Title

Towards Achieving Carbon Neutrality in California: Forecasted Transportation Expenditures on Fossil Fuel Vehicles and Zero Emission Vehicles from 2020 to 2045

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Publication Date

2021-06-01

DOI

10.17610/T6VW2J

CAPSTONE PROJECT REPORT

UCLA Institute of Transportation Studies

Towards Achieving Carbon Neutrality in California:

Forecasted Transportation Expenditures on Fossil Fuel Vehicles and Zero Emission Vehicles from 2020 to 2045

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Client: Luskin Center for Innovation

June 2021

Rebuilding California SB1

PSR Pacific Southwest Region UTC
University Transportation Center

Technical Report Documentation Page

1. Report No. N/A	**2. Government Accession No.** N/A	**3. Recipient's Catalog No.** N/A
4. Title and Subtitle Towards Achieving Carbon Neutrality in California: Forecasted Transportation Expenditures on Fossil Fuel Vehicles and Zero Emission Vehicles from 2020 to 2045		**5. Report Date** 2021 **6. Performing Organization Code** UCLA-ITS
7. Author(s) Allison Yang		**8. Performing Organization Report No.** LAS2032
9. Performing Organization Name and Address Institute of Transportation Studies, UCLA 3320 Public Affairs Building Los Angeles, CA 90095-1656		**10. Work Unit No.** N/A **11. Contract or Grant No.**
12. Sponsoring Agency Name and Address UCLA Institute of Transportation Studies www.its.ucla.edu		**13. Type of Report and Period Covered** Final **14. Sponsoring Agency Code** UC ITS

15. Supplementary Notes

DOI: 10.17610/T6VW2J

16. Abstract

California has a goal to reach carbon neutrality in the transportation sector by 2045. As the vehicle fleet becomes cleaner and greener, the way consumers, firms, and businesses spend money on transportation will shift, driving changes in employment in fossil fuel vehicle and ZEV-related sectors. The paper explains the fundamental relationship between how consumers spend their money and consequent changes in the workforce, characterize Californians' current transportation-related spending, and forecast changes in these spending patterns that will drive employment changes across transportation-related supply chains between now and 2045. We assess three key categories of expenditures (vehicle purchase, fuel, and maintenance costs) segmented by four general vehicle classifications. We find that if California achieves carbon neutrality in the transportation sector by 2045, California will spend $23.3 billion less across the three key transportation expenditure categories in 2045 compared to 2020, with overall expenditures falling from $175.4 billion to $152.1 billion. All three key expenditure categories will be lower in 2045 than in 2020. By 2045, all new vehicle purchases will be made on ZEVs, and the majority of fuel and maintenance costs will be made on ZEVs. Understanding how expenditures will change can help identify which industries and occupations will be highly impacted by transportation decarbonization. This can inform how private and public agencies manage this transition to ensure it produces equitable, high quality jobs, especially for those workers whose jobs may be eliminated.

17. Key Words California, clean vehicles, transportation finance, transportation planning	**18. Distribution Statement** No restrictions.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 57	**22. Price** N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

UNIVERSITY OF CALIFORNIA
Los Angeles

TOWARDS ACHIEVING CARBON NEUTRALITY IN CALIFORNIA

Forecasted Transportation Expenditures on Fossil Fuel Vehicles and Zero Emission Vehicles from 2020 to 2045

A comprehensive project submitted in partial satisfaction of the requirements for the degree Master of Urban and Regional Planning

by

Allison Yang

Client: Luskin Center for Innovation
Faculty Advisor: Michael Manville

2021

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Executive Summary

Project Justification
This report is part of a larger technical report *Workforce Impacts of Achieving Carbon-Neutral Transportation in California* (working title) published by the UCLA Luskin Center for Innovation. The primary value of the technical report is to highlight trends in zero emission vehicle (ZEV)-related job creation and internal combustion engine vehicle (ICEV)-related job loss. The purpose of this report, Chapter 3 of the technical report, is to forecast changes in key transportation-related expenditures from 2020 to 2045. Understanding how expenditures will change can help identify which industries and occupations will be highly impacted by transportation decarbonization. This can inform how private and public agencies manage this transition to ensure it produces equitable, high quality jobs, especially for those workers whose jobs may be eliminated.

Background
California, a leader in climate change policy, is determined to achieve carbon neutrality in its transportation sector by 2045. We expect the proportion of clean vehicles in the vehicle fleet to become progressively larger as we move toward 2045. As more and more Californians begin driving battery electric and hydrogen fuel cell vehicles, we anticipate California will spend less overall on transportation. ZEVs incur lower maintenance costs than ICEVs across all major vehicle categories, substantially in the case of light-duty vehicles (LDVs). This translates to less spending on maintenance and therefore fewer jobs related to maintenance. ZEVs are also substantially more fuel-efficient than ICEVs, both now and in projected future years. ZEV owners and operators therefore spend less on fuel, leading to contraction the overall size of the fuels supply chain workforce. The rates at which industries expand and contract will depend largely on our findings.

Research Question

How will expenditures on fossil fuel vehicles and zero emission vehicles in California change between 2020 and 2045?

Methodology

Expenditure estimates are non-specific with regards to source, covering consumers, businesses, and governments. With regards to jobs created to meet the demand such expenditures generate the exact source of the money spent is inconsequential. The expenditure projections cover the following key categories:

- *New Vehicle Purchases.* Used vehicle sales are not considered as they are significantly less impactful than new vehicle sales on the overall labor market. We calculated annual new vehicle purchase expenditures by multiplying average vehicle purchase price with the number of vehicles purchased each year.
- *Fuel Consumption for Transportation* across the three predominant fuel types: fossil fuels, electricity, and hydrogen. Fossil fuel incorporates consumption of both gasoline

and diesel. We calculated fuel expenditures by multiplying the on-road fleet numbers by the annual fuel cost per vehicle.

- *Maintenance and Repairs,* calculated by multiplying vehicle miles traveled (VMT) by maintenance cost per mile by on-road fleet vehicle totals.

All three of these expenditure categories are distinguished by the three prominent drivetrain technologies (ICEV, BEV, and FCEV) and four vehicle categories (LDVs, MDVs, HDVs, and Buses).

Drivetrain Technologies	
ICEV	Internal combustion engine vehicle
BEV	Battery electric vehicle
FCEV	Fuel cell electric vehicle

4 General Vehicle Categories	
LDV	Light duty vehicle
MDV	Medium duty vehicle
HDV	Heavy duty vehicle
Buses	Transit Buses and School buses

Data underlying these estimates largely comes from UC Davis Institute of Transportation, which has forecasted a scenario (CNS LC1) in which California meets its 2045 carbon neutrality goal. Such data includes projected vehicle sales figures, vehicle purchase prices, vehicle miles traveled (VMT), fuel consumption and EV charging demand. Supplemental data from external sources is used where required and includes estimated maintenance costs by drivetrain technology and vehicle class, and estimated fuel prices.

Findings

We find that if California achieves carbon neutrality in the transportation sector by 2045, California will spend $23.3 billion less across the three key transportation expenditure categories in 2045 compared to 2020, with overall expenditures falling from $175.4 billion to $152.1 billion (a 13.3% drop). All three key expenditure categories will be lower in 2045 than in 2020. Across the next 25 years, new vehicle purchases will remain the largest expenditure category, with fuel costs second, and maintenance costs last. New vehicle purchase expenditures will remain relatively constant between 2020 and 2045, while fuel and maintenance expenditures will see larger declines. By 2045, all new vehicle purchases will be made on ZEVs, and the majority of fuel and maintenance costs will be made on ZEVs.

Conclusions and Recommendations

Our findings emphasize that the transition to a green vehicle fleet will lower California’s overall transportation expenditures due to the lower fuel and maintenance costs associated with ZEVs. As the vehicle fleet becomes cleaner, many jobs related to the procurement of fossil fuels and the production of fossil fuel vehicles (also known as ICEVs) will be eliminated and workers will need to be retrained in new clean-energy industries. We recommend the following actions be taken to more accurately gauge how expenditures may change in the coming years:

- Explore how expenditures may change based on alternative timelines
- Compare actual numbers with our estimated numbers over time
- Promoting the widespread adoption of ZEVs to facilitate California’s carbon neutral goal

It is important to note that forecasting future conditions is rife with uncertainty, even more so when nascent industries and unprecedented expansion of particular technologies are involved. The rate of ZEV adoption in California depends largely on new ZEV policy, new ZEV technologies, and changing consumer preferences.

Because our estimates are based on factors that may change between now and 2045, we recommend exploring other scenarios in which California reaches its carbon neutrality goal at a different time. Our same methodology can be used with different inputs to obtain these results. As time passes, comparing actual figures with our forecasted figures will also give insight on how accurate our predictions may be. We can then adjust our numbers to better reflect real-world trends. Finally, California's goal is ambitious, and promoting the widespread adoption of ZEVs is critical to California reaching its carbon neutrality goal. This may come in the form of providing greater incentives for ZEV owners, encouraging automobile manufacturers to innovate, implementing more charging infrastructure, and spreading awareness of the perks of owning a ZEV.

Introduction

This paper is one chapter of a larger report that seeks to outline the workforce implications of transitioning to a zero-emissions vehicle (ZEV) fleet in California by 2045. As the vehicle fleet becomes cleaner and greener, the way consumers, firms, and businesses spend money on transportation will shift, driving changes in employment in fossil fuel vehicle and ZEV-related sectors. The purpose of this paper is to explain the fundamental relationship between how consumers spend their money and consequent changes in the workforce, characterize Californians' current transportation-related spending, and forecast changes in these spending patterns that will drive employment changes across transportation-related supply chains between now and 2045.

Background

California has a goal to be carbon neutral by 2045. Achieving carbon neutrality in California's transportation sector is projected to create over 7.3 million full-time equivalent (FTE) job-years worth of work over the next 25 years, resulting in hundreds of thousands of permanent jobs and the creation of new, billion- or multi-billion-dollar industries (CNS Draft Intro, 2020). This transition will lead to an influx of new jobs in ZEV-related sectors alongside the accompanying decline in jobs in fossil fuel-burning internal combustion engine vehicle (ICEV)-related sectors. In order to assess how employment in these sectors will change between now and 2045, we must examine how consumer expenditures--a key driver of change in the labor market--will vary over time.

Currently, there is very little research on how expenditures may change over the next decades and projections past 2030 simply do not exist. However, we anticipate that overall expenditures will decline as the vehicle fleet becomes greener since ZEVs are generally associated with lower maintenance costs and lower fuel costs. The rates at which ZEV-related industries expand and ICEV-related industries contract will depend largely on our findings.

Research Question

How will expenditures on fossil fuel vehicles and zero emission vehicles in California change between 2020 and 2045?

In organizing our analysis, we assess three key categories of expenditures segmented by four general vehicle classifications. The examined areas of expenditure are:

- ***Vehicle purchase expenditures***, which include vehicle costs spent buying new domestic and imported cars, trucks, and buses.
- ***Fuel expenditures***, which include purchases on gasoline, diesel, and electricity.
- ***Maintenance costs***, which include default maintenance (scheduled) and repair (unscheduled) costs.

We do not anticipate major changes in expenditures in the transportation services supply chain arising from California's ZEV transition. Past decades have shown that public transit agencies, rental fleets, and public fleets remain relatively consistent in their yearly expenditures. Transportation companies that maintain private fleets will take steps to update their vehicle fleets to become more compliant with newly introduced, more stringent emissions guidelines. Such upgrades are reflected in the vehicle numbers provided by the UC Davis Institute of Transportation Studies (ITS) scenario, which envisions California meeting its zero-emissions in the transportation sector goal by 2045. We are not focusing on expenditures in the aviation and maritime industries, as planes and ships are expected to continue relying on fossil fuels into 2045.

The remainder of this paper will take the following form. First, it will examine existing literature regarding the factors that influence changes in consumer spending as well as the cost savings associated with zero emission vehicles. Second, we will explain our methodology in calculating current and future transportation expenditures based on four vehicle categories: light-duty vehicles (LDVs), heavy-duty vehicles (HDVs), medium-duty vehicles (MDVs), and buses. In our analysis, fossil fuel vehicles refer to vehicles that run on gasoline or diesel and zero emission vehicles include both battery electric vehicles and fuel cell electric vehicles. We will characterize expenditure estimates for each of these four vehicle categories for both fossil fuel vehicles and zero emission vehicles in the following sections. Finally, we will discuss our findings and consider how these estimates may be influenced by changes in travel behavior or new policy.

We find that if California achieves its zero-emissions in the transportation sector goal by 2045, California will spend $23.3 billion less across the three key transportation expenditure categories in 2045 compared to 2020, with overall expenditures falling from $175.4 billion to $152.1 billion (a 13.3% drop). All three key expenditure categories will be lower in 2045 than in 2020. Across the next 25 years, new vehicle purchases will remain the largest expenditure category, with fuel costs second, and maintenance costs last. Because our estimates are based on factors that may change between now and 2045, we recommend exploring other scenarios in which California reaches its carbon neutrality goal at a different time.

