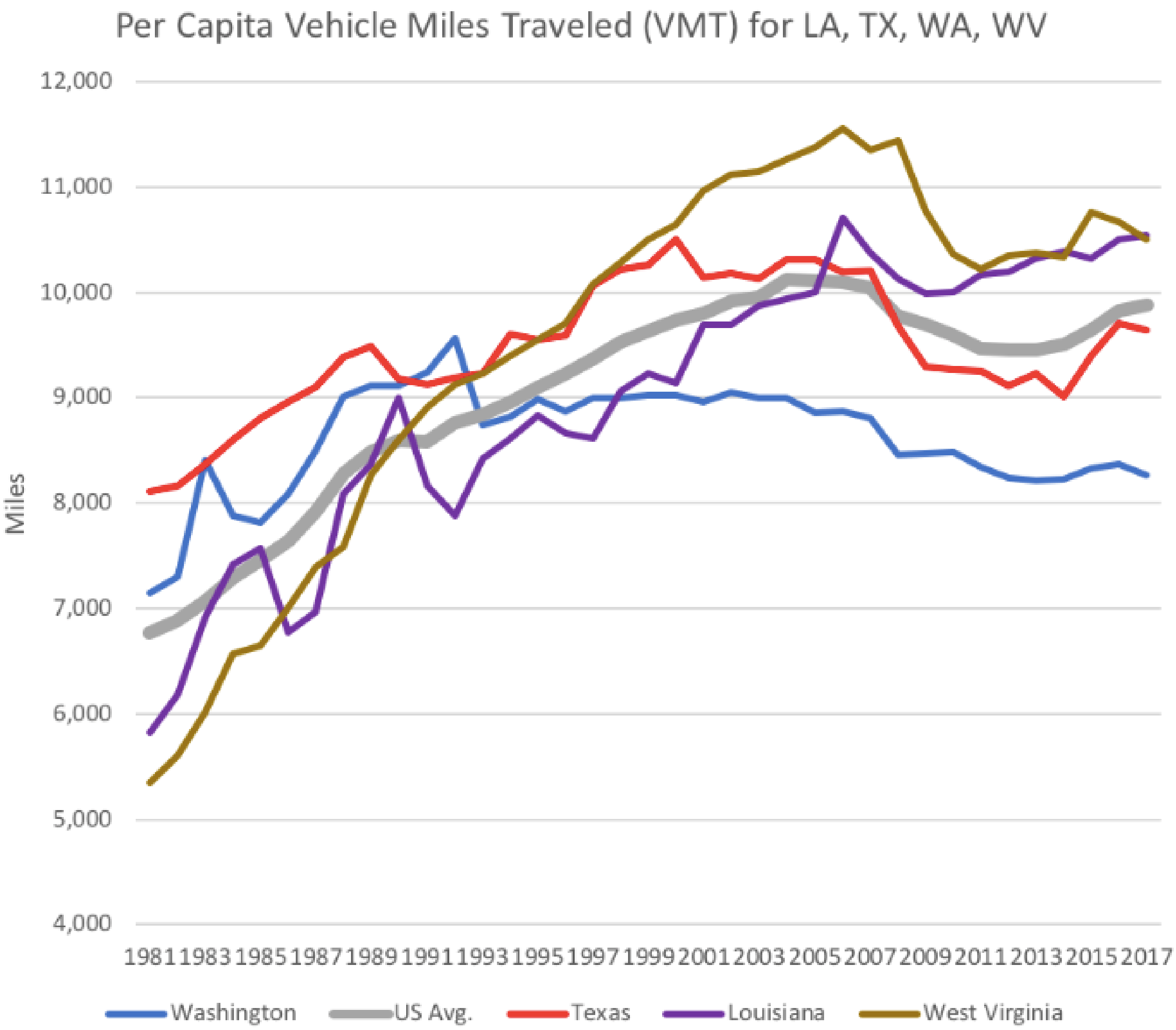


(b)

Figure 23. Per-Capita VMT Trends for U.S., California, and Example States - Eno Transp. Found. (2019) [28]

Shown below in model runs performed by UC Irvine below are modeled results for daily VMT from each California county from the California Statewide Travel Demand Model (CSTDM) (Figure 24). Also note that these VMT estimates are for passenger vehicles only whereas that data in Figure 23 and Table 7 represent total VMT including heavier duty vehicles. The chart gives a sense of the modeled (i.e. approximate) distribution of VMT around the state on a per-county basis, with counties of varying size and population.

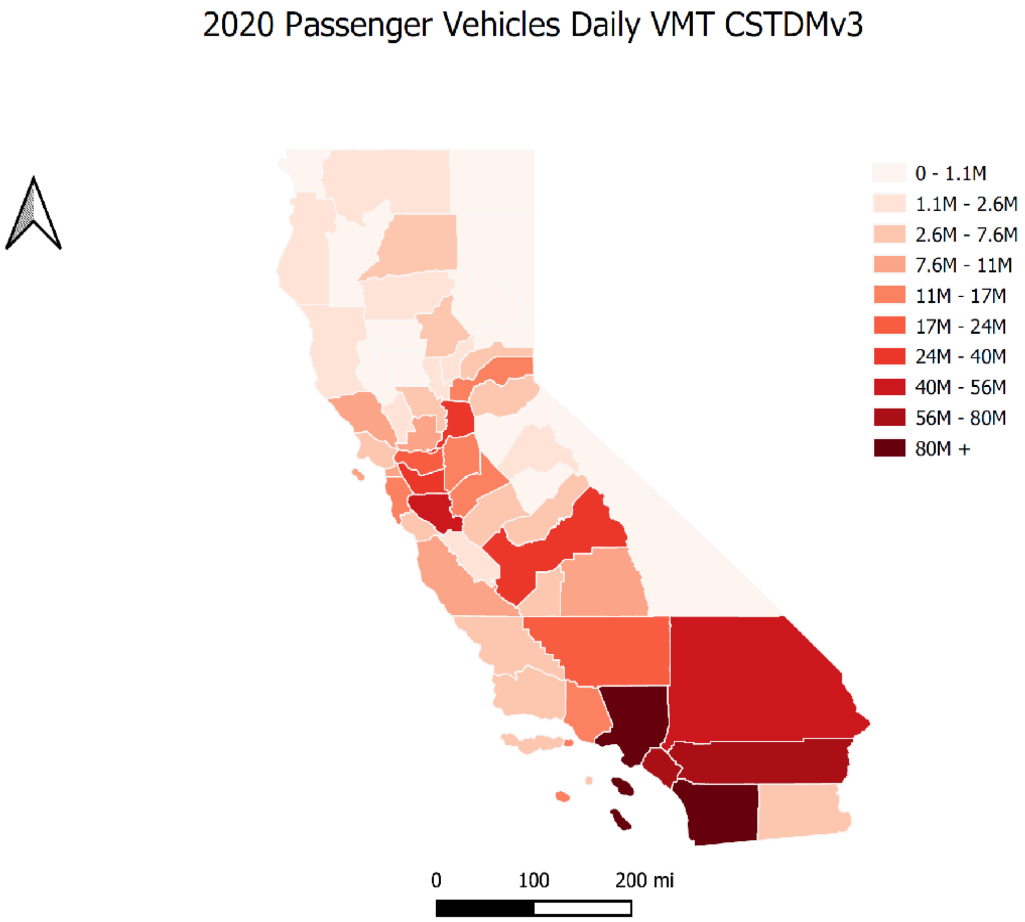


Figure 24. Modeled Daily VMT for Light-Duty Cars in California by County from CSTDM

1.4.2 VMT by Travel Mode

(Figure 25) below shows trends in U.S. VMT over the last 118 years, broken down by vehicle mode (including all passenger vehicles (LDVs) as well as trucks, buses, and motorcycles). (Figure 25) shows that passenger vehicles have long dominated aggregate VMT on U.S. roads. In 2018, passenger vehicles comprised 89% of U.S. VMT. Truck traffic was a distant second at 9%, followed by motorcycles (1%) and buses (1%).

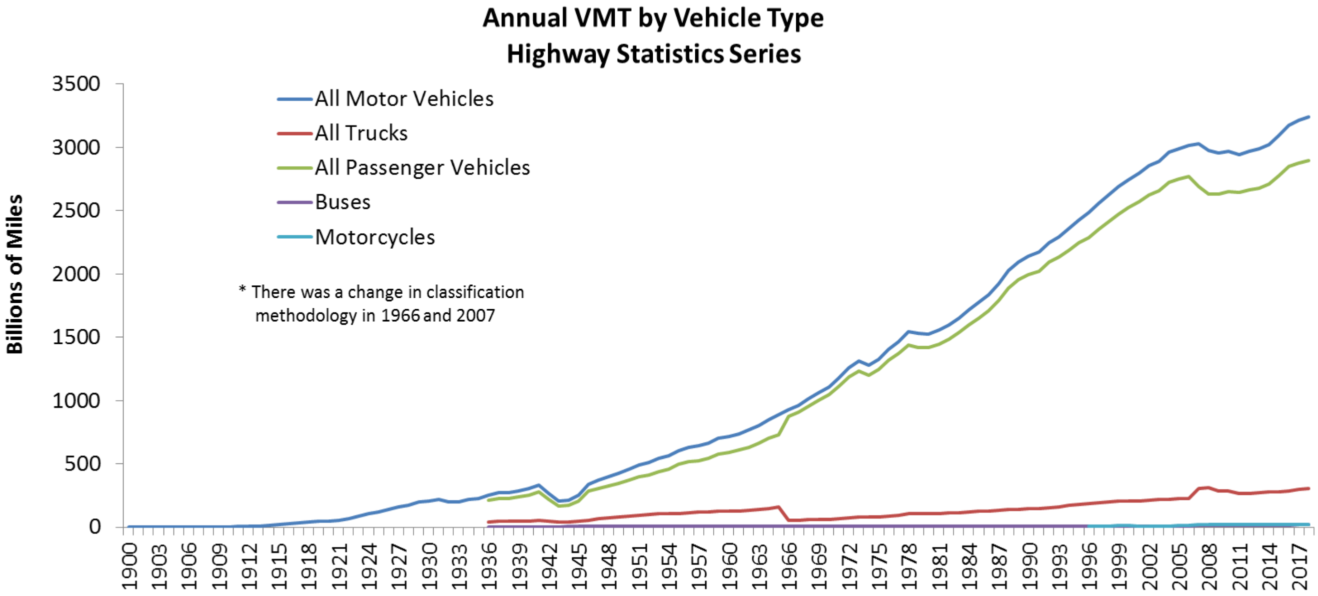
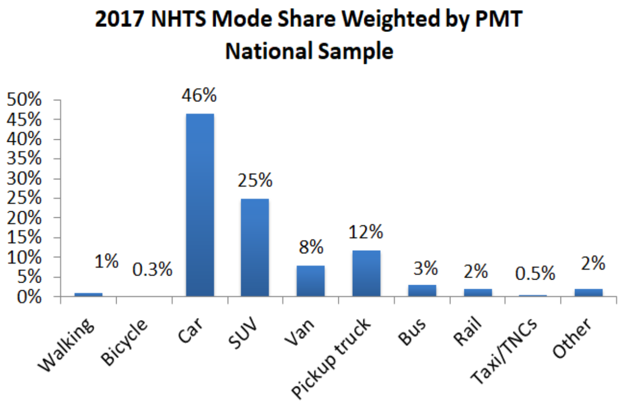


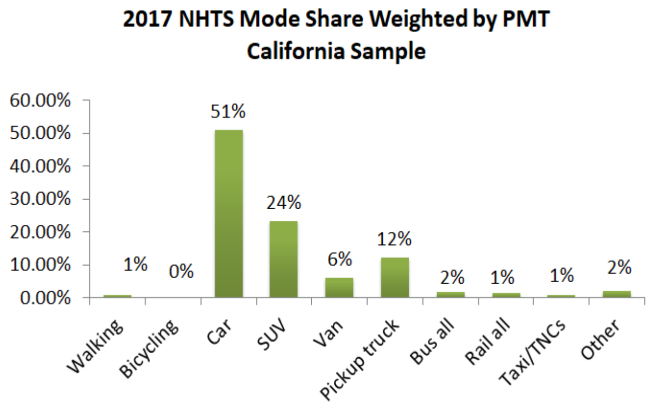
Figure 25. Trends in U.S. VMT by Mode (Data Source: U.S. DOT Office of Highway Policy Information, 1900 to 2018) [29].

The FHWA's Highway Statistics Series provides perhaps the most comprehensive time-series measurement of VMT of any resource. However, it does not contain information on non-motor vehicles (such as rail transit and bicycles), nor does it break out VMT by vehicle function (such as TNCs). For estimates of these measures, different data sources need to be consulted. Such sources include household surveys, such as the National Household Travel Survey (NHTS) and the California Household Travel Survey (CHTS). However, when assessing travel by modes that a passenger takes, the measure often used is "person miles traveled" (PMT) rather than VMT.

The latest NHTS was conducted in 2017 and the latest CHTS was conducted from 2010 to 2012. The NHTS also had a California sample, where additional California household samples were purchased by the state and Metropolitan Planning Organizations (MPOs). Data from these surveys provide a snapshot of travel behavior and distances by mode, but strictly for passenger travel. The distribution of mode by PMT for both surveys is shown below (Figure 26). The NHTS data are for the U.S. as a whole, the California households within the NHTS, and the CHTS.

The distributions are displayed in percentages for direct comparison, and have close alignment. Self-driven automotive modes in the NHTS survey cover 90% of PMT in the national sample, 93% in the California NHTS sample, and 91% of PMT in the CHTS. The PMT accounted for by other modes, including walking, bicycling, and public transit, are very similar across the three surveys. A small but notable difference is the increased use of taxis/TNCs in the NHTS (0.5% of PMT) relative to the older CHTS data (0.15% of PMT). This difference is likely driven by the expansion of TNCs that most notably occurred after the last CHTS was completed. The level of taxi/TNC use in the California NHTS and national sample is also very similar, 0.5% nationally as compared to 0.77% in California (rounded to 1% in the figure).


2017 NHTS Mode Share Weighted by PMT
National Sample
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
1%
0.3%
46%
25%
8%
12%
3%
2%
0.5%
2%
Walking
Bicycle
Car
SUV
Van
Pickup truck
Bus
Rail
Taxi/TNCs
Other


2017 NHTS Mode Share Weighted by PMT
California Sample
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
1%
0%
51%
24%
6%
12%
2%
1%
1%
2%
Walking
Bicycling
Car
SUV
Van
Pickup truck
Bus all
Rail all
Taxi/TNCs
Other

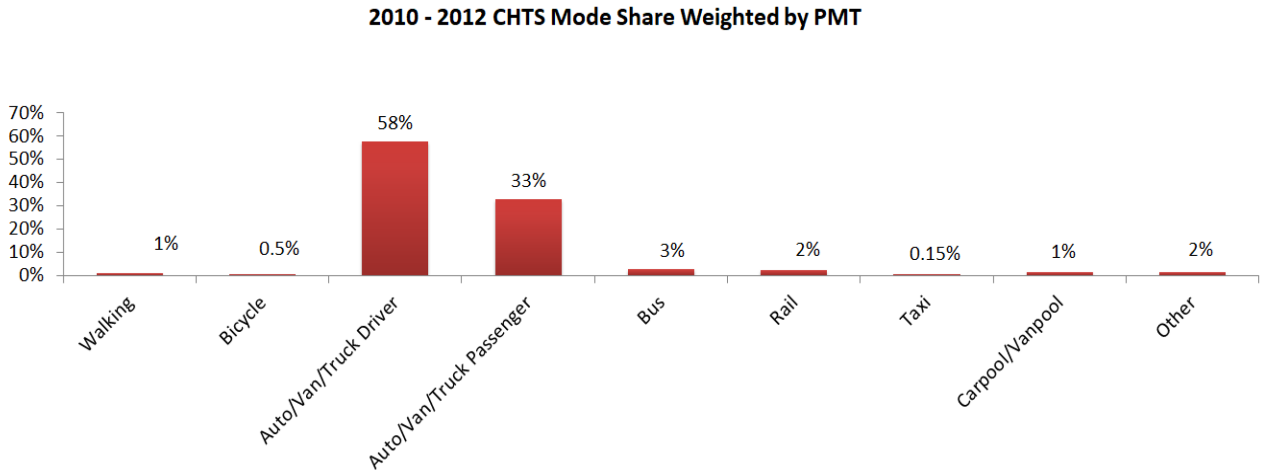

2010 - 2012 CHTS Mode Share Weighted by PMT
70%
60%
50%
40%
30%
20%
10%
0%
1%
0.5%
58%
33%
3%
2%
0.15%
1%
2%
Walking
Bicycle
Auto/Van/Truck Driver
Auto/Van/Truck Passenger
Bus
Rail
Taxi
Carpool/Vanpool
Other

Figure 26. Passenger-Miles Traveled by Mode in National and California Datasets

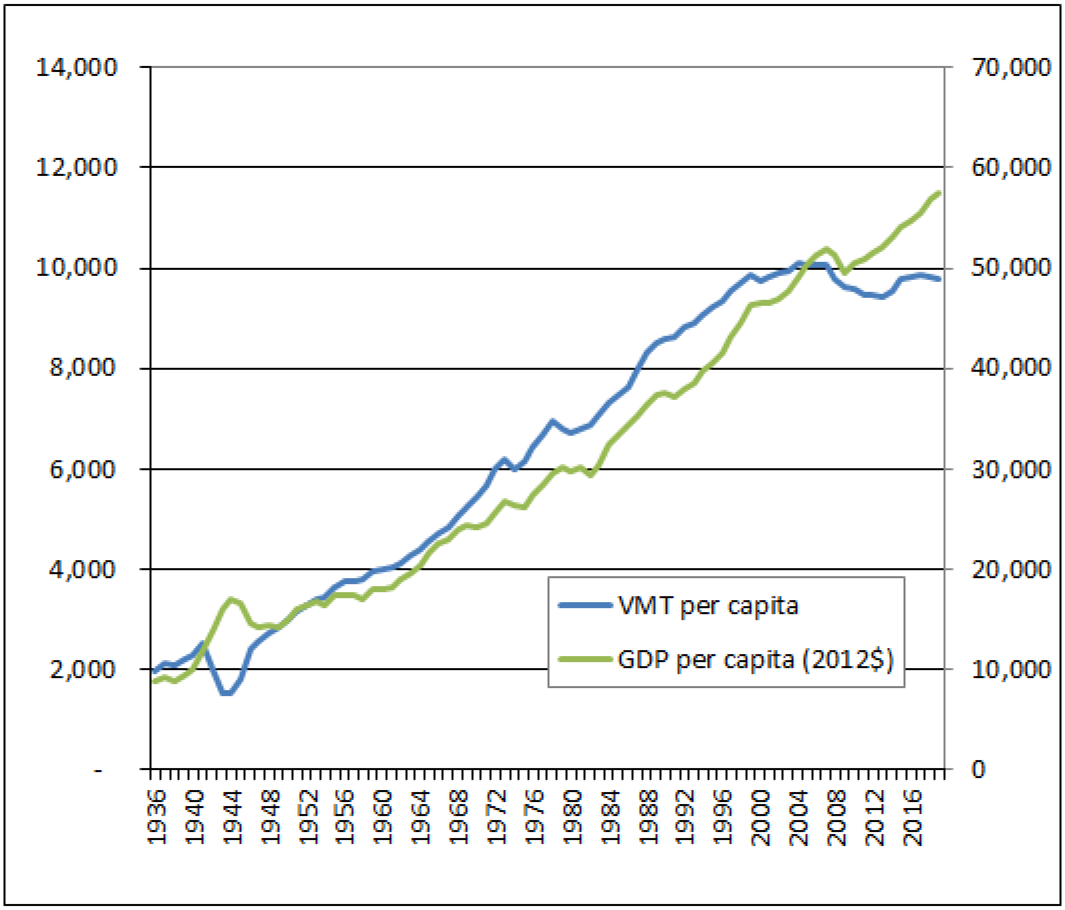


Figure 27. VMT per capita compared to GDP per capita from 1936 to 2016.

1.4.3 VMT impacts of shared mobility

Shared mobility has proliferated throughout California and the broader nation during the 21st century. The modern shared mobility industry in the United States arguably began with carsharing and expanded into bikesharing, TNCs (also known as ridehailing and ridesourcing), dockless micromobility (scooters and bicycles), and microtransit. Sometimes, shared mobility modes are used to connect to other modes. There is also limited vertical integration within the industry, in that operators of one mode have not operated other modes. TNCs have more recently broken this mold, in that Uber and Lyft have both invested in micromobility (bikesharing and e-scooters). However, Uber's recent divestiture of its micromobility operator is a reversal of this trend. Research over more than two decades has evaluated the degree to which these modes impact travel behavior and vehicle ownership of users. Impacts of shared mobility vary by mode, and understanding of more recently emerged modes is still evolving. Insights can be gained from summaries of research that is currently available. Table 7 and Table 8 present a summary of selected research on carsharing as excerpted from [30]. The summarized impacts are focused on vehicle ownership and VMT change.

Table 7. Summary of Roundtrip Carsharing Impact Studies

Operator and Location	Authors, Year	Number of Vehicles Removed from the Road Per Carsharing Vehicle	Members Selling Personal Vehicle %	Members Avoiding Vehicle Purchase %	VMT/VKT Change % per Member
Round Trip Carsharing Studies					
Short-Term Auto Rental - *San Francisco, CA*	(Walb & Loudon, 1986) [31]		15.4	43.1	
Arlington Carsharing (Flexcar and Zipcar) *Arlington, VA*	(Price & Hamilton, 2005) [32]		25	68	-40
	(Price, DeMaio, & Hamilton, 2006) [33]		29	71	-43
Carsharing Portland - *Portland, OR*	(Katzev, 1999) [34]		26	53	
	(Cooper, Howe, & Mye) [35]		23	25	-7.6
City Carshare - San Francisco, CA	(Cervero, 2003) [36]		2.5	60	-3.0a/-58.0b
	(Cervero & Tsai, 2004) [37]	6.8	29.1	67.5	-47.0a/ 73.0b
	(Cervero, Golub, & Nee, 2007) [38]				-67.0a/ 24.0b
PhillyCarshare - *Philadelphia, PA*	(Lane, 2005) [39]	10.8c	24.5	29.1	-42
TCRP Report – Surveyed Members of More Than Nine Carsharing Companies - *North America*	(Millard-Ball, ter Schure, Fox, Burkhardt, & Murray, 2005) [40]				-63
Surveyed Members of Eleven Carsharing Companies	(Martin & Shaheen, 2011) [41]				-27
	(Martin, Shaheen, &	9.0-13.0	23	25	

	Lidicker, 2010) [42]				
Zipcar - *U.S.*	(Zipcar, 2005) [43]	20	32	39	-79.8
Modo - Vancouver, Canada	(Namazu & Dowlatabadi, 2018) [44]	5		55	

Source: Shaheen et al., 2019 [30]

Table 8. Summary of One-way and Person-to-Person (P2P) Carsharing Impact Studies

Operator and Location	Authors, Year	Number of Vehicles Removed from the Road Per Carsharing Vehicle	Members Selling Personal Vehicle %	Members Avoiding Vehicle Purchase %	VMT/VKT Change % per Member
One Way Carsharing Studies					
Car2Go (U.S. and Canada)	(Martin & Shaheen, 2016) [45]	7.0-11.0	2.0-5.0	7.0-10.0	-6.0 to -16
Car2Go (Vancouver, Canada)	(Namazu & Dowlatabadi, 2018) [44]	6		55	
Car2go (San Diego, CA)	(Shaheen, Martin, & Bansal, 2018a) [46]				
Peer to Peer Carsharing					
Getaround, RelayRides (Turo), and eGo Carshare *U.S.*	(Shaheen, Martin, & Bansal, 2018b) [47]		0.14	0.19	
Getaround Portland, OR	(Dill, McNeil, & Howland, 2017) [48]			0.44	

Source: Shaheen et al., 2019 [30]

Overall, carsharing studies overwhelmingly find that carsharing reduces vehicle ownership and overall household VMT. Net changes in VMT at the personal or household level (depending on the study) have ranged from about 8% to upwards of 80%. Most members of carsharing exhibit very limited impacts from carsharing, while others can experience more profound effects. For example, Martin and Shaheen found that the majority of carsharing users actually increased their emissions as a result of exposure to carsharing [41]. Such users were generally carless, and hence drove more as a result of having access to a vehicle. However, the individual increase in VMT was small on a per user basis. At the same time, a minority of users reduced their VMT by amounts far greater, due to shedding of personal vehicle, or suppressing the need to acquire a personal vehicle. The resulting reduction in VMT from these actions was found to be much greater on an individual basis, and collectively resulted in a net reduction of household VMT overall. This dynamic has generally been found and confirmed in various subsequent work evaluating the overall household-level VMT impacts of carsharing.

A number of studies have also been conducted evaluating the impacts of bikesharing and TNCs. These studies find a mixture of impacts with respect to how bikesharing and TNCs influence mode use and VMT. For example, Table 9 and

Table 10 summarize the impacts noted from bikesharing studies, as excerpted from Shaheen et al. [30]. The table shows the program under study and selected calculations of impact that were reported by the studies. In general, shared micromobility has been shown to have some significant impacts on mode use and the resulting change in VMT. One note about the studies is that they do not cover the VMT imposed by systems as they move bicycles around as part of rebalancing operations. Rather, these studies focus on the demand side of activities and travel behavior changes due to shared micromobility services.

Table 9. Summary of Docked Bikesharing Impact Studies

Study Name ***Location***	**Authors, Year**	**Mode Use**	**Environment**
Capital Bikeshare Member Survey Report *Washington, D.C.*	LDA Consulting, 2013 [49]	After joining bikesharing: - 54% of respondents started or ended a bikesharing trip at a Metrorail station in the last month - 50% drove a car less often - 60% used a taxi less often - 61% ride Metrorail less often and 52% ride a bus less often - 52% decreased walking*	After joining bikesharing: - ¼ of respondents reduced their driving miles - On average, driving was reduced by 198 miles per year
Bikeshare's impact on car use: Evidence from the United States, Great Britain, and Australia Washington, D.C. and Minneapolis-St. Paul	Fishman et al., 2014 [50]	**Washington, D.C.:** - 45% replaced public transit - 31% replaced walking - 7% replaced driving a vehicle - 6% replaced personal bicycle - 6% replaced taxi - 4% generated new trips **Minneapolis-St. Paul:** - 20% replaced public transit - 37% replaced walking - 19% replaced driving a vehicle - 8% replaced personal bicycle - 3% replaced taxi - 8% generated new trips**	**Estimated car travel reduction per bike of:** - 153 mi (247 KM) in Washington, D.C. - 83 mi (135 KM) in Minnesota
Bikeshare's impact on active travel: Evidence from the United States, Great Britain, and Australia *Washington, D.C. and Minneapolis-St. Paul*	Fishman et al, 2015 [51]	**Bikesharing trips replaced sedentary modes by:** - 42% in Minneapolis-St. Paul. - 58% in Washington, D.C.***	

Are bikeshare users different from regular cyclists? *Washington, D.C.*	Buck et al., 2013 [52]	**For annual members:** - 45% replaced public transit - 31% replaced walking - 7% replaced driving a vehicle - 6% replaced personal bicycle - 6% replaced taxi - 4% generated new trips **For short-term users:** - 53% replaced walking - 35% replaced public transit - 5% replaced taxi - 2% replaced personal bicycle - 2% generated new trips - 2% other - 1% replaced driving a vehicle	

Shaheen et al., 2019 [30]

* Respondents asked if they had changed their use of any five non-bicycle types of transportation.

** Thinking about your last journey on bikeshare, which mode of transport would you have taken had it not existed?

*** Respondents asked what alternative mode they would typically have used for that trip before bikesharing was introduced.

Table 10. Summary of Dockless Bikesharing Impact Studies

Study Name ***Location***	**Authors, Year**	**Mode Use**	**Environment**
Dockless Bikesharing			
Electric Bikesharing in San Francisco: An Evaluation of JUMP Electric Bikesharing during an Early Pilot Deployment *San Francisco, CA*	Shaheen et al., forthcoming [53]	- 10% replaced driving a vehicle - 14% replaced transportation network company trip (TNC, e.g., Lyft, Uber) - 26% replaced public transit - 8% replaced walking - 24% replaced personal bicycle - 4% replaced a motorcycle or scooter - 1% replaced scooter sharing - 5% other+	
Dockless Scooter Sharing			
2018 E-Scooter Findings Report *Portland*	Portland Bureau of Transportation, 2019 [54]	- 37% replaced walking - 19% replaced driving a vehicle - 15% replaced a taxi or TNC - 5% replaced personal bicycle++	Estimated e-scooters prevented automobiles from emitting 122 metric tons of carbon dioxide during the four-month pilot, equivalent to removing nearly 27 average passenger vehicles from the road for a year.

Shaheen et al., 2019 [30]
+If JUMP were not available, how would you have made this trip instead?
+ Respondents thought about what mode they would have used for their last e-scooter trip, if the e-scooters had not been available.

Shared e-scooters have emerged as the most recent micromobility mode. E-scooters are often mixed in with other dockless modes, although there are prominent systems that focus exclusively on e-scooters. A number of studies have evaluated the impact that e-scooters have had on mode shift. Many of those studies have been city specific and asked questions probing the trip that would have been taken in the absence of e-scooter availability. As noted in

Table 10, e-scooters replace active modes such as walking and bicycling, but also driving a personal vehicle or taxi/TNC use. Other city-specific studies have uncovered similar findings. For example, in Chicago, it was found that 32% of survey respondents would have taken ridehailing and 11% would have driven [55]. A study of bikesharing in Greater Sacramento looked at how s-bikes and e-scooters impacted behavior, and found that 35% of e-bike trips substituted for car travel [56]. These findings suggest that e-scooter and e-bike provisions are reducing personal automobile use and associated VMT.

Since 2012, TNCs have further expanded shared mobility access to urban and rural regions across California. A number of studies have begun to shed light on VMT impacts. A summary of VMT-related findings from three studies are presented in Table 11 as excerpted from Shaheen et al. [30]. These studies explored how TNCs impacted on-road VMT within two major U.S. cities: New York City and San Francisco. These studies focus on the VMT of TNC vehicles. They do not comment on reductions in VMT that may result from shifts in travel behavior and vehicle ownership. However, their estimates include the operating phases of TNCs, including deadheading and traveling to pick up passengers. This mileage includes shifts to TNCs from active modes and public transit. The results of these studies suggest that the aggregate amount of TNC-induced VMT on urban roads within these major markets is notable.

Table 11. Summary of Studies on VMT from TNC Vehicles

City ***Study Author*** **Data Time Period**	**Key Trip Metrics**	**Key Mileage Metrics**
San Francisco, CA *SFCTA* 1 month, late-2016 [57]	*TNC trips comprise* • **15% of total vehicle trips** (intra-SF, avg. weekday) • **9% of total person trips** (intra-SF, avg. weekday)	*TNC mileage comprises...* • **20% of intra-SF VMT** (avg. weekday) • **6.5% of total VMT** (avg. weekday) • **10% of total VMT** (avg. Saturday)
New York City, NY *Schaller Consulting* Full year, 2016 [58]	*TNC trips comprise...* • 80 million vehicle trips (in 2016) • 133 million person trips (in 2016)	*TNC mileage comprises...* • **7% of total VMT** (in 2016) *TNC mileage equates to an estimated increase of...* • **3.5% citywide VMT** (in 2016) • **7% VMT** in Manhattan, western Queens and western Brooklyn (in 2016)
New York City, NY *Schaller Consulting* June 2013 and June 2017 [59]	*TNC/taxi trips increased by...* • **15% between June 2017 and June 2013** (Manhattan CBD, avg. weekday) • **133 million person trips** (in 2016)	*TNC/taxi mileage increased by...* • **36% between June 2017 and June 2013** (Manhattan CBD, avg. weekday)

Shaheen et al., 2019 [30]

Research has shown that there are different types of users of TNC vehicles that relate to their impact on energy consumption. Circella et al. [55] noted that there exist four latent classes of modality styles of TNC users, including drivers, active travelers, transit riders, and car passengers. They found that drivers, who generally have higher vehicle ownership, have a relatively limited impact on energy consumption from TNC use. Active travelers, who generally have a low energy use profile, exhibited relatively high emissions from TNC. The VMT by mode is of course also context specific to land use. Urban regions show much higher mode shares for public transit, walking, bicycling, taxis, and TNCs. A recent study by Fehr and Peers reveals that TNCs have very different impacts on VMT depending on location [60]. The study examined traffic impacts from recent growth in TNC use in six urban areas, including the San Francisco Bay Area. TNC share of regional VMT ranged from 1.1% to 2.7%, with the highest value in the Bay Area. In core urban areas, the share of VMT from TNCs was as high as 12.8% in San Francisco. For comparison, the share of VMT from TNCs was 6.9% in Washington, DC, 7.7% in Boston, and as low as 1.9% in the core urban area of Seattle. Figure 28 below provides maps showing the primary study findings.

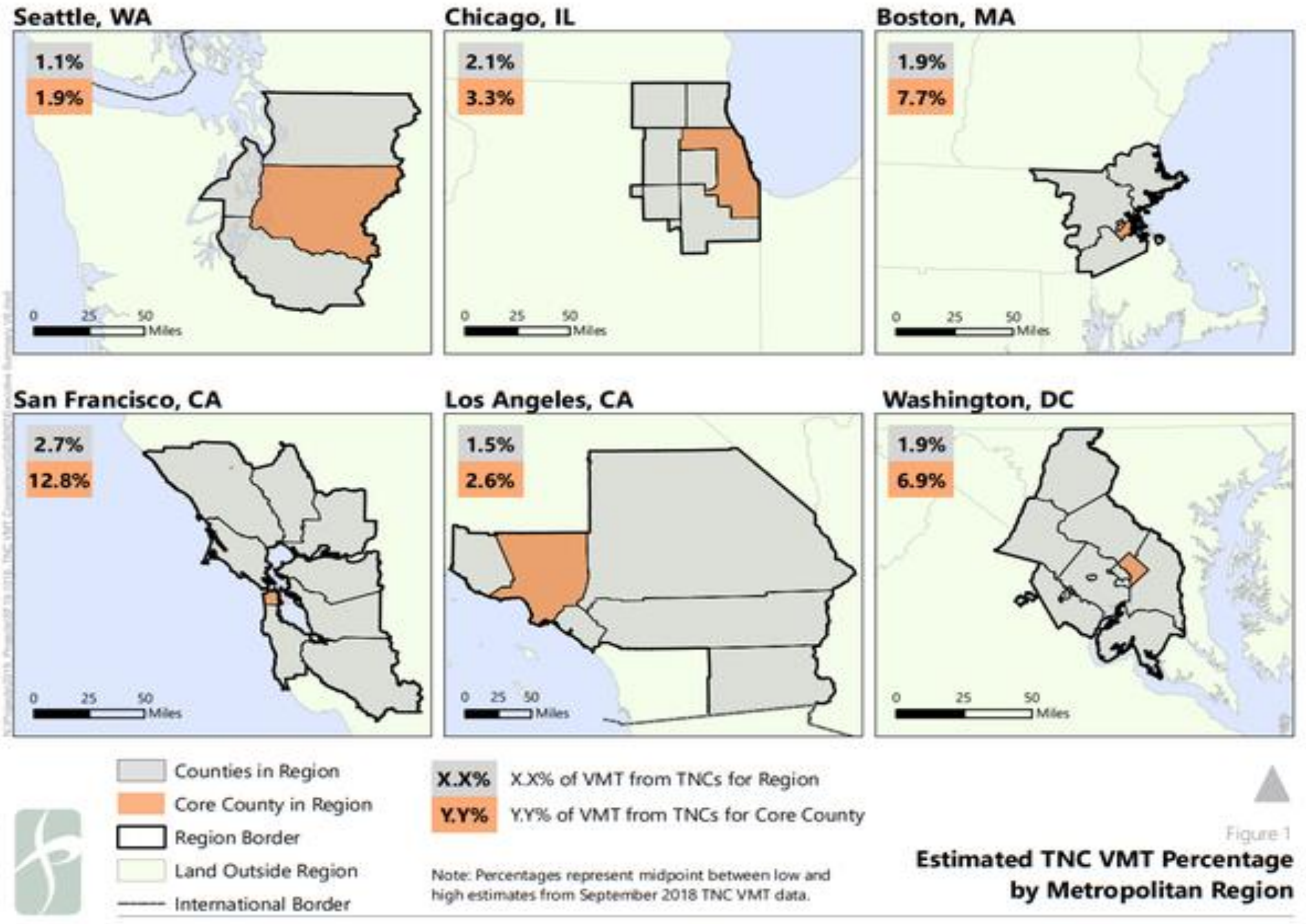


Figure 28. Estimated TNC VMT Percentage for Six U.S. Regions Fehr and Peers (2019) [60].

Finally, studies of automated vehicles (AVs) have begun to emerge. At present AVs in California are being tested, but to date, there are no shared AVs in operation and no private AVs operating at higher than SAE Level 2 autonomy, which requires the driver to be prepared to intervene immediately. Several studies have been conducted evaluating how AVs might influence travel behavior, VMT, and fuel consumption. Some studies evaluate how AVs influence travel on specific populations. Other studies evaluate how a fleet of shared automated vehicles (SAVs) operating in an urban environment would impact emissions and personal vehicle ownership. These studies also explore the charging dynamics of such systems assuming the fleet will be electrically powered.

Harper et al. evaluated implications of AVs provided to specific types of underserved populations, including non-drivers, older adults, and adults with travel-restrictive medical conditions [61]. Their analysis showed that AVs provided to these populations increased annual LDV VMT by 14% overall. Most of this increase (65%) was from current adult non-drivers, while the remaining increase was roughly split between older drivers without a medical condition (16%) and adult drivers with travel-restrictive medical conditions (19%). Harb et al. [62] evaluated AV-induced changes in the travel behavior of populations who currently do not often drive, including retirees and children. The results showed that the service for these populations led to an 83% increase in VMT, 21% of which was with empty vehicles.

SAVs are generally simulated under a variety of assumptions about fleet operations. Increases in fleet size will change VMT as the larger fleet of SAVs would serve more people (sometimes in a pooled capacity) and drive more zero-occupancy miles. A number of studies suggest that SAVs could increase these zero-occupancy miles anywhere from 8% to 16% depending on the market penetration rate [63]–[65]. Commensurately, reducing fleet size could lower energy consumption and emission levels, although researchers disagree on the likely magnitude of these changes. Results from Fagnant and Kockelman [66] and Zhang et al. (2015) [67] suggest that SAVs would result in lower carbon monoxide (CO) and volatile organic compound (VOC) emissions, due to system efficiencies and fewer engine cold starts.

In addition to changing fleet size, dispatching right-sized SAVs could help reduce energy consumption and emissions further by allowing one and two-person trips to be served by smaller vehicles. Martinez and Viegas [68] report findings from a study of Lisbon suggesting that right-sizing SAV vehicles would result in a 40% reduction in GHG emissions. Greenblatt and Saxena [69] found that right-sized automated taxis operating on electricity could reduce GHG emission rates per distance by 94% as compared to current day conventional vehicles. Wadud et al. [70] found that vehicle right-sizing would result in up to a 45% reduction in energy use, based on use of conventional fuels. Notably, not all researchers believe that SAVs will have a positive environmental impact. For example, Lu et al. [71] concluded SAVs will result in higher energy consumption and GHG emissions as a result of increased VMT.

As experience shared mobility and autonomous vehicle systems grows, so too will the more collective understanding of their role and contribution to broader impacts on VMT. What is clear from the existing body of literature is that shared mobility has played a central role in innovative mobility services within urban and increasingly less dense land use environments. As they continue to evolve, such as through the implementation of automation, so too will the nature of their VMT impacts. Tracking these impacts will require continuity of research and collaboration with the industry, as well as continued engagement on issues of data, public transit integration, and municipal cooperation.

1.4.4 VMT and land use

Land use policies are an essential component of a package of strategies for reducing VMT. The relationship between travel behavior and land use has received much scholarly attention over the past three decades, partly to understand the extent to which VMT from private vehicle use can be reduced by changing the built environment in urban areas. Researchers have identified several characteristics of the built environment that can significantly impact travel behavior: population and employment density, land use mix, and street network connectivity. These characteristics determine the level of accessibility that individuals have to needed or desired destinations from their home or other locations and thus influence their travel choices [72]–[76]. A number of studies have found that characteristics of the built environment explain more than half of the VMT difference between compact urban and sprawling suburban neighborhoods after accounting for the fact that different kinds of people choose to live in different kinds of places (a phenomenon known as residential self-selection) [72]–[76].

Research on the relationship between the built environment and travel behavior is mostly cross-sectional, meaning that it shows how differences in the built environment are associated with differences in travel behavior. These studies do not directly show how travel behavior will change as a result of changes in the built environment. They can give an indication of how much change might be possible. A meta-analysis of over sixty empirical studies [73] found that the weighted-average elasticity of VMT with respect to each of density, land use mix, and street connectivity ranges from -0.04 to -0.12, suggesting that doubling each of these three variables could decrease VMT by ~25%. Regional accessibility, defined, for example, as the number of jobs accessible within 30 minutes of travel, appears to have a larger (in magnitude) elasticity (-0.15 to -0.22) [77]. While most empirical studies analyze travel at the neighborhood level, several studies have shown that metropolitan scale elasticities of various urban form variables are larger (ranging from -0.24 to -0.38) than neighborhood-level elasticities, and that population density matters [78]–[80]. Accounting for population distribution yields even larger effects. Indeed, a regional-scale study conducted by Lee and Lee (2020) [81] found a value of -0.63 for the elasticity of destination accessibility after controlling for self-selection.

It is important to note that while changes in the built environment may not be sufficient for meeting VMT reduction goals on their own, they are essential to this effort. Other strategies for reducing VMT, such as investments in transit systems and in bicycle and pedestrian infrastructure, depend on changes in the built environment. Transit systems, for example, depend on sufficiently high residential and employment densities. Walking and bicycling are viable as modes of transportation only when destinations are within walking and bicycling distance. Conversely, investments in alternatives to driving are essential to efforts to increase residential and employment densities.

Among measures of urban form, density has received considerable attention ever since the landmark study of Newman and Kenworthy (1989a, 1989b) [82], [83]. Researchers have also paid increasing attention to the location of employment centers in relation to residential areas to analyze commuting [84], [85]. The issue of jobs and housing balance is a critical one that the state is grappling with through various measures designed to encourage in-fill housing development, including provision of low-income units in larger development projects. Researchers have also proposed indices to measure sprawl at larger scales [86], and to capture various aspects of sprawl [87].

1.4.5 Transit systems in California

Data collected for the American Public Transportation Association (APTA) reports detailed transit-system operation and fuel use by type from over 80 transit agencies in California.

Table 12 summarizes key operational statistics for California transit agencies, including vehicles operated, passenger travel, cost and revenue per passenger, and total vehicle revenue miles. Data from 2015 and 2018 are presented to show changes over that period.

As shown, transit use and fare revenue dipped some from 2015 to 2018 with lower ridership levels and revenues, and small increases in vehicles operated and operating expenses. Vehicle revenue miles increased slightly from 2015 to 2018 but fare revenues relative to operating expenses dropped somewhat, along with total revenues. The implications of these trends, along with the recent drop in transit ridership due to Covid-19, suggests that in order to increase transit use in California as one VMT reduction measure, additional policy actions will be required such as subsidized transit passes for low-income groups and improvements to transit system efficacy through planning and system expansion.

Table 12. Operational Statistics for California Transit Agencies – 2015 / 2018

Statistic	Year 2015	Year 2018	Measure
Vehicles Operated in Maximum Service (VOMS)	18,447	19,022	Vehicles
Fare Revenues per Unlinked Passenger Trip	$2.31	$2.06	Dollars
Fare Revenues per Total Operating Expense	0.18	0.14	Ratio
Passengers per Hour	14.26	11.87	Passengers
Cost per Passenger	23.14	22.36	Dollars
Fare Revenues Earned	1,872,801,900	1,816,926,037	Dollars
Total Operating Expenses	6,274,286,314	7,360,370,696	Dollars
Unlinked Passenger Trips	1,435,298,779	1,293,074,046	Trips
Vehicle Revenue Miles	660,672,051	690,837,942	Miles

Source: APTA, 2015 and 2018 [87]

These transit agencies in California use a broad mix of fuels, including gasoline, diesel, liquefied petroleum gas (LPG), and liquefied natural gas (LNG) to biodiesel (BD), renewable diesel (RD), electricity, hydrogen, and miscellaneous types such as waste restaurant fry oil. Table 13 below presents fuel-type statistics for 2015 and 2018 as reported to APTA by the 82 reporting transit agencies. As shown, gasoline and diesel use have remained fairly constant, BD use has dropped somewhat, while battery electric bus electricity use has more than doubled.

Table 13. Fuels Types and Amounts Used by California Transit Agencies – 2015 / 2018

Fuel Type	Year 2015	Year 2018	Measure
Diesel	46,047,172	48,412,390	Gallons
Gasoline	20,694,710	18,637,749	Gallons
Liquefied Petroleum Gas	7,532,347	2,099,190	Gallons
Compressed Natural Gas	86,560,355	88,910,762	Gallons
Biodiesel	303,686	66,584	Gallons
Other Fuels (Including hydrogen and used fry oil)	7,532,347*	1,785,182	Gallons or equivalent
Electricity-Propulsion	713,575,016	779,942,081	Kilowatt-hours
Electricity-Battery	1,358,800	3,157,141	Kilowatt-hours

Note: Electricity-Propulsion refers to systems powered by electric rail or catenary type systems. *2015 data for “other fuels” appears to be erroneous (duplicates LPG data) [87]

Overall, as shown in above, transit systems account for only about 2% of overall fuel use in California [83] . However, transit systems provide critical transportation support services for disadvantaged communities (DACs) and others with disabilities and therefore provide a public good especially when operated efficiently. California is pursuing a strategy of zero-emission transit buses through its Innovative Clean Transit Rule to transition bus fleets to battery and fuel cell technologies by 2040 (see policy section) as well as encouraging greater use of transit and light rail. Greater use of these lower emission modes is an important part of the overall ability to get to carbon neutrality in the transportation sector in the next 25 years.

1.4.6 Transportation pricing strategies

There are a number of mechanisms by which transportation system pricing can be used to influence and potentially decrease per capita VMT. These include roadway and bridge tolls, high-occupancy toll (HOT) lanes, cordon pricing for vehicles entering inner city areas, and a variety of other measures including subsidized transit passes for low income citizens. Adverse impacts on lower income populations are clearly a concern with any type of pricing strategy. Key questions include the type of program and details of implementation, with possible means-based pricing/tolling strategies, as well as what is done with the revenues generated from the program. These details can greatly impact whether a pricing policy is regressive, neutral, or progressive from a social equity perspective. These and further environmental justice (EJ) issues are discussed in Section 1.8 below.

In a broad review of VMT reduction policy strategies, Boarnet and Handy [89] identify pricing strategies as leading options because they can be implemented and have effect relatively quickly, as well as impact a broad base of travelers. Pricing strategies also generate revenues that can be used for transportation enhancement projects as well as offsets for any regressive taxation impacts. Boarnet and Handy classify pricing policies into “link and cordon toll,” “VMT fees,” “fuel prices,” and “parking pricing” categories. The effect sizes estimated from the literature for these categories are shown in Table 14 below.

Table 14. Pricing Policy Effect Estimates by Category [89]

Pricing Policy	Elasticity (unless otherwise noted)	Source
Link and Cordon Tolls	-0.1 to -0.45	ARB policy brief on road user pricing
VMT fees	-11% to -14.6% reduction from shifting gas tax to VMT fee	ARB brief on road user pricing, from Oregon VMT fee experiment
Fuel prices	-0.026 to -0.1 (short-run) -0.131 to -0.762 (long-run)	ARB brief on gas price
Parking pricing	-0.3 for demand for parking spaces	ARB parking pricing and parking management brief

Also in a recent white paper, Shaheen et al. [90] review seven types of pricing strategies: 1) cordon/area pricing, 2) distance-based pricing, 3) dynamic congestion pricing, 4) means-based pricing, 5) flat-rate tolls, 6) full-facility tolls, and 7) managed lanes. They note that various forms of pricing may be effective at reducing congestion and overall VMT while generating revenue for public agencies. For example, in London, Stockholm, and Singapore where cordon or area pricing has been implemented, the results have been successful with respect to congestion reduction [91]. Further details on the London, Stockholm, and some other regional pricing program experiences are included below.

An important finding from early implementation experiences is that pricing approaches may only be effective at reducing congestion if other transportation modes, including public transit and active transportation infrastructure, are available and accessible, as was the case with London, Stockholm, and Singapore [92] and [93] The pricing mechanism used, for example flat-rate or dynamic, will also influence the degree of effectiveness of the strategy. Dynamic pricing fluctuates with congestion, with the price of the toll rising with congestion. Thus, dynamic pricing is more effective at reducing peak period congestion, whereas flat-rate pricing is less effective since it does not incentivize drivers to change the time of day that they travel. In addition, not all pricing approaches produce the same equity outcomes. For example, if alternatives to driving are not readily available, roadway pricing can be a regressive tax on lower income who pay a higher relative percentage of their wages on transportation services than middle and higher income groups. The details of the equity impacts depend strongly on how the project revenues are then distributed. For example, revenues could be simply returned to regional general funds, or instead at least in some measure targeted to return to especially lower-served communities for transportation and jobs/work balance enhancement type projects.

An assessment of several roadway pricing or tolling projects in the U.S. and Europe, found that significant reductions of VMT were achieved in some of these program [94]. For example, in 2006-07 the state of Oregon performed a “Road User Fee Pilot Test” project to experiment with a road user based fee structure rather than a gasoline tax. This simulation was done in the Portland area where drivers were asked to behave as if they were paying the proposed tax, but did not actually have to pay it. The fees increased during peak times and in congested zones. Both overall VMT reductions (10-13%) and mode choice changes during the peak hours (away from driving and towards transit, especially for those living near transit stations) were observed. A similar study was conducted in the Puget Sound area with a sample of over 400 vehicles, and a hypothetical tolling and road charge scheme. The study found a 12% reduction in VMT and also decreases in average travel time from lower congestion, as was also observed in Oregon [95].

Another well-known project known as the “Stockholm Trial” was a cordon pricing program for Central Stockholm was started in 2006. The program demonstrated a reduction of traffic volume in inner Stockholm of 16% in the morning and 24% in afternoon/early evening, as well as a 14% reduction in VMT in the charging zone. Finally, in a well-known London cordon-pricing implementation, VMT reductions of 15% for four-wheel vehicles were reported after the first year of the initial Central London implementation in 2003-2004, and an 18% reduction in vehicles coming into the zone. The trips were instead made by transit (50-60%), diversion around the cordon zone (20-30%), and shifting to bicycle, motorcycle, or taxi (8-10%). A subsequent expansion of the project to a “Western Extension” around 2006 showed a 14% reduction in vehicle traffic and an 11% reduction in VMT among four-wheel vehicles [94].

Finally, with regard to broader transportation financing strategies, we note that the state of California has mechanisms by which it can use broader transportation financing regimes to influence MPO level efforts to emphasize VMT reduction. As state money flows from the state government to the MPOs to support regional transportation system enhancement projects, the state could require stronger regional efforts to reduce per -capita VMT as conditions for full funding [95]. These are already occurring in context of the currently required long-range Sustainable Community Strategies but without strong mechanisms for achieving specific desired outcomes. More specific policies such as VMT-based road fees, along with the recent shift to examining VMT impacts versus level of service for CEQA compliance, could help to deliver more reliable reductions in regional VMT. These could be combined with strategies for revenue return to lower income groups and for transportation improvements in local communities to avoid regressive taxation impacts on lower income groups.

1.4.7 Active transportation

Active transportation includes walking and bicycling. A 2018 Legislative Analyst's Office Primer on California's Transportation System, based on three national household travel surveys conducted between 2001 and 2017, found the following:

- 11–13% of all trips in California are walking trips, 2% higher than the national average. However, only 3% of workers commute by walking.
- Between 2001 and 2017, the share of bicycle trips in California increased slightly but still only represents 1% of trips. Only 1% of workers commute by bike.

Most of the existing literature focuses on the linkage between pedestrian/bicycle policy interventions and the use of the pedestrian/bicycle infrastructure; whereas, the linkage between active transport policy interventions and VMT is less well understood. Moreover, where evidence for notable increases in bicycling/walking use and decreases in VMT from bicycle/walking related policies exists, it is difficult to parse out the direct impact of individual policies (Winters et al. 2017) [96]. However, Winters et al. (2017) find that groups of policies that produce convenient, safe, and connected walking and biking infrastructure can notably promote active travel. Moreover, the study argues that comprehensive policy frameworks that incentivize active transport travel at a societal level, city level, route level, and individual level are necessary to achieve significant gains in active travel.

Scheepers et al. [93] review the literature related to the effectiveness of policies that aim to shift travelers from the personal vehicle to active transport modes. The study segments the policies/interventions into: work-place based interventions, architecture and urbanistic adjustments (i.e. the built environment), population-wide interventions, and bicycle renting system interventions. Their review of the literature claims that nearly all studies find a positive impact of a policy/policies on mode shift; however, the studies in the literature rarely present the statistical significance of their findings. Moreover, the authors claim that their review of the literature also finds that a combination of interventions is needed to promote active travel and reduce personal vehicle usage, rather than individual policies [97].

The Scheepers et al. review finds that while mass media campaigns appear to be beneficial when implemented alongside other interventions, the media campaign itself is neither a necessary nor sufficient condition for a mode shift from personal vehicle to active transport modes [97]. Regarding economic incentives and disincentives, the results highlighted in the review indicate that sustained incentives and disincentives can shift travelers to active transport from the personal car; however, when the incentives/disincentives expire, travelers tend to switch back to the personal vehicle.

Empirical results indicate that the benefits of bicycle and pedestrian infrastructure are most likely to accrue in metropolitan areas rather than rural areas [89]. Unfortunately, the VMT benefits of active transport infrastructure investments are typically minor as they only benefit travelers who live and complete activities within the geographical region of the infrastructure investment. Hence, the VMT reduction benefits of active transportation infrastructure investments are likely most beneficial alongside land use changes that result in higher density and higher diversity of activity types within cities. The increased density and diversity typically allows travelers to travel shorter distances, thereby, making active transport modes competitive with vehicle-based modes for these trips. Investments in active transportation infrastructure can help to provide pathways for higher density developments to be built, and then the infrastructure such as bike lanes and pedestrian paths can be more fully utilized over time.

In a relevant California study, Marshall and Garrick (2010), using data from 24 cities in California, find that increases in bike lane length increase the commute mode share proportion of bicycling [98]. Moreover, the study finds that interactions between the road network structure, and the connectivity of the road network, significantly influence the commute mode share of bicycling and walking in complex ways.

1.4.8 Truck/freight VMT

Truck traffic in California is unevenly distributed geographically. Southern California has significant travel by all classes of trucks. Medium and heavy-duty trucks also show significant travel through the Central Valley and other freight corridors (Figure 29, Figure 30, Figure 31).