Literature Review

How Expenditures Shape Employment

Most research supports the notion that U.S. consumer spending and employment are closely tied.[1] When consumers shop, they directly support jobs in firms that produce, transport, and sell goods and services. They also indirectly support jobs that supply the inputs necessary for production of said goods and services.[2] For example, when a consumer purchases a new car, they are supporting not only the jobs of employees at the plant where the vehicle was assembled, but also workers who manufactured the vehicle's component parts and those who produced and refined the raw materials necessary for said parts.

Additionally, large-scale investment in transportation infrastructure has historically generated widespread, second-order economic benefits. In the short-run, building transportation infrastructure creates jobs in construction and supporting occupations.[3] In the long-run, modernized transportation systems offer greater efficiency and reliability, lowering the costs of moving people and goods and buoying economic well-being on a large scale.[4]

Why will transportation-related expenditures change?

Past studies demonstrate that the way that consumers, firms, and governments spend money on transportation-related goods and services is mainly influenced by (1) new ZEV policies, (2) improving ZEV technologies, and (3) changing consumer preferences.

California is a global leader in renewable energy, largely due to its innovative climate change policies. It is the only state authorized by the Clean Air Act (CAA) to adopt motor vehicle emission standards that are more stringent than federal standards (ZEV Task Force, 2018). Transportation is the largest source of the state's greenhouse gas (GHG) emissions -- about 40 percent comes from light-duty vehicles alone.[5] Transportation policy can shape vehicle miles travelled (VMT) and GHG emissions, most obviously by incentivizing zero-emission vehicles.[6]

Increasingly strict ZEV policies designed to move away from reliance on fossil fuels call for improving ZEV technologies. In order to achieve new emissions goals, state agencies must set standards with the cooperation of major automakers who deploy advanced technologies to meet fuel economy requirements. The California Air Resources Board manages the Zero Emission Vehicle (ZEV) program that is a California state regulation that requires automakers to sell a certain percentage of vehicles that use the cleanest available technologies.[7] Transforming the

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[1] Barello, Stephanie Hugie. "Consumer spending and U.S. employment from the 2007-2009 recession through 2022." Monthly Labor Review, U.S. Bureau of Labor Statistics, October 2014. https://doi.org10.21916/mlr.2014.34.
[2] Ibid.
[3] Wachs, Martin. "Transportation, Jobs, and Economic Growth." Access Magazine. 2011. https://www.accessmagazine.org/wp-content/uploads/sites/7/2016/01/access38_transportation_growth.pdf
[4] Ibid.
[5] Chapple, Karen. "Integrating California's Climate Change and aFiscal Goals: The known, the Unknown, and the Possible." California Journal of Politics and policy, 8(2). 2016. https://doi.org/10.5070/P2cjpp8230563
[6] Ibid.
[7] ICCT. "Overview of global zero-emission vehicle mandate programs." 2019. https://theicct.org/sites/default/files/publications/Zero%20Emission%20Vehicle%20Mandate%20Briefing%20v2.pdf

vehicle market will require automakers to continue producing an expanding array of models with longer electric ranges in a variety of price points to meet the different needs and preferences of car owners.[8]

Consumers' knowledge and preferences also impact the vehicle market. The vast majority of consumers have little understanding and many misconceptions about the abilities and advantages of ZEVs, how they operate, and the charging experience.[9] ZEVs represent innovation, and many consumers, especially environmentally active consumers, are predisposed to such innovation.[10] As the market becomes more saturated with ZEVs and consumers learn more about their environmental benefits, attitudes toward ZEVs will become increasingly positive. According to surveys, there is a significant correlation between consumer knowledge of ZEVs and purchasing behavior. The more knowledge one has, the more likely one is to purchase a ZEV.[11]

Will transportation expenditures increase or decrease as the vehicle fleet becomes greener?

In organizing our analysis, we assess three key categories of expenditures segmented by four general vehicle classifications (light-duty vehicles, heavy-duty vehicles, medium-duty vehicles, and buses). The examined areas of expenditure are:

- ***Vehicle purchase expenditures***, which include vehicle costs spent buying new domestic and imported cars, trucks, and buses.
- ***Fuel expenditures***, which include purchases on gasoline, diesel, and electricity.
- ***Maintenance costs***, which include default maintenance (scheduled) and repair (unscheduled) costs.

These definitions are provided by the U.S. Bureau of Labor Statistics.[12]

There is conflicting evidence on whether the total cost of ownership for electric vehicles is greater or lower than that of fossil fuel vehicles. One study that defines cost-of-ownership as purchase price, fuel, maintenance costs, and deprecation found that fossil fuel light-duty vehicles are cheaper to own and operate over the first three years.[13] A different study, which assumes TCO is a representation in dollars of how much owning a vehicle will cost over the lifetime of the vehicle, finds that a battery electric light-duty car is more expensive to own than an equivalent fossil fuel car over a 20-year lifetime.[14]

However, these higher costs may be attributed to high vehicle purchase price. Battery electric vehicles are significantly more expensive to manufacture than comparable ICEVs due primarily

[8] ZEV Task Force. "Multi-State ZEV Action Plan: Accelerating the Adoption of Zero Emission Vehicles." 2018. https://www.nescaum.org/topics/zero-emission-vehicles
[9] Ibid.
[10] Mills, Michael. "Environmentally-Active Consumers' Preferences for Zero Emission Vehicles: Public Sector and Marketing Implications." Public Sector and Marketing Implications, Journal of Nonprofit & Public Sector Marketing. 2008. https://www.tandfonline.com/doi/abs/10.1300/J054v19n01_01
[11] ZEV Task Force. 2018.
[12] US Bureau of Labor Statistics. "Consumer Expenditure Surveys. 2015. https://www.bls.gov/cex/csxgloss.htm
[13] Baldwin. "EV vs. Gas: Which Cars Are Cheaper to Own?" 2020. https://www.caranddriver.com/shopping-advice/a32494027/ev-vs-gas-cheaper-to-own/
[14] Brennan, John W., and Barder, Timothy E. "Battery Electric Vehicles vs. Internal Combustion Engine Vehicles." Arthur D. Little. 2016. https://www.adlittle.de/sites/default/files/viewpoints/ADL_BEVs_vs_ICEVs_FINAL_November_292016.pdf

to the cost of battery manufacturing.[15] The resulting cost burden acts as a significant barrier for wider adoption of BEVs. If battery costs were to decline, BEVs could become much less costly to own and maintain. The electricity costs associated with operating a BEV is significantly lower than the gasoline cost required to operate a comparable fossil fuel vehicle over the same distance.[16] In addition, maintenance costs for BEVs are typically lower than that of fossil fuel vehicles.[17]

A study by the International Council on Clean Transportation assesses battery electric vehicle costs in the 2020-2030 timeframe, comparing costs for fossil fuel and electric cars. The study forecasts that the purchase prices for fossil fuel cars will remain relatively constant around $31,000, but the purchase price for electric vehicles will fall considerably from about $43,000 in 2020 to $28,000 in 2030.[18] The study states that vehicle purchase price is the most important factor affecting the relative costs of the technologies, but fuel savings are second.[19] ICCT looks at fuel costs in 2025. In 2025, the first-owner fuel cost for an average new car buyer is $5,400 for gasoline, compared to about $1,800-$2,000 in electricity for electric vehicles.[20] The study does not give annual or lifetime maintenance costs but provides maintenance costs per mile. For fossil fuel cars, maintenance costs are assumed to be $0.061 per mile, compared to $0.026 per mile for electric cars.[21]

There are very few existing studies on the effects of a ZEV transition of medium and heavy-duty vehicle fleets. ICF released a first-of-kind comprehensive study assessing the environmental and economic benefits of alternative fuel truck technologies, specifically in California[22]. ICF calculates the total cost of ownership as the cumulative cost to the first owner of a vehicle, including vehicle capital, operation and maintenance, and any necessary infrastructure, minus incentives and regulatory requirements. The study demonstrates that electric trucks and buses are the least costly to own and operate across almost all truck and bus classes by 2030. They also emit the least pollution and are most environmentally friendly. ICF also notes that costs for electric trucks and buses are falling due to the rapidly declining cost of batteries. From now to 2030, purchase prices for electric trucks will become increasingly comparable to that of diesel trucks. By 2030, maintenance costs for electric trucks will be 50 percent lower than maintenance costs for diesel trucks. There is limited literature on how these expenditures will evolve from now until 2045, as most studies thus far have no extrapolated data beyond 2030.

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15 Ibid.
16 Ibid.
17 Ibid.
18 ICCT. "Overview of global zero-emission vehicle mandate programs." 2019. https://theicct.org/sites/default/files/publications/Zero%20Emission%20Vehicle%20Mandate%20Briefing%20v2.pdf
19 Ibid.
20 Ibid.
21 Ibid.
22 ICF International. "Comparison of Medium- and Heavy-Duty Technologies in California." ICF International. December 11, 2019. https://caletc.com/wp-content/uploads/2019/12/ICF-Truck-Report_Final_December-2019.pdf

Data Use and Methodology

Data Use

In order to characterize the current and future levels of expenditures on fossil-based fuels and vehicles and zero-emissions fuels and vehicles, we relied primarily on data from the UC Davis Institute of Transportation Studies (UCD ITS). Researchers at UCD ITS have forecasted a low-carbon trajectory consistent with California meeting its emissions-reduction goals for the transportation sector. We will refer to this trajectory as the CNS LC1 (Carbon Neutral Scenario Low Carbon 1) from this point forward. The CNS LC1 scenario illustrates a potential breakdown for how Californians will purchase vehicles from 2020 to 2050. Our current and projected fuel prices out to 2030 come from the California Energy Commission (CEC) and are extrapolated based on forecasted trends to 2045. Our maintenance costs for light-duty vehicles are derived from data published by the International Council on Clean Transportation (ICCT)[23], while maintenance costs for trucks and buses rely on information published by ICF International[24] as well as estimates from UCD ITS. All future expenditure projections are in 2020 dollars.

Methodology

We will characterize expenditure estimates—vehicle purchase expenditures, fuel expenditures, and maintenance expenditures —for each of these four vehicle categories for both fossil fuel vehicles and zero emission vehicles. In our analysis, fossil fuel vehicles refer to vehicles that run on gasoline or diesel and zero emission vehicles include both battery electric vehicles and fuel cell electric vehicles. These estimates are based on a weighted average that directly reflects the composition of the on-road fleet (Appendix A).

Our four general vehicle categories are outlined below, with information regarding inclusion of EMFAC Vehicle Types available in Table A:

- ***Light-duty vehicles (LDVs)*** - LDVs include all passenger cars and light-duty trucks. Passenger cars are classified as all sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers, and includes passenger cars pulling recreational or other light trailers. Light-duty trucks are four-wheel, two-axle vehicles that can be used for cargo transport, but are used primarily for passenger transport.
- ***Heavy-duty Vehicles (HDVs)*** - HDVs include long haul trucks, short haul trucks, and heavy-duty vocational trucks. Long haul trucks are Class 7-8 tractor trailers that do not typically return to base for refueling and have very high vehicle miles travelled (VMT). Short haul trucks are Class 7-8 tractor trailers that typically return to base for refueling and have moderate VMT. Heavy-duty vocational trucks are heavy duty trucks that use power take-off (PTO), such as refuse trucks.

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[23] Lutsey, Nic, and Michael Nicholas. "Update on Electric Vehicle Costs in the United States through 2030." The International Council on Clean Transportation, April 2, 2019. https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf.

[24] ICF International. "Comparison of Medium- and Heavy-Duty Technologies in California." ICF International. December 11, 2019. https://caletc.com/wp-content/uploads/2019/12/ICF-Truck-Report_Final_December-2019.pdf

- ***Medium-duty Vehicles (MDVs)*** - MDVs include medium-duty vocational trucks, medium-duty urban trucks, and heavy-duty pickup trucks. Medium-duty vocational trucks are medium-duty trucks that use PTO (e.g. utility bucket trucks). Medium-duty urban trucks are medium-duty delivery trucks used primarily for cargo transport (e.g. step vans, box trucks). Heavy-duty pickup trucks are Class 2b-3 trucks (light/medium trucks under 14,000 pounds).
- ***Buses*** - Buses include transit buses and other bus types. A transit bus is a passenger vehicle with a capacity of 15 or more persons primarily used for transport within cities.

Table A. Vehicle Categorization delineated by EMFAC2007 Vehicle Type

Category	Description	EMFAC2007 Vehicle Type
Light-Duty Vehicles (LDV)	Passenger cars Light trucks	*LDA* *LDT1* *LDT2* *MDV*
Heavy-Duty Vehicles (HDV)	Long haul trucks Short haul trucks Heavy-duty vocational trucks	*T7 CAIRP* *T7 Tractor* *T7NNOOS* *T7 Ag* *T7 CAIRP Construction* *T7 Other port* *T7 POAK* *T7 POLA* *T7 Tractor Construction* *T7 Public* *T7 Single* *T7 Single Construction* *T7 SWCV*
Medium-Duty Vehicles (MDV)	Medium-duty vocational trucks Medium-duty urban trucks (delivery) Heavy-duty pickup trucks	*T6 Public* *T6 Utility* *T6 Ag* *T6 CAIRP Heavy* *T6 CAIRP Small* *T6 Instate Construction Heavy* *T6 Instate Construction Small* *T6 Instate Heavy* *T6 Instate SMall* *T6 OOS* *T6 OOS Small* *T6TS* *LHD1* *LHD2*
Buses	Transit buses Other buses	*SBUS* *UBUS* *OBUS*

We will now define each type of expenditure and explain the steps we took to calculate current and future expenditures.