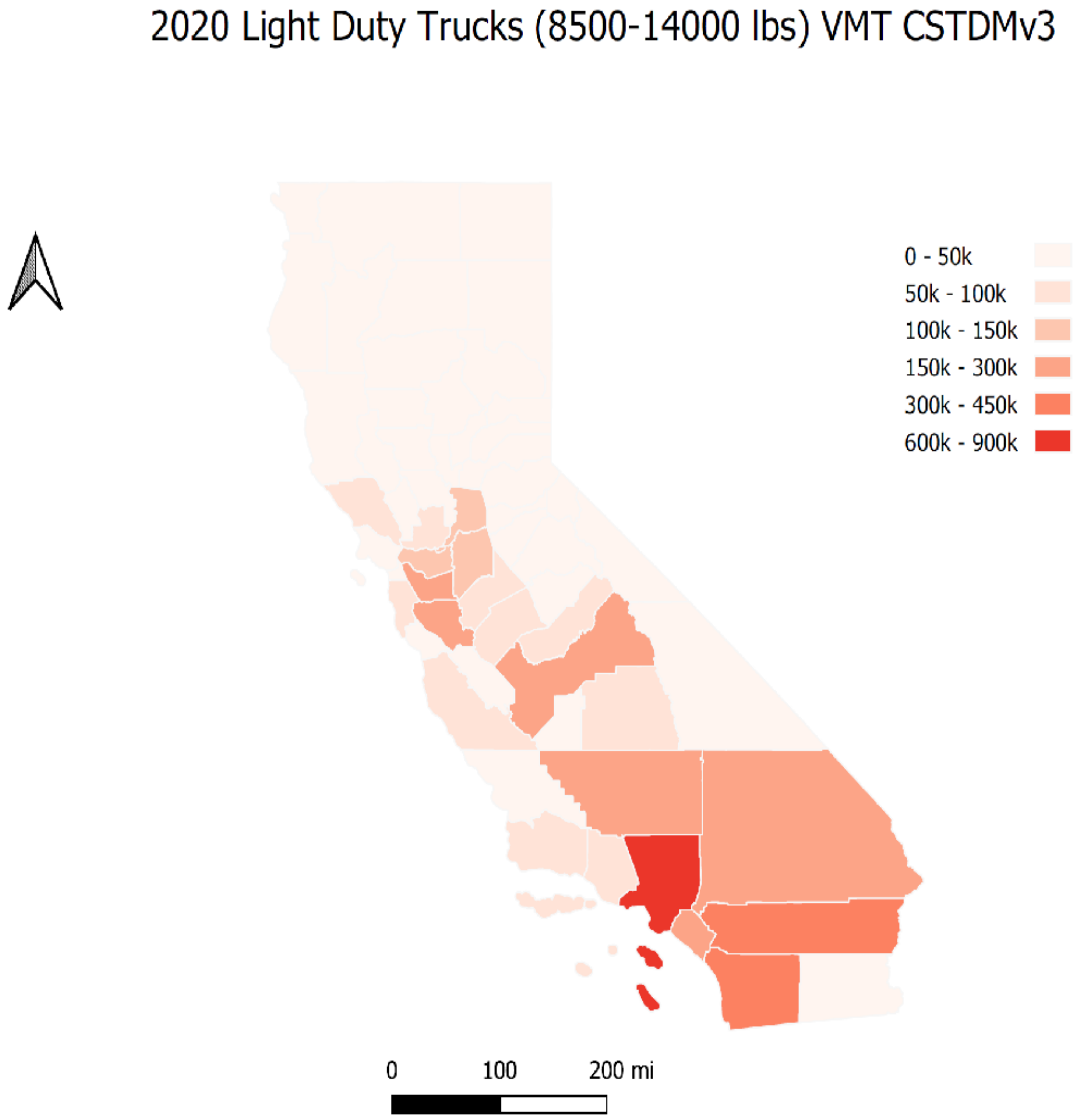


Figure 29. Daily VMT for Light Duty Trucks in California by county

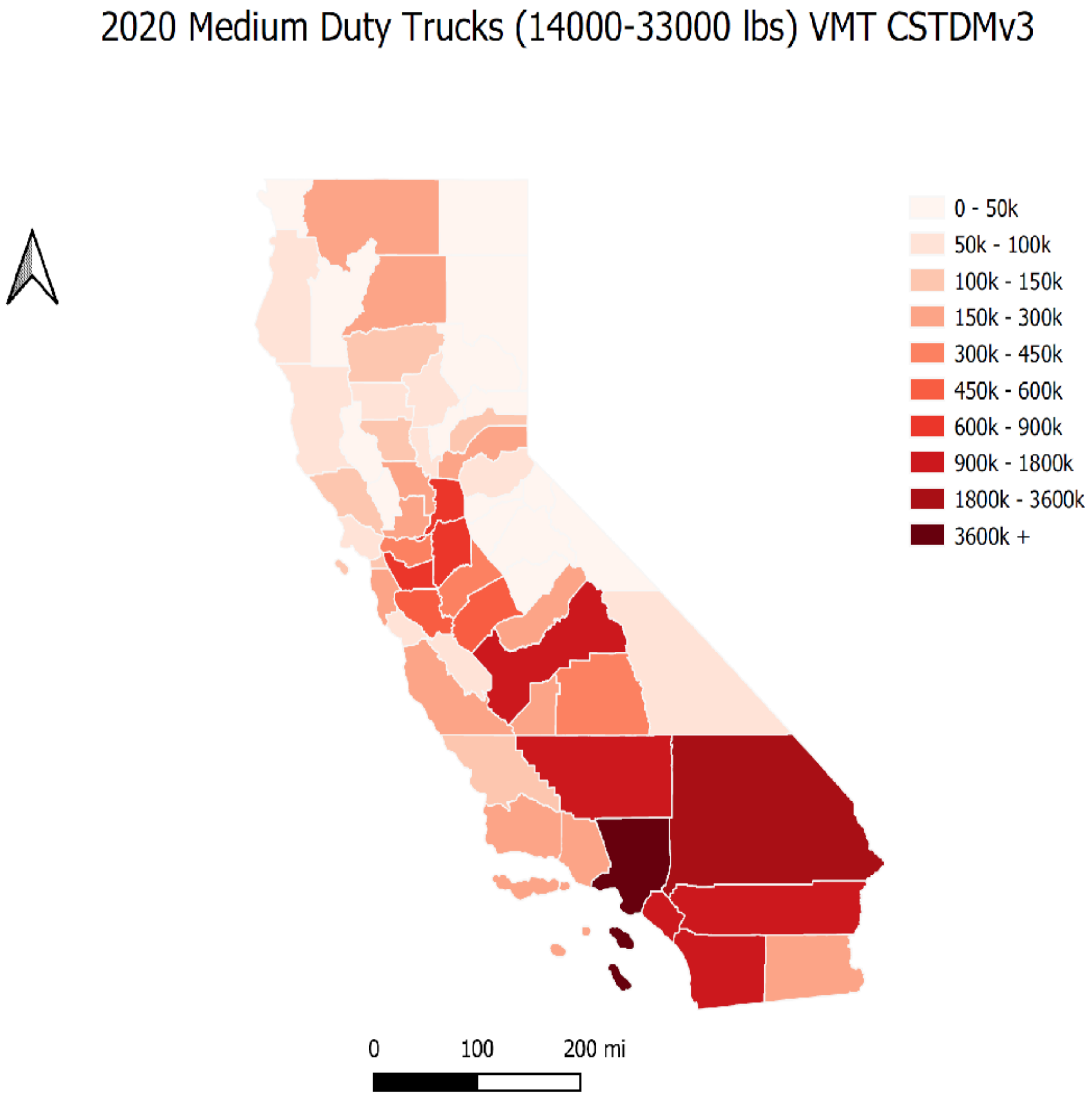


Figure 30. Daily VMT for Medium Duty Trucks in California by county

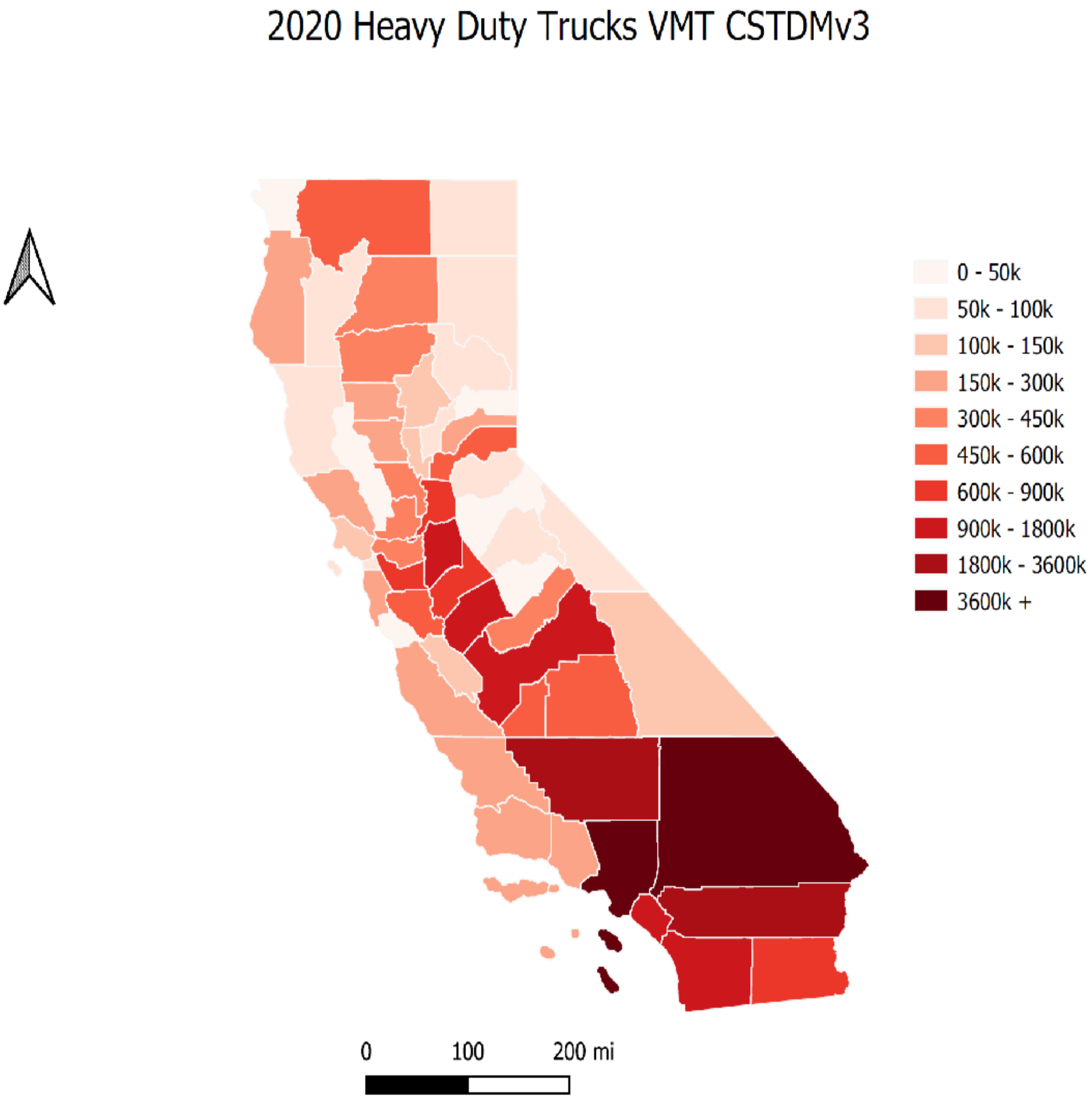


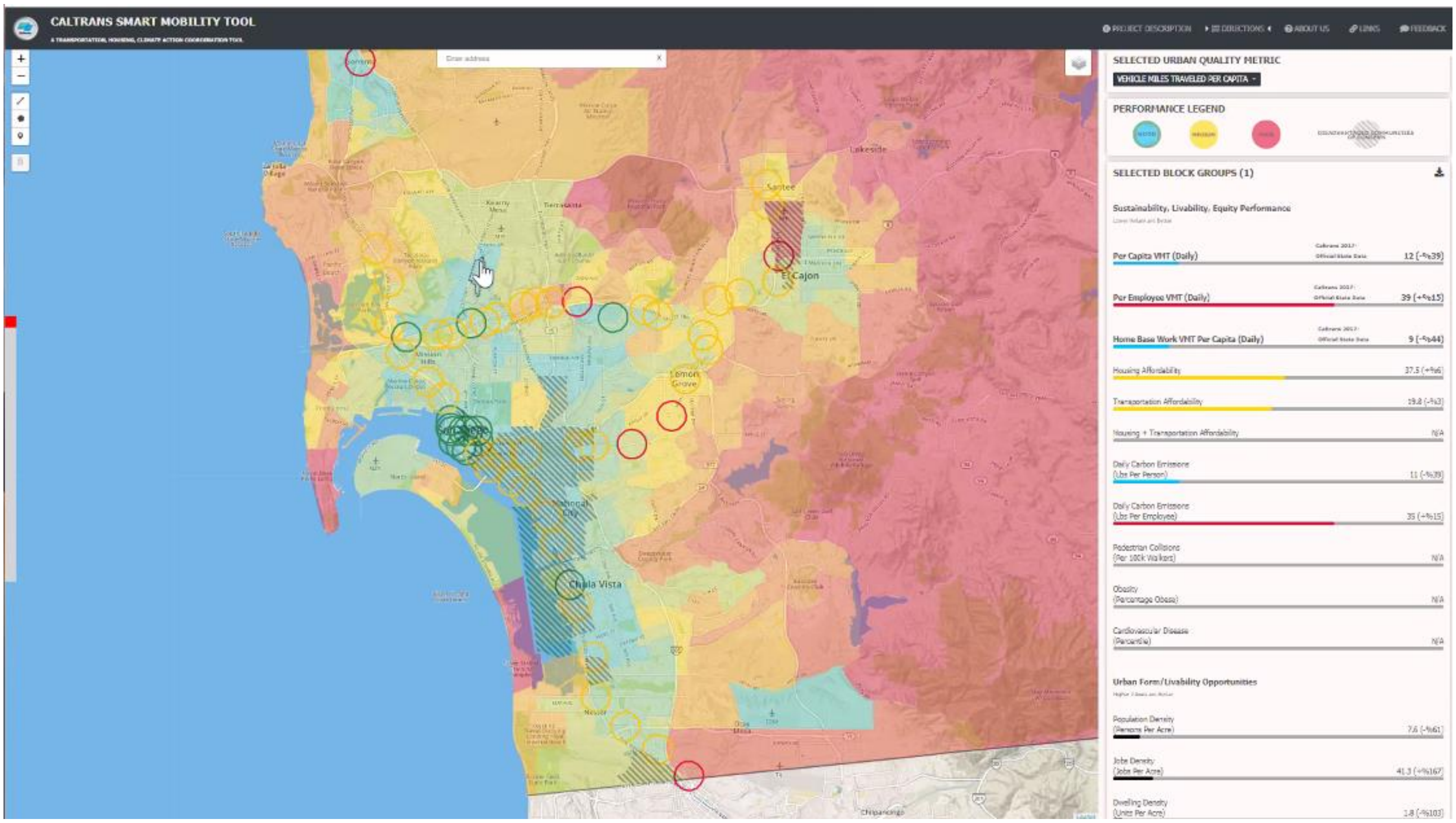
Figure 31. Daily VMT for Heavy Duty Trucks in California by county

1.4.9 Recent VMT Policy and Future VMT Policy Analysis Tools

The State of California Governor's Office of Planning and Research (OPR) is developing VMT analysis tools and resources based on the passage of SB 743 (Steinberg) [99]. SB 743 has shifted analysis of project level impacts under CEQA from level-of-service based impact analysis to a VMT-based analysis. This effectively amounts to a shift from managing congestion to a focus on managing and reducing VMT [100]. SB 743 took effect, statewide, on July 1, 2020.

Measures such as SB 743 that are more directed are needed to complement and help support the Sustainable Communities Strategy (SB 375) that encourages municipalities to consider strategies for VMT reduction in their planning, and requires them to identify plans for meeting GHG reduction targets. SB 743 allows for a shift in the focus to metrics much more closely tied to actual VMT levels and potential reductions, making them much more useful for assessing targets toward the state's environmental goals. This gives the state a better chance of success with its programs when combined with many other strategies for addressing VMT discussed above that include: land use and job/housing balances, enhanced transit system use, use of low-carbon intense new mobility, microtransit, and active mobility modes, and roadway and parking pricing strategies.

With regard to policy analysis tools for VMT reduction that have a spatial component, Professor Bruce Appleyard of San Diego State University, with support from Caltrans, has developed a tool called the Smart Mobility Tool that is now under beta release (https://testsmartgrowthcalculator.netlify.app/ Figure 32). This tool covers the several major urban areas of California. It groups local areas into eight different place types and provides a graphical depiction of key land use and transportation indicators by census tract, such as access to transit, carbon footprints, and commuter and home-based work travel along with overall per capita VMT. Model data files can be easily downloaded and then modified with the projected impact of specific policies, an analysis strategy that the project team is considering for further use in the project.



SELECTED URBAN QUALITY METRIC

VEHICLE MILES TRAVELED PER CAPITA

PERFORMANCE LEGEND

SELECTED BLOCK GROUPS (1)

Sustainability, Livability, Equity Performance

Per Capita VMT (Daily)	Caltrans 2017 - Official State Data	12 (-%39)
Per Employee VMT (Daily)	Caltrans 2017 - Official State Data	39 (+%15)
Home Base Work VMT Per Capita (Daily)	Caltrans 2017 - Official State Data	9 (-%44)
Housing Affordability		37.5 (+%6)
Transportation Affordability		19.8 (-%3)
Housing + Transportation Affordability		N/A
Daily Carbon Emissions (Lbs Per Person)		11 (-%39)
Daily Carbon Emissions (Lbs Per Employee)		35 (+%15)
Pedestrian Collisions (Per 100k Walkers)		N/A
Obesity (Percentage Obese)		N/A
Cardiovascular Disease (Percentile)		N/A

Urban Form/Livability Opportunities

Population Density (Persons Per Acre)	7.6 (-%61)
Jobs Density (Jobs Per Acre)	41.3 (+%167)
Dwelling Density (Units Per Acre)	1.8 (-%103)

Figure 32. Caltrans Smart Mobility Tool

1.5 Fuels

California depends primarily on gasoline and diesel refined from petroleum to power its transportation system. 84% of California's transportation energy is currently provided by petroleum, a value that is actually much lower than most other industrialized economies. For example, about 95% of total U.S. transportation energy is derived from petroleum, with the alternatives being mostly ethanol blended into gasoline, whereas California consumes a significant amount of biodiesel (BD), renewable diesel (RD), renewable natural gas (RNG) and other non-petroleum fuels. The majority of petroleum is consumed as gasoline, the dominant fuel for light-duty passenger and commercial vehicles. MDVs and HDVs predominantly rely on diesel fuel (Figure 33). An increasing amount of biofuels have been blended into California's fuel supply over the last decade.

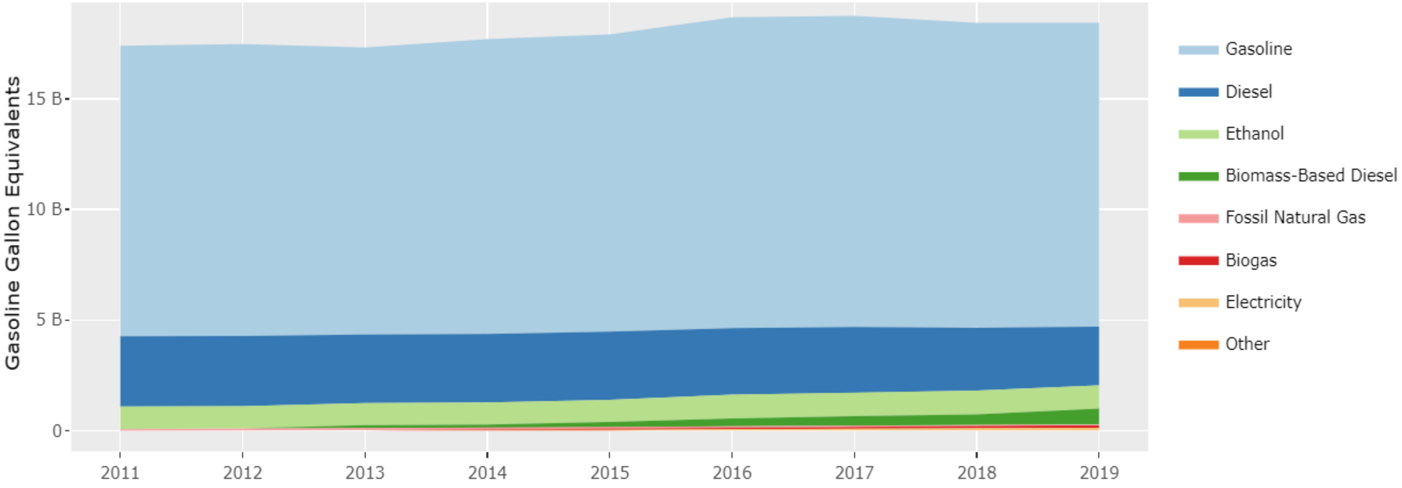


Figure 33. Transportation Fuel Consumption in California. The LCFS was largely responsible for creating and growing a market for biomass-based diesel substitutes, like BD and RD. They have become a significant contributor to California's fuel supply. Other fuels, like electricity, represent a small but growing share of the fuel market.

The first biofuel blended into transportation fuels at large scale was ethanol. The Federal Energy Independence and Security Act of 2007 expanded the use of ethanol as a substitute for gasoline, leading to a 10% ethanol blend (E10) becoming the default retail formulation in California and the rest of the United States. California’s gasoline specifications differ from many other parts of the United States in that California has stricter requirements for fuel volatility as well as permissible levels of sulfur, aromatics, benzene and other harmful components. The petroleum fraction of California’s retail gasoline is known as California Air Resources Board Oxygenate Blend (CARBOB).When mixed with ethanol, it yields a less-polluting formulation of gasoline called California Reformulated Gasoline (CaRFG) than what commonly used elsewhere in the country. California also has more stringent diesel standards, it was one of the first states to require ultra-low sulfur diesel, which reduces the formation of diesel particulate matter (PM) and enables the use of advanced diesel particulate filters to further reduce emissions. Additional standards set guidelines for aromatic hydrocarbon content and lubricity.

Since 2011, California’s fuel consumption has stayed relatively stable, with some periods of modest growth. Demand declines in the aftermath of the 2008–2011 recession were counteracted by robust economic growth in the decade that followed. At present, California has a number of policies intended to reduce the consumption of petroleum, ranging from tailpipe GHG-emissions standards that support the deployment of more efficient vehicles to transportation demand policies like SB 375 [101], which requires metropolitan areas to reduce per-capita VMT over time. Despite these policies, aggregate travel in California has generally increased over time and has been only partially counteracted by vehicle-efficiency improvements, leading to a generally growing aggregate demand for fuel.

The supply of transportation fuels to California has undergone a significant shift since California’s adoption of the LCFS. In order to meet the LCFS declining carbon intensity target, fuel suppliers must either reduce the carbon intensity of their products or buy credits from alternative-fuel producers. This directs a significant revenue stream from deficit-generating fuel providers (those selling petroleum gasoline and diesel) to alternative-fuel providers, while also creating an incentive for conventional fuel producers to help alternative fuels make it to market (since credits are only generated when fuels are actually used for transportation). Revenue generated from credits for electricity are required to be reinvested in projects to further promote electrification in the transportation sector. Estimated total revenue for alternative-fuel producers under the LCFS has exceeded $6 billion since the program's inception (Figure 34)

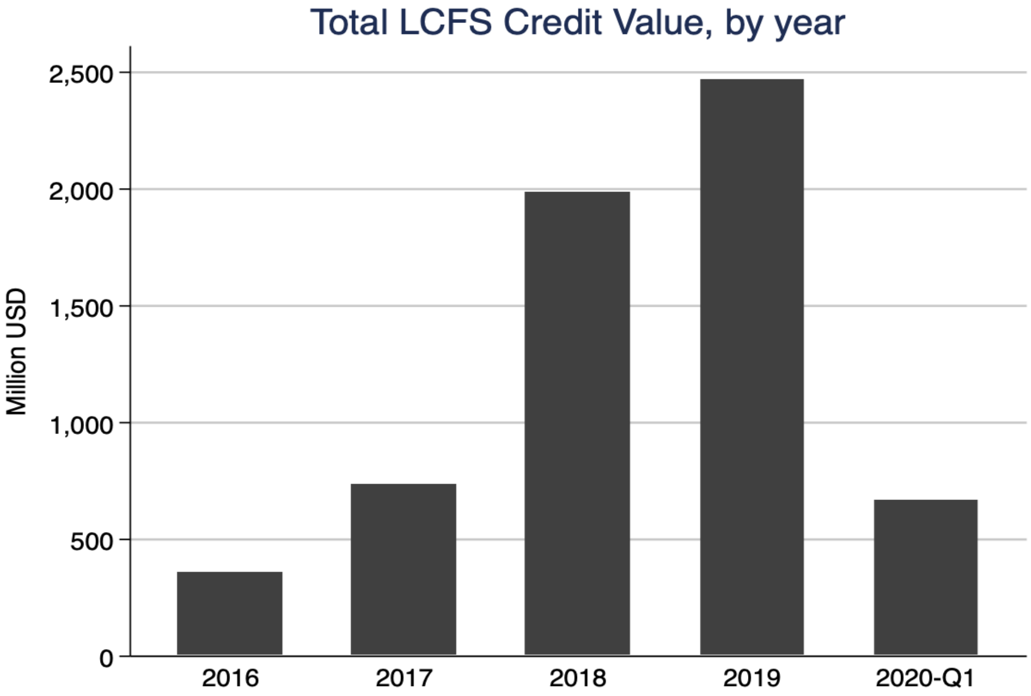


Figure 34. Total LCFS credit value 2016 through First Quarter of 2020. Credit values estimated by multiplying total yearly deficits by volume-weighted average price for the year.

LDVs in California are predominantly fueled by E10. The overwhelming majority of ethanol used in this blend is produced from corn, mostly grown in the Midwest and shipped to California by rail. When the LCFS was first adopted, most projections predicted that cellulosic ethanol would become a major compliance fuel under the program, delivering significant carbon reductions compared to corn. In practice, commercial-scale cellulosic ethanol has proved more difficult to produce than expected, due to challenges in procuring and handling feedstock at a low enough cost to be competitive, as well as difficulties overcoming inhibitory byproduct creation and scaling up the cellulosic production technologies to consistently produce viable commercial yields. Several early demonstration projects closed after cost overruns and under-performance. Many corn-ethanol producers have adopted cellulosic "add-on" modules designed to consume the cellulose in corn kernel fiber in order to increase ethanol yield; these modules typically add only 2–4% to the corn facility's yield.

In the long-term future (>10 years), electricity is likely to be the dominant alternative fuel in the LDV space, especially if critical decarbonization targets are to be met. At present, though, only around 600,000 plug-in vehicles are in use in California out of an LDV fleet of around 26 million. Hence the impact of EVs on overall transportation-fuel consumption in California is relatively small at present, and will continue to be until the fleet expands further. Alternative fuels, like biofuels, are therefore the predominant source of near-term emissions reductions and will continue to be for the next decade or more.

Since there are more cost-effective alternatives to diesel than gasoline at present, the gasoline pool in California has exhibited relatively minimal change since the inception of the LCFS. Ethanol remains the largest credit generator (Figure 35). As a whole, alternative fuels in the gasoline pool do not produce enough LCFS credits to offset deficits from petroleum-gasoline consumption. Gasoline producers instead purchase credits from diesel substitute producers to satisfy their LCFS obligations.

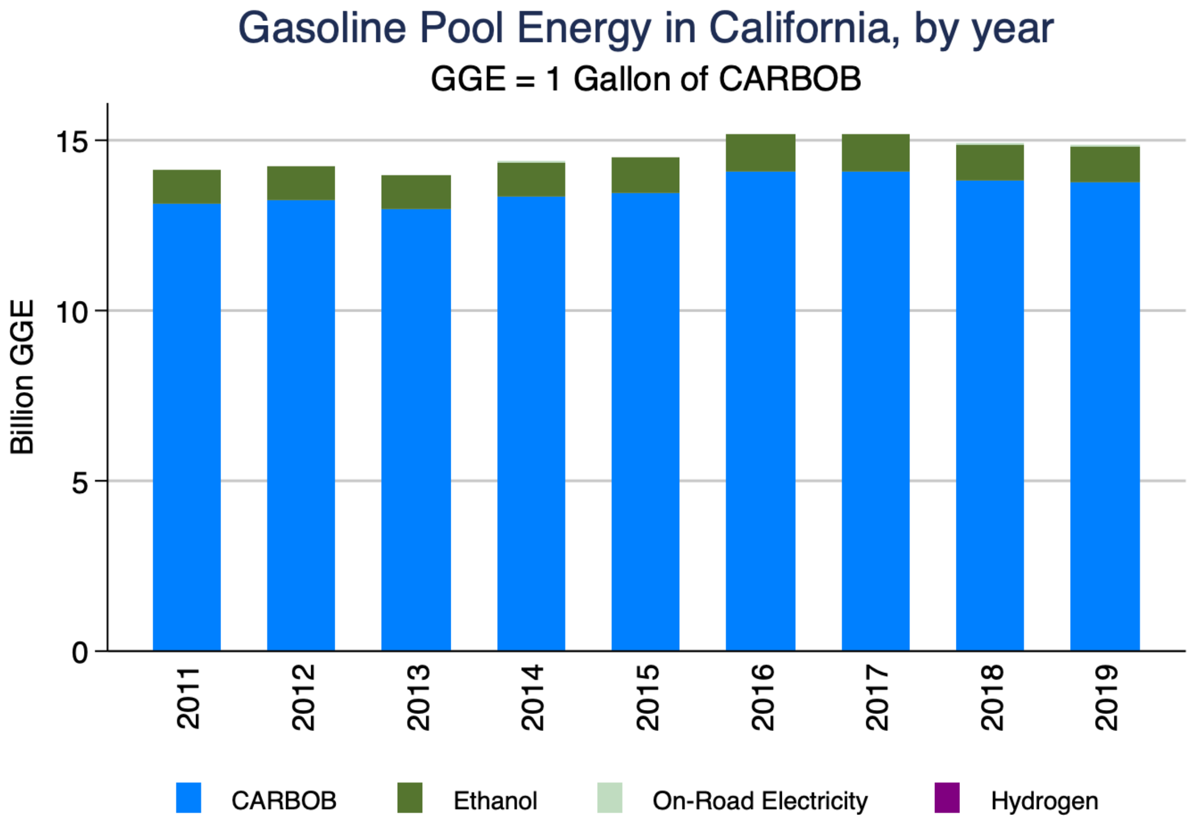


Figure 35. The gasoline pool has remained relatively stable year over year.

The diesel pool has seen a greater shift towards alternative fuels and a greater diversity of fuel options, due primarily to the more rapid commercialization of large-scale biomass based diesel fuels- BD and RD- than equivalents in the gasoline pool. Lower carbon diesel substitutes include:

Biodiesel (BD)

Biodiesel is made by esterification of from vegetable, animal or used food oils to yield Fatty Acid Methyl Esters, which are often abbreviated as FAME and used as another name for biodiesel. BD can be blended into conventional or RD at up to a 20% level without requiring modifications to engines or fuel systems. BD typically reduces total lifecycle GHG emissions by 30–60% relative to conventional diesel, depending on the feedstock used in BD production. BD also reduces formation of PM due to BD's lower sulfur content [102], and other chemical differences. In some older engines, BD may increase emissions of nitrogen oxides (NOx). CARB has issued a number of rules designed to mitigate this possibility. BD blends can sometimes suffer gelling or viscosity loss at cold temperatures, and so may require special handling and may not be suitable for all applications.

Renewable diesel (RD)

Renewable diesel is made by hydrotreating vegetable or waste food oils in a process similar to that of a petroleum refinery. The resulting fuel meets the technical specifications for conventional diesel fuel, most notably ASTM D975, which means that it can be burned in any diesel engine at any concentration without modification, making it a "drop-in" fuel, compatible with existing vehicles and fuel distribution infrastructure. RD typically achieves comparable or marginally higher lifecycle GHG emissions than BD, due to the more energy-intensive production process. RD also significantly reduces PM and slightly reduces NOx when substituted for petroleum diesel.

Natural Gas and Renewable Natural Gas (NG and RNG)

Several engine manufacturers have developed engines, aimed at the HDV market, that burn natural gas (NG). NG engines typically emit less PM than diesel-powered engines. Advanced, extremely low NO_x versions of NG engines have recently entered the market. NG engines running on fossil-fuel-based NG offer a 10-20% reduction in lifecycle GHG emissions relative to conventional diesel-powered engines; NG can burn cleaner than diesel, but there are often significant fugitive releases of methane associated with production and distribution of fossil-fuel-based NG. Natural gas engines also generally require spark-ignition engines instead of more efficient compression-ignition ones. Renewable natural gas (RNG) can be captured from decomposing organic matter and can offer significantly lower lifecycle GHG emissions. In some cases, RNG generation prevents the release of methane. This generates large additional GHG credits that can be applied to the fuel, resulting in RNG sources which have a negative assessed GHG value. This avoided methane credit is appropriate as long as other policies have not required mitigation of fugitive methane sources. In California, SB 1383 and the Short-Lived Climate Pollutant Reduction Strategy sets a target to achieve a 40% reduction in methane emissions by 2030. Anaerobic digesters are a likely option for compliance with organic waste disposal and manure management requirements of SB 1383 and a significant expansion of in-state RNG production from digesters is anticipated. Even with anticipated expansion, however the total supply of RNG from in-state sources is likely to be limited. Jaffe and Parker [103] evaluated potential in-state supply and found a maximum potential production around 82 billion standard cubic feet per year, equal to about 560 million diesel-equivalent gallons of fuel, however production under likely economic conditions would be lower. Depending on the reductions that can be achieved through incentives for voluntary mitigation, CARB anticipates that mandatory methane reduction requirements will be necessary to achieve the target. CARB has indicated that projects in place prior to the effective date of a mandatory methane reduction would still be eligible for avoided methane credit to reduce the carbon intensity of the resulting RNG under the LCFS for up to 10 years, while new projects implemented after such regulation takes effect would only be eligible for emission reductions that exceed the methane reduction requirements. This means that very low-carbon RNG, despite comparatively small volumes, could play a significant role in California's fuel pool through the early to mid-2030's.

Electricity

In addition to alternative fuels for combustion engines, electricity is taking on a larger role in the medium- and HDV sector. Electric motors offer a couple of advantages in medium- and heavy-duty applications, in addition to their much higher fundamental levels of efficiency. These advantages include high torque, the ability to reclaim energy from regenerative braking, and lower emissions in applications that often occur in proximity to workers or sensitive populations. Electric vehicles also provide a strong contribution to meeting state-wide emissions targets and offer an opportunity to be used as flexible demand or even electricity storage, when combined with appropriate grid upgrades. Electric motors also offer an opportunity to decarbonize the fuel supply for vehicles as the electric grid reduces its emissions, as well as the potential to integrate vehicle charging in grid-supportive patterns, which can help accommodate high levels of variable renewable energy on the grid.

Hydrogen

Hydrogen fuel cells offer an alternative to batteries for electric drive trains, so most of the advantages of an electric vehicle also apply to hydrogen ones. While the hydrogen fuel cell system ultimately produces electricity, hydrogen's chemical form enables seasonal energy storage; that is, using electrolysis to store excess electricity for later use. FCEVs also typically offer quicker refueling times than batteries and a superior energy density by mass than most battery types, though their energy density by volume tends to be lower than most batteries.

Petroleum diesel still comprises the majority of fuel in the MDV and HDV spaces, but alternatives have made significant inroads into this market. With a variety of diesel alternatives available, and numerous test and demonstration projects supported by federal, state, local, and philanthropic support, there has been a greater diversity of fuel types in the diesel pool than in the gasoline pool. There has also been a significantly higher rate of aggregate credit generation in the diesel pool, leading to a net flow of credits generated by diesel substitutes towards meeting compliance obligations arising from gasoline use. In particular, BD and RD have proved cost-effective and scalable under current technological and economic conditions (Figure 36).

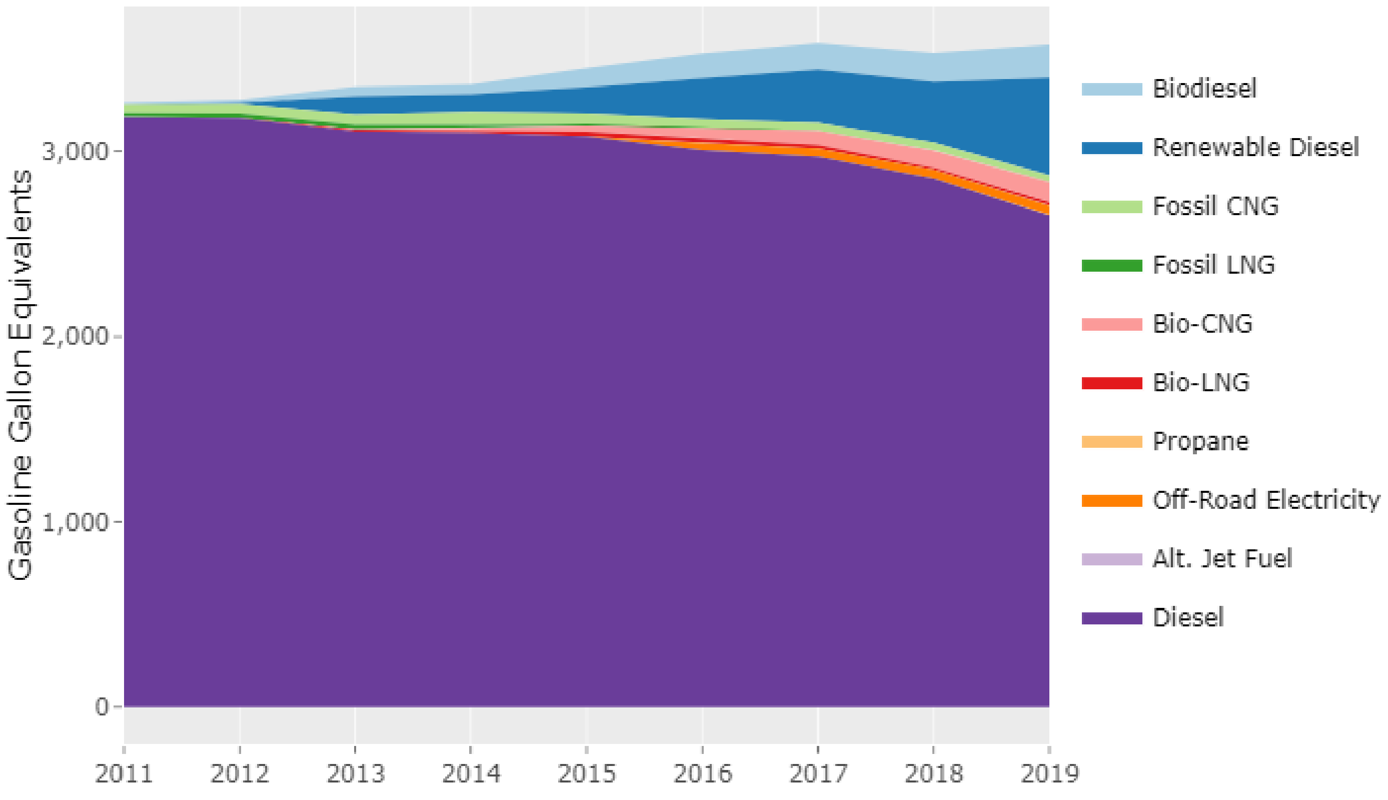


Figure 36. Diesel and Diesel Substitute Consumption in California. Under the LCFS Fuel use by MDV and HDVs has significantly shifted from almost entirely fossil-based to around one-sixth renewable over the last decade.

Overall, the LCFS has supported significant deployment of advanced, low-carbon fuel technology into the California market. While ethanol still dominates the total volume of non-petroleum fuels, it has been eclipsed as a credit-generation option by several diesel substitutes (Figure 37). The coming decade of fuel market evolution in California will likely continue this trend. Ethanol's contribution to the fuel pool, and to LCFS credit generation is likely limited by the "blend wall," the maximum amount of ethanol which can be blended into retail gasoline. There have been some preliminary steps taken towards lifting the blend wall, possibly to a 15% standard blend (E15), however significant barriers exist before it could be widely deployed. Absent a transition from an E10 to E15 standard, or a significant deployment of flex-fuel vehicles which can use up to 85% ethanol, there may be limited opportunities to increase the total amount of ethanol in the fuel pool. Deploying CCS at ethanol production facilities has been proposed as a method for reducing the carbon intensity of the resultant fuel, which could allow more LCFS credit generation and lower GHG emissions from the same volume of fuel [104]. Without either a higher blend wall or significant reductions in carbon intensity, ethanol will likely produce a significant but declining share of total compliance credit under the LCFS. BD and RD will likely continue to be the most important compliance fuels for the next several years. The growth potential of BD and RD may be limited by the availability of low-carbon feedstocks, such as waste oils from food processing, or may be augmented by the emergence of cellulosic technologies. Without the development of advanced technology and ample supplies of sustainable, low-carbon feedstock, biofuels will struggle to contribute to the attainment of California's long-term emissions goals.

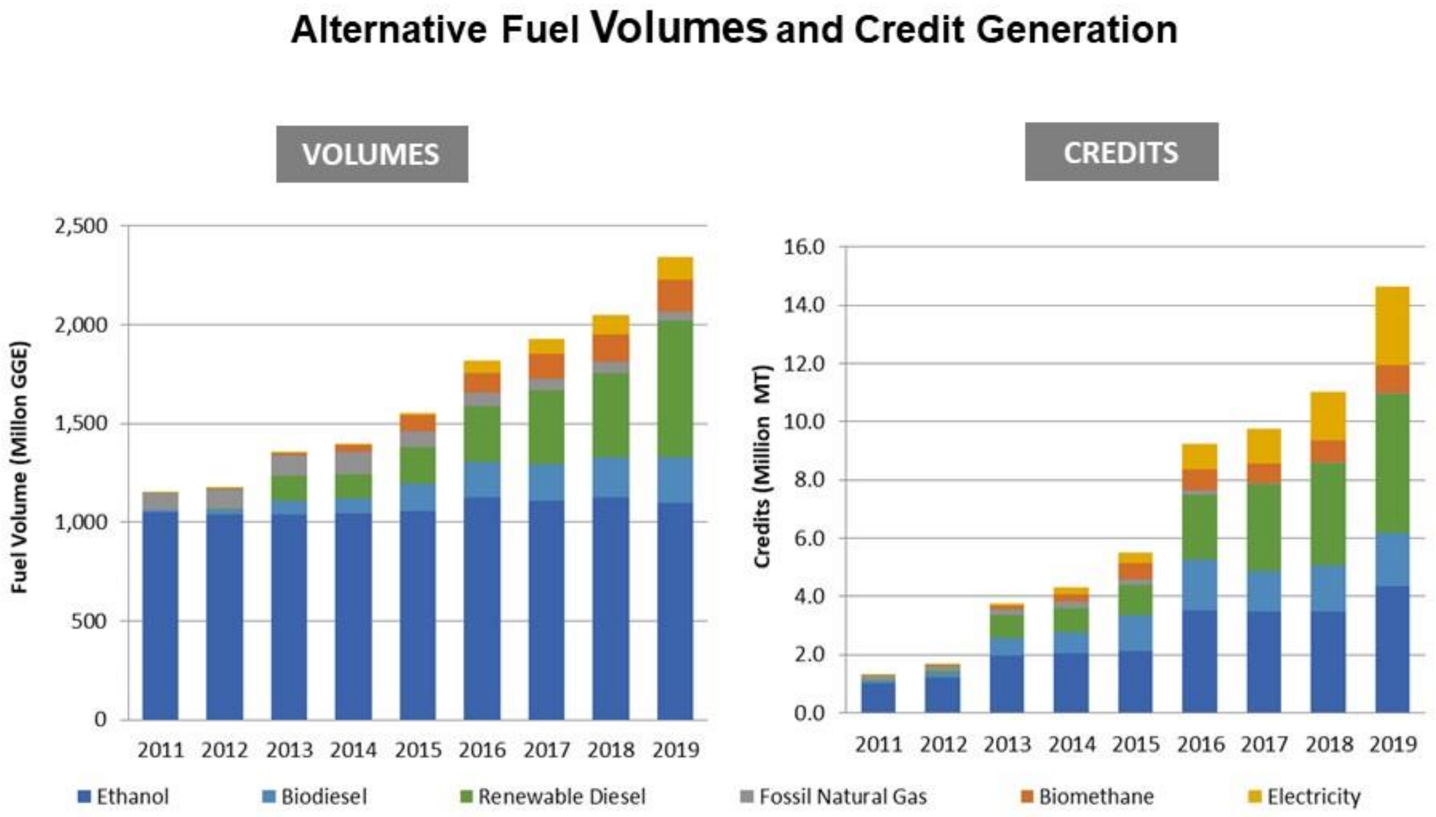
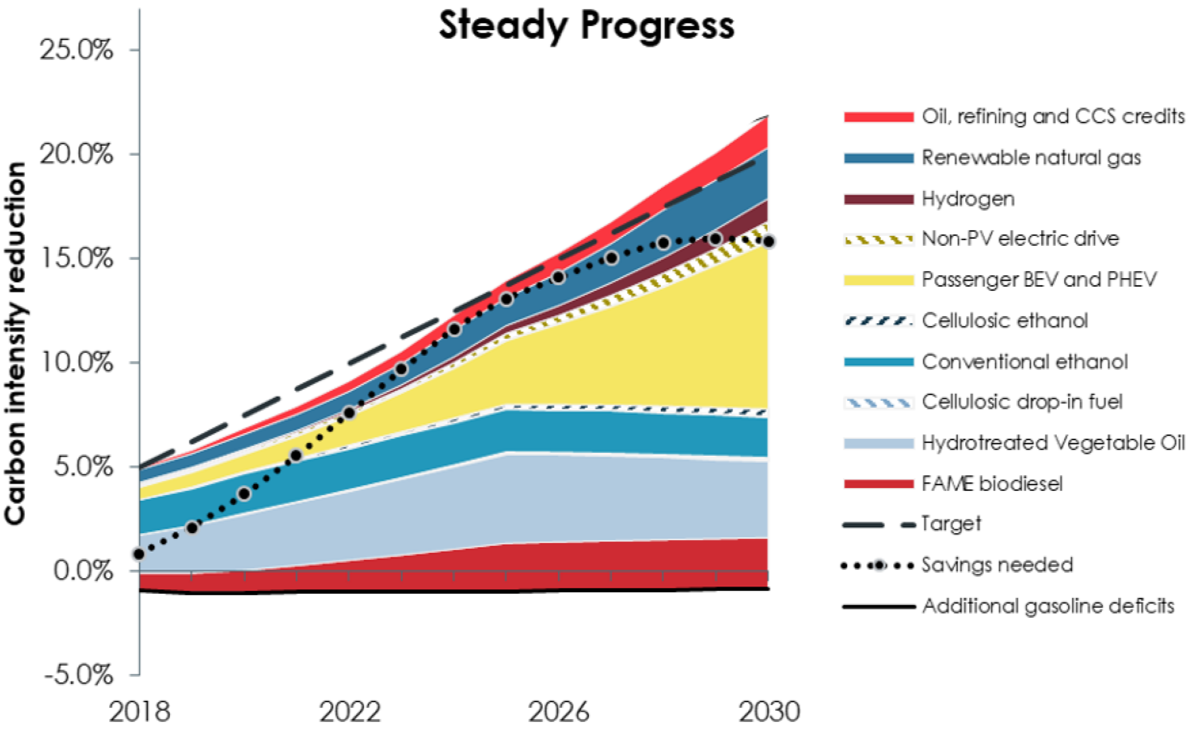


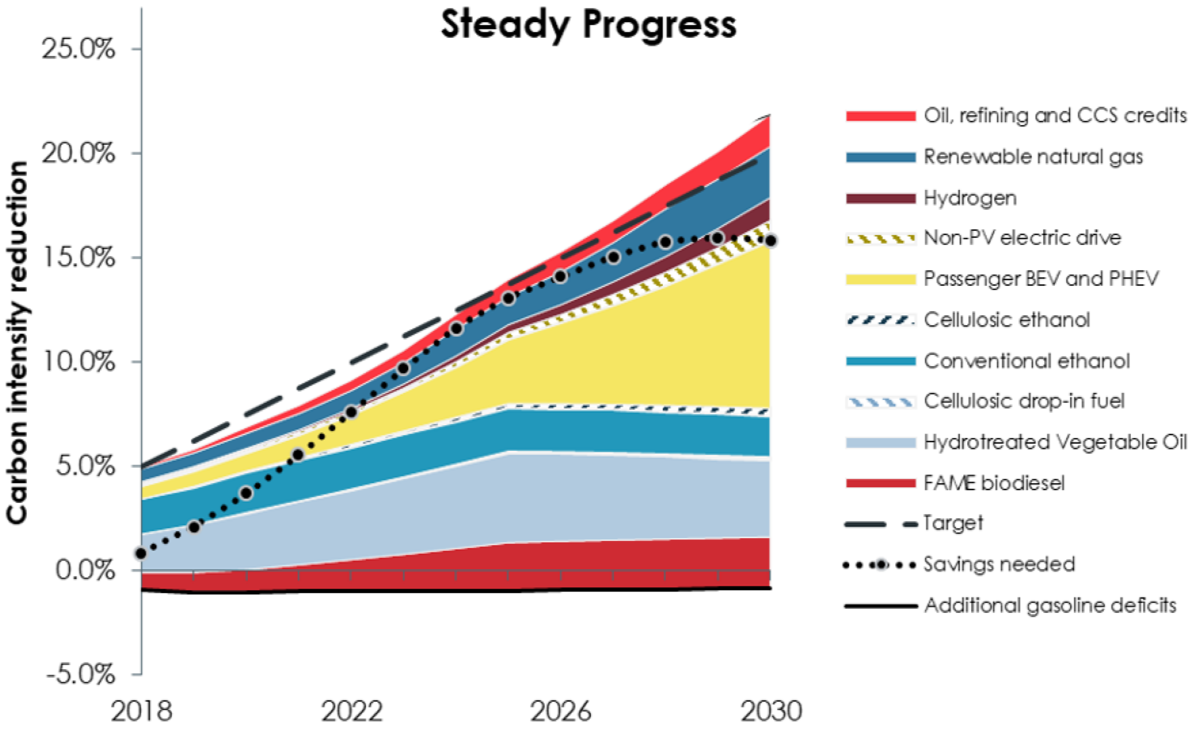
Figure 37. Fuel Volumes and LCFS Credit Generation by fuel. Ethanol dominates the volume of low-carbon fuels consumed but other fuels play a greater role in compliance with the LCFS.

The ability of the LCFS to meet its 20% carbon intensity reduction target by the end of this decade will likely depend on progress in deploying PEVs. PEVs serve as a significant credit generator while simultaneously displacing gasoline, the dominant generator of deficits. Few, if any other technologies, can provide zero or near-zero carbon transportation at the scale likely required to achieve a 2045 carbon neutrality target. But PEV technology should not be considered a silver bullet on its own. Barring an unexpectedly rapid advance in PEV technology, California will need to rely on diverse portfolio of solutions in order to meet its decarbonization targets in 2030 and beyond (Figure 39).



Source: California's Clean Fuel Future

Figure 38. Expected compliance with the LCFS by fuel



Source: California's Clean Fuel Future

Figure 39. Expected compliance with the LCFS by fuel

1.6 Equity and Environmental Justice

1.6.1 History and principles of environmental justice

The concept of Environmental Justice (EJ) originated as a response to the limitations of traditional environmentalism. Mainstream environmentalism successfully championed the efforts to protect, conserve, and replenish wildlife and wilderness, but did little to address the conditions in human-made environments. Environmental concerns not addressed by the environmentalism narrative included the inequitable distribution of environmental harms and benefits in minority communities, recognition of historical precedents that hindered communities of color to secure cleaner environments, and a lack of outreach and engagement with groups in those historically disenfranchised communities burdened with adverse environmental conditions.

Post-war zoning codes and land use practices are viewed as the sponsors of the inequities that incited the EJ movement. These regulating mechanisms allowed for whites to secure newer, cleaner, and more prosperous environments while explicitly suppressing communities of color to harmful, dangerous, and dirtier urban spaces. The right to clean and prosperous environments would eventually be absorbed as an element of the Civil Rights Movement. By the 1980s, the environmental justice framework had solidified and defined its purpose: the protection for all people regardless of race, color, nationality, or income from environmental and health hazards, and equal access to the healthy environments in which to live, learn, work, and play [105].

While the history of environmental justice dates back generations, many EJ advocates recognize the start of the modern EJ movement with the drafting and adoption of the 17 Principles of EJ established at the First National People of Color Environmental Leadership Summit held in Washington, D.C. in 1991 [108] (See Appendix).

The preamble to these principles attributed the existential threats to peoples and the land they live on to hundreds of years of colonization and oppression.[6] The 1991 Summit helped catalyze a series of Executive Orders issued by President Bill Clinton directing each federal agency to "make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations," including tribal populations (Executive Order 12898) [106].

1.6.2 California's commitment to social equity

Due in large part to community advocacy spanning generations, in 2001 California became one of the first states to codify EJ in statute. California legislators have recently issued a suite of policies aimed at directing investment towards and providing protections for disadvantaged communities (DACs). These investments carry with them an explicit connection to EJ concerns. Notably, SB 535 (passed in 2012) channels proceeds from the state cap-and-trade program's Greenhouse Gas Reduction Fund (GGRF) to projects benefiting DACs. 2017's AB 1550 requires projects funded by the GGRF after that year to be located within (and directly benefit) DACs in order to count towards the 25% statutory investment minimums set by SB 535. Based on the 2020 California Climate Investment Legislative Report, 39% of the $2.6 billion of GGRF funds allocated since 2017 have gone towards projects directly located in and benefiting DACs.

California has established numerous additional policies and programs meant to address social and environmental disparities statewide. Many of these policies and programs rely on CalEnviroScreen, a GIS-based tool that identifies DACs based on a diverse suite of characteristics [107]. The product of multiple state agencies' collaboration with researchers and a broad array of stakeholders, CalEnviroScreen is currently in its third iteration and is housed at the California Office of Environmental Health Hazard Assessment (OEHHA).

In addition, California has made significant efforts in addressing the barriers limiting accessibility to clean transportation options for low-income, DAC, and tribal communities. SB 350 (De Leon, 2015) directed a series of reports that seek to identify and understand the challenges of such communities in securing clean transportation and mobility options. This resulted in pathways and implementation of programs targeting transportation equity by promoting active transportation, zero emission heavy-duty and light-duty vehicles, micro-mobility projects, and EV charging infrastructure funding in low-income, tribal and DAC

Furthermore, many state agencies now have formal advisory committees focused on equity issues, such as the California Air Resources Board, Environmental Justice Advisory Committee, the California Energy Commission and California Public

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[6] Indeed, the rise in civil unrest catalyzed by the May 2020 murder of George Floyd in Minneapolis grew in large part out of grievances directly related to this history of racialized colonization and oppression that contributed to the rise of the EJ movement as well as a reaction to EJ injustices themselves.

Utilities Commission Disadvantaged Community Advisory Group, and the California Public Utilities Commission Low-income Oversight Board. These groups represent diverse transportation and energy interests and allow for more inclusive policies to be developed to support social equity goals.

1.6.3 Transportation as an environmental justice issue

The EJ framework argues that low income and historically disadvantaged communities should not be burdened with environmentally adverse spaces. That in fact, low income communities and DACs have the right to spaces that promote health, safety, and prosperity. Therefore a low-carbon transportation system to navigate those spaces in addition to the impacts and by-products of those modes are fundamental and should be considered in the EJ discourse.

The legacy of redlining, discriminatory lending practices, and racial covenants produced low income communities and DACs that were and continue to be burdened with poor quality of life, lack of public investment, and systematic oppression. Irresponsible zoning practices have sited polluting operations such as heavy industry and refineries in the vicinity of these same communities. To meet the demands of early suburbanization, many of these communities were often relegated as easily displaceable and bifurcated by transportation projects. Proximity to high emissions and toxins, coupled with disproportionate resource allocation, has resulted in range of adverse health conditions and few resources for mobility in low income communities and DACs.

Perhaps the most highlighted EJ concern in transportation in the disproportionate exposure to on-road particulate matter (PM). A 2019 study by the Union of Concerned Scientists (UCS) [108], found that in California exposure to PM from on-road sources (PM 2.5) is 10% higher than the state average in households with the lowest incomes. Additional findings indicate that African Americans and Latinos in California are on average exposed to more on-road PM than their white counterparts; 43% higher and 10% higher, respectively. This study also found that California households living without a personal vehicle are the most exposed to vehicle pollution, as they are likely to live in heavy-traffic urban areas. In other words, households that are least likely to have a car-dependent lifestyle, are most exposed and most burdened with the negative by-products of transportation (UCS, 2019) [108].

Energy operations for California's vast transportation sector have also impacted the local environment of DACs. Since the first comprehensive study in the U.S. on toxic facilities by the United Church of Christ (1987), findings indicate that polluting facilities are most likely to be situated in areas characterized with a high percentage of minorities [109]. This topic was revisited 20 years later (Bullard et al., 2008) [110] only to find presence of the same disproportionate allocation of oil refineries, gas power plants, and toxic waste disposal still disproportionately located in minority communities. Findings from a 2018 study (Mikati et al., 2018) [111] quantify the nationwide burden of PM to be 1.35 times higher in low-income communities than the overall population. Race continues to be a determining factor in exposure to PM, as the study finds particulate burden in non-whites to be 1.28 times higher.

High exposure to on-road pollution and pollutants emanating from toxic facilities have severe health implications. Cardiovascular diseases, respiratory problems, and premature deaths have all been linked to increased level of PM [112]. The high concentration of DACs near heavy traffic infrastructure and toxic facilities renders these communities as most vulnerable to these health hazards. According to the American Lung Association, health threats from polluting environments are exacerbated in DACs as a direct result of their lower social and economic standing. Lack of access to proper health care, grocery stores, poorer job opportunities, dilapidated housing, and harsher work conditions are factors that intensify adverse health conditions and increases the risk of harm.

Access to transportation resources has the potential to significantly increase quality of life and opportunities for life choices. However, the cost of vehicle ownership, maintenance and insurance, public transit fares, and ride hailing fees, can hinder mobility for those with limited financial resources. While on average households in the U.S. spend around 20% of their income on transportation, the burden on low-income households can be as high as 30% of their income.

The number of communities that can be considered affordable dramatically decreases when the definition of affordability also incorporates social, economic, and environmental cost especially for overburdened communities. Low-income minorities coping with rising housing prices are forced to lower-cost housing, often located at a distance from employment hubs in central urban cores. This further impacts their social and economic standing, impedes access to critical services such as health care and grocery stores, and reduces proximity to economic opportunity and higher wage employment opportunities. In addition to these social, economic, and environmental costs, there are significant transportation-related costs. As a consequence of these housing and other land use implications, low-income individuals typically travel longer distances out of necessity, thus increasing their own cost burden of transportation. Unfortunately, the sprawling nature of cities in California makes it difficult for them to be adequately served by mass transit

Race also plays a crucial role regarding the travel choices an individual makes and the modes they use. Over-policing in communities of color has created an environment of fear and anxiety that discourages mobility via driving, bicycling, or walking for daily routine tasks. Consequently, low-income minority communities are further obstructed from accessing crucial resources that can provide a venue for social mobility and equally placing increased pressure on the need to transform the transportation system.

Sustainability for a future low-carbon transportation system will require active efforts to ensure that EJ concerns are addressed. A sustainable low-carbon transportation system should seek to minimize the environmental burdens and health implications on low income communities and DACs. Most importantly, a truly sustainable system should seek to extend the benefits of low-carbon transportation to low income communities and DACs in California in a manner which galvanizes social reform, by increasing connectivity for crucial life opportunities such as heath, employment, and education. Developing a sustainable low-carbon transportation system will require active efforts now.

1.6.4 Equity and environmental justice coordination

In this study, the researchers responsible for incorporating an equity lens and an EJ perspective will work collaboratively with the other research teams. They will collaborate with the teams examining the topics concerned with health and labor and employment. The respective leads of the health and labor and employment research teams both have a strong grasp of and commitment to equity and EJ. The equity and EJ research team will also serve an advisory role to technical aspects of this study, including those teams researching heavy-duty and LDVs, VMT, and fuels. Collectively, these research teams will work in an iterative fashion with both state agency representatives working on EJ as well as civic and community stakeholders statewide who advocate for the elevation and implementation of EJ principles into state policies. The research teams and Equity and EJ team are committed to maintaining a high degree of accountability for the public and stakeholders. All parties are working in partnership to provide a space that allows for input, feedback, and comments of best practices for dissemination of results. By taking these measures this research seeks to ensure that the research conducted is clear and transparent.

Understanding the transportation needs and perspectives of residents and stakeholders in DACs is critical to moving towards a more just transportation system. By connecting people from the most vulnerable communities to key life opportunities, transportation can serve as a cornerstone piece to increasing quality of life. The perspectives of residents and stakeholders in low income communities and DACs is also critical to guiding and informing this report and the anticipated policy and implementation impacts. This working group will engage with organizations that have already developed a relationship with state agencies and have made significant strides forward in advocating and empowering EJ communities. These efforts will be guided by CalEPA guidelines prioritizing equity, health, environment, resilience and adaptation, high road jobs, affordability and access, and minimizing impacts beyond our borders. This group has been and will continue to coordinate efforts with and support community engagement activities by the Health and Labor and Employment working groups.

This working group's approach will involve outreach to the following groups inviting them to provide input:

- Transportation Equity and Environmental Justice Advisory Group (TEEJAG) coordinated by the Center for Regional Change at UC Davis
- Community Air Protection Program Consultation Group coordinated by CARB
- Disadvantaged Communities Advisory Group (DACAG) coordinated by the CEC and the California Public Utilities Commission (CPUC)
- Last Chance Alliance, a coalition of advocacy groups

1.7 Health

1.7.1 Current state of local pollutants, health impacts

On-road motor vehicles (cars, trucks, and buses) generate air pollutants throughout their lifecycles (vehicle and fuel production, vehicle operation, and end-of-life). These pollutants endanger public health, especially for vulnerable groups, including children, low income groups, and communities of color. The main pollutants from the operation of motor vehicles powered by ICEs include [113][114]: particulate matter (PM), carcinogenic volatile organic compounds, nitrogen oxides, ground-level ozone, carbon monoxide, and sulfur dioxide. Some of these pollutants are directly emitted from vehicles, and others are the result of chemical reactions in the atmosphere (e.g., secondary PM).

Particulate matter (PM). Airborne PM is a complex mixture of solid particles and/or liquid droplets ranging in size from 0.01 μm to more than 10 μm.[7] It is common to distinguish between coarse ($PM_{10-2.5}$), fine ($PM_{2.5}$), and ultrafine ($PM_{0.1}$ or UFP). More specifically, the US EPA defines $PM_{2.5}$ as particles collected by a sampler with an upper 50% cut-point of 2.5 μm aerodynamic diameter and a specific, sharp penetration curve as defined in 40 CFR Part 58 [115]. Ultrafine particles (UFP) are particles with a diameter of <0.1 μm based on physical size, thermal diffusivity, or electrical mobility [115].

PM is composed of both primary and secondary components. Primary PM comes directly from the operation of internal combustion engines as well as other anthropogenic and natural activities. Secondary PM are produced by atmospheric chemical reactions, including the oxidation of precursor gases such as SO_2 and NO_x to acids, followed by neutralization with ammonia, and partial oxidation of its organic components. The characteristics of PM mixtures depend on their sources, chemical composition, transport characteristics, atmospheric lifetime, and removal processes.

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[7] PM_x denotes particles with a diameter under x micron (10^{-6} meters).

Because of their size, PM components can penetrate deep into the lungs and enter the bloodstream. The available scientific evidence shows that short-term (typically from a few hours to within one week), moderate-term (over one week to one month) and long-term (over one month) exposure to $PM_{2.5}$ can have a wide range of health impacts, ranging from inflammation of the airways and lungs to chronic inflammation, increased risks of heart, lung, and neurological diseases, premature mortality, and adverse pregnancy outcomes [115]. It is understood that there is no safe threshold under which exposure to ambient PM has no adverse health effects (WHO, 2006) [116]. Although the largest health impact of PM comes from long-term exposure to $PM_{2.5}$ or UFP, short-term exposure to high enough concentrations of PM can also exacerbate lung and heart conditions, strongly affect quality of life (including mental health), increase hospital and emergency department admissions, and contribute to premature deaths. Children, the elderly and those with pre-existing cardiovascular disease and respiratory disease (such as asthma) are particularly at risk. Evidence of the adverse health impacts of $PM_{10\text{-}2.5}$ is growing, particularly for respiratory health effects, but there are still some uncertainties [115]. There is also increasing evidence of association between exposure to ambient UFPs and a range of health effects (including respiratory and cardiovascular effects, as well as mortality), but understanding this linkage and eliciting causality effects are complicated by the difficulty of consistently measuring ambient UFP concentrations [115].