Vehicle Purchase Expenditures

Vehicle purchase expenditures are the costs spent buying new cars, trucks, and buses. Used vehicles are omitted from our data because the new vehicle market is more relevant to production and workforce changes.

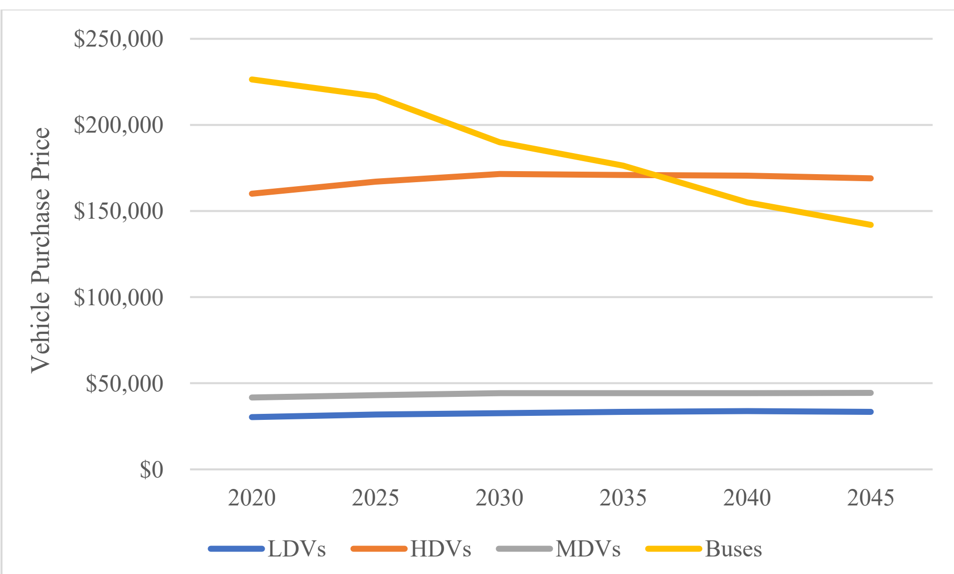
Forecasted New Vehicle Sales Data

To calculate new vehicle purchase expenditures, we multiplied the purchase price for an average vehicle in its class by the number of new vehicles purchased. We rely on purchase price estimates and sales figures provided by the CNS LC1 scenario.

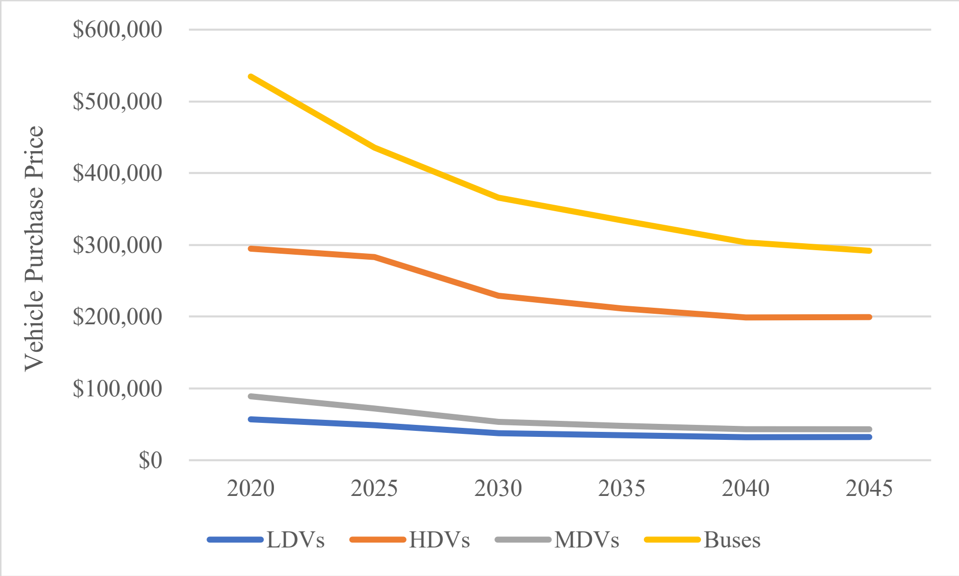
We estimate that the purchase price of fossil fuel vehicles will remain relatively constant over time (Figure A). While ZEVs are currently more expensive than fossil fuel vehicles, the purchase price of ZEVs is expected to decline over time and become comparable to that of fossil fuel vehicles. It should be noted that the purchase price of electric buses is consistently much higher than that of fossil fuel buses, but thus far this has not appeared to significantly hinder purchasing of electric buses (see Appendix D).

Figure A. Purchase prices of new vehicles in California by fuel type in 2020 US Dollars by 5-year increments, 2020-2045.

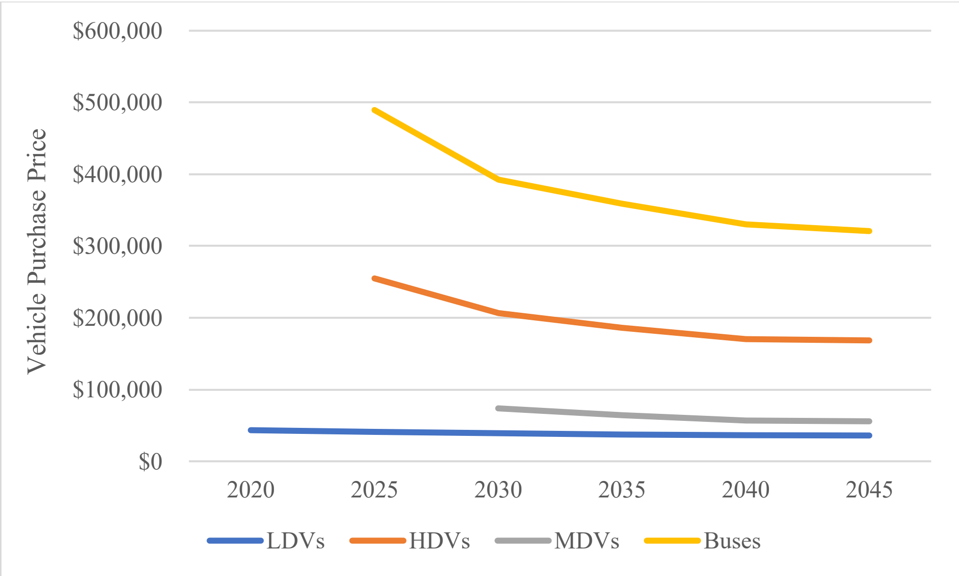
Fossil Fuel Vehicles



Battery Electric Vehicles

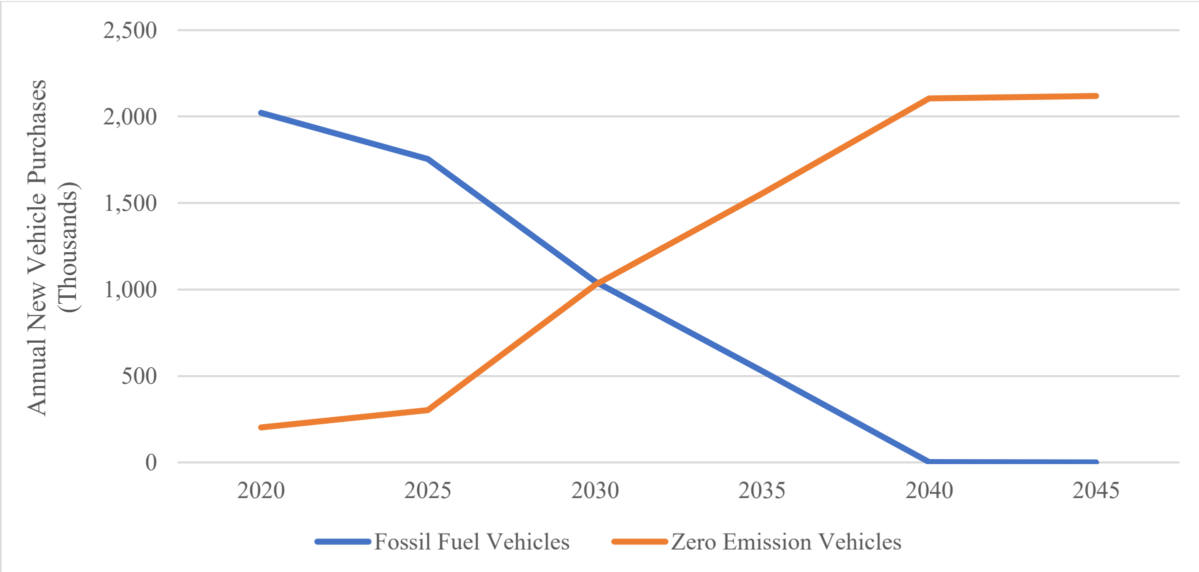


Fuel Cell Electric Vehicles



In Figure B, we provide estimates for the number of vehicles purchased from now to 2045. Unsurprisingly, fossil fuel vehicles currently account for an overwhelming majority of total new vehicles purchased. However, the sales of new fossil fuel vehicles will cease by 2045 while the sales of new zero-emission vehicles will continue to climb. As the total number of vehicles on the road (Appendix B) is not expected to fluctuate drastically over time, total vehicle purchase expenditures therefore also stay relatively level.

Figure B. Number of new fossil fuel and zero-emission vehicles purchased annually in California in thousands by 5-year increments, 2020-2045. For a breakdown of ZEVs by drivetrain technology, see Appendix D.



Fuel Expenditures

Fuel expenditures are spent on gasoline and other fuels. In this report, we will be focusing on gasoline, diesel, electricity, and hydrogen.

Forecasted Fuel Cost Data

We obtained our fuel expenditure estimates by multiplying the on-road fleet by average annual fuel cost per vehicle. For on-road fleet numbers, we used estimates from the CNS LC1 scenario (Appendix B). To find average fuel cost per vehicle, we multiplied fuel price (Appendix F) by annual vehicle miles traveled (Appendix G), then divided by fuel efficiency (Appendix H).

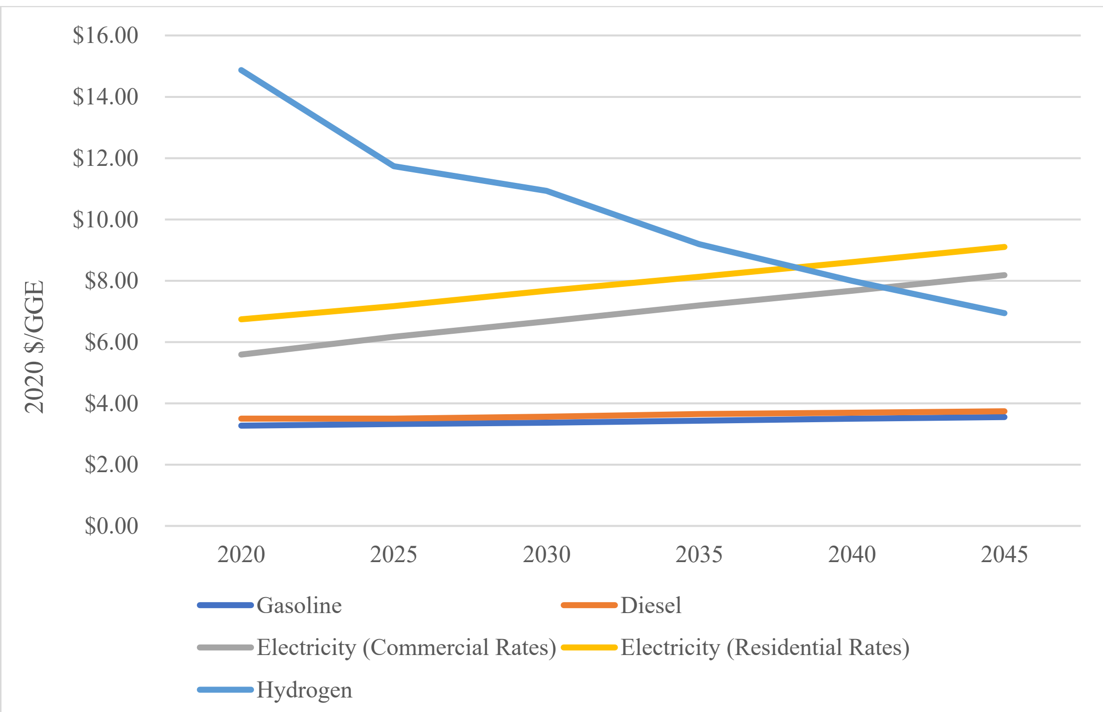
The fuel price forecasts for gasoline, diesel, electricity, and hydrogen out to 2030 come from the mid-demand scenario projections of the California Energy Commission (CEC). To estimate fuel costs for gasoline, diesel, and electricity through 2045, we used linear best fit calculations based on forecasted trends while removing certain outlier years (see Appendix F). To estimate fuel costs for hydrogen, we used a best fit exponential curve that reflects a trend of lowering costs at a diminishing rate.

Electricity prices are given as dollars per gallon of gasoline equivalent (GGE). GGE is a standardized fuel efficiency unit used to compare the energy content of all fuels and is the amount of a given fuel type with energy content equal to the energy contained in one gallon of gasoline. The CEC used the conversion factor of 1 GGE = 32.1764 kWh, consistent with the California Air Resources Board's (CARB) Low Carbon Fuel Standard (LCFS) regulations.

Hydrogen prices are also given as dollar per gasoline gallon equivalent (GGE). As fuel consumption figures for hydrogen are provided in kg, we convert these to GGE using the CARB LCFS conversion factor of 1 GGE = 0.96525 kg.

For fossil fuel vehicles, we use the cost of gasoline in our calculations for LDVs, and the cost of diesel for that of HDVs, MDVs, and buses. These assignments reflect the primary fuel type for these vehicle categories. For electric vehicles, we applied the residential rate of electricity to calculations for LDVs, and the commercial rate of electricity to that of HDVs, MDVs, and buses. This reflects the fact that, historically, a large majority of LDV electric vehicle charging occurs at residences, while non-LDVs are likely to charge predominantly at either public commercial or private fleet-owned stations. Figure C illustrates our estimated fuel prices through 2045. All prices are in 2020 US dollars.

Figure C. Fuel price estimates in California by type over 5-year increments in 2020 $/GGE, 2020-2045.



For annual vehicles miles travelled, we assumed a vehicle lifetime of ten years. We took the average of VMT estimates for vehicles age 0 to age 9 from the CNS LC1 scenario (Appendix G). Our fuel efficiency estimates come from the same source (Appendix H).

Maintenance Expenditures

Maintenance costs include default maintenance (scheduled) and repair (unscheduled) costs. Maintenance and repairs cover a number of distinct parts and services, detailed in Table B.

Table B. Services Included in Maintenance Costs

• Tires • Tubes • Lubrication • Filters • Coolant • Additives • Brake and transmission fluids • Oil change • Tire repair • Audio equipment	• Brake work including adjustment • Front-end alignment • Wheel balancing • Steering repair • Shock absorber replacement • Clutch and transmission repair • Drive shaft and rear-end repair	• Electrical system repair • Exhaust system repair • Body work and painting • Motor repair • Repair to cooling system • Drive train repair • Other maintenance and services • Auto repair policies

**Battery replacement costs for electric vehicles are not included because reliable data for replacement vehicles and expected costs are not available at this time.*

Forecasted Maintenance Cost Data

We calculated maintenance cost estimates by multiplying vehicle miles traveled, maintenance cost per mile, and on-road fleet vehicle totals. Vehicle miles traveled estimates and on-road fleet estimates came from the CNS LC1 scenario (Appendices H and B). We adopted the vehicle maintenance costs for trucks (HDVs and MDVs) and buses from “Comparison of Medium- and Heavy-Duty Technologies in California” published by ICF[25] and the CNS LC1 scenario. Some maintenance costs for trucks were estimated using formulas within the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool developed by Argonne National Laboratory (ANL). For maintenance costs for LDVs, we relied on estimates from “Update on Electric Vehicle Costs in the United States through 2030” published by ICCT.[26] A more detailed methodology concerning the data sources for each vehicle type can be seen in Appendix F.

[25] ICF International. “Comparison of Medium- and Heavy-Duty Technologies in California.” ICF International. December 11, 2019. https://caletc.com/wp-content/uploads/2019/12/ICF-Truck-Report_Final_December-2019.pdf

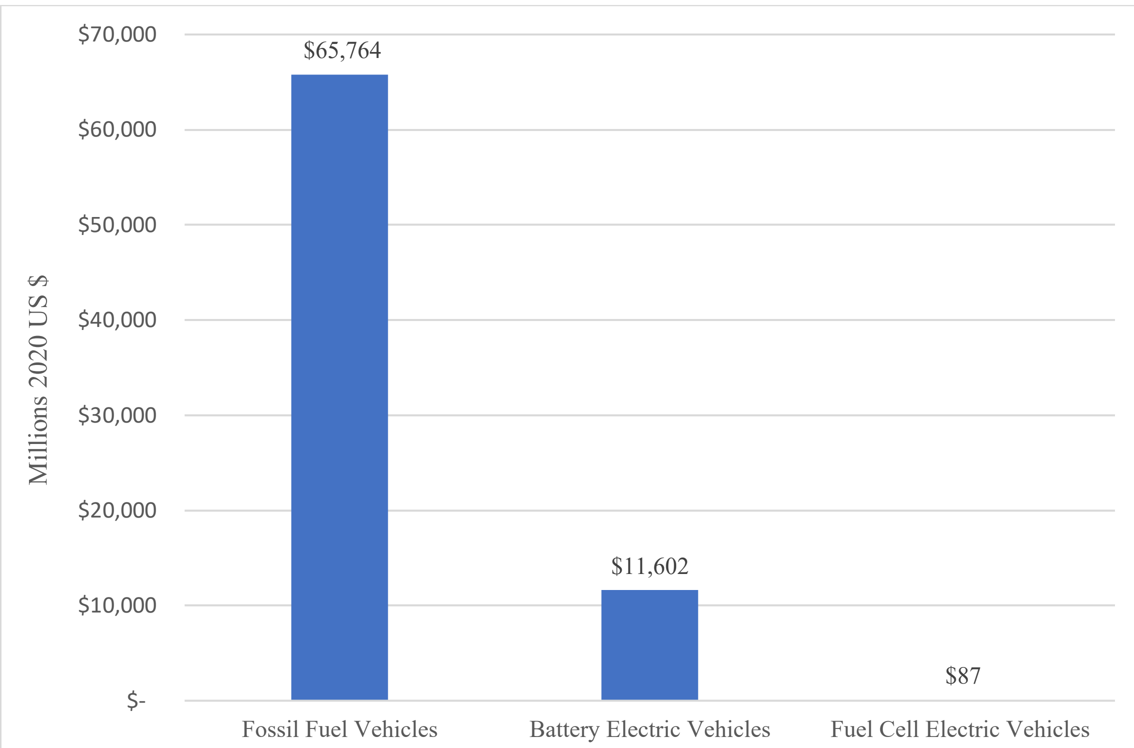
[26] Lutsey, Nic, and Michael Nicholas. “Update on Electric Vehicle Costs in the United States through 2030.” The International Council on Clean Transportation, April 2, 2019. https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf.

Findings

Baseline New Vehicle Purchase Expenditures

We estimate that total vehicle purchase expenditures in 2020 will be approximately $77.2 billion. Currently, a significant majority of vehicle purchase expenditures — $65.7 billion — are on fossil fuel vehicles (Figure C). Electric vehicles make up a substantially smaller portion ($11.3 billion), while fuel cell electric vehicles only account for $87 million of the total. There are no purchase expenditures on fuel cell trucks and buses, only LDVs. This aligns with our estimates for the number of vehicles purchased, as fossil fuel vehicles account for most of the vehicle sales in 2020.

Figure C. New vehicle purchase expenditures in California by fuel type in millions of 2020 US dollars, 2020.



Projected New Vehicle Purchase Expenditures

Key Takeaways:

- Total annual new vehicle purchase expenditures drop $1.4 billion from $77.5 to $75.8 billion between 2020 and 2045.
- Purchases on new fossil fuel vehicles drop from $65.8 billion in 2020 to $0 in 2045.
- Purchases on new zero emission vehicles will rise by $64.1 billion between now and 2045, reaching $75.8 billion in 2045.

Between 2020 and 2045, total new vehicle purchases will remain relatively constant in the mid- to high- $70 billion range (Figure D). However, the portion of those purchases made up of fossil fuel vehicles versus ZEVs changes dramatically over time. The sale of new fossil fuel vehicles will steadily decline each year, with no new sales of new fossil fuel LDVs and buses by 2040 (Table B). By 2045, all new vehicles sold will be zero emission vehicles, creating a major, commensurate shift in new vehicle expenditures. The overall magnitude of vehicle purchase expenditures will fall by around $1.4 billion between now and 2045.

Figure D. Total annual new vehicle purchase expenditures in California by fuel type over 5-year increments in billions of 2020 US dollars, 2020-2045. Fossil fuel vehicle sales in 2040, while not 0, constitute such a small portion that they are nearly invisible in this graph.

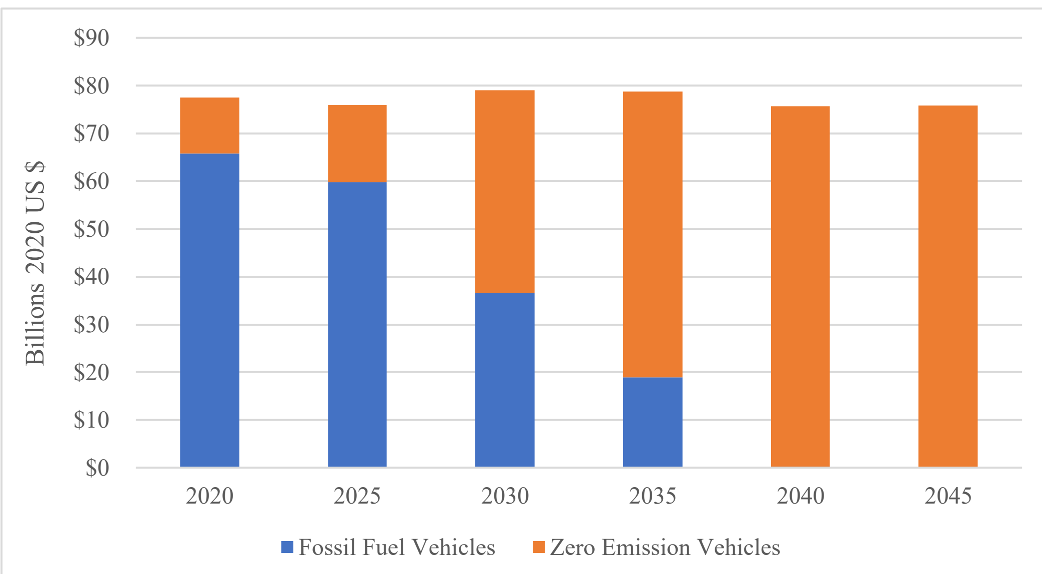


Table B. Annual new vehicle purchase expenditures in California by vehicle category and fuel type over 5-year increments in millions of 2020 US dollars, 2020-2045.

	2020		2025		2030		2035		2040		2045	
	FFV	ZEV	FFV	ZEV	FFV	ZEV	FFV	ZEV	FFV	ZEV	FFV	ZEV
LDVs	$57,811	$11,449	$52,542	$14,069	$31,825	$36,644	$16,248	$51,583	$0	$64,485	$0	$64,437
HDVs	$3,346	$9	$3,111	$498	$2,106	$1,761	$1,045	$2,908	$101	$3,878	$0	$3,998
MDVs	$3,880	$9	$3,679	$618	$2,574	$2,297	$1,514	$3,566	$100	$5,323	$0	$5,552
Buses	$727	$71	$494	$1,002	$190	$1,689	$92	$1,771	$0	$1,814	$0	$1,807
Total by Fuel Type	$65,764	$11,689	$59,826	$16,187	$36,696	$42,390	$18,898	$59,829	$$201	$75,500	$0	$75,793
Total Overall *	$77,452,314,250		$76,013,120,510		$79,086,178,000		$78,727,408,780		$75,701,040,600		$75,793,489,360	

**These figures are totals based on non-rounded, underlying estimates. Other reported numbers are rounded to the nearest million. Any discrepancies between totals and figures in table are a result of rounding error. For all detailed figures, see Appendix E.*

Intuitively, relative distribution of expenditures across vehicle categories and technologies resemble those of vehicles purchased. If we consider the breakdown of fossil fuel vehicles into our four vehicle categories, a significant majority of vehicle purchase expenditures are on LDVs, followed by MDVs, HDVs, and buses (Figure E). This follows for zero emission vehicles (Figure F).

Figure E. Annual new vehicle purchase expenditures for fossil fuel vehicles in California by vehicle category over 5-year increments in billions of 2020 US dollars, 2020-2045.