As of 2019, large areas in California were not in attainment with the national annual ambient standard for $PM_{2.5}$ (12.0 and 15 $\mu g/m^3$ for the annual arithmetic mean averaged over 3 years for primary and secondary $PM_{2.5}$; see US EPA, 2020) [117], including the San Joaquin Valley, most of the Bay Area, and counties in the Los Angeles South Coast Air Basin (US EPA, 2020) [117]. The annual California Ambient Air Quality Standard is 20 $\mu g/m^3$ PM_{10}, while there is no annual NAAQS for PM_{10}.

Some of the resulting health effects of PM on Californians have been documented in a number of studies [118]–[124], including for vulnerable groups. Children are especially at risk for air pollution because they have immature lungs, they tend to spend more time outdoors, and they often have higher breathing rates than adults. For example, Ostro et al. (2009) reported that components of $PM_{2.5}$ are associated with hospitalization for children for respiratory diseases such as asthma, bronchitis, and pneumonia. A number of other effects of exposure to fine particulate matter have been documented in the literature, such as preterm birth and low birth weight (e.g., see the meta-analysis of Li et al., 2017 [125] as well as Sheridan et al 2019 [126]; Basu et al 2014, 2017 [127], [128]) and stillbirth (Ebisu et al 2018 [129]).

$PM_{2.5}$ has also been found to be a major cause of environmental health inequality in the US, and in California in particular [130]. In a recent analysis of socio-economic and health characteristics at the census tract level, Liévanos (2019) [131] reported that the percentages of Latinx, non-Latinx Black, and non-Latinx Asian populations in census tracts are strongly and positively correlated with $PM_{2.5}$ percentile rankings, which shows that minority populations not only reside in areas with higher levels of $PM_{2.5}$, but they are also disproportionately affected by $PM_{2.5}$ air pollution.

Overall, CARB estimates that gasoline combustion was responsible in 2012 for 8% to 21% of $PM_{2.5}$ concentrations depending on the air basin considered [132]. Compared to gasoline exhaust, diesel exhaust is characterized by a substantially larger rate of PM release, on an equivalent fuel energy basis. Diesel PM consists mostly of carbon particles (~90% of which have a diameter under 1 μm) coated with organic and inorganic substances. The latter consists of soluble organic compounds, a number of which have been found to be potent mutagens and carcinogens [133]. Lowering the current annual $PM_{2.5}$ standard of 12 $\mu g/m^3$ to between 8 and 10 $\mu g/m^3$ could prevent as many as 4,600 annual premature deaths, 850 heart and lung disease hospitalizations, and 2,100 asthma emergency room visits in California (CARB, 2018) [132].

Volatile organic compounds (VOCs). VOCs are organic compounds that have high vapor pressure at ordinary ambient temperatures. Gasoline sources emit over 350 volatile organic compounds, including the toxicants toluene, m-xylene, propylene, benzene, n-hexane, formaldehyde, ethylbenzene, isobutene, 1,2,4-trimethylbenzene, and 1,3-butadiene. These are the most highly emitted VOCs from gasoline sources, along with acetaldehyde and propionaldehyde, that are known for their potential toxicity [132].

Significant sources of VOCs include chemical plants, gasoline stations, oil-based paints, autobody shops, and print shops. Emissions of gasoline-related VOCs with the most significant health concerns have been declining in California over the past two decades [132].

VOCs from gasoline-related sources can react with nitrogen oxides in the presence of sunlight to generate ozone, a key ingredient of smog. Reactions with other chemicals in the atmosphere can also produce a range of potentially toxic compounds, such as carbonyls, dicarbonyls, peroxynitrates (e.g., PAN, which are powerful respiratory and eye irritants, and are often present in smog), and phenols [132].

Short-term exposure to VOCs from internal combustion engines may irritate the eyes and the respiratory tract, increase the risk of asthma, cause headaches and nausea, and trigger visual disorders and memory problems. Long-term exposure to VOCs may also cause fatigue, damage the liver, kidneys, and central nervous system, cause birth defects and cancer [132], [134], [135]. Recent research has shown increased cancer sensitivity in children from early life exposure [135]. Although the cancer risk attributable to some of the most common carcinogenic VOCs emitted by gasoline has been dropping over the last two decades in California, some of the cancer risks for these substances still exceeded 1 in 1 million in 2014, and the cancer risks of a number of other gasoline-related VOCs are still unknown [132].

Nitrogen oxides (NO_x). Nitrogen oxides designate a group of seven gases, the two most common and hazardous are nitric oxide and nitrogen dioxide. NO_x results mostly from high temperature combustion. Substantial sources of NO_x include motor vehicle exhaust, the combustion of coal, oil, diesel, and natural gas (especially from electric power plants), industrial furnaces, and boilers. NO_x contributes to the formation of ground-level ozone and secondary PM (see above).

In recent years, NO_x concentrations throughout California have been below state and national ambient air quality standards except for a small area in Southern California along Highway Route 60 [136].

NO_x has direct and indirect effects on health. Short term exposure can irritate the respiratory system (also the eyes and the skin), aggravate respiratory diseases including asthma, and cause nausea, headaches, and abdominal pain. Long-term exposure to NO_x can, at low levels, cause asthma and respiratory infection, and at high levels impact female fertility, lead to genetic mutations, and even cause death [137]. Despite declines in ambient concentrations, NO_x levels are still of concern for health in California [118], [138], [139], particularly in the non-attainment area in Southern California.

According to CARB, gasoline-attributable fractions for NOx ranged in 2012 from 14% in the San Joaquin Valley Air Basin to approximately 30% in the South Coast Air Basin [140].

Ozone (O_3). Ozone is a highly reactive gas, which can be generated by natural or anthropogenic processes. It occurs both in the Earth's upper atmosphere (the stratosphere) and in the lower level of the atmosphere (the troposphere). While stratospheric ozone is formed naturally through interactions between UV radiation and oxygen, ground-level ozone is formed via photochemical reactions between a number of volatile organic compounds (VOCs) and nitrogen oxides (NO_x)

[141]. Pollutants leading to the formation of ground-level ozone are emitted from many sources including motor vehicles, various industries, fossil fuels, paints, and a number of consumer products [142].

Ozone is a key contributor to photochemical smog (or haze). Ground-level ozone can damage a wide range of materials, such as rubber, plastics, fabrics, paints, and metals. It can also damage sensitive vegetation and ecosystems, especially during the growing season, by reducing photosynthesis, impairing plant growth, damaging leaf cells, and making plants more susceptible to disease and insect damage.

Breathing ground-level ozone can have a number of adverse health effects, including inflammation of the airways, leading to coughing, throat irritation, chest discomfort, wheezing, and shortness of breath. Moreover, exposure to higher daily ozone concentrations have been shown to be associated with asthma attacks, increased hospital admissions, and in the most severe cases (older adults are more at risk), premature death [143]. Indeed, there is increasing evidence that long-term exposure to ozone can increase stillbirth, as well as respiratory and cardiorespiratory premature mortality [116], although available evidence is not as strong for the latter. Research shows that people who spend more time exercising outdoors are at greater risk from ozone exposure. In addition to people with asthma symptoms, children are especially at risk because they spend more time outdoors, tend to engage in more vigorous activities than adults, and inhale more air pollution than adults as a fraction of their weight [142].

Most of California is in non-attainment for both the 2015 and the 2008 8-hour ozone concentration federal standards [144]. Under the 2015 8-hour standard, the NAAQS for ozone is 0.070 ppm (down from 0.075 ppm in the 2008 primary and secondary standards), calculated as the fourth-highest daily max 8-hour concentration averaged over 3 years [145]. Ozone pollution is particularly severe in the Los Angeles-South Coast Air Basin and in the San Joaquin Valley [146]. The fraction of ambient ozone concentrations attributable to motor vehicles is currently not known precisely but it is thought to be substantial.

Carbon monoxide (CO). Carbon monoxide is a colorless, odorless toxic gas. The incomplete combustion fuels such as gasoline, natural gas, or wood generates carbon monoxide. CO can also be generated via photochemical reactions in the atmosphere from methane and non-methane hydrocarbons, other VOCs, and organic molecules in surface waters and soils [147]. Although CO can be emitted by a variety of sources, such as motor vehicles, power plants, incinerators, and wildfires, most atmospheric emissions of CO come from mobile sources.

Breathing air with high CO concentrations reduces the amount of oxygen that can be transported in the bloodstream, causing dizziness, confusion, fatigue, vomiting, and (at higher concentrations) death. Short-term exposure to CO for people with cardiovascular disease can further reduce their ability to respond to the increased oxygen demands of exercise or stress; inadequate oxygen delivery to the heart may lead to chest pain and decreased exercise tolerance. Overall, unborn babies (whose mothers are exposed to high levels of CO during pregnancy), infants, elderly people, and people with chronic heart disease, anemia, or respiratory problems are most at risk from exposure to elevated levels of CO [148].

There are currently no areas in California classified out of attainment with the California Ambient Air Quality Standards (20 ppm for the 1-hour average and 9 ppm for the 8-hour average).

We also note that CO contributes indirectly to climate change because it participates in chemical reactions in the atmosphere that produce ozone, which is a greenhouse gas. CO also has a weak direct effect on climate. For these reasons, CO is classified as a short-lived climate forcing agent. As a result, reducing CO emissions is considered a possible strategy to mitigate the effects of global climate change [147].

Sulfur dioxide (SO_2). Sulfur dioxide is a gas at ambient temperatures, which has a pungent, irritating odor. SO_2 is the most prevalent member of the sulfur oxides (SO_x) family in the atmosphere, and the one of concern for human exposure.

SO_2 results from burning fuels that contain sulfur. Common sources include motor vehicles (especially those with diesel engines), locomotives, ships, industrial processes (such as natural gas and petroleum extraction), oil refining, and metal processing.

SO_2 can react in the atmosphere to form PM, and thus reduce visibility by creating a haze. SO_2 also contributes to soil and surface water acidification and acid rain. This acidification harms susceptible aquatic and terrestrial ecosystems. In particular, acidification slows down growth and injures trees, and it can locally cause the extinction of various aquatic species. Moreover, SO_2 deposition promotes chemical reactions that facilitate the accumulation of mercury in water and soil, increasing the risks linked to mercury ingestion in human populations.

Exposure to SO_2 can impair breathing and exacerbate asthma. People with asthma, especially children, are particularly at risk [149].

There are currently no areas in California classified out of attainment with the national or the California Ambient Air Quality Standards (The 1-hour and 24-hour averages for the California AAQS are 0.25 ppm and 0.04 ppm respectively).

A look at (Figure 40, Figure 41, Figure 42, and Figure 43; data extracted from EMFAC 2017 [20]) shows that while PM_x and NO_x emissions from transportation decreased substantially over the last decade, both SO_x and CO_2 emissions have been increasing.

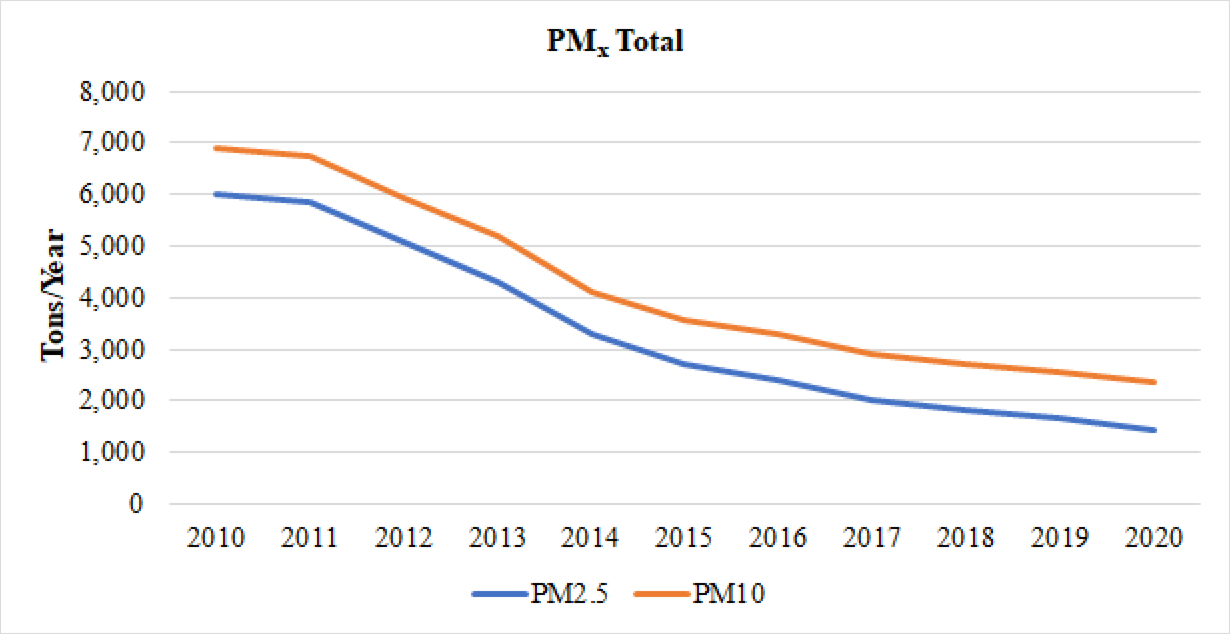


Figure 40. Evolution of total annual PM emissions from transportation in California

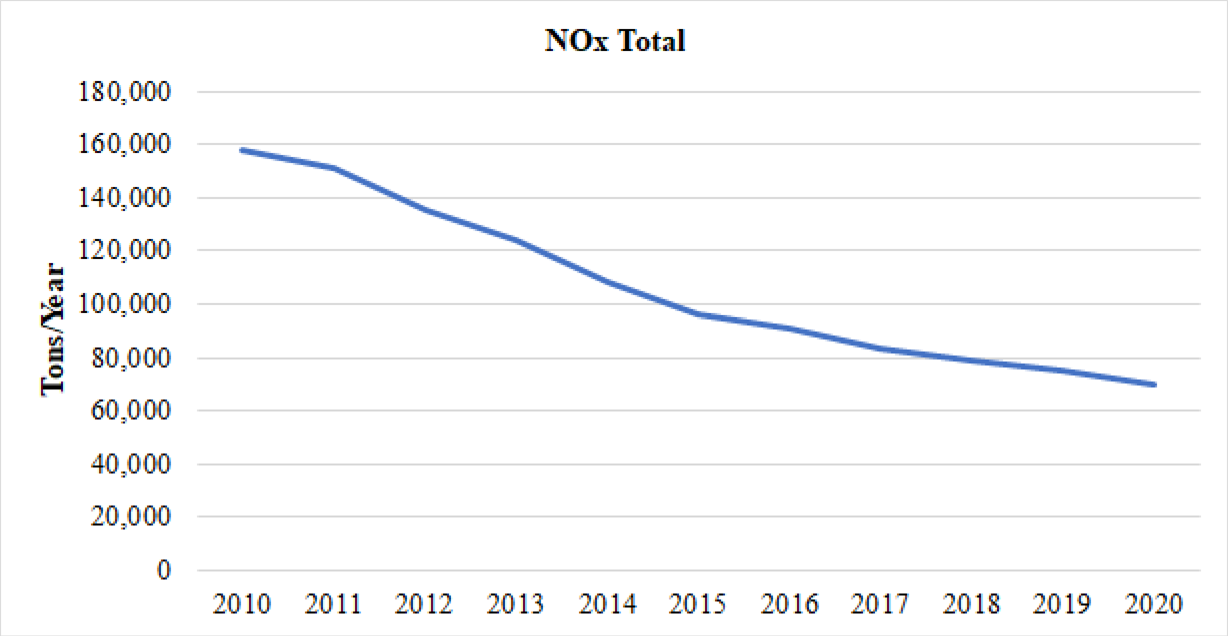


Figure 41. Evolution of total annual NO$_x$ emissions from transportation in California

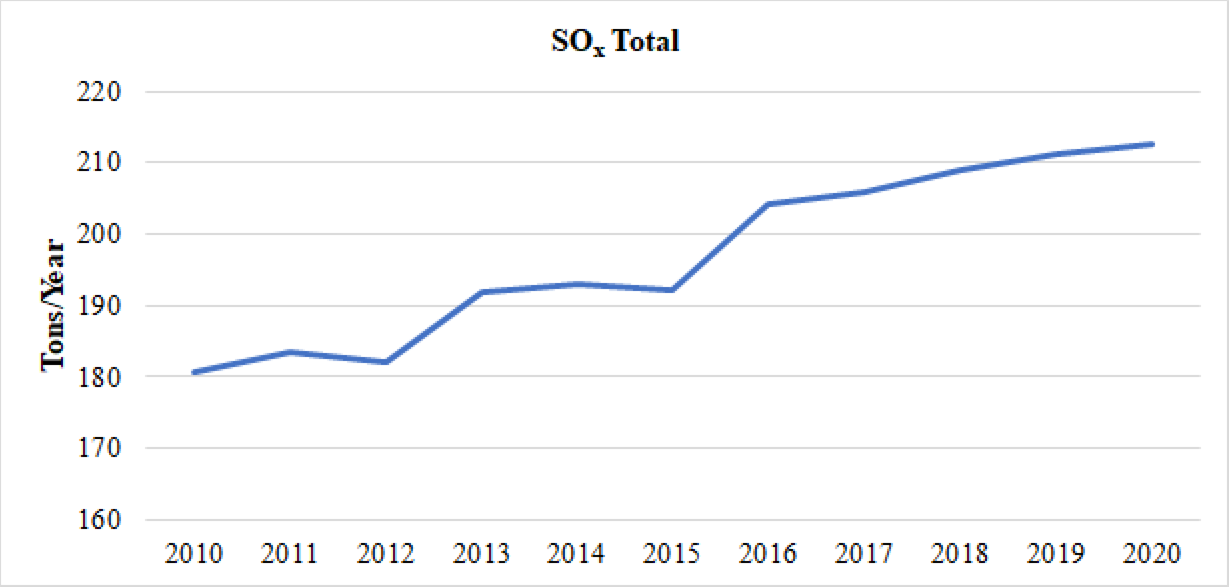


Figure 42. Evolution of total annual SO_x emissions from transportation in California

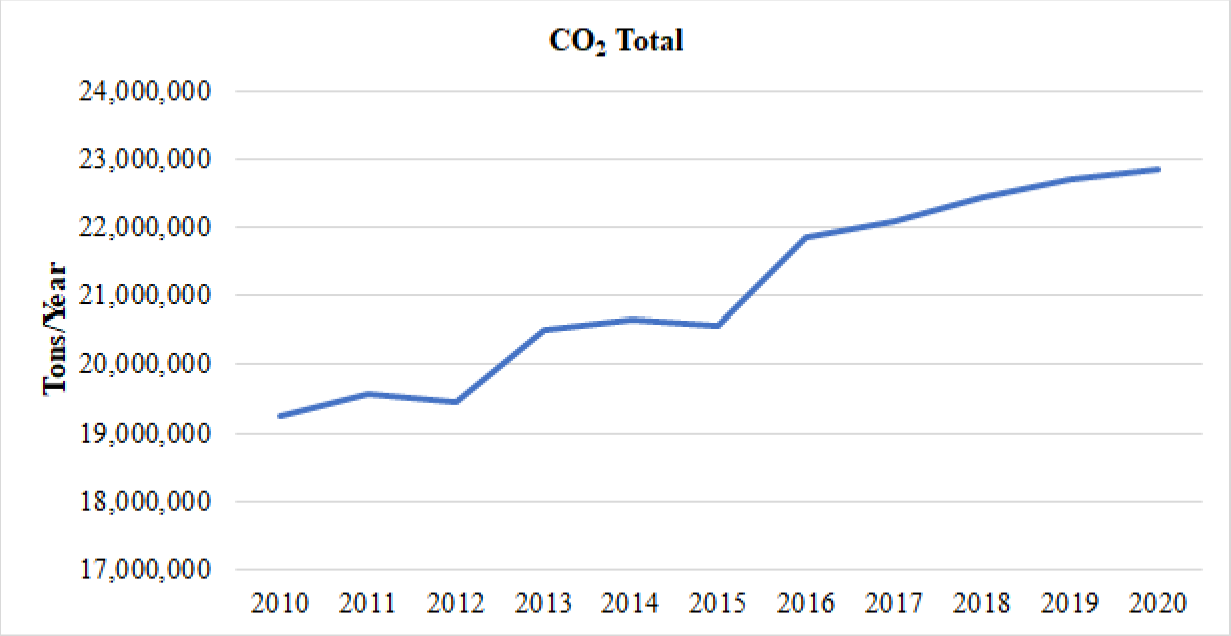


Figure 43. Evolution of total annual CO_2 emissions from transportation in California

Finally, we note that the extraction, the processing, and the combustion of fossil fuels also generates greenhouse gases such as carbon dioxide (CO_2) or methane (CH_4), which contribute to global climate change, and the increase in frequency in many parts of the world of extreme events such as heat waves, floods, and tornados. As noted in Nissan and Conway (2018), mitigating climate change has many health co-benefits, including respiratory infections among children or ischaemic heart disease in adults

Overall, the last two decades have seen substantial declines in air pollution for most key pollutants generated by the transportation sector in California (with the exception of SO_x). As mentioned above, however, the health burden for PM, ozone, and NOx remains substantial and it still affects disproportionately children, the elderly, and racial minorities. It is also becoming urgent to tackle the increase of greenhouse gas emissions (see Figure 43) if California is to meet its climate objectives.

1.7.2 Active transportation

Increased automobile use not only increases emissions of GHGs and local air pollutants, but also increases the occurrence of physical crashes, injuries, and deaths. Increased reliance on automobiles also contributes to reduced rates of physical activity and increased rates of obesity. There are multiple ways of decreasing the external impacts of motor-vehicle use, including adding safety features (such as forward-collision warning, automatic emergency braking, blind spot detection, and pedestrian detection), switching transportation modes (i.e., taking transit instead of driving), increasing the cost of driving (i.e., by taxing fuel), or changing land use to decrease demand for driving.

One avenue that seems particularly promising is active mobility (e.g., walking and biking). Approximately half of the car trips in the United States are less than five miles, distances at which active mobility is feasible. Promoting active mobility could have a number of health benefits [150], [151], including a reduction in heart disease, stroke, diabetes, dementia, depression, and some cancers.

Based on experiences in Europe, Asia, and Australia, reducing car dependency in California will likely take a combination of “soft” and “hard” policies [152]. “Soft” policies include informational campaigns about the health benefits of active mobility and the adverse environmental impacts of driving, providing real-time information to support personal travel planning, convenient e-ticketing, and discounted or free public transportation passes. “Hard” policies include infrastructure changes, road and parking pricing, and higher vehicle taxation. In Denmark, for example, the registration tax for a new car varies between 85% and 105% of the car’s purchase price. The Danish government has also consistently invested in public transit and bicycling infrastructure, while implementing voluntary travel behavior change measures. As a result, approximately a third of Danes bike to work. The resulting health benefits of this high level of bicycling have been estimated to reduce annual sick days by 1.1 million in Copenhagen alone.

In terms of safety, annual fatalities for pedestrians ranged from 1.6–2.1 per 100,000 people between 2004 and 2014. For bicyclists, annual fatalities ranged from 0.3–0.4 per 100,000 people over the same period. These California values are notably higher than national averages.

1.8 Labor and employment

California’s transportation economy is a vast and complex system of diverse, interconnected industries. In order to examine the broader implications of the state’s transition to ZEVs for the transportation workforce, it is helpful to compartmentalize transportation-related industries into supply chains: sets of linked firms that each fulfill a distinct role with respect to a particular aspect of transportation, and which are interdependent upon each other. Three such supply chains are considered herein:

A) **Fuels**, the supply chain responsible for production, processing, and distribution of the energy sources Californians utilize to power transportation;

B) **Vehicles**, the supply chain that manufactures and distributes means of conveyance;

C) **Transportation services**, the supply chain that facilitates transport of passengers and goods.

Together, these three supply chains directly employed 850,529 workers across 71 distinct industries statewide in 2019 (see Figure 44). The majority of these are divided relatively equally among vehicles and transportation services, which employed 339,491 and 386,825 workers, respectively. Fuels, the smallest of the three chains in terms of workers, employed the remaining 124,213.

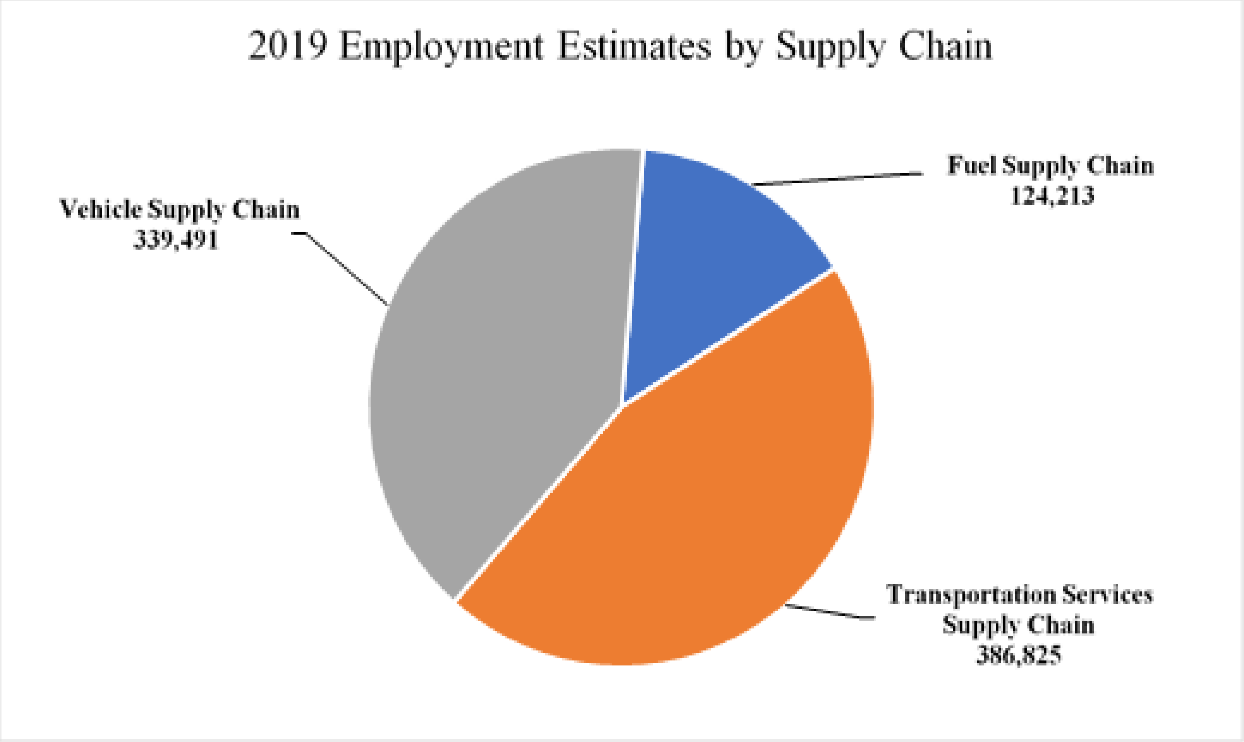


Figure 44. 2019 Employment Estimates by Supply Chain in California's Transportation Sector

Workforce Alignment of Industry Data between Studies 1 & 2

The selection of which industries to consider within Studies 1 and 2 is determined by the nature of the driving policy strategies upon which each study respectively focuses. Study 1 examines a variety of policies—including incentives focus upon vehicle purchase & leasing, fuels. refueling infrastructure, etc. —that shift consumer preferences and economic demand towards ZEVs. This shift will lead to ZEVs subsuming an increasing portion of the vehicles market currently dominated by ICEVs, a change that will lead to alternative fuels (predominantly electricity) displacing consumption of fossil fuels for transportation. This drop in demand for fossil fuels will ripple through the entire fossil fuel supply chain, causing a workforce contraction at the extraction, refining, and distribution stages. For this reason, Study 1 considers an expansive array of industries related to all parts of the fossil fuel supply chain.

In contrast, Study 2 constitutes an in-depth examination of policies aimed at reducing the production of transportation fossil fuel activity in California. These strategies include production quotas, well-head setbacks, restriction on new licenses, etc., and will likely lead to lower levels of extraction and refining in the state. Given this focus, Study 2 does not consider industries related to the distribution of fossil fuels to consumers, as distribution and consumption are likely to remain mostly unchanged as a result of Study 2's considered policies in isolation.

It is important to stress that, from the perspective of a typical consumer, implementation of these industry-side policies would simply produce an increase in gasoline and diesel prices. Short-term fuel demand tends to be relatively inelastic, and consumer response to these price changes is therefore unlikely to reduce transportation-related emissions in a sufficiently short time frame to meet the state's goals. However, increased fossil fuel prices lower the threshold for Study 1 policies to be effective. For instance, higher gasoline prices combined with incentive programs that reduce the barrier to ZEV adoption may make a given consumer transition much sooner than they would otherwise. The two sets of policies, while targeting distinct components of the transportation landscape, are thus complimentary.

Also important to note is that Study 2 has examined multi-year trends within the fossil fuel extraction and refining sectors, and uses averages from select years to provide baseline employment figures in these industries that are reflective of conditions in the longer term. Study 1's baseline figures are meant only to provide a point of reference for the discussion of employment shifts out to 2045. In the interest of having this reference reflect current conditions as closely as possible, only employment figures for 2019 are used.

Usage of data from past years in Study 2 also leads to inclusion of some industries that have since been reclassified, and therefore do not appear in Study 1's figures. However, the jobs represented by these defunct industry classifications are included under their more current NAICS codes.