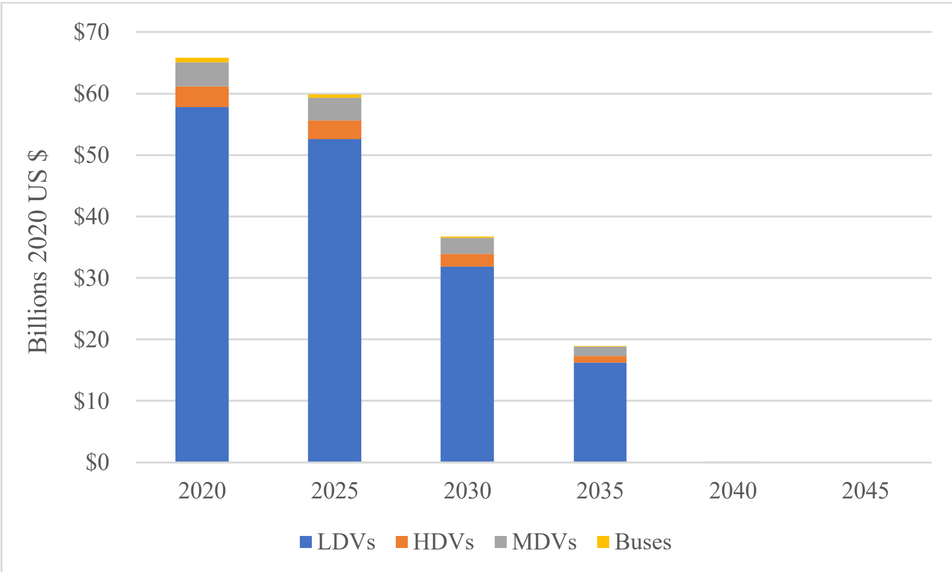
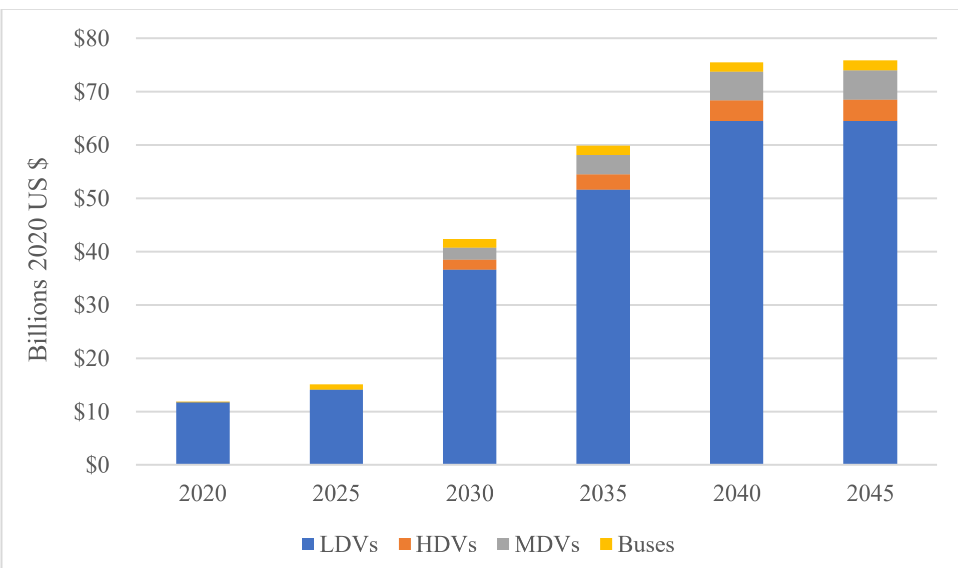


Figure F. Annual new vehicle purchase expenditures for zero emission vehicles in California by vehicle category over 5-year increments in billions of 2020 US dollars, 2020-2045.



For zero emission vehicles, the vast majority of ZEV vehicle purchase expenditures are on battery electric vehicles. Currently, there are no sales of fuel cell trucks and buses. Over the next 25 years, however, a growing amount of purchase expenditures will be made on these vehicles (Table C). While the number of battery electric LDVs purchased will continue to dwarf that of fuel cell electric LDVs, vehicle purchase expenditures on fuel cell electric HDVs will rise to surpass expenditures on battery electric HDVs.

Table C. Annual new vehicle purchase expenditures in California for zero emission vehicles by technology type over 5-year increments in millions of 2020 US dollars, 2020-2045.

	2020		2025		2030		2035		2040		2045	
	BEV	FCEV	BEV	FCEV	BEV	FCEV	BEV	FCEV	BEV	FCEV	BEV	FCEV
LDVs	$11,513	$87	$13,242	$827	$33,681	$2,963	$46,275	$5,309	$57,594	$6,891	$56,718	$7,719
HDVs	$9	$0	$394	$104	$1,170	$590	$1,734	$1,174	$1,926	$1,953	$1,856	$2,143
MDVs	$9	$0	$618	$0	$1,549	$748	$2,410	$1,156	$3,626	$1,697	$3,757	$1,794
Buses	$71	$0	$836	$166	$1,332	$357	$1,398	$373	$1,438	$376	$1,415	$391
Total by Fuel Type	$11,602	$87	$15,090	$1,098	$37,732	$4,659	$51,817	$8,012	$64,584	$10,916	$63,746	$12,047
Total Overall*	$11,688,578,580		$16,187,143,530		$42,390,413,420		$59,828,909,220		$75,500,143,100		$75,793,489,360	

**These figures are totals based on non-rounded, underlying estimates. Other reported numbers are rounded to the nearest million. Any discrepancies between totals and figures in table are a result of rounding error. For all detailed figures, see Appendix E.*

If we compare vehicle purchase expenditures from 2020 and 2045, we see the total amount spent on new vehicles is relatively equal -- just $1.4 billion lower in 2045, a 2.1% decrease (Table D). This is expected since the total number of vehicles purchased will not fluctuate greatly over time (Appendix D). The greatest disparity between the two years is found in the composition of vehicle fuel types. In 2020, zero emission vehicles account for roughly 14.8% of the total (Table B). In 2045, they account for 100%.

Table D. New vehicle purchase expenditures in California comparison between 2020 and 2045 in 2020 US dollars.

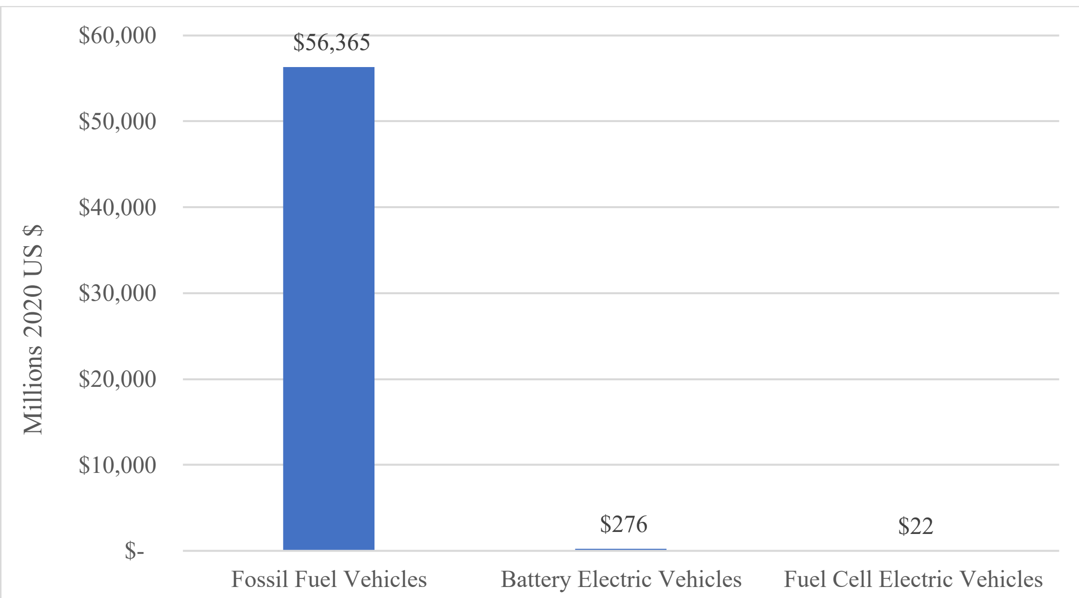
Vehicle Fuel Type	2020	2045	Difference	Percent Change
Fossil Fuel Vehicles	$65,763,735,670	$0	-$65,763,735,670	100% decrease
Zero Emission Vehicles	$11,688,578,580	$75,793,489,360	+$64,104,910,780	548.4% increase
Total Overall	$77,452,314,250	$75,793,489,360	-$1,658,824,890	2.1% decrease

Baseline Fuel Expenditures

California currently spends approximately $56.7 billion on transportation-related fuel costs (Figure H). Fossil fuels make up nearly $56.4 billion of this total and are easily the largest category. Electricity for BEVs is the next largest, though far behind at $272 million, and only $22 million is currently spent annually on hydrogen for FCEVs.

When current fuel expenditures are examined by vehicle category, fossil fuel vehicles have much higher fuel expenditures than ZEVs do (Table E). Again, this is expected due to the low number of ZEVs currently on the road (see Appendix B). Fossil fuel LDVs accrue the vast majority of total fuel expenditures – approximately 72 percent. Among fossil fuel vehicles, fuel expenditures are highest for LDVs, followed by HDVs, MDVs, and finally buses. For electric vehicles, fuel expenditures are also highest for LDVs, but are second highest for buses, then MDVs, and lastly, HDVs.

Figure H. Transportation fuel expenditures in California by fuel type in millions of 2020 US dollars, 2020.



Projected Fuel Expenditures

Key Takeaways:

- Total overall fuel expenditures in 2045 are projected to be over $13.1 billion lower than current fuel expenditures, dropping from $56.7 billion in 2020 to $43.5 billion in 2045.
- Fuel expenditures for fossil fuel vehicles are expected to drop $42.1 billion to $14.2 billion between now and 2045.
- Fuel expenditures for zero emission vehicles are expected to increase by $29 billion to nearly $29.3 billion between now and 2045.

Overall total fuel expenditures are expected to substantially decrease by 2045 (Figure H). This decline in total overall fuel expenditures is expected, given the greater proportion of zero emission vehicles in the on-road fleet (Appendix B) and the fuel efficiency advantages such vehicles offer (Appendix H). Although electricity and hydrogen prices per GGE are higher than gasoline and diesel prices, these efficiency increases mean electric vehicle owners will spend less on fuel than fossil fuel owners to travel the same distances. Extrapolating therefrom, a vehicle fleet with more electric vehicles and fewer fossil fuel vehicles will drive total fuel expenditures down. Trends towards greater vehicle fuel efficiency overall -- for both fossil fuel and electric vehicles -- will also contribute to lower overall fuel costs.

Over time, ZEVs will make up an increasingly large proportion of fuel expenditures, while fuel expenditures for fossil fuel vehicles will decrease (Figure I). By 2045, the majority of fuel expenditures will be made to supply electric vehicles. LDVs consistently make up the majority of fuel expenditures for both fossil fuel vehicles and ZEVs (Table E, Figures J and K). HDVs are the second most costly vehicle category, followed by MDVs, and then buses. This holds true from now to 2045.

Figure I. Total annual fuel expenditures in California by fuel type over 5-year increments in billions of 2020 US dollars, 2020-2045.

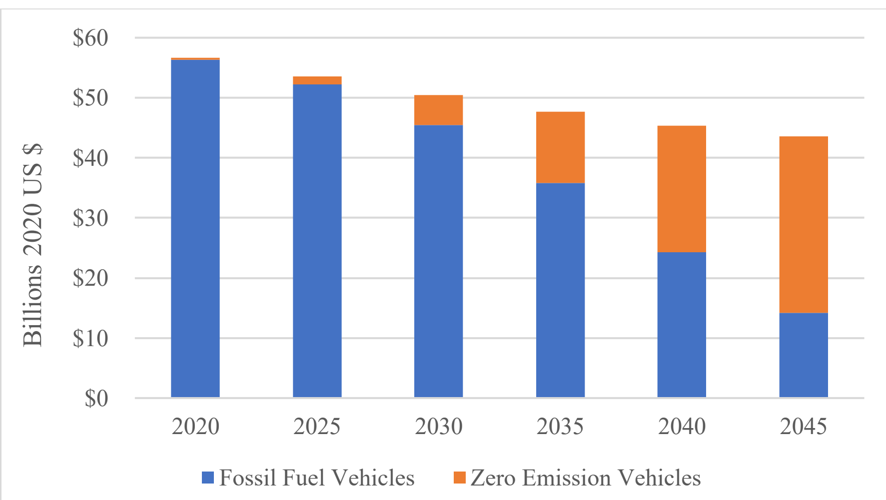


Table E. Annual fuel expenditures in California by vehicle category and fuel type over 5-year increments in millions of 2020 US dollars, 2020-2045.

	2020		2025		2030		2035		2040		2045	
	FFV	ZEV	FFV	ZEV	FFV	ZEV	FFV	ZEV	FFV	ZEV	FFV	ZEV
LDVs	$40,895	$288	$39,399	$994	$33,824	$3,414	$26,607	$8,105	$18,182	$14,287	$10,912	$20,218
HDVs	$10,092	$.162	$8,706	$142	$7,869	$991	$6,122	$2,549	$3,991	$4,673	$2,199	$6,259
MDVs	$4,662	$.450	$3,603	$42	$3,390	$319	$2,831	$837	$1,901	$1,525	$1,040	$2,161
Buses	$716	$9	$541	$81	$413	$268	$301	$428	$177	$589	$77	$676
Total by Fuel Type	$56,365	$298	$52,248	$1,259	$45,496	$4,991	$35,862	$11,829	$24,251	$21,075	$14,227	$29,314
Total Overall*	$56,663,170,231		$53,506,728,518		$50,487,271,942		$47,690,342,234		$45,325,548,460		$43,541,764,337	

**These figures are totals based on non-rounded, underlying estimates. Other reported numbers are rounded to the nearest million. Any discrepancies between totals and figures in table are a result of rounding error. For all detailed figures, see Appendix J.*

Figure J. Annual fuel expenditures for fossil fuel vehicles in California by vehicle category over 5-year increments in billions of 2020 US dollars, 2020-2045.

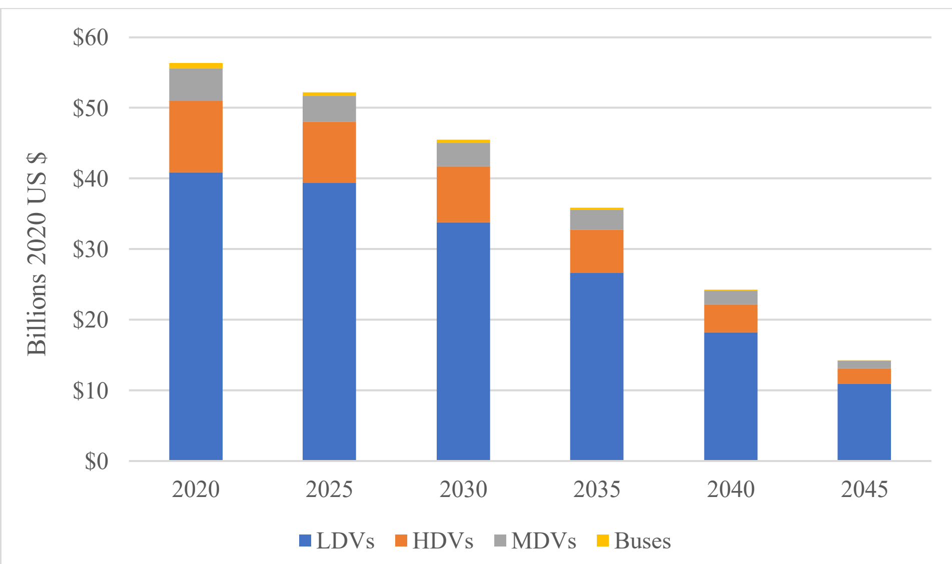
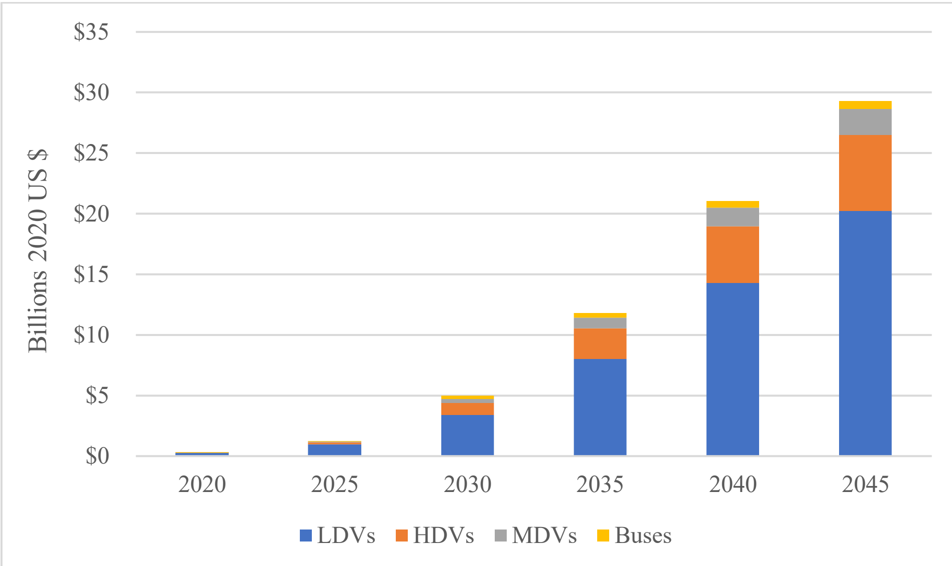


Figure K. Annual fuel expenditures for zero emission vehicles in California by vehicle category over 5-year increments in billions of 2020 US dollars, 2020-2045.



For zero emission vehicles, battery electric vehicles make up a greater portion of fuel expenditures (Table F). However, fuel expenditures on fuel cell electric vehicles will increase steadily to make up approximately half of total fuel expenditures for ZEVs. For battery electric vehicles, LDVs will remain the largest category by far. For fuel cell electric vehicles, trucks and buses make up a much larger portion of fuel costs than they do for BEVs. In particular, HDVs will be the largest category for fuel cell electric vehicles by 2035.

Table F. Annual fuel expenditures in California for zero emission vehicles by technology type over 5-year increments in millions of 2020 US dollars, 2020-2045.

	2020		2025		2030		2035		2040		2045	
	BEV	FCEV	BEV	FCEV	BEV	FCEV	BEV	FCEV	BEV	FCEV	BEV	FCEV
LDVs	$266	$22	$809	$186	$2,586	$828	$6,157	$1,858	$11,335	$2,952	$16,491	$3,727
HDVs	$.163	$0	$516	$91	$262	$729	$635	$1,914	$1,096	$3,577	$1,462	$4,797
MDVs	$.450	$0	$42	$0	$199	$120	$517	$320	$990	$535	$1,483	$678
Buses	$9	$0	$57	$24	$171	$96	$306	$122	$428	$161	$521	$155
Total by Fuel Type	$276	$22	$957	$301	$3,218	$1,773	$7,615	$4,213	$13,848	$7,226	$19,957	$9,357
Total Overall*	$297,811,568		$1,258,559,737		$4,991,356,876		$11,828,643,185		$21,074,530,116		$29,314,323,945	

**These figures are totals based on non-rounded, underlying estimates. Other reported numbers are rounded to the nearest million. Any discrepancies between totals and figures in table are a result of rounding error. For all detailed figures, see Appendix J.*

Looking more closely at changes in fuel expenditures between 2020 and 2045, we see a substantial – 23.2 percent – decrease in overall fuel expenditures (Table G). Whereas zero emission vehicles only account for a tiny fraction of total fuel expenditures in 2020, they make up approximately two-thirds of total fuel costs in 2045.

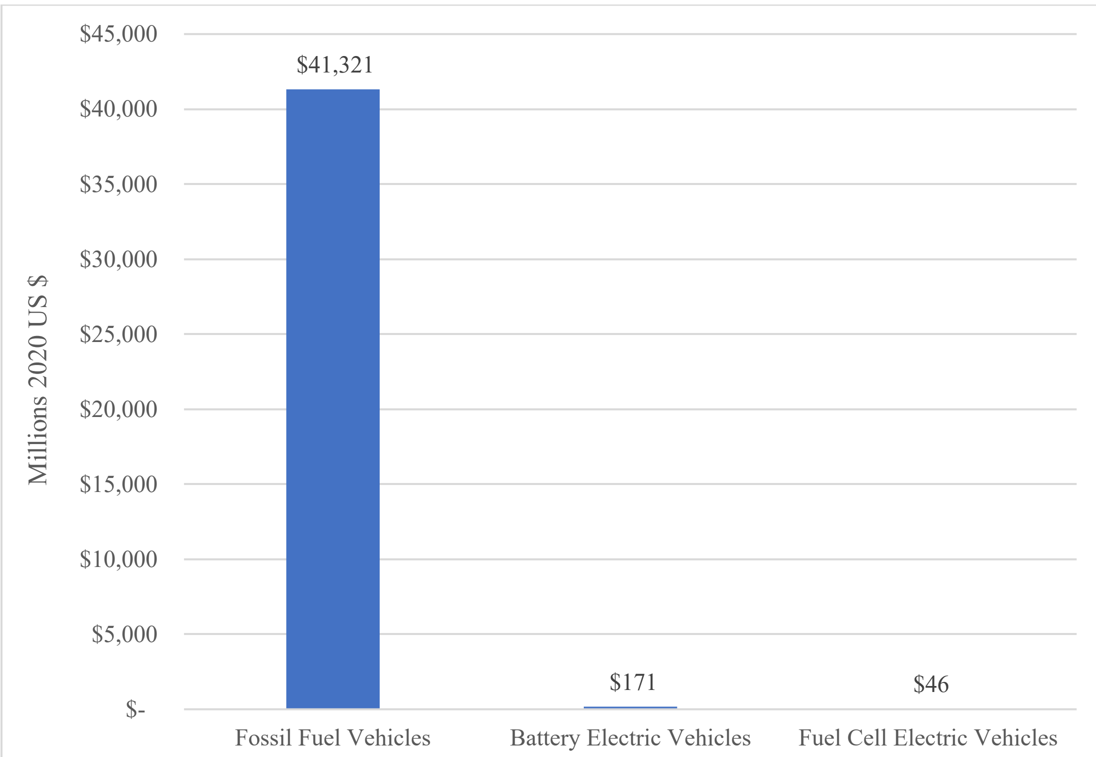
Table G. Fuel expenditures in California comparison between 2020 and 2045 in 2020 US dollars.

Vehicle Fuel Type	2020	2045	Difference	Percent Change
Fossil Fuel Vehicles	$56,365,358,663	$14,227,440,391	-$42,137,918,271	74.8% decrease
Zero Emission Vehicles	$297,811,568	$29,314,323,945	+$29,016,512,377	9743,3% increase
Total Overall	$56,663,170,231	$43,541,764,337	-$13,121,405,894	23.2% decrease

Baseline Maintenance Expenditures

We estimate that total maintenance expenditures in California in 2020 will be approximately $41.5 billion. Fossil fuel vehicles make up a significant majority of these expenditures -- $41.3 billion (Figure L). Battery electric vehicles are the next largest category, far behind at $171 million. Fuel cell electric vehicles currently only account for $46 million, less than 1 percent of total maintenance expenditures.

Figure L. Maintenance expenditures in California by fuel type in millions of 2020 US dollars, 2020.



For both fossil fuel vehicles and ZEVs, LDVs make up the greatest proportion of maintenance expenditures (Table I). The primary driver of this is the sheer size of the LDV fleet compared to other vehicle categories. For fossil fuel vehicles, MDVs have the second highest expenditure total, followed by HDVs and then buses. This corresponds to the composition of the on-road fleet (see Appendix A). For electric vehicles, buses have the next highest expenditure total, with MDVs third and HDVs last. Again, this aligns with the numbers of each type of vehicle currently on the road.

Projected Maintenance Expenditures

Key Takeaways:

- Total maintenance costs in 2045 will be $19.2 billion lower than current maintenance costs, decreasing from $41.5 billion to $32.8 billion.
- ZEV maintenance costs will make up over half of overall maintenance costs by 2045.
- From 2020 to 2045, maintenance costs for fossil fuel vehicles will fall $28.5 billion to $12.8 billion.
- From 2020 to 2045, maintenance costs for zero emission vehicles will increase nearly $12.2 billion to $12.3 billion.

Total maintenance expenditures are expected to decline substantially between 2020 and 2045 (Figure M). Zero emission vehicles will account for an increasingly large portion of total maintenance expenditures each year. By 2045, the majority of overall maintenance expenditures will come from zero emission vehicles. It is expected that total maintenance expenditures will fall because zero emission vehicles are typically cheaper to maintain. As the vehicle fleet becomes increasingly green, more cars will have lower maintenance costs, contributing to a lower total.

The breakdown of maintenance expenditures into the four major vehicle categories illustrates that for both fossil fuel vehicles and zero emission vehicles, LDVs amass the highest costs by far, followed by MDVs, HDVs, and then buses (Table I, Figures N and O). This aligns with the number of vehicle types on the road (Appendix B). By 2045, expenditures on zero emission vehicles will surpass that of fossil fuel vehicles for each of the four vehicle categories.

Figure M. Total annual maintenance expenditures in California by fuel type over 5-year increments in billions of 2020 US dollars, 2020-2045.

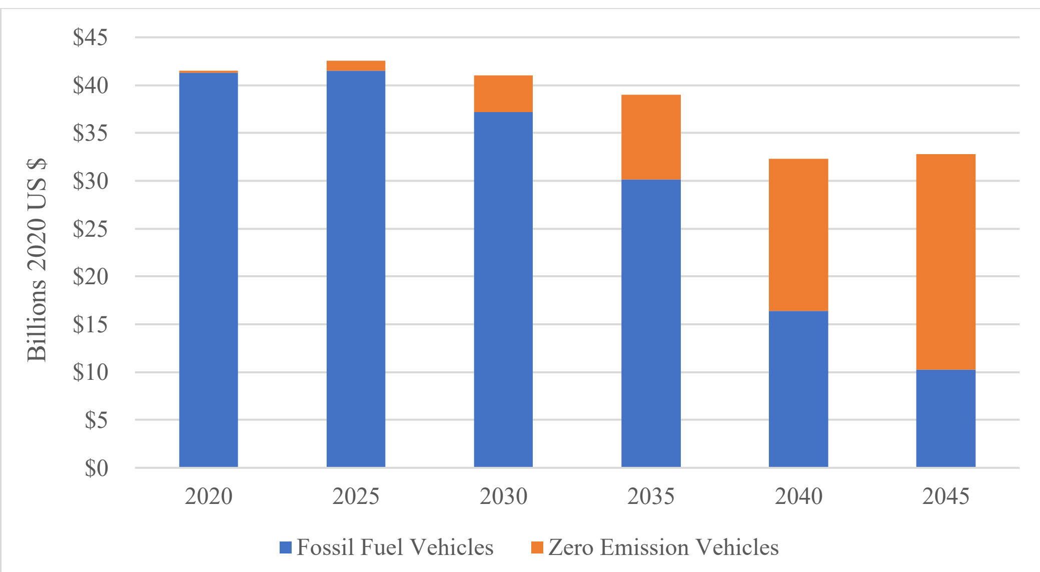


Table I. Annual maintenance expenditures in California by vehicle category and fuel type over 5-year increments in millions of 2020 US dollars, 2020-2045.