Table 15

NAICS Code	Industry	Considered in:		Study 1 Estimate (2019)	Study 2 Estimate (2016-18)
		Study 1	Study 2		
4471	Gasoline Stations (Public)	Yes	No	186	
4471	Gasoline Stations (Private)	Yes	No	63,573	
23829	Other Building Equipment Contractors	Yes	No	10,763	
211120	Crude Petroleum Extraction	Yes	Yes	3,135	3,517
211130	Natural Gas Extraction	Yes	No	1,294	
213111	Drilling Oil and Gas Wells	Yes	Yes	3,024	2,434
213112	Support Activities, Oil-Gas Operations	Yes	No	6,792	

237120	Oil and Gas Pipeline Construction	Yes	Yes	10,016	10,580
324110	Petroleum Refineries	Yes	Yes	10,839	10,692
324191	Petroleum Lubricating Oil and Grease Manufacturing	Yes	No	727	
324199	All Other Petroleum and Coal Products Manufacturinga	Yes	No	95	
325193	Ethyl Alcohol Manufacturing	Yes	Yes	225	225
333132	Oil and Gas Field Machinery and Equipment Manufacturing	Yes	No	1,374	
333914	Measuring, Dispensing, and Other Pumping Equipment Manufacturing	Yes	No	1,838	
424710	Petroleum Bulk Stations and Terminals	Yes	Yes	2,951	2,978
424720	Petroleum and Petroleum Products Merchant Wholesalers	Yes	Yes	5,139	4,678
454310	Fuel Dealers	Yes	No	2,654	
486110	Pipeline Transportation of Crude Oil	Yes	Yes	508	617
486210	Pipeline Transportation of Natural Gas	Yes	No	390	
486910	Pipeline Transportation of Refined Petroleum Products	Yes	Yes	775	634

The goal of this chapter is to broadly describe the present-day state of these supply chains as it relates to labor and employment in California. We explore how each chain is likely to be impacted by the transition to ZEVs, the magnitude of these supply chains and their component industries in terms of the number of jobs they provide, and the quality of jobs as measured by wages and benefits. Wage figures presented herein incorporate both salary and several types of benefits. However, unionization rates—a key measure of job quality, and one correlated with higher wages—have thus far been difficult to identify for specific California industries. On a nation-wide basis, workers in industries related to transportation supply chains (e.g. construction, extraction, production, and transport) had higher unionization rates in 2019 (between 12.8% and 18.5%) than the national average (10.5%), and California's overall unionization rate (16.5%) also exceeded the national average [153]. One could make reasonable assumptions regarding unionization in California's transportation-related industries based on these trends, but more refined data collection is needed.

We also highlight notable geographic areas in which certain industries are concentrated, and wherever possible, characterize the demographics of certain industries under scrutiny. However, at this point in time, information detailing the racial, ethnic, gender, and age characteristics of the state's transportation workforce in a systemic fashion has not been found.

The information that follows will thus serve as a baseline for future policy analysis. In this future analysis we will model a middle-of-the-road workforce scenario for the three transportation supply chains and assess how various policy options may assist California policy makers in navigating the transition to ZEVs. Apart from this work, the state may wish to consider options for addressing the aforementioned lack of workforce unionization and demographic data through a large-scale survey, analysis of census data, or similar efforts.

1.8.1 Employment in the fuels supply chain

California's fuels supply chain is made up of two fairly distinct sets of industries: those related to the production of fossil fuels, and those that produce electricity. Workers in the fossil fuel supply chain extract and convert feedstock (e.g. crude oil) into transportation fuels (e.g. gasoline), distribute those transportation fuels to refueling stations, and operate said stations for wholesale and retail use by drivers or fleet operators. Workers in the electricity supply chain perform similar tasks, but more skewed towards constructing and operating generation and distribution infrastructure.

An important note: wage figures discussed for workers by industry below incorporate several non-income elements related to job quality, including stock options, benefits, and employee contributions to retirement. Except where noted, these data are derived from the Quarterly Census of Employment and Wages (QCEW) data from the U.S. Bureau of Labor Statistics (BLS).

Transition Impacts

Of the three transportation supply chains, the transition to ZEVs will have the greatest impact on workers within the fuels supply chain. A shift towards electricity and hydrogen in place of combusting fossil fuels for transportation will reduce demand for petroleum products. Consequently, employment in oil and gas extraction, fossil-fuel refining, and fossil-fuel distribution industries will drop. The degree to which this occurs in the upstream and midstream portions of the fossil fuel supply chain will depend on the availability and magnitude markets for petroleum products outside California. Additionally, because the oil- and gas-extraction industries and in-state refineries will continue to produce fuel for aviation, maritime, and out-of-state consumers for the time being, it is unlikely that employment in these industries will be completely eliminated as a result of California's transition to ZEVs. However, such a transition may eventually eliminate employment associated with the distribution of fossil fuels for transportation (i.e. the delivery and sale of gasoline and diesel).

However, the ZEV transition will create new supply chains to provide alternative energy for transportation. Electricity will likely be the dominant player in this space, but industries offering other fuels like hydrogen will also expand. Employment in clean electricity generation and carbon-neutral fuel production and electricity transmission and distribution will increase. New charging station and refueling infrastructure will create new jobs for the construction, operation, and maintenance for these facilities and the manufacturing of necessary components and equipment. In the long-term, California's renewable energy industries will also expand to meet increased demand, as will electricity providers like utilities and CCAs as they increase their delivery of electricity as a transportation fuel.

Magnitude

In 2019, California's fuels supply chain had approximately 124,213 workers across 9,655 establishments (Table 15 and Table 16). Gasoline stations dominate these figures, comprising a significant majority of establishments (7,064) and a slim majority of workers (63,573). Oil and gas pipeline construction, other building equipment contractors, and petroleum refineries are in a virtual three-way tie for second place, each with between 10,000 and 11,000 workers. Employment figures for the electricity supply chain are quite low (1,091), as they are scaled to the (very low) proportion of electricity that is currently used for transportation.

Quality and Qualifications

Earnings within the fossil fuel supply chain have a wide range, with gasoline station operators earning $28,296 annually while workers classified under the Crude Petroleum Extraction NAICS code earn an estimated $285,697 annually, on average. The electricity sector's earnings range is narrower by comparison, with the lowest earners being electrical contractors ($78,506 annually) and the highest earners being workers within electric power generation industries ($156,563 annually), as classified by NAICS code.

Skills and educational requirements for employment exhibit similar variation, ranging from minimal (i.e. high school diploma) to a four-year degree or highly technical training. A small portion (11%) of California's oil and gas industry employees had less than a high school education in 2017 [154].

Geographic Distribution

Some fuel supply chain industries are fairly homogeneous in their distribution throughout the state. The quintessential example is gasoline stations, and fossil fuel pipelines crisscross the state south of Sacramento. On the electricity-generating side, jobs related to power generation and distribution are similarly dispersed, as power plants and substations are found throughout California.

However, other parts of the fuel supply chain are limited to particular geographic areas. Petroleum refineries are concentrated in the Los Angeles, Bakersfield, and San Francisco Bay Areas [155]. Most oil extraction sites are located in Southern California proximate to refining facilities, with the vast majority of active wells being located in the San Joaquin Valley sub-region (LAEDC 2019) [154]. The San Joaquin Valley is heavily represented in several other measures of industry activity as well. NG extraction sites are mostly contained in the Sacramento Valley area in Northern California [155].

As a caveat, while the location of particular infrastructure certainly correlates with related employment, more research is called for to assess the strength of this link.

Demographics

Current demographic data for the fuel supply chain comes from the U.S. Census Bureau's Quarterly Workforce Indicators (QWI) dataset. In 2019, the industries in California's fuel supply chain were predominantly White (between 67.15% and 86.71% of industry workers), with the next highest racial group being Asian (between 3.59% and 22.98%). No other racial group in this supply chain attained double digit percentages in 2019. Worker sex were similarly stratified in 2019, with men making up a vast majority of workers in the fuel supply chain (from 56.58% to 87.85%). Regarding ethnicity, most workers were Hispanic or Latino (from 54% to 78.64% of industry workers).

Table 15. 2019 Employment Estimates for California's Fossil Fuel Supply Chain

Industries	NAICS Code	Establishments	Estimated Annual Employment	Estimated Annual Wages
Crude Petroleum Extraction	211120	86	3,135	$285,697
Natural Gas Extraction	211130	38	1,294	$132,088
Drilling Oil and Gas Wells	213111	123	3,024	$144,655
Support Activities, Oil-Gas Operations	213112	258	6,792	$84,284
Oil and Gas Pipeline Construction	237120	176	10,016	$88,333
Other Building Equipment Contractors	23829	815	10,763	$94,870
Petroleum Refineries	324110	106	10,839	$174,905
Petroleum Lubricating Oil and Grease Manufacturing	324191	32	727	$81,919
All Other Petroleum and Coal Products Manufacturing[a]	324199	4	95	$93,366
Oil and Gas Field Machinery and Equipment Manufacturing	333132	36	1,374	$74,397
Measuring, Dispensing, and Other Pumping Equipment Manufacturing	333914	78	1,838	$82,690
Petroleum and Petroleum Products Merchant Wholesalers	424720	372	5,139	$90,171
Gasoline Stations (Public)	4471	8	186	$28,918
Gasoline Stations (Private)	4471	7,064	63,573	$28,296
Fuel Dealers	454310	273	2,654	$62,253
Pipeline Transportation of Crude Oil	486110	29	508	$108,244

Pipeline Transportation of Natural Gas	486210	25	390	$143,470
Pipeline Transportation of Refined Petroleum Products	486910	64	775	$120,545
Employment Totals		9,587	123,122	

Note. Estimated employment based on existing employment multiplied by the percentage of EV electricity consumption in comparison to total electricity consumption in California, roughly 0.68%.

Table 16. 2019 Employment Estimates for California's Electricity Supply Chain

Industry Title	NAICS Code	Establishments	Estimated Annual Employment	Estimated Annual Wages
Electric Power Generation	22111	2	92	$156,563
Electric Power Transmission and Distribution	22112	1	31	$138,832
Power and Communication Line and Related Structures Construction	237130	3	121	$120,993
Electrical and Wiring Contractors	23821	65	761	$78,506
Turbine and Turbine Generator Set Units Manufacturing	333611	1	31	$130,256
Electrical Equipment Manufacturing	33531	2	55	$83,170
Employment Totals		74	1,091	

1.8.2 Employment in the Vehicle Supply Chain

Workers in California's vehicle supply chain manufacture LDVs, MDVs, and HDVs, and the replacement parts necessary to maintain these vehicles. They also perform required maintenance and repairs for vehicles.

Transition Impacts

Unlike the fuels supply chain, the vehicle supply chain is unlikely to undergo a dramatic transformation in response to the state's transition to ZEVs. However, there will be notable changes to the products being produced and the technology those products utilize within the vehicle manufacturing sector as ICEVs are phased out in favor of BEVs, PHEVs, and FCVs. No vehicle manufacturer currently produces and assembles all components in-house, however, muting the impact of the transition on vehicle producers themselves. Instead, vehicle manufacturers purchase components from third parties and assemble these components at a vehicle manufacturing plant. The decentralized nature of this supply chain means that many of the negative impacts of the transition on traditional component manufacturing will occur outside the state. However, there will likely be some disruption to manufacturers as they retrain and shift their workforce to focus on ZEVs.

This will likely be accompanied by an expansion of the upstream industries supplying vehicle manufacturers with battery components and the industries producing the raw inputs for battery manufacturing. Similar, though likely smaller, increases will occur for fuel cell manufacturing.

In the downstream portion of the supply chain, employment for combustion-engine and power-train maintenance and repair will decline. Because all-electric vehicles require less maintenance than do fossil-fuel vehicles, we may see reductions in automotive repair shops, although employment in body shops needed to repair damage from vehicle collisions will not be impacted. Nascent trends are emerging wherein EV manufacturers (namely Tesla) are adopting a proprietary maintenance and repair model with branded repair shops, backed up by threats of litigation. Should this practice become more common, it would threaten small and independently owned automotive repair businesses. In contrast, the fundamental business model of vehicle dealerships should not be substantially altered by the ZEV transition, independent of other trends that may affect overall demand for personal vehicles.

Should all-electric micromobility vehicles such as scooters, bicycles, and neighborhood electric vehicles continue to become more common, employment will increase with the expansion of these industries. However, demonstrated volatility and worrisome fiscal situations for companies operating in this space make such expansion uncertain, and other factors discussed in Section 1.7.3 below call into question how attractive the micromobility industry is as a source of employment. The potential for this industry to create jobs also depends on whether required parts are manufactured and assembled within California or out of state. Potential does exist for the development of micromobility manufacturing capacity in the state, but whether it will emerge is purely speculation at this point.

Magnitude

In 2019, California's vehicle supply chain had approximately 346,398 workers across 26,643 establishments (Table 17, 18, & 19). A sizeable portion of these workers (118,818) are employed by new car dealers. Other major industries include general automotive repair (39,859) and private automotive parts and accessories stores (34,950). The current employment totals for industries specific to California's EV supply chain are fairly small (7,816).

Quality and Qualifications

The earnings among vehicle supply chain workers tend to be lower, on average, than the fuels sector, with most vehicle supply chain industries having an average annual income between $30,000 and $60,000. In only one industry, miscellaneous electrical equipment manufacturing, do average annual wages exceed $100,000. The largest industry by employment, new car dealers, slightly exceeds the typical range with average annual wages of $68,473. As in the discussion of the fuels supply chain, these figures include several types of non-wage benefits.

Educational and skill barriers to entry for workers in the vehicle supply chain cover a wide range. At one end, entry-level positions in small-scale assembly facilities and automotive repair may require a high school diploma or less. Jobs closer to the industry median commonly require vocational training or certifications beyond the high school level, while the highest echelons of engineers and other professionals will typically have a four-year degree or graduate-level education.

Geographic Distribution

Economic cluster analysis indicates that regional specialization in automotive manufacturing is low in California, with only the Los Angeles metropolitan area having a notable location quotient—a measure of the degree to which a region is aligned towards a particular industry compared to the nation as a whole—of 0.32 [156]. For comparison, the Detroit, MI metropolitan area has an automotive specialization of 6.74. Jobs related to automotive manufacturing are also concentrated in Los Angeles and the adjoining Riverside area. Ongoing trends and current wage figures indicate that the San Jose area may be a budding center for manufacturing of automotive technology and components.

With respect to downstream sales and maintenance businesses, no data on general geographic trends in vehicle distribution (i.e. dealerships) has yet been identified, though industry groups like the California New Car Dealers Association may be able to provide some insights in this area. Intuitively, dealerships and the large number of jobs they provide are likely to be clustered in high-population urban areas, given the minimum demand requirements necessary for such businesses to remain solvent.

Demographics

California's vehicle supply chain is highly diverse and highly fragmented. As such, no source of industry-wide demographic information has been identified at this time.

Table 17. 2019 Employment Estimates for California's General Vehicle Supply Chain

Industry Title	NAICS Code	Establishments	Estimated Annual Employment	
Industrial Truck, Trailer, and Stacker Manufacturing	333924	36	440	$52,610
Motor Vehicle Manufacturing	3361	81	17,870	$94,361
Motor Vehicle Body Manufacturing	336211	89	3,412	$57,554
Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing	336330	44	608	$46,417
Motor Vehicle Brake System Manufacturing	336340	16	588	$54,758
Motor Vehicle Seating and Interior Trim Manufacturing	336360	51	903	$52,181
Motor Vehicle Metal Stamping	336370	15	387	$50,702
New Car Dealers	441110	1,998	118,818	$68,473
Used Car Dealers	441120	1,398	12,825	$51,511
Automotive Parts and Accessories Stores (Public)	441310	3	14	$27,774

Automotive Parts and Accessories Stores (Private)	441310	3,544	34,950	$35,814
Passenger Car Rental	532111	1,403	17,788	$49,684
Passenger Car Leasing	532112	48	204	$87,289
Truck, Trailer, and RV Rental and Leasing	532120	604	7,619	$57,618
Other Commercial and Industrial Machinery Equipment Rental and Leasing	532490	1,238	12,016	$67,498
Other Automotive Mechanical and Electrical Repair and Maintenance	811118	542	2,837	$46,546
All Other Automotive Repair and Maintenance	811198	1,236	4,869	$47,227
Employment Totals		12,346	243,055	

Table 18. 2019 Employment Estimates for California’s Motor Vehicle Supply Chain

Industry Title	NAICS Code	Establishments	Estimated Annual Employment	
Other Engine Equipment Manufacturing	333618	28	415	$91,699
Motor Vehicle Gasoline Engine and Engine Parts Manufacturing	336310	117	2,297	$66,355
Motor Vehicle Transmission and Power Train Parts Manufacturing	336350	57	955	$68,331
Other Motor Vehicle Parts Manufacturing	336390	174	4,614	$52,345
Motorcycle, Bicycle, and Parts Manufacturing	336991	123	1,899	$51,769

Automobile and Other Motor Vehicle Merchant Wholesalers	423110	600	11,975	$85,843
Motor Vehicle Supplies and New Parts Merchant Wholesalers	423120	2,006	23,162	$59,619
Motor Vehicle Parts (Used) Merchant Wholesalers	423140	217	2,293	$58,273
General Automotive Repair	811111	9,681	39,859	$46,156
Automotive Exhaust System Repair	811112	222	651	$38,149
Automotive Transmission Repair	811113	457	1,578	$42,596
Automotive Oil Change and Lubrication Shops	811191	669	5,829	$31,614
Employment Totals		14,351	95,527	

Table 19. 2019 Employment Estimates for California's Electric Vehicle Supply Chain

Industry Title	NAICS Code	Establishments	Estimated Annual Employment	
Storage Battery Manufacturing	335911	45	1,686	$72,446
Miscellaneous Electrical Equipment Manufacturing	335999	201	6,130	$106,820
Employment Totals		246	7,816	

1.8.3 Employment in the Transportation Services Supply Chain

Workers in the transportation services supply chain drive a variety of vehicles to transport passengers and goods, manage and maintain both public and private vehicle fleets, and provide a range of public transit services.

Transition Impacts

The transition to ZEVs is unlikely to significantly impact employment within the transportation services supply chain. The fundamental operating model of transportation services firms and agencies will not be altered by changes to the types of vehicles they use to provide their services, though requirements for maintenance personnel may drop as higher-longevity EVs are adopted. Demand for professional drivers and the type and size of fleets maintained should not be affected by the transition itself, assuming affected entities have the capital to replace their fleet entirely. Here, we treat the impacts of this transition as distinct from the transition towards autonomous and connected vehicles and from land use or transportation policies which may affect overall demand for transportation. These impacts will be felt regardless of whether Californians' are utilizing ZEVs or fossil fuel-burning vehicles, and will depend on the trajectory of a separate set of vehicle technologies and public policies.

One potential exception to this low-impact characterization is the taxi industry, which has continued to operate a large number of "legacy" ICEVs. The costs of phasing out these vehicles in favor of ZEVs *en masse* over a relatively short time period could be a major hurdle for taxi firms.

Workers within related industries are employed by rental car companies, car sharing companies, public transit agencies, municipal or corporate fleet managers, delivery companies (e.g., FedEx, UPS, Amazon, etc.), long-haul freight companies, and TNCs. As aforementioned, TNC drivers have often been employed as independent contractors, as have taxi drivers, food and package delivery persons, and workers driving drayage trucks and long-haul tractor trailers.

Magnitude

In 2019, California's transportation services supply chain had approximately 386,825 workers across 22,564 establishments (Table 20). The vast majority of these (305,227) work in industries related to goods transportation (Figure 45). The three largest industries by employee count—General Freight Trucking (93,912), Couriers and Express Delivery Services (85,029), and Specialized Freight Trucking (40,716)—together compose a majority of employment in this supply chain.

As noted previously, these figures do not include independent contractors. This creates particularly notable challenges for estimating transportation services employment, as major TNCs like Uber and Lyft have historically classified their drivers as independent contractors.

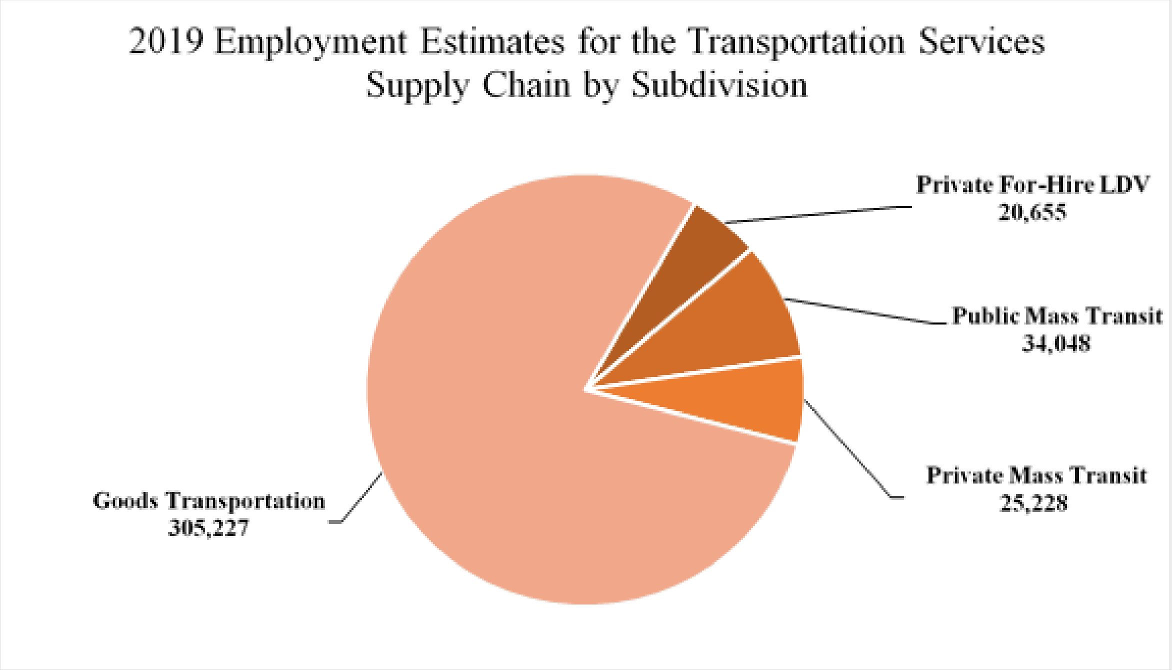


Figure 45. 2019 Employment Estimates for the Transportation Services Supply Chain by Subdivision

Quality and Qualifications

Similar to the vehicle supply chain, earnings among transportation services employees tend to fall within the $30,000 and $60,000 annual wage range. Interestingly, public employees consistently out-earn their private counterparts across multiple industries. This trend is likely due, in part, to the action of public sector unions.

The aforementioned three largest industries in the supply chain all fall into this $30,000 to $60,000 range, with trucking industries falling towards the higher end. In only two industries does BLS' QCEW data report average annual wages exceeding $100,000: public support activities for road transportation and taxi service. The latter of these reports an outlandishly high figure ($432,072), which may be the result of excluding rank-and-file drivers from the NAICS code classification. A more representative figure for the typical taxi employee is $36,920 average annual wages, derived from BLS' Occupational Employment Statistics (OES). This figure includes passenger vehicle drivers within the industry, though it may not be completely representative as it also includes employees in limousine services and some TNC contractors.

Access issues for workers in these spaces skew more towards monetary barriers than educational or skill barriers, as drivers may need to obtain particular licenses or pay for trainings. These barriers are especially high for TNC drivers, as since their inception these companies have sought to offload the most burdensome capital costs—most obviously, the vehicles themselves—onto their workers.

Geographic Distribution

Generally, transportation services employment is distributed loosely around particular epicenters related to the goods and freight being transported (e.g. ports) and the populations being served, whether passengers or consumers (i.e. high-population urban areas). This trend tends to extend to both rank-and-file workers and contractors and higher-level white-collar jobs within companies, which tend to locate corporate offices in large cities.

Demographics

As with the vehicles supply chain, California's transportation services supply chain is made of a multitude of distinct and disparate companies and agencies, both public and private. As such, no source of demographic data on an industry- or supply chain-wide scale has been identified at this time.

Addressing Micromobility

While not a central focus of this report, the rise of micromobility services in recent years and their theoretical potential to help fill a niche in transportation services makes them worth addressing briefly. Unfortunately, the ability to discuss workforce baselines and trends in the micromobility industry is severely limited by opaque corporate policies and worker (mis)classification practices. Companies operating in this space have proved reluctant to share employment or operations data and some emulate TNCs by classifying workers as independent contractors, hindering accurate assessment of their workforce profile.

These workers' positions are stereotypically low quality, with low wages and poor job security. The precarity of this work is compounded by the high volatility the industry has exhibited thus far, even more so as the COVID-19 pandemic has created a precipitous drop in demand and companies have laid off large parts of their workforce. Combined with the fact that micromobility options—the quintessential example being e-scooters—have questionable environmental benefits at best, there is scant evidence that the industry should be prioritized as an avenue to reducing emissions while creating high-quality jobs.

Table 20. 2019 Employment Estimates for California's Transportation Services Supply Chain

Industry Title	NAICS Code	Establishments	Estimated Annual Employment	
General Freight Trucking	4841	9,811	93,912	$53,764
Specialized Freight Trucking	4842	3,724	40,716	$55,536
Bus and Other Motor Vehicle Transit Systems (Public)	485113	61	16,049	$75,179
Bus and Other Motor Vehicle Transit Systems (Private)	485113	76	4,163	$45,493
Interurban and Rural Bus Transportation (Public)	485210	8	1,045	$58,927
Interurban and Rural Bus Transportation (Private)	485210	28	1,069	$42,167
Taxi Service	485310	160	10,527	$432,072***
Limousine Service*	485320	642	5,400	$40,774
School and Employee Bus Transportation (Public)	485410	106	5,488	$47,629
School and Employee Bus Transportation (Private)	485410	188	11,380	$39,991
Charter Bus Industry	485510	175	3,188	$45,645
Special Needs Transportation	485991	443	10,485	$37,184
All Other Transit and Ground Passenger Transportation*	485999	307	4,728	$51,678

Industry Title	NAICS Code	Establishments	Estimated Annual Employment	
Scenic and Sightseeing Transportation, Land (Public)	487110	3	492	$39,867
Scenic and Sightseeing Transportation, Land (Private)	487110	144	2,140	$51,995
Motor Vehicle Towing	488410	1,279	12,075	$43,190
Other Support Activities for Road Transportation (Public)	488490	5	489	$104,012
Other Support Activities for Road Transportation (Private)	488490	390	3,288	$43,939
Postal Service (Public)**	491110	1,402	33,234	$66,089
Postal Service (Private)	491110	105	742	$36,008
Couriers and Express Delivery Services	492110	976	85,029	$46,290
Local Messenger and Local Delivery	492210	1,088	16,717	$48,419
Solid Waste Collection (Public)	562111	1	7	$43,200
Solid Waste Collection (Private)	562111	858	17,462	$67,224
Hazardous Waste Collection	562112	130	4,192	$70,715
Other Waste Collection	562119	154	1,141	$52,312
Automobile Driving Schools	611692	300	1,667	$29,096
Employment Totals		22,564	386,825	

*TNCs Lyft and Uber fall under different NAICS codes, 485320 (Limousine Services) and 485999 (All Other Transit and Ground Passenger Transportation) respectively. However, this data is from before the enactment of California's AB5, so drivers are not counted among these estimates.
**USPS carrier employment estimate based on BLS percent of industry employment, 53.78%.
***This high number has two plausible explanations: the wage estimate omits driver expenses (leasing costs for vehicles and the cost of insurance), or, since these data only capture employees (and may therefore exclude taxi drivers themselves), the revenue generated by taxi companies is distributed across a small number of people. See above for discussion.

2 Other Impacts and Externalities

Pollution from transportation is a classic externality: the costs of the pollution are not paid by the person emitting it. However, there are many other externalities in the transportation system. Some are easier to quantify than others, but the damage is no less real.

Table 21 shows a list of the external costs of motor-vehicle use that will be affected by different transportation scenarios. We distinguish monetary from non-monetary costs because the former are already observed in monetary terms (dollars) whereas the latter must be converted to monetary terms via an additional valuation step. As a result, non-monetary costs are much more uncertain. We include non-monetary impacts of motor-vehicle infrastructure because long-run scenarios that dramatically reduce motor-vehicle use may affect the scale, configuration, and location of motor-vehicle infrastructure.

For the final report, we plan to quantify the external costs shaded in green: crash costs, oil-use costs, air-pollution costs, climate-change costs, and noise costs. That analysis will use a unified set of assumptions and methods to estimate air-pollution and climate-change costs. The methods and assumptions for that analysis generally will not be the same as those used in the detailed health-effects analysis presented elsewhere in this report. In the final report we will explain the differences between the detailed health-effects analysis and the less detailed but more comprehensive air-pollution external cost analysis.

Table 21. Monetary and non-monetary external costs of motor-vehicle use.

Monetary externalities	Nonmonetary externalities
• **Travel delay**, monetary costs imposed by others: extra consumption of fuel, and foregone paid work • **Crash costs** not accounted for by economically responsible party: property damage, medical, productivity, legal and administrative costs • **Oil use**, **macroeconomic adjustment losses** of GDP due to oil-price shocks • **Oil use**: **military expenditures** related to use of Persian-Gulf oil by MVs • **Oil use**: the annualized cost of the Strategic Petroleum Reserve (SPR) • **Oil use, pecuniary externality**: increased payments to foreign countries for non-transport oil, due to ordinary price effect of using oil for MVs^	• **Travel delay**, imposed by other drivers, that displaces unpaid activities • **Crash costs** not accounted for by economically responsible party: pain, suffering, death, lost nonmarket productivity • **Air pollution** **– road-dust, brake & tire wear** **– upstream emission** **– vehicle emissions** Effects on human health, crops, materials, visibility, ecosystems* • **Climate-change** due to life-cycle emissions of GHGs • **Noise** from MVs • **Water pollution**: leaking storage tanks, oil spills, urban runoff, road deicing • **Other externalities:** solid waste from motor vehicle (MV) use, vibration damages, fear of MVs and MV-related crime **Nonmonetary impacts of the MV infrastructure#** • **Land use change**: loss of habitat and biodiversity due to highways and other MV infrastructure • **Socially divisive effect of roads** as physical barriers • **Esthetics** of highways and vehicle and service establishments

MV = motor vehicle; GNP = gross national product; GHG = greenhouse gas; SPR = Strategic Petroleum Reserve. Areas shaded green will be quantified in the final report.

* The cost of crop loss, and some of the components of other costs of air pollution (e.g., the cost of medical treatment of sickness caused by MV air pollution), technically should be classified as monetary externalities.

Although these are nonmonetary environmental and social costs of total MV use, they are not costs of *marginal* MV use, and hence technically are not externalities.

^ Within a country, pecuniary externalities are transfers between entities and not actual net social costs. However, if the transfer is between countries, then there is a net loss to one country (which at the global scale is balanced by the gain to the other country). If one takes a country-perspective and thus counts the oil-use pecuniary external cost as a real cost, then for consistency one also should take a country-specific perspective with respect to climate-change damages.

3 Special Section: COVID-19 and Transportation

The novel coronavirus (COVID-19) global pandemic upended all aspects of life in California, and transportation has been no exception. This topic is evolving rapidly, so recent detailed data is challenging to come by. It will take years to develop a full understanding of the pandemic's effects. However, data from various sources has made some top-line impacts for California clear. First, travel fell dramatically as the state entered lockdown. Second, transit use was particularly hard hit, as most voluntary riders preferred to avoid shared spaces and agencies reduced service. Third, pollution from transportation fell—but not as much as might be expected since truck traffic continued largely unabated. Fourth, petroleum prices fell dramatically, sending prices for oil futures contracts negative for a brief period. Fifth, in markets that have begun to recover, car travel has returned much more rapidly than other modes. Sixth, transportation budgets (including for clean transportation programs) have been dramatically impacted in the short and medium terms.

3.1 Impacts

3.1.1 Impacts to travel amount

California entered a state of lockdown in spring 2020. Governor Newsom issued a statewide directive to stay home except for critical needs (such as travel to work for essential employees, grocery shopping, and time-sensitive medical appointments). The data show that people responded by traveling much less. Caltrans data shows 20% less travel volume for March 2020 compared to March 2019, and 40% less travel volume for April 2020. Technology companies with access to user cell-phone data such as Google similarly reported a dramatic reduction in travel statewide, with some of the most affected counties reducing shopping and workplace travel by more than 60% [157]. Underlying this was an unprecedented increase in unemployment and a major shift to work-from-home. Some companies have announced that they will make at least some aspects of their work-from-home policies permanent, which could also permanently affect transportation demand. However, research on telecommuting in general finds that workers often add other trips during their day, which could limit to benefits of telecommuting to emissions after restrictions lift.

3.1.2 Impact to transit, pooling, and other modes

All state transit agencies have faced enormous disruptions and drops in ridership. The California Transit Association reports [158] that some agencies saw ridership drop more than 90%. Large markets were amongst the hardest hit, including LA Metro (75%), San Diego Metropolitan Transit System (75%), Sacramento Regional Transit (80%) and BART (94%). While fares are only one source of revenue for transit agencies, reduced ridership is causing a revenue challenge and may erode public support if ridership numbers don't recover.

Federal stimulus programs included some support for transit. $3.7 billion of the $25 billion in federal funds that have been allocated to date to support transit in the wake of the pandemic were directed to California [159]. This temporary infusion of federal transit funding to the state helped mitigate short-term funding challenges for some agencies, however, the longer-term prospects for transit in the current policy environment are less clear and more support has not been forthcoming. There is also significant uncertainty as to riders' willingness to return to transit even though transit has not been a major vector in transmission in countries that have mostly recovered from covid. Agencies are exploring options to increase user confidence as the economy reopens.

The pandemic's impacts on bicycling and walking are more complex. Many people are turning to these modes as a form of exercise during the pandemic, and some cities have closed streets to vehicles in order to supply more space for active transportation. However, these trips are unlikely to be a substitute for driving, and it is unclear how long-lasting these effects might be.

COVID-19 has also had a chilling effect on shared new mobility modes. Uber and Lyft both suspended their pooled-ride services. The longer-term impacts of COVID-19 on ridesharing is not yet known, though several research projects are underway to begin to evaluate the effect on traveler willingness to share space.

3.1.3 Impact on pollution and climate emissions

One of the major news narratives of the pandemic is the reduction in local pollution and CO_2 emissions due to sudden decreases in personal and economic activity. Air quality has indeed improved in many cities. Ozone, a pollutant produced from the combination of NOx emissions with VOCs, dropped 14% in the Los Angeles area.

The pandemic's effect on CO_2 emissions has also been significant at a global scale. A recent paper in *Nature* estimated that total daily CO_2 emissions fell by more than 15% compared to 2019 for the period of peak confinement. Surface emissions (36% reduction) and air-transportation (60% reduction) emissions were the most affected (Figure 46).

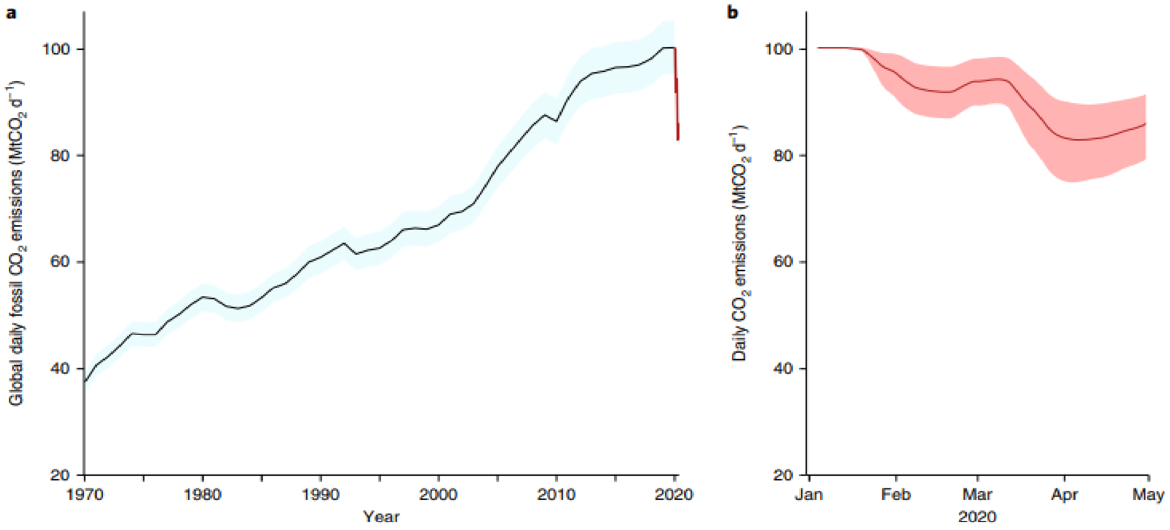
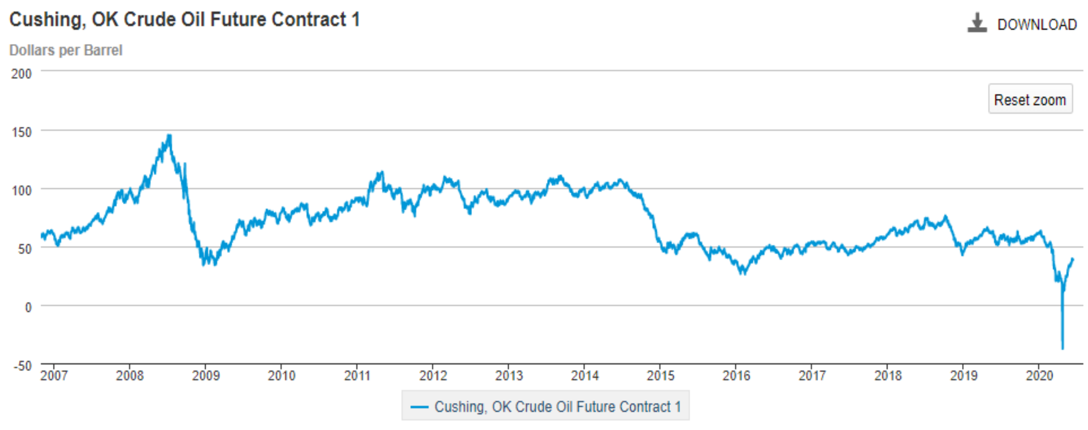


Figure 46. Impact of Covid-19 on GHG emission. From https://www.nature.com/articles/s41558-020-0797-x

3.1.4 Impact on petroleum prices

COVID-19 induced a drop in demand for gasoline and diesel at a time when there was already an oversupply in global oil markets due to ongoing geopolitical disagreements about supply cuts and flattening global demand. These factors together drove oil and petroleum prices sharply lower, and actually created a short-term period of negative prices in oil futures.

Low oil prices have several interacting effects. First, low prices and futures price uncertainties are creating economic challenges for energy companies (especially smaller companies) and have already led to several announced bankruptcies, including Whiting Petroleum and Diamond Offshore. At the same time, sustained low gas prices make driving cheaper and may make EVs and other alternative transportation modes less competitive (Figure 47).



Source: U.S. Energy Information Administration

Figure 47. History of crude oil prices (future contracts). Prices spiked and then fell in 2008 before and during the Great Recession. In 2020, futures prices fell suddenly and were briefly negative, in part due to reduced demand from covid.3.1.5 Data from recovering markets

A major policy question is what the recovery from COVID-19 in California will mean for activity, energy use, pollution, and emissions. If recovery is rapid, and people return to driving while avoiding transit, emissions will rapidly return to pre-pandemic levels. Early data from countries (such as China) and states and counties that have begun to reopen is cautionary: car travel has rebounded much faster than transit.

Yet some markets are linking the recovery from COVID-19 to positive changes in transportation. For example, France is coupling their recovery strategy with increased incentives for PEVs as part of the stimulus package. Many European countries are pushing bicycling and other clean transportation as a way to recover in a way that also contributes to fighting climate change.

3.1.6 Budget impacts

COVID-19 has created major deficits for California. Although California came into the year with a $5.6 billion surplus, Governor Newsom has announced an expected $54 billion deficit based on the latest state projections. This deficit will quickly burn through the state’s “rainy day” fund. As of this writing, there is extensive discussion on how the state can develop a balanced budget as required by the state constitution. The budget situation means that funds for transportation incentives and other transportation programs are likely to be extremely limited for at least the next year.

4 Current Policy Context

4.1 Overall

California has a long history of environmental protection relating to vehicle emissions. California was the first state to regulate emissions from motor vehicles, and California researchers played an instrumental role in advancing the science of air pollution. When the federal government passed the Clean Air Act Amendments in 1970, which created most of the air-pollution-control policy that protects Americans today, California was granted a special position of leadership, allowed to push its air-pollution-control measures ahead of the rest of the country. Other states were also empowered to follow California's lead.

California was also the first state to take comprehensive action on climate change. California adopted tailpipe GHG emission standards in 2003, followed by the Global Warming Solutions Act (AB 32) in 2006. The latter policy established a comprehensive portfolio of climate policies and required GHG emissions to be reduced to 1990 levels by 2020. This made California a global leader in climate policy. Several policy measures adopted under authority granted by AB 32 have direct impacts on transportation. This authority was extended in 2017 by the passage of SB 32, which committed the state to continue reducing emissions: specifically, to achieve a 40% reduction in GHGs from 1990 levels by 2030.

SB 498 directed CARB to review the effectiveness of its programs to increase the adoption of ZEVs in all sectors, and to make policy recommendations to increase the use of ZEVs for personal use and in fleets, which resulted in a report released in December 2019. The report noted that the Federal government is backsliding in vehicle emissions, VMT is increasing, and will require an aggressive approach to meet its GHG emissions reduction goals. It also emphasizes the need to improve ZEV penetration. The report reviews 28 ZEV regulatory, incentive, and supporting programs [160].

Based on the lessons learned from the programs, CARB lays out recommended policies in detail through the following:

1) Incentives and pricing strategies,
2) Lower fuel costs,
3) ZEV refueling infrastructure,
4) Local policies,
5) Fleet adoption,
6) Outreach and education,
7) Technology incubation and workforce development, and
8) Program flexibility.

The report ends with recommendation for California fleets to convert to ZEVs. These are summarized as: "assess fleet needs, research zero-emissions options, collaborate with stakeholders, develop and implement a strategic plan to acquire and utilize ZEVs, share your ZEV fleet experiences."

On September 23, 2020, Governor Gavin Newsom signed and executive order setting a goal that the state will mandate 100% ZEV sales in for passenger vehicles by 2035 and medium and heavy duty trucks by 2045 [161]. The order directs

CARB to lead the development and proposal of the implementation plan. Although this report was written prior to Executive Order N-79-20, a final analysis of the impacts of this new and aggressive order will be included.

The California Energy Commission has also invested up to $100 million per year in funds to help achieve California's emissions reduction goals through their Clean Transportation Program, which funds projects for electric and hydrogen vehicles and infrastructure, medium and heavy duty vehciles, biofuels, and workforce development [162].

4.1.1 Cap and trade

California's cap-and-trade program—the first in the nation for GHG emissions—is at the heart of the state's climate policy. The cap-and-trade program works by requiring permits to emit CO_2. Any major emitter of carbon (or distributor of fuels which would emit carbon when burned) must surrender enough permits at the end of every compliance period (typically three years) to cover their emissions. Permits are auctioned on a quarterly basis and can be freely traded once issued, which creates an effective carbon price. Emitters must acquire additional permits to expand their emissions and can sell excess permits if they reduce their emissions. Certain industries, including utilities and those deemed as risk to competition from external rivals (including petroleum refineries) are given an allocation of permits to cover their expected emissions; all others must buy their permits. Cap-and-trade revenue is reserved for a specified set of uses. Utilities return revenue to ratepayers as a yearly rebate from sales of permits the utilities are allocated. Revenue from auctioned permits is used to fund a variety of transportation and energy projects, including high-speed rail project, construction and operation of public transit, expansion of affordable housing, PEV rebates, and others.

4.2 LDV

4.2.1 Fuel economy standards

The Clean Air Act grants waivers for California to set state fuel-efficiency standards based on GHG emissions regulations (g CO_2/mile) that are more stringent than those set by the federal government. Because California makes up such a large percentage of the national auto market, OEMs were forced to build two sets of cars to meet each of the two standards until 2012, when the Obama administration introduced the Corporate Average Fuel Economy (CAFE) standard. To meet the CAFE standard, carmakers would have to achieve an average fuel economy of 54.5 miles per gallon (mpg) across their fleet by 2025. The Trump administration has indicated that it will roll those fuel-economy rules back in the Safer Affordable Fuel Efficiency (SAFE) Act. The Trump administration has formally revoked California's waivers under the Clean Air Act, which will likely lead to a lengthy legal challenge. Meanwhile, officials in California have negotiated with several automakers to meet separate standards of 50 mpg by 2026. These standards are not as strict as the CAFE standards but are stricter than the SAFE standards (40 mpg). Car companies want a single standard, and those that have already planned and invested to meet the CAFE rule feel they are at a disadvantage if the rule is rolled back.

4.2.2 ZEV mandate

The ZEV mandate has been the most important policy driver of clean vehicle sales in the last decade. The ZEV mandate was first implemented by California and has since been adopted by ten other states. The ZEV mandate works using a credit trading structure through mandates for automakers, requiring a minimum number of ZEV credits. Automakers are required to sell a minimum percentage of ZEVs, which increases each year. Automakers that cannot meet the requirement can purchase credits from other automakers to exceed the minimum percentage. For instance, Tesla sells 100% ZEVs, so they inevitably have credits to sell. The ZEV mandate forced automakers to begin EV design and development, which has spurred new technologies and led to the emergence of American EV companies like Tesla and Rivian [163].

4.2.3 Clean Miles Standard

2018's SB 1014 established the Clean Miles Standard, which requires TNCs to track and be accountable for their emissions. CARB is tasked with developing and enforcing the regulation, which has evolved into a GHG emissions per passenger mile standard. TNCs will be able to meet the standard by supporting electrification of their vehicles, increasing occupancy, shifting passengers to shared micromobility, or a combination. Questions still remain about ways to implement this regulation without disadvantaging TNC drivers, who are responsible for obtaining their own vehicles, as well as negatively impacting riders, especially those who are low-income, due to increased prices.

4.2.4 Incentives

Consumer incentives have spurred PEV purchases and demand. Federal and state purchase incentives help offset the higher upfront cost of PEVs. The stacking of these incentives can provide tens of thousands of dollars back to the consumer.

The Clean Vehicle Rebate Project (CVRP) was created by AB 118 in 2007. Eligible new vehicles and incomes (BEVs, and FCEVs) are eligible for up to $7000 in rebates on a purchase or lease. The CVRP has received $1.18 billion in funds from the GGRF and has allocated $682 million to eligible consumers [164]. Other incentives can be stacked depending on income and vehicle eligibility.

Under its original implementation, CVRP rebates were concentrated to a large number of high-income individuals who could afford to purchase a PEV without an incentive. As a result, in 2015, SB 1275 required CARB to develop additional transportation equity programs using GGRF funds. In 2016 CARB implemented an income cap for the CVRP program, and lower income applicants were eligible for an increased rebate amount.[8] [165]. When combined with the federal tax incentive program, consumers are eligible for up to $7,000 for FCEVs, $12,000 for BEVs, and $11,000 for PHEVs).

It can be burdensome to apply to and wait for rebates for several months. Another incentive program, the Rebate Now program is piloted in San Diego, where drivers can be pre-approved to apply the rebate directly to the vehicle purchase instead of waiting until they apply for a rebate.

Non-monetary incentives have also been implemented, such as HOV and HOT lane access through the Clean Air Vehicle (CAV) program, and free or reduced parking in city centers. Lower income households are eligible for both the CVRP rebate and the CAV program, but higher income households must choose one of the two programs.

Equity Programs

Clean Cars 4 All is a program funded with GGRF money that gives financial incentives to lower-income households to retire ICE vehicles and replace them with new or used hybrid vehicles, ZEVs, or other mobility options, and install EVSE equipment and installation. The program offers up to $9,500 towards the purchase of a new vehicle, or $7,500 in

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[8] The income cap was reduced in 2016, and is currently $150,000 for single, and $204,000 for head of household, $300,000 for joint filings.

incentives or alternative mobility options and can be stacked with CVRP rebates. Unlike CVRP, used vehicles are eligible for this program. Income eligibility is dependent on which air district residents live in, and is on track to be operating in the South Coast, San Joaquin Valley, Bay Area, and Sacramento region. This income cap was recently extended to electric bicycles. When CVRP is stacked with Clean Cars 4 All, consumers can receive up to $16,500 from California programs for the purchase of a FCEV [166].

CARB has also implemented programs providing financing assistance, like the Clean Vehicle Assistance (CVA) Program for income eligible buyers for new and used vehicles. The CVA program provides financing assistance and grant money to eligible purchasers. This can be combined with the CVRP program for eligible drivers, although eligibility is different for each program. CARB is partnering with GRID Alternatives and the Greenlining Institute to streamline all of the available incentives to low-income consumers, to help increase awareness of the programs available to them, and expanding education and outreach efforts [167].

CARB has developed the several clean mobility projects and car sharing projects throughout the state, including the Clean Mobility Options Project for organizations to develop a clean mobility program. The program provides vouchers to support zero-emission ridesharing, bike-sharing, and innovative transit. Agencies can apply for up to $1 million in voucher funds that will cover costs of vehicles, infrastructure, planning, outreach, and operations. Eligible organizations are non-profits, public agencies, and tribal authorities [168].

4.2.5 Infrastructure Funding and Goals

In 2012, Governor Brown issued Executive Order B-16-2012, which implemented a goal to deploy 1.5 million ZEVs by 2025 and directed several state agencies to ensure readiness of supporting infrastructure [169]. This effort has been led by the CEC. SB 350 and SB 32 have since further supported efforts for ZEV infrastructure. This legislation collectively aided the installation of 14,000 public chargers by 2017. In 2018, Governor Brown signed executive order B-48-18 which requires infrastructure for the adoption of 5 million ZEVs by 2030, including 200 hydrogen stations, and 250,000 chargers, including 10,000 DCFCs [169], [170].

AB 1236, signed in 2015 by Governor Brown, requires streamlined permitting to approve electric vehicle charging stations [171]. The Governor’s office has compiled a guidebook for electric vehicle permitting [172] and hydrogem permitting [173]. These resources will help encourage the installation of EVSE to meet the needs of California’s EC goals by 2035, buy reducing upfront costs for permitting and reducing permitting time through streamlining.

The signing of SB 1 in 2018 created the Road Maintenance and Rehabilitation Account (RMRA) and increased funding for transportation projects. SB 1 guidance states that Caltrans and cities and counties should fund “advanced automotive technologies” which includes charging and fueling opportunities for ZEVs. SB 1 also imposes a $100 fee on PEVs per year to compensate for the fact that PEVs pay little or no fuel taxes. Analysis indicates that PEV fees are not a sustainable funding mechanism for transportation goals [174].

4.3 HDV

Although only 7% of the vehicles on the road are medium and heavy duty, those vehicles account for 35% of the California’s NO_x emissions. HDVs are responsible for 22% of all emissions from the transportation sector.

4.3.1 Fuel economy

California regulates the emissions profiles of medium- and heavy-duty trucks according to a rule CARB adopted in 2008. The Tractor-Trailer Greenhouse Gas Regulation (TTGGR) requires that new trucks add aerodynamic features and tires to improve fuel efficiency by 8%, as well as sleep-in cabs that meet EPA specifications [175]. CARB also implemented the Smog and Particulate Rule, which requires a diesel particulate filter in vehicles made after 2014. Such filters cut PM emissions by 95% or more and curb other harmful emissions as well [176], [177].

In 2007 the US congress directed the USDOT to develop a set of standards for the medium and heavy duty trucking industry. The national rule for emissions standards in the heavy-duty trucking industry was developed in 2011 by the EPA and NHTSA in two phases. Phase 1 applied to trucks Model Year 2014-2018 and applied to combination tractors, heavy-duty pickup trucks and vans, and vocational vehicles. Phase 2 standards applies to tractor-trailers for Model Year 2018-2027 to semi-trucks, vans, large pickup trucks, and buses, and Model Year 2021-2027 work trucks. Phase to implementation is divided by sector to help manufacturers meet the requirements. The Trump administration has proposed to roll back these standards [178].

In December 2018, CARB adopted the Innovative Clean Transit Regulation (ICT) requiring all state transit agencies to transition to a 100% zero-emission bus (ZEB) fleet, also encouraging first and last mile connectivity. Beginning in 2029, new bus purchases must be 100% ZEB, and the full fleet must be 100% ZEB by 2040. Large transit agencies were required to submit a rollout plan by July 1, 2020, and small agencies are required to submit their rollout by 2023 [179].

4.3.2 Zero-emission trucks

CARB recently voted on July 25th, 2020 to approve the California Advanced Clean Truck Rule, which requires medium- and heavy-duty truck makers to manufacture and sell a minimum and increasing number of zero-emission trucks in California. Beginning in 2024, at least 9% of vocational trucks certified Class 4–8 need to be zero-emissions, and 5% of all other truck classifications, a percentage that increases each year. By 2035, zero-emission truck/chassis sales would need to be 55% of Class 2b – 3 truck sales, 75% of Class 4 – 8 straight truck sales, and 40% of truck tractor sales [180].

4.3.3 Incentives and programs

Multiple programs have been implemented through the California Climate Investments Program, including the Hybrid and Zero-emission Voucher Incentive Project (HVIP) includes the Clean Truck and Bus Vouchers program and the zero-emission truck and bus pilot. The Clean Truck and Bus Voucher program offers vouchers up to $315,000 to city and county private and public operators for the purchase of zero-emission, hybrid, and low-NO_x trucks and buses. The zero-emission truck and bus pilot program grants funding to local air districts, transit agencies, school districts, and other public entities and non-profits to partner with technology providers.

Another example of CCI funds includes the Zero and Near Zero-Emissions Freight Facilities (ZANZEFF), which provides funding for reducing the emissions from goods movement by providing funding opportunities for industry partners working to develop zero-emissions technologies that can be adopted widely in the future [181]. Projects receiving funding were chosen in alignment with the Caltrans Sustainable Transportation plan [182].

The Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer Program) has allocated approximately $1 billion in grant funding to date to improve air pollution from older engines in California. The program was created in 1998 to fund lower-emission heavy-duty engine incentives, and CARB and legislation (AB1571) have since established a framework for the program [183].

4.3.4 Freight and goods movement

Governor Brown signed Executive Order B-32-15 in 2015, calling for the development of a freight action plan to establish targets for freight efficiency, boost zero-emission technologies, and increase the competitiveness of California's freight system [5]. Ships are the largest source of emissions in the Los Angeles and Long Beach ports, which disproportionately impact surrounding communities. Cap-and-trade funds are allocated to improve freight efficiency, especially in communities designated by CalEnviroScreen proximate to ports. Through working with CARB, the largest ports in the state have achieved an 80% reduction in PM emissions, a 90% reduction in SO_x emissions, and a 50% reduction in NO_x emissions since it was signed [184].

4.4 California policies related to VMT

The transportation sector is responsible for the largest share of GHG emissions, as discussed in previous sections. Passenger VMT has consistently increased for numerous reasons, including population growth and urban sprawl. A wide range of policy-related solutions could be employed to reduce per capita and total VMT in California as the state's population grows. Several current policies in the state related to VMT are discussed below. Extended and additional policies are being contemplated for inclusion in the future.

4.4.1 Sustainable communities

In 2008, Governor Schwarzenegger signed SB 375, California's Sustainable Communities and Climate Protection Act to help meet the goals of AB 32, California's Global Warming Solutions Act. Meeting SB 375 goals requires a coordination between transportation and land use on a regional scale is required to reduce GHG emissions from the transportation sector.

SB 375 requires each of California's 18 Metropolitan Planning Organizations (MPOs) to work with CARB to establish a GHG reduction target for 2020 and 2035 for each region; these targets must be updated, at minimum, every 8 years. Each MPO will adopt a Sustainable Communities Strategy (SCS) as part of their regional transportation plan, which details how each region will meet these targets. Bolstering existing housing legislation, SB 375 requires each MPO to coordinate their regional housing needs allocation with their SCS. CARB reviews each SCS and determines if the plan in place will meet the target requirements; if CARB decides the target will not be met through their plan, the MPO must prepare an Alternative Planning Strategy (APS).

Reducing VMT per capita will play a large part in meeting GHG-reduction goals outlined in SB 32. The Sustainable Communities and Climate Protection Act of 2008 (SB 375) directs CARB to set emissions-reduction targets. Specifically, MPOs must develop Sustainable Communities Strategies (SCSs) that recommend transportation, land use, and housing policies to reach regional emissions targets. In transportation, GHG-reduction policies include policies that guide transportation choices towards lower per capita VMT options [185]. Based on these metrics, SB 150 was passed in 2017 to require that CARB prepare a report for the legislature every four years to discuss the progress on SB 375. The first report was published in 2018 [186]. The most recent iteration of the report states that California is not on track to meet its VMT reduction goals, as VMT per capita continues to increase. Reducing emissions from transportation is required for the state to meet future GHG reduction targets, and other equity, economic, housing, and public health benefits are at risk.

In 2018, California's Natural Resources Agency implemented SB 743 to update CEQA guidelines. Specifically, SB 743 directed the Governor's Office of Planning and Research to evaluate alternatives to Level of Service (LOS) as a mechanism for evaluating the impacts of transportation and develop guidelines. California Natural Resources Agency implements the regulation process. Starting July 1, 2020, these quantitative measurements include VMT, VMT per capita, automobile trip generation rates, and trips generated. SB 743 was also amended to allow cities and counties to opt out of LOS standards in certain areas with infill development.

4.4.2 Bicycle and pedestrian modes

The Caltrans Active Transportation Program (ATP) was created in 2013 after passage of SB 99. The ATP aims to make California a national leader in active transportation. The program is managed by Caltrans and the California Transportation Commission and administered by the Division of Local Assistance, Office of State Programs. The original budget for the ATP in 2013 was $123 million per year, of which $88.5 million comes from the federal government. 2017's SB 1 directed another $100 million per year to the ATP [187], [188].

Among other goals associated with the program (including increasing active mode shares, increasing safety for non-motorized travel modes, and improving public health), the ATP explicitly aims to support California's GHG-reduction goals related to 2008's SB 375 and 2009's SB 341. The ATP also funds the Active Transportation Resource Center (ATRC), which provides a wide variety of technical and non-technical documentation associated with active transportation projects.

4.4.3 Innovative mobility systems

The Clean Miles Standard (SB 1014) aims to lower per capita VMT by utilizing a GHG per PMT approach. CARB will regulate and cap GHG per PMT for TNCs, but is still working out details about cap enforcement, as well as equitable ways to implement the rule and distribute revenue. The cap will also apply to micromobility companies (e.g., companies supplying e-scooters and e-bikes). SB 1014 requires CARB to establish baseline emissions from TNC vehicles, as measured on a per-passenger-mile basis. This includes emissions from all stages of TNC vehicle operation, including periods 1, 2, and 3[9]. The legislation requires baseline emissions to be established for miles traveled via zero-tailpipe-emission modes including scooters, walking, and biking.

2019's SB 400, Reduction of Greenhouse Gases Emissions: Mobility Options, classifies bike-share and e-bikes alongside public transit and car sharing as a "cleaner and more efficient motor vehicle or a mobility option," and therefore allows those modes to be included in the Clean Cars 4 All program.

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[9] Period 1 (P1) is the period of time after a driver logs into a TNC application but is not yet matched with a passenger. During this time period, the driver awaits a ride request through the TNCs; Period 2 (P2) starts when a match is made and accepted by the driver, but before the passenger has entered the vehicle. During this period of time, the driver is en route to pick up the passenger; Period 3 (P3) begins when a passenger has been picked up and is an occupant of the TNC driver's vehicle. This period of time lasts until the driver completes the transaction (on the online-enabled application or platform), or until the ride is completed, whichever is later.

4.4.4 Funding

State and local governments can utilize funding to increase alternative transportation modes like transit and active transportation. In 2019, Governor Newsom signed Executive Order N-19-19 to redouble the state's efforts to reduce GHG emissions. Transportation is the only sector in California where GHG emissions have continued to increase, so one of the provisions of that executive order directed Caltrans to leverage more than $5 billion to reduce GHG for transportation through the California State Transportation Agency (CalSTA). This will better align infrastructure projects with climate goals, and through investment in transportation projects that support transit-oriented development, and supporting infrastructure for pedestrians and cyclists. For example, programs like the Affordable Housing and Sustainable Communities Program (AHSC) will help support climate goals through investment of GGRF money [189].