	2020		2025		2030		2035		2040		2045	
	FFV	ZEV	FFV	ZEV	FFV	ZEV	FFV	ZEV	FFV	ZEV	FFV	ZEV
LDVs	$32,741	$201	$32,860	$789	$29,131	$2,712	$23,410	$6,303	$16,415	$11,203	$10,234	$15,686
HDVs	$2,904	$.064	$3,025	$28	$2,856	$195	$2,301	$578	$1,562	$1,176	$894	$1,818
MDVs	$4,705	$.933	$4,806	$77	$4,511	$459	$3,869	$1,219	$2,726	$2,359	$1,540	$3,685
Buses	$881	$15	$827	$134	$707	$446	$559	$770	$353	$1,135	$166	$1,367
Total by Fuel Type	$41,321	$217	$41,517	$1,029	$37,204	$3,813	$30,139	$8,870	$16,415	$15,872	$10,234	$22,557
Total Overall *	$41,537,853,701		$42,545,872,012		$41,017,221,256		$39,009,004,680		$32,287,852,367		$32,790,150,082	

**These figures are totals based on non-rounded, underlying estimates. Other reported numbers are rounded to the nearest million. Any discrepancies between totals and figures in table are a result of rounding error. For all detailed figures, see Appendix L.*

Figure N. Annual maintenance expenditures for fossil fuel vehicles in California by vehicle category over 5-year increments in billions of 2020 US dollars, 2020-2045.

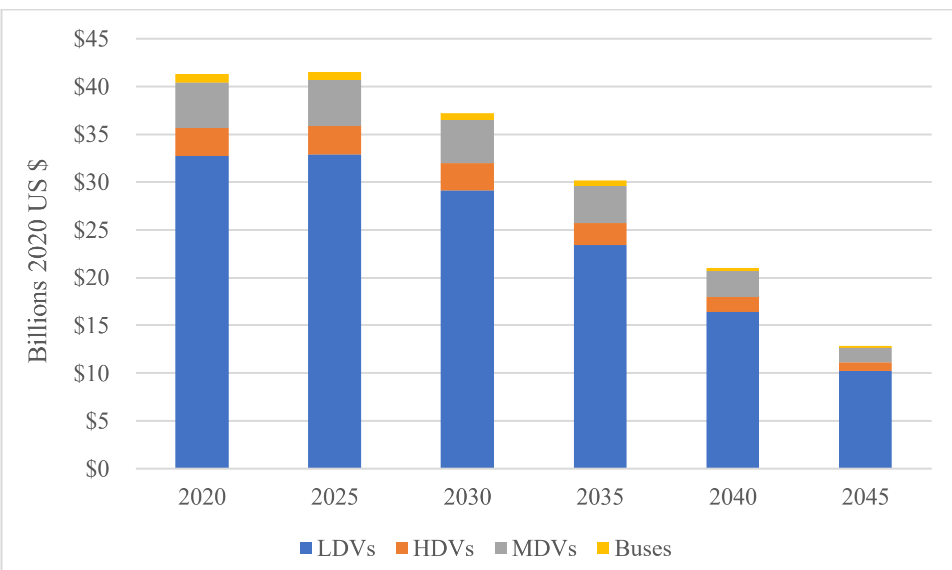
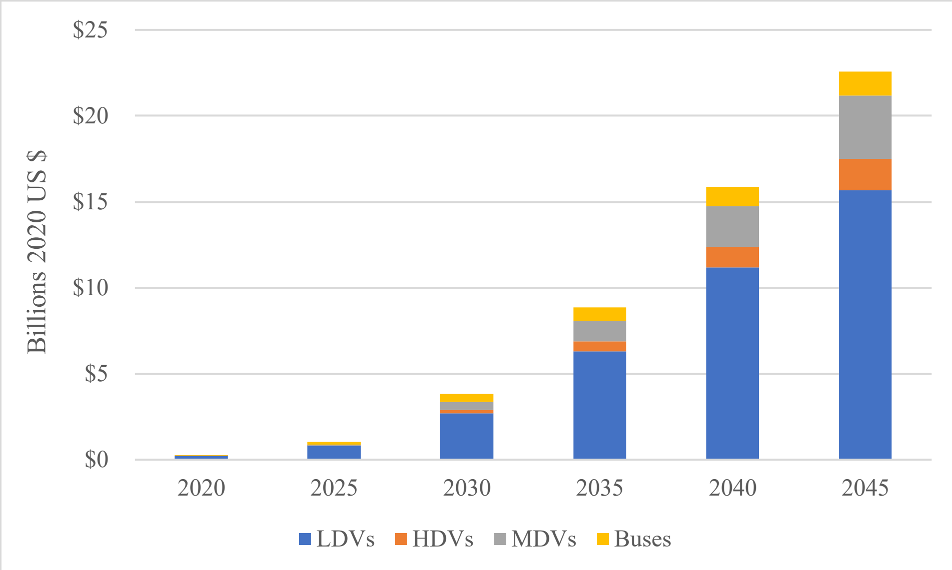


Figure O. Annual maintenance expenditures for zero emission vehicles in California by vehicle category over 5-year increments in billions of 2020 US dollars, 2020-2045.



For zero emission vehicles, the maintenance expenditures for both battery electric vehicles and fuel cell electric vehicles will increase steadily over time (Table J). While maintenance costs for battery electric LDVs, MDVs, and buses are greater than maintenance costs for their fuel cell electric counterparts from now until 2025, this is not true for HDVs. The maintenance costs for fuel cell electric HDVs will surpass maintenance costs for battery electric HDVs by 2030. This gap will increase substantially each year. The gap between battery electric LDVs and fuel cell electric LDVs will narrow over time until maintenance cost estimates are about equal.

Table J. Annual maintenance expenditures in California for zero emission vehicles by technology type over 5-year increments in millions of 2020 US dollars, 2020-2045.

	2020		2025		2030		2035		2040		2045	
	BEV	FCEV	BEV	FCEV	BEV	FCEV	BEV	FCEV	BEV	FCEV	BEV	FCEV
LDVs	$155	$46	$463	$326	$1,468	$1,245	$3,313	$2,990	$5,769	$5,434	$7,995	$7,691
HDVs	$.064	$0	$17	$12	$83	$112	$210	$368	$3,530	$822	$491	$1,328
MDVs	$.933	$0	$77	$0	$379	$81	$948	$271	$1,805	$554	$2,828	$857
Buses	$15	$0	$108	$26	$327	$119	$584	$186	$842	$293	$1,033	$334
Total by Fuel Type	$171	$46	$665	$364	$2,256	$1,557	$5,055	$3,815	$8,770	$7,103	$12,347	$10,210
Total Overall*	$216,807,601		$1,028,935,044		$3,812,776,346		$8,870.047,986		$15,872,476,687		$22,556,554,510	

**These figures are totals based on non-rounded, underlying estimates. Other reported numbers are rounded to the nearest million. Any discrepancies between totals and figures in table are a result of rounding error. For all detailed figures, see Appendix L.*

Although maintenance costs for zero emission vehicles will see a massive increase between now and 2045, we will see a 21 percent decrease in total maintenance costs (Table K). This can be attributed to the relatively constant total number of vehicles on the road (Appendix B). The number of total vehicles will remain similar, but the proportion of zero emission vehicles to fossil fuel vehicles will be extremely high by 2045. ZEVs tend to have lower maintenance costs than their fossil fuel counterparts.

Table K. Maintenance expenditures in California comparison between 2020 and 2045 in 2020 US dollars.

Vehicle Fuel Type	2020	2045	Difference	Percent Change
Fossil Fuel Vehicles	$41,321,046,100	$10,233,595,572	-$31,087,450,528	75.2% decrease
Zero Emission Vehicles	$216,807,601	$22,556,554,510	+$22,339,746,910	10,304% increase
Total Overall	$41,537,853,701	$32,790,150,082	-$19,198,106,791	21.1% decrease

2020 versus 2045 Key Expenditure Comparisons

Key takeaways:

- California will spend $23.3 billion less across the three key transportation expenditure categories in 2045 compared to 2020, with overall expenditures falling from $175.4 billion to $152.1 billion (a 13.3% drop).
- All three key expenditure categories will be lower in 2045 than in 2020.
- Across the next 25 years, new vehicle purchases will remain the largest expenditure category, with fuel costs second, and maintenance costs last.

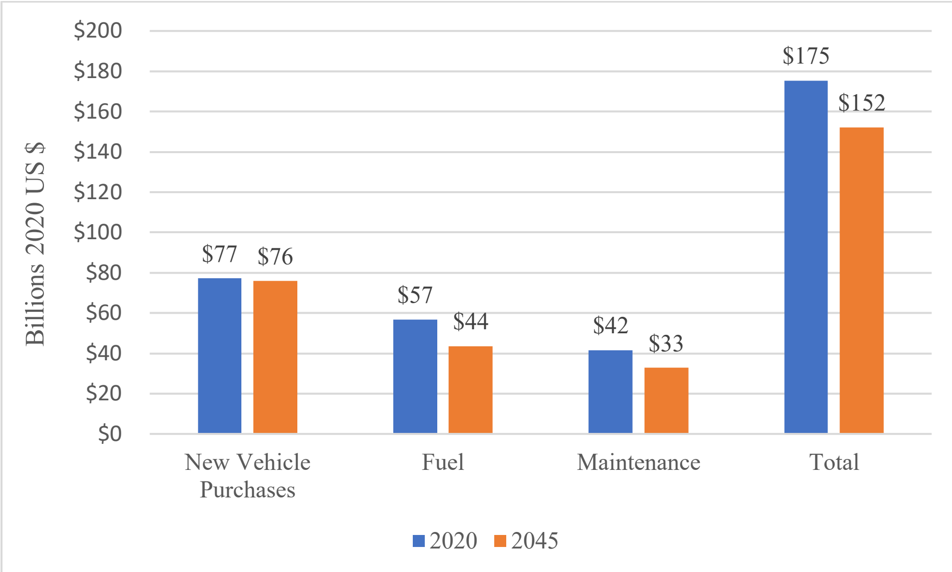
All three expenditure categories will be lower in 2045 than in 2020 (Figure P). Vehicle purchase expenditures will see the smallest decrease of $1.4 billion (1.8%), with fuel expenditures and maintenance expenditures witnessing much larger drops (Table L). Fuel expenditures will be lower by $13.1 billion (23.2%), and maintenance expenditures will fall by $19.2 billion (21.1%). Total overall expenditures will drop from $175.4 billion to $152.1 billion (13.3%).

For all three key expenditure categories, expenditures for ZEVs will increase over time while expenditures for fossil fuel vehicles will gradually decrease. By 2045, new vehicle purchase expenditures will solely be on ZEVs, whereas current new vehicle purchase expenditures are primarily going towards fossil fuel vehicle sales. Fuel expenditures and maintenance expenditures now are largely expenses related to fossil fuel vehicles. The majority of fuel expenditures and maintenance expenditures in 2045, however, will go towards ZEV-related expenses. Because of the growing proportion of ZEVs to fossil fuel vehicles on the road, combined with the lower maintenance and fuel costs of EVs in particular, overall fuel and maintenance expenditures will fall.

Table L. Key expenditure estimates in California comparison between 2020 and 2045 in 2020 US Dollars.

Key Expenditure	2020	2045	Difference	Percent Change
New Vehicle Purchases	$77,212,742,250	$75,793,489,360	-$1,419,252,890	1.8% decrease
Fuel	$56,658,609,924	$43,541,764,337	-$13,116,845,587	23.2% decrease
Maintenance	$41,537,853,701	$32,790,150,082	-$19,198,106,791	21.1% decrease
Total	$175,409,205,875	$152,125,403,779	-$23,283,802,096	13.3% decrease

Figure P. Comparison of 2020 and 2045 key expenditure estimates in California by fuel type in billions of 2020 US dollars.



Recommendations and Conclusions

Conclusions

- California will spend $23.3 billion less on transportation expenditures in 2045 compared to 2020, with overall expenditures falling from $175.4 billion to $152.1 billion (a 13.3% drop).
- All three key expenditure categories will be lower in 2045 than in 2020.
- New vehicle purchases will remain the largest expenditure category, followed by fuel costs, and then maintenance costs.
- New vehicle purchase expenditures will remain relatively constant between 2020 and 2045, while fuel expenditures and maintenance expenditures will see a larger decline.
- By 2045, the majority of transportation expenditures will be made on ZEVs.

Why are our findings significant?

The goal of this study was to characterize Californians' current and future transportation-related spending as the vehicle fleet becomes greener. Our findings strengthen the notion that the total cost of ownership for zero emission vehicles is lower than that of fossil fuel vehicles. As the vehicle fleet phases out fossil fuel vehicles, California as a whole will save billions of dollars on transportation costs. The changes in these spending patterns can inform how employment across transportation-related supply chains may change between now and 2045. We can use our findings to evaluate which specific industries and occupations will be highly impacted by transportation decarbonization. This information will be valuable to private, public, and labor leaders trying to facilitate a just and equitable transition for workers in affected industries.

How do our findings compare to other research in this area?

Our study is one of the first to consolidate transportation-related expenditure data for California, and no other has projected these costs past 2030. Due to the dearth of other previous research in this area, there is not a lot of similar data to which we can compare our findings to. In fact, we used much of the data that currently exists as assumptions in our own study.