Fuel taxes are not only revenue sources, but can also influence travel behavior in ways that reduce VMT. SB 1 indexed the gasoline tax to inflation (raising it from 30 to 42 cents per gallon), increased vehicle-registration fees, and increased diesel fuel taxes. Investment priorities for additional funds will improve transit and active transportation infrastructure.

4.5 Fuels

4.5.1 Low Carbon Fuel Standards (LCFS)

The LCFS sets a declining target for the average carbon intensity of its entire fuel pool, assessed across the full fuel lifecycle (including the production of raw materials, conversion into fuel, transport to market, and consumption in vehicles). California fuel producers are required to comply with this target by reducing emissions from their fuels, blending in lower-carbon fuels, or buying credits from low-carbon fuel producers. Each LCFS credit represents one metric ton of emissions in excess of the required reduction for a given year.[10] Fuels that marginally reduce emissions receive a small amount of credit per gallon sold, while very low carbon fuels can receive much greater incentives. The intent of the LCFS is to create a strong incentive to support the deployment of new, low-carbon technologies while creating a market-based performance incentive for the deployment of currently available technologies. While some credits can be generated by improving the efficiency of existing refineries, shifting to lower-carbon alternative fuels is the most common mechanism to meet LCFS targets. The most common alternative to petroleum at present is biofuels, though electricity is rapidly growing as a vehicle fuel and will likely supply an increasing fraction of total fuel consumption in future years. The LCFS has significantly expanded the use of biofuels in California since it was implemented in 2011, increasing the fraction of non-petroleum fuel used in California from 7% to 16%, on an energy-content basis. At present, the LCFS offers around $200 per ton of emissions reduced and has made California one of the most attractive markets for alternative fuel producers.

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[10] It is important to note that even though LCFS credits and cap-and-trade permits are both instruments that nominally represent one metric ton of emissions, they are not comparable or exchangeable for each other. Cap-and-trade permits represent a metric ton of CO_2 or equivalent. LCFS credits represent the reduction in life cycle emissions of a metric ton of CO_2 equivalent, compared to that year's standard. In practical terms, LCFS credits are typically more expensive than cap-and-trade credits, but the aggregate market for them is much smaller.

4.5.2 Electricity Decarbonization (SB100)

Electrification of passenger vehicles, along with a significant fraction of medium- and heavy-duty vehicles, is a central pillar of California's long-term transportation decarbonization plan. While the superior efficiency of electric motors gives EVs a lower emission footprint per mile of travel under current conditions, the long-term decarbonization goals California has adopted cannot be met without a significant decarbonization of California's electric grid. California has primarily used an RPS, along with price effects from its cap-and-trade program, to reduce emissions from its electric fleet. First adopted in 2002 as a result of SB 1078, the RPS requires a certain amount of California's retail electric sales to come from renewable sources, including wind, solar, geothermal and small hydroelectric projects. SB 1078 required 20% of California's generation to come from renewable sources by 2017. That target was extended in 2015 to a 50% requirement by 2030 under SB 350 and further by SB 100 to 60% by 2030. SB 100 additionally requires that eligible renewable energy resources and zero-carbon resources supply 100% of retail sales of electricity.

4.5.3 EV and FCEV Infrastructure

California has recognized the need to deploy charging infrastructure to support the transition to plug-in vehicles. In 2018, Governor Jerry Brown issued Executive Order B-48-18 which set targets for 250,000 EV charging stations, including 10,000 DC fast chargers to be deployed by 2025, as well as 200 hydrogen fueling stations. This builds upon several existing state actions to expand the amount of EV charging infrastructure available, including grant and incentive programs from the CEC and charger installation supported by utilities using either rate-based revenue or the proceeds from sales of LCFS credits from residential EV charging.

SB 350 (2015, de Leon) helped set the landscape for EV charger installation, by making utilities, under the guidance of the CPUC, responsible for planning and managing the development of EV charging infrastructure sufficient to support California's long-term EV goals. It also supported the development of EV rate structures for electrical utilities, to support EV charging, encourage off-peak charging and protect EV users from the risk that charging could advance them into a higher cost tier under previously existing plans [148].

4.5.4 Fuel taxes

Fuel taxes in California, like the rest of the United States, are primarily a mechanism for funding road maintenance and improvements. Fuel taxes also intended to reduce the consumption of petroleum by increasing its price. The federal government imposes fuel excise taxes of 18.4 cents per gallon on gasoline and a 24.4 cents per gallon on diesel. These taxes were last adjusted in 1993 and are not indexed to inflation, which has caused the taxes to decline in real value over time. California adds a number of statewide fuel taxes including per-gallon excise taxes, sales tax, and price-based taxes. In 2017, state gas taxes were increased by SB 1. Gas taxes in California now total over 55 cents per gallon. Gas-tax revenue is expected to add over $50 billion dollars in total aggregate transportation funding over the next decade, narrowing the anticipated revenue-expenditure gap for transportation by about two-fifths.

4.6 Equity and environmental justice

Low-income and DACs are disproportionately burdened with the negative impacts from land development practices and transportation-generated pollution. California has enacted several laws directing funding to EJ communities and requiring EJ to be a consideration in planning. SB 1000, signed in 2016, requires local governments to identify EJ communities and address environmental inequities in various plans. In addition, CalEPA has developed a screening tool called CalEnviroScreen to identify communities that are disproportionately affected by several metrics related to pollution.

The Community Air Protection Program, AB 617, was established in 2017, requiring localities through local air agencies to reduce exposure to air pollution in the most impacted communities. The program includes incentives to deploy cleaner energy and more efficient technologies, requires retrofitting pollution controls on industrial sources, increased penalty fees, and increases transparency of emissions data [191].

Policymakers in California have also recognized the importance of EJ at the local and regional levels. For instance, SB 375 established cyclical planning processes in 18 regions with the goal of reducing GHG emissions and achieving state policy goals. Among other things, the Act's SCS requirement addresses a number of co-considerations, including social equity. Unfortunately, while each region has adopted an SCS plan, a 2018 CARB Progress Report on SCS milestones showed that California is currently not meeting its CO_2 emissions-reduction goals. VMT per capita is rising statewide. In the regions covered by California's four largest MPOs, commuting times have increased for both single-occupancy vehicles and public transit.

5 Business as Usual Scenario

5.1 Concept

The study will build low-carbon projections off of a “business as usual” (BAU) projection. The projection will assess past trends and how those trends may continue (or change) into the future in the absence of new policies. The projection will also consider how existing policies may “bend the curve” of CO_2 and other key metrics of interest. We describe the status of the BAU projection and the underlying assumptions below.

The BAU projection (and other projections) will be summarized using the UC Davis’ Transportation Transitions Model (TTM). This model was used in a STEPS “80-in-50” study (UCD 2019), which assessed a reduction of 80% of CO2 emissions from road vehicles in California by 2050. This study also developed a BAU projection for California that helps form the basis of the BAU for this report. The BAU has been further calibrated to CARB’s EMFAC data and modeling efforts, and specific policies and their potential impacts have been taken into account.

5.2 Tools

The TTM is a transparent spreadsheet model that projects California road transportation from 2000 to 2050 in terms of vehicle sales and stocks, vehicle travel, energy use and CO_2 emissions. The TTM is calibrated to ARB Vision/EMFAC but also takes into account other historical data and estimates that in some cases deviate from this source. The TTM includes a wide range of technology and cost data and projections, as well as cost factors for vehicles and fuels that allow estimation of the magnitudes of the investments and subsidies required to achieve a transition to low and zero emission transportation.

Based on the Argonne VISION model modified by CARB [192] the TTM includes relevant economic costs associated with zero-emission vehicles based on a detailed component-level analysis for key technologies, such as fuel storage, batteries, fuel cells, and electric drivetrains. As in the rest of this analysis, the TTM is disaggregated into different categories. Disaggregation makes it possible to determine which vehicle and fuel technologies may be appropriate for specific vehicle types (e.g., BEVs are currently unsuitable for long-haul trucks but possible for short-haul trucks).

The TTM comprises a vehicle module and a fuel module, as shown in the figure below. The vehicle module covers vehicle sales, stocks, travel, efficiency, energy use and CO_2 emissions for California road vehicles, broken into two LDV classes, two bus types, three medium-duty truck types and three heavy-duty truck types.

The fuel module calculates fuel costs and carbon intensities. This fuel module represents economic costs and also includes a detailed representation of fuel infrastructure deployment and scale required to adequately assess the full impacts of shifting to low-carbon fuels and vehicles. The fuel module provides a representation of all the necessary resource, production, transport, and refueling station elements in the TTM. The fuel module includes four primary elements of a generic fuel pathway:

- **Resource supplies.** Energy resources used in the production of the alternative fuel, plus the prices and quantities of these resources.

- **Production/conversion facilities.** Production facilities are modeled with information about resource inputs, conversion efficiency, and facility costs.
- **Fuel transport.** Finished transportation fuels must be transported to the refueling stations. This process is modeled from a cost and energy input perspective.
- **Refueling stations.** The cost and energy inputs of building refueling infrastructure is modeled.

The fuel module receives information about fuel demand and number of vehicles from the vehicle module and outputs fuel costs and fuel carbon intensities.

The model also can be interacted with a separate “truck choice” model to help estimate future vehicle sales shares by technology type for different truck classes. In this project, the truck technology analysis will be handled separately by the freight task group (Figure 48).

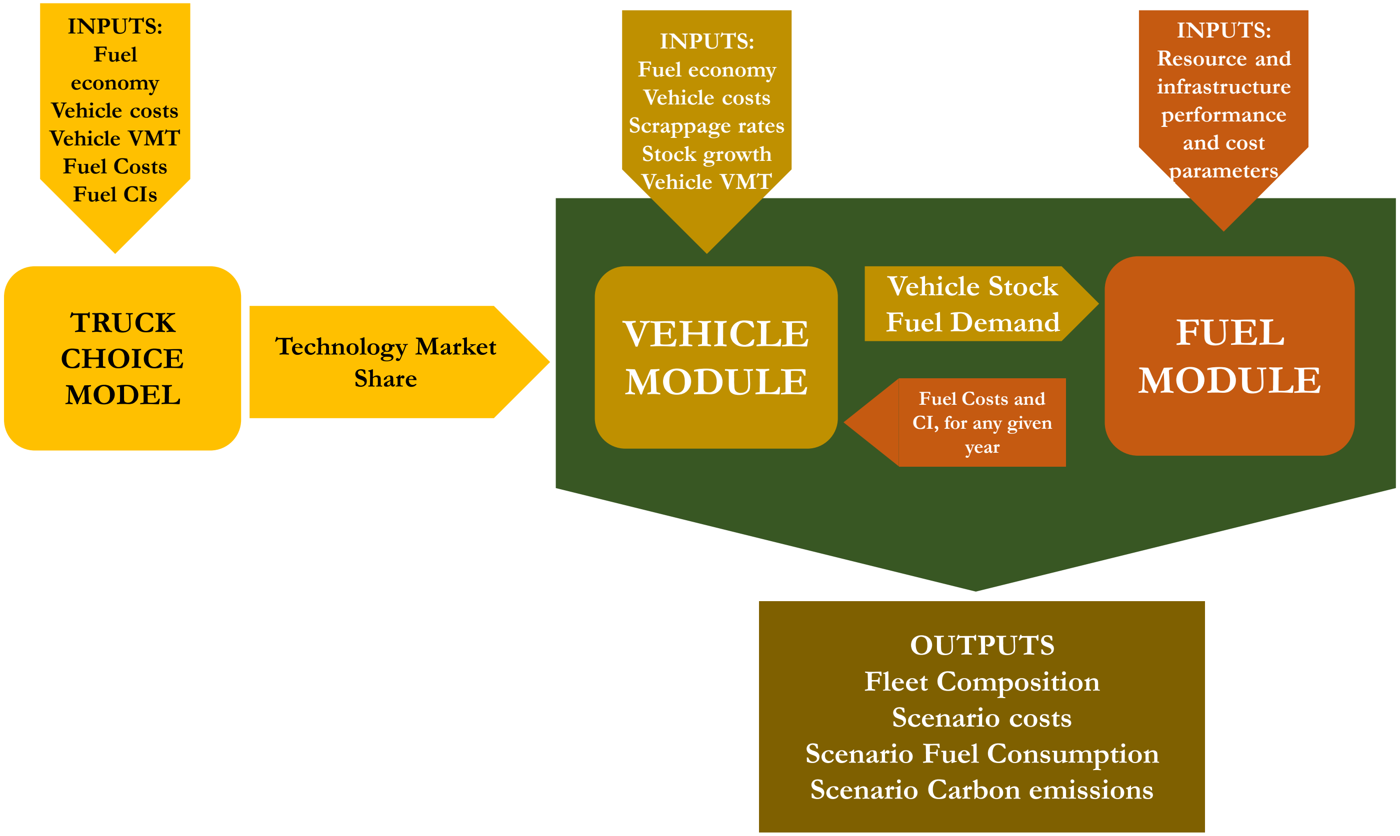

Figure 48. Basic modeling flow in the TTM. (Notes: VMT, vehicle miles travelled; CI, carbon intensity.)

5.3 Policy approach

The BAU reflects existing trends and considers how these trends will be affected by a number of existing California transportation and CO2 related policies. Table 22 summarizes these and also indicates how the treatment of these policies here is similar to or different than CARB's treatment in their current scoping plan development.

Table 22. Existing Policies to target reduction of GHG emissions in the transportation sector

Policy	General impact	Proposed treatment
Low-carbon fuel standard (LCFS)	20% reduction in average transportation fuel CI by 2030 vs 2010	Assume this occurs; work with teams to determine BAU penetration of ZEVs and resulting electricity use, and then determine the amount and types of biofuels as a "backfill" exercise Assume LCFS target maintains 1.25% per year increase after 2030.
LDV ZEV sales requirements in 2025	1.5 million target based on credit system.	Must determine what this actually means for LDV BEV/PHEV/FCEV sales/stocks through 2025, we assume that 1.5 million ZEVs are actually sold (including BEVs, PHEVs, and FCEVs).
LDV ZEV cumulative sales by 2030	5 million Governor's target	We do not assume this is met due to lack of existing supporting policies. LDV team has recommended we assume 3 million based on some growth rates in sales shares from 2025-2030.
Municipal transit buses sales share by 2030	100% ZEV sales share by 2030	We assume this is achieved, then stays constant. We assume a high share of these are BEV vs FCV.
MDV/HDV ZEV 2030 Advanced Clean Truck (ACT) rule	Do not include, not law yet - may become law by summer	This policy will, if fully implemented and achieved, result in up to 60% ZEV sales shares for various truck types by 2035. Since not to be considered BAU, this will instead go into the low Carbon scenarios. Instead for the BAU we have assumed electrification of delivery trucks related to the last mile delivery regulation. This is expected to result in deployment of increasing numbers of zero-emission trucks primarily for class 3-7 last mile delivery trucks in California. This measure assumes ZEVs comprise 2.5 percent of new Class 3–7 truck sales in local fleets starting in 2020, increasing to 10 percent in 2025. The overall average for all trucks is about 2% ZEV sales by 2025.
VMT	SB-375 target - 10% reduction by 2020	California did not achieve VMT reductions by 2020. VMT task team is looking at other dynamics, but for the BAU is not expecting much deviation from a constant VMT/capita trend

5.4 Results

The resulting BAU includes a range of projections described above, such as growth in travel that is consistent with population growth. There is also a proportional growth in sales and stocks of vehicles to support this travel. This leads to a BAU assumption of a significant grown in both LDV and truck travel (Figure 49).

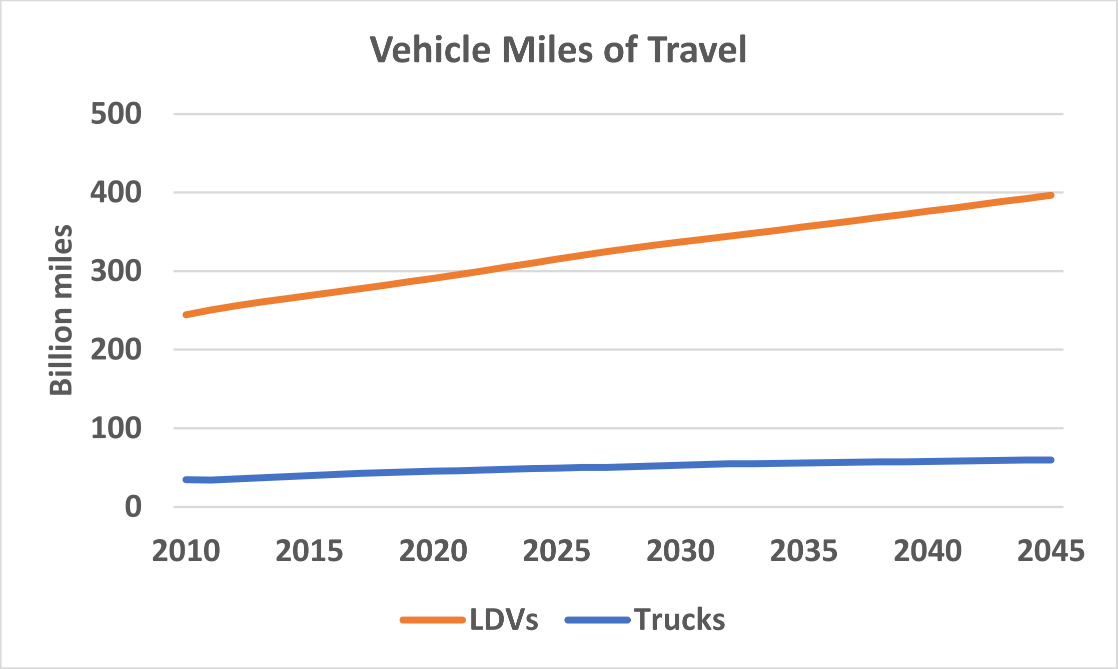

Figure 49. Vehicle miles travelled in the BAU increase steadily

The ZEV projections by vehicle type are shown in (Figure 50) below. The sales of ZEV transit buses, per current law, reach 100% of the market by about 2030; ZEV LDVs reach 10% sales share by 2025 (stocks of 1.5 million vehicles, and 20% sales share by 2030 (stocks of about 3 million vehicles). They remain flat thereafter as the market is not assumed to grow without further policies. Nearly all of the ZEV vehicles in this BAU are electric or plug-in hybrid, with a small share that are fuel cell.

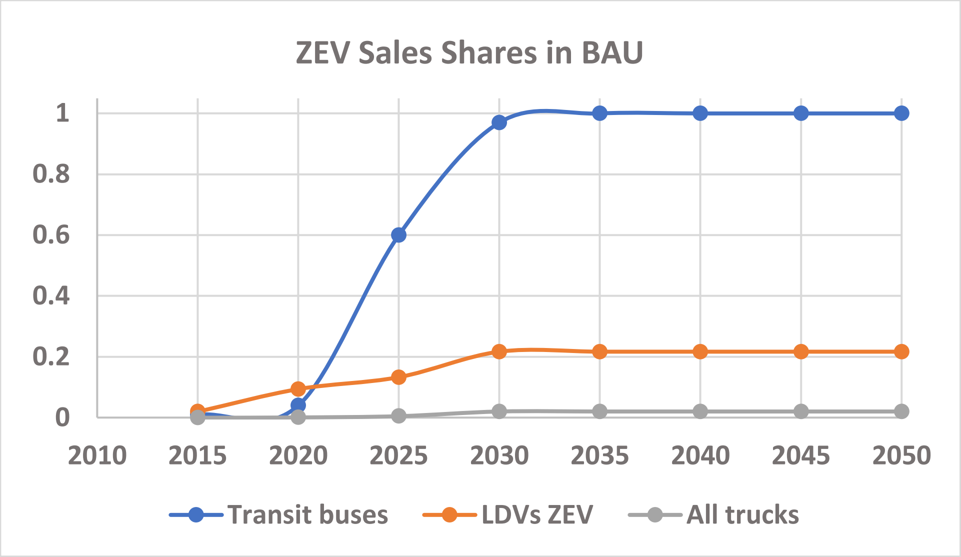

Figure 50. Market penetration of zero-emission LDVs, trucks, and buses in the BAU

The net effect of this BAU on road vehicle (car, truck and bus) energy use is shown in (Figure 51). Energy use drops mostly due to an improvement in conventional vehicle fuel economy, with only a very small shift toward electricity or hydrogen due to ZEVs. The energy mix for transportation in the state remains predominantly petroleum based.

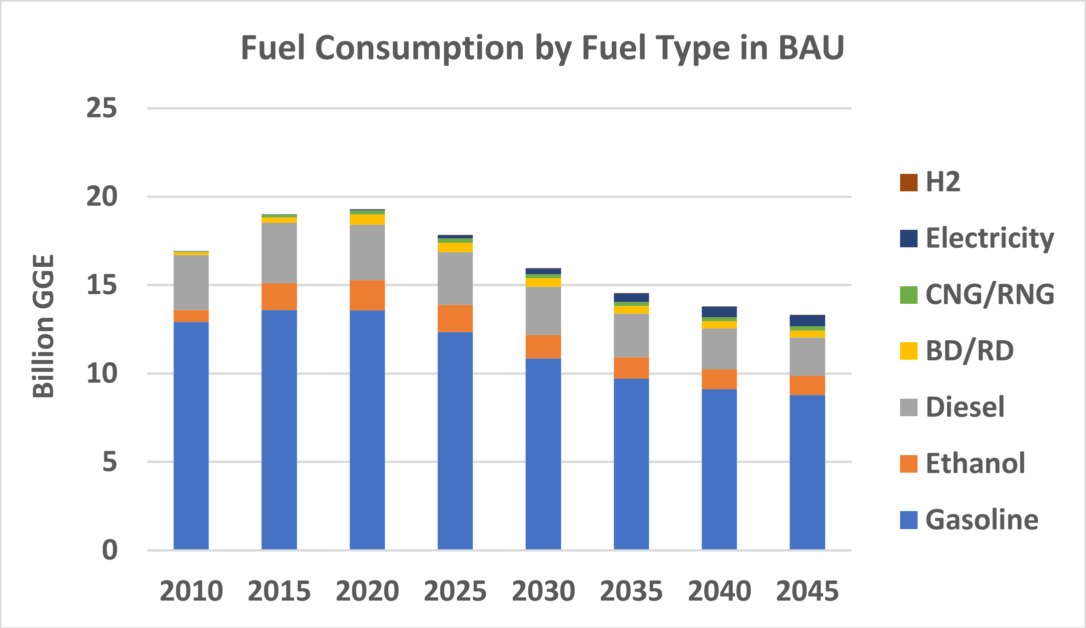

Figure 51. The fuel mix in the BAU shifts only modestly towards lower carbon fuels. Note CNG/RNG is compressed natural gas/renewable natural gas. BD/RD is biodiesel/renewable diesel,

Similarly, CO_2 emissions change in proportion to energy use, with some increase through 2020 then a slow decline to 2045 (Figure 52). The net change compared to 2010 is about 10%.

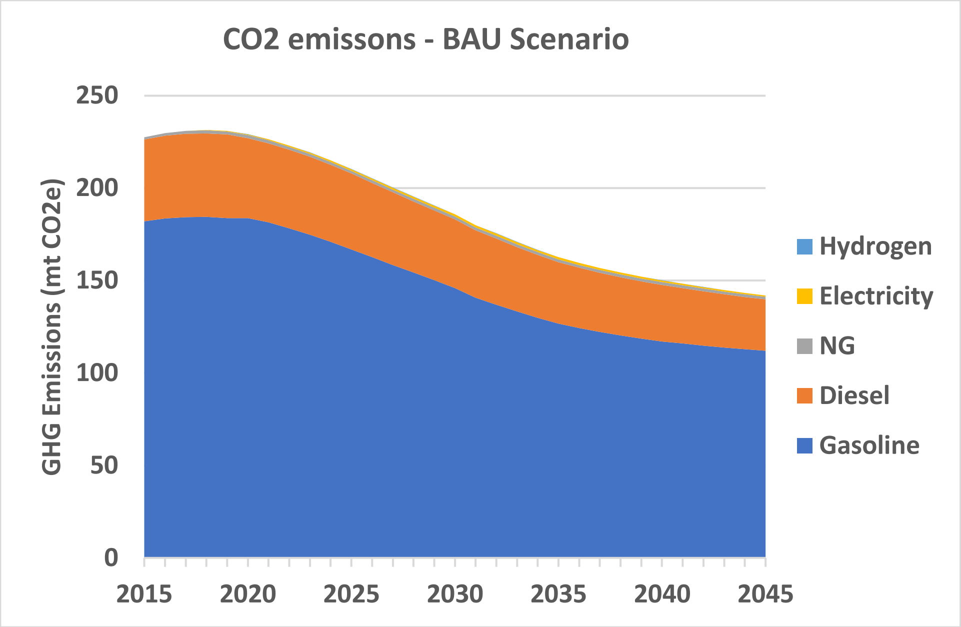

Figure 52. Overall emissions in the BAU shrink, then flatten

5.5 Benchmarking

The most important benchmarking activity for setting this baseline is to ensure that principal variables are aligned with historical data as presented in EMFAC for 2010–2020. The energy use and other travel indicators have been calibrated in this manner. We have also compared the BAU project to some other projections and found that in general the results are similar, though there is variation across available projections. An example is shown in (Figure 53) below. All of the more recent projections cited show very similar ZEV LDV stock growth in their BAU scenarios, reaching about 3 million in 2030.

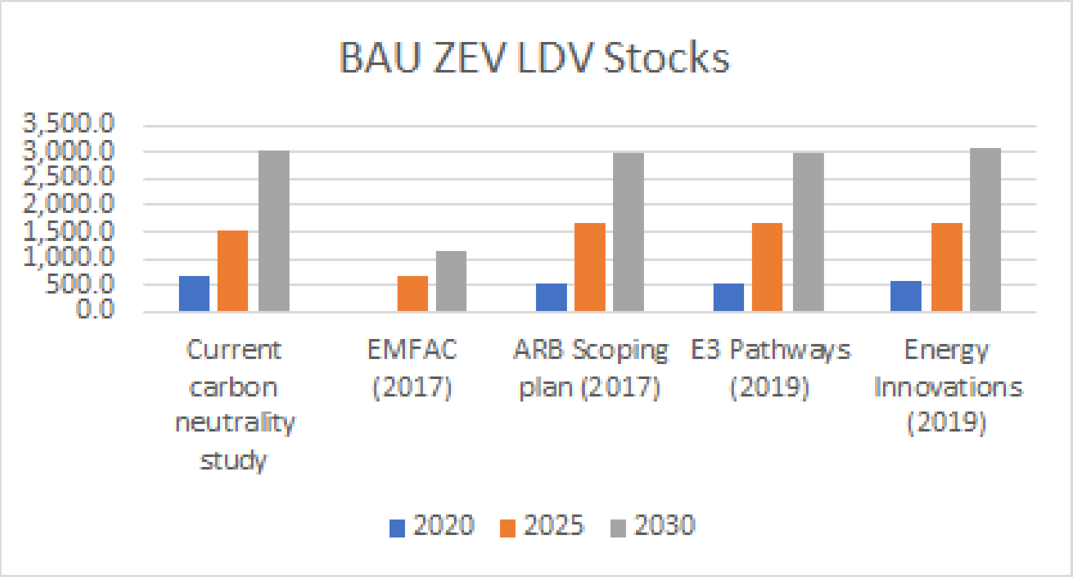

Figure 53. Comparison to this study's BAU (left) to other prominent BAU studies of the transportation sector for LDV stocks.

Appendix

Environmental Justice Principles [193]

(1) Affirms the sacredness of Mother Earth, ecological unity and the interdependence of all species, and the right to be free from ecological destruction.

(2) Demands that public policy be based on mutual respect and justice for all peoples, free from any form of discrimination or bias.

(3) Mandates the right to ethical, balanced and responsible uses of land and renewable resources in the interest of a sustainable planet for humans and other living things.

(4) Calls for universal protection from nuclear testing, extraction, production and disposal of toxic/hazardous wastes and poisons and nuclear testing that threaten the fundamental right to clean air, land, water, and food.

(5) Affirms the fundamental right to political, economic, cultural and environmental self-determination of all peoples.

(6) Demands the cessation of the production of all toxins, hazardous wastes, and radioactive materials, and that all past and current producers be held strictly accountable to the people for detoxification and the containment at the point of production.

(7) Demands the right to participate as equal partners at every level of decision-making, including needs assessment, planning, implementation, enforcement and evaluation.

(8) Affirms the right of all workers to a safe and healthy work environment without being forced to choose between an unsafe livelihood and unemployment. It also affirms the right of those who work at home to be free from environmental hazards.

(9) Protects the right of victims of environmental injustice to receive full compensation and reparations for damages as well as quality health care.

(10) Considers governmental acts of environmental injustice a violation of international law, the Universal Declaration On Human Rights, and the United Nations Convention on Genocide.

(11) Must recognize a special legal and natural relationship of Native Peoples to the U.S. government through treaties, agreements, compacts, and covenants affirming sovereignty and self-determination.

(12) Affirms the need for urban and rural ecological policies to clean up and rebuild our cities and rural areas in balance with nature, honoring the cultural integrity of all our communities, and provided fair access for all to the full range of resources.

(13) Calls for the strict enforcement of principles of informed consent, and a halt to the testing of experimental reproductive and medical procedures and vaccinations on people of color.

(14) Opposes the destructive operations of multi-national corporations.

(15) Opposes military occupation, repression and exploitation of lands, peoples and cultures, and other life forms.

(16) Calls for the education of present and future generations which emphasizes social and environmental issues, based on our experience and an appreciation of our diverse cultural perspectives.

(17) Requires that we, as individuals, make personal and consumer choices to consume as little of Mother Earth's resources and to produce as little waste as possible; and make the conscious decision to challenge and reprioritize our lifestyles to ensure the health of the natural world for present and future generations.

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