Limitations

It should be noted that our findings depend on a scenario that assumes California will reach its zero-emissions in the transportation sector goal by 2045. However, California may reach its goal at a faster or slower rate than anticipated, as this depends largely on changes in policy, consumer preferences, and improving ZEV technologies. For example, we cannot be certain that travel by private automobile will be as popular in a decade as they are now—perhaps Californians will be more transit-oriented. Likewise, government intervention can spur or hinder innovation in the transportation industry and we have no way of predicting the agendas of future administrations. We discuss how Governor Newsom's recent executive order may impact our estimates below.

How will Governor Newsom's Executive Order impact our estimates?

On September 23, 2020, California Governor Gavin Newsom issued an executive order to require all new vehicles sold to be zero-emission vehicles by 2035. Under this order, the

California Air Resources Board (CARB) would implement the phaseout of new fossil-fuel cars and light trucks and also require medium- and heavy-duty trucks to be zero-emission by 2045. Our estimates, based on UC Davis ITS' scenario, estimate that sales of new fossil fuel cars and light trucks (LDVs) will drop to zero five years later than what Governor Newsom's plan entails. Our fossil fuel medium- and heavy-duty truck sale estimates follow the trajectory of Governor Newsom's plan.

If the goals outlined in the Governor's executive order are achieved, the steeper drop in ICEV LDV new vehicle sales would lead to some variations in the expenditure forecasts outlined above, although overall total purchase expenditures are likely to stay relatively constant. Since ZEVs and fossil fuel vehicles will become increasingly comparable in price and overall number of vehicles purchased is unlikely to change drastically, the speedier transition's impact on this category is likely to be muted.

A faster transition to an all emissions-free vehicle fleet will speed up the accompanying declines in fuel costs and maintenance costs. We expect to see overall fuel costs and maintenance costs drop earlier than our estimates suggest, since electric vehicles are typically associated with lower annual fuel and maintenance costs. However, because our vehicle sales estimates for HDVs, MDVs, and buses will remain consistent with the new scenario introduced by the executive order, only LDV sales will be majorly impacted. Therefore, we expect the declines in each key expenditure category to come primarily from LDV expenditures.

Recommendations

We recommend the following to promote California's goals and to gain a more comprehensive idea of what expenditures may look like:

- Exploring how expenditures may change based on alternative timelines
- Compare actual numbers with our estimated numbers over time
- Promoting the widespread adoption of ZEVs

Because we only investigated how expenditures may change if California reaches its carbon-neutral goal in 2045, it is worthwhile to explore how expenditures may change if California follows a different trajectory. For example, California may reach its carbon neutral goal in 2040 or 2050 rather than 2045. This would alter the estimates we just put forth, but new estimates can be found using our same methodology. As time passes, comparing actual figures with our forecasted figures will also give insight on how accurate our predictions may be. We can then adjust our numbers to better reflect real-world trends.

If California's vehicle fleet is to become zero net carbon emissions in 2045, it is important for the government to take certain steps to promote the adoption of ZEVs. As stated, new ZEV policy, new ZEV technologies, and changing consumer preferences will all contribute to widespread ZEV adoption. Since we estimate that the vehicle purchase price of ZEVs will be more expensive than that of fossil fuel vehicles until around 2030, we must consider how to incentivize consumers to purchase ZEVs over fossil fuel vehicles until their prices become more comparable. This may entail providing financial incentives to purchasing ZEVs, the ability to use HOT lanes, or simply increasing public awareness of the cost savings of owning a ZEV. Some consumers may have concerns about battery life and the difficulties of charging a ZEV. The public and private sectors can focus on assuaging these fears by implementing more ZEV charging stations. It should be noted that it is still unclear who will be responsible for adding new charging infrastructure. Improvements in battery life and drops in battery costs can also encourage the adoption of ZEVs.

Appendix A. On-Road Fleet Composition

We identified four general vehicle categories: light-duty vehicles (LDVs), heavy-duty vehicles (HDVs), medium-duty vehicles (MDVs), and buses. The estimates for each vehicle category are based on a weighted average that directly reflects the composition of the on-road fleet. The following tables demonstrate the breakdown of each vehicle category (fossil fuels, battery electric vehicles, and fuel cell electric vehicles) into percentages of the on-road fleet. These estimates come from the CNS LC1 scenario.

Table A. On-road fleet composition for fossil fuel LDVs in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
Cars	55%	53%	51%	48%	45%	40%
Light-duty trucks	45%	47%	49%	52%	55%	60%

Table B. On-road fleet composition for fossil fuel HDVs in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
Long Haul Diesel	58%	57%	58%	60%	62%	66%
Short Haul	13%	13%	13%	13%	13%	13%
Heavy-duty vocational	29%	30%	29%	27%	25%	22%

Table C. On-road fleet composition for fossil fuel MDVs in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
MD Urban diesel	16%	17%	18%	18%	19%	19%
MD Vocational diesel	2%	2%	2%	2%	1%	1%
HD pickup diesel	40%	43%	44%	45%	47%	48%
MD Urban gas	5%	4%	3%	2%	1%	1%
HD pickup gas	37%	33%	32%	32%	32%	32%

Table D. On-road fleet composition for fossil fuel buses in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
Transit bus diesel	27%	23%	18%	17%	11%	12.4%
Other bus diesel	33%	45%	61%	69%	78%	87%
Transit bus gas	15%	15%	11%	7%	6%	0%
Other bus gas	25%	17%	11%	7%	6%	0%

Table E. On-road fleet composition for battery electric LDVs in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
Cars	67%	61%	59%	58%	57%	57%
Light-duty trucks	33%	47%	41%	42%	43%	43%

Table F. On-road fleet composition for battery electric HDVs in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
Long Haul	0%	23%	24%	17%	16%	14%
Short Haul	0%	6%	5%	11%	13%	14%
Heavy-duty vocational	100%	70%	71%	72%	71%	71%

Table G. On-road fleet composition for battery electric MDVs in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
MD Urban	25%	35%	37%	37%	34%	32%
MD Vocational	2%	4%	3%	3%	3%	3%
HD pickup	73%	62%	60%	60%	63%	65%

Table H. On-road fleet composition for battery electric buses in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
Transit bus	99%	86%	81%	76%	69%	65%
Other bus	1%	14%	19%	24%	31%	35%

Table I. On-road fleet composition for fuel cell electric LDVs in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
Cars	100%	63%	48%	42%	41%	39%
Light-duty trucks	0%	37%	52%	58%	59%	61%

Table J. On-road fleet composition for fuel cell electric HDVs in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
Long Haul	0%	100%	90%	88%	88%	86%
Short Haul	0%	0%	10%	12%	11%	10%
Heavy-duty vocational	0%	0%	0%	0%	1%	4%

Table K. On-road fleet composition for fuel cell electric MDVs in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
MD Urban	0%	0%	27%	26%	23%	21%
MD Vocational	0%	0%	3%	2%	2%	2%
HD pickup	0%	0%	70%	72%	75%	77%

Table L. On-road fleet composition for fuel cell electric buses in California in percentages over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
Transit bus	0%	100%	80%	75%	69%	67%
Other bus	0%	0%	20%	25%	31%	33%

Appendix B. On-Road Fleet Numbers

The on-road fleet represents the number of vehicles in California that regularly use the nation's roadways. Tables M-O illustrate the on-road fleet numbers from 2020-2045 for each vehicle type. This data comes from the CNS LC1 scenario.

Table M. On-road fleet numbers for fossil fuel vehicles in California over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
LDVs	29,408,000	29,094,000	25,755,000	20,390,000	12,089,000	8,538,000
HDVs	304,000	320,000	299,000	236,000	157,000	87,000
MDVs	1,357,000	1,320,000	1,234,000	1,056,000	735,000	414,000
Buses	52,000	47,000	38,000	29,000	18,000	8,055
Total	31,121,000	30,781,000	27,326,000	21,711,000	12,999,000	9,047,055

Table N. On-road fleet numbers for battery electric vehicles in California over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045
LDVs	350,000	1,006,000	3,085,000	6,959,000	12,109,000	16,781,000
HDVs	23	4,262	21,000	53,000	89,000	118,000
MDVs	310	26,000	125,000	313,000	605,000	910,000
Buses	1,006	7,000	21,000	37,000	52,000	63,000
Total	351,339	1,043,262	3,252,000	7,362,000	12,855,000	17,872,000

Table O. On-road fleet numbers for fuel cell electric vehicles in California over 5-year increments, 2040-2045.

	2020	2025	2030	2035	2040	2045

LDVs	7,000	70,000	325,000	856,000	1,581,000	2,313,000
HDVs	0	1,000	10,000	33,000	74,000	122,000
MDVs	0	0	30,000	100,000	208,000	324,000
Buses	0	1,000	5,000	8,000	13,000	15,000
Total	7,000	72,000	370,000	997,000	1,876,000	2,774,000

Appendix C. Vehicle Purchase Price

Vehicle purchase price represents the average price of a vehicle in its vehicle category. Tables P-R illustrate the vehicle purchase prices for each vehicle type from 2020-2045. These estimates come from the CNS LC1 scenario.

Table P. Vehicle purchase prices for fossil fuel vehicles in California over 5-year increments in 2020 US dollars, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$30,347	$31,863	$32,675	$33,227	$33,833	$33,300
HDVs	$160,073	$167,083	$171,504	$170,971	$170,462	$168,956
MDVs	$41,730	$43,170	$44,063	$44,211	$44,196	$44,419
Buses	$226,387	$216,604	$190,085	$176,225	$154,853	$141,971

Table Q. Vehicle purchase prices for battery electric vehicles in California over 5-year increments in 2020 US dollars, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$56,997	$48,863	$37,465	$34,898	$32,484	$32,281
HDVs	294796	$283,378	$229,060	$211,238	$198,949	$199,302
MDVs	$89,034	$72,125	$53,908	$47,926	$43,288	$43,148
Buses	$534,676	$435,262	$365,809	$334,423	$303,391	$291,853

Table R. Vehicle purchase prices for fuel cell electric vehicles in California over 5-year increments in 2020 US dollars, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$43,341	$41,332	$39,501	$37,650	$36,077	$35,903
HDVs	N/A*	$254,854	$206,456	$186,308	$169,940	$168,446
MDVs	N/A*	N/A*	$73,738	$63,884	$56,755	$55,707
Buses	N/A*	$489,502	$392,396	$358,769	$329,839	$320,783

**For these values, a weighted average using percentages of the on-road fleet was not used due to lack of vehicles on the road.*

Appendix D. Vehicles Purchased

Vehicles purchased represent the number of new vehicles purchased in California. Tables S-U provide the number of vehicles purchased for years 2020-2045. These estimates come from the CNS LC1 scenario.

Table S. Number of new fossil fuel vehicles purchased in California over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	1,905,000	1,649,000	974,000	489,000	0	0
HDVs	20,900	18,620	12,280	6,110	590	0
MDVs	92,990	85,220	58,420	34,250	2,270	0
Buses	3.210	2,280	1,000	520	0	0
Total	2,022,100	1,755,120	1,045,700	529,880	2,860	0

Table T. Number of new battery electric vehicles purchased in California over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	202,000	271,000	899,000	1,326,000	1,773,000	1,757,000
HDVs	30	1,390	5,110	8,210	9,680	9,310
MDVs	102	8,570	28,730	50,290	83,760	87,080
Buses	132	1,920	3,640	4,180	4,740	4,850
Total	202,264	282,880	936,480	1,388,680	1,871,180	1,858,240

Table U. Number of new fuel cell electric vehicles purchased in California over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	2,000	20,000	75,000	141,000	191,000	215,000
HDVs	0	410	2,860	6,300	11,490	12,720
MDVs	0	0	10,150	18,100	29,900	32,210
Buses	0	340	910	1,040	1,140	1,220
Total	2,000	20,750	88,920	166,440	233,530	261,150

Appendix E. Vehicle Purchase Expenditure Calculation

To calculate new vehicle purchase expenditures, we multiplied the purchase price for an average vehicle in its class (Appendix C) by the number of new vehicles purchased (Appendix D). Tables V-X illustrate detailed figures for vehicle purchase expenditures.

Vehicle Purchase Expenditure = purchase price x # of new vehicles purchased

Table V. New vehicle purchase expenditures for fossil fuel vehicles in California in 2020 US dollars over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$57,811,035,000	$52,542,087,000	$31,825,450,000	$16,248,003,000	$0	$0
HDVs	$3,345,525,700	$3,111,085,460	$2,106,069,120	$1,044,632,810	$100,572,580	$0
MDVs	$3,880,472,700	$3,678,947,400	$2,574,160,460	$1,514,226,750	$100,324,920	$0
Buses	$726,702,270	$493,857,120	$190,085,000	$91,637,000	$0	$0
Total	$65,763,735,670	$59,825,976,980	$36,695,764,580	$18,898,499,560	$200,897,500	$0

Table W. New vehicle purchase expenditures for battery electric vehicles in California in 2020 US dollars over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$11,513,394,000	$13,241,873,000	$33,681,035,000	$46,274,748,000	$57,594,132,000	$56,717,717,000
HDVs	$8,843,880	$393,895,420	$1,170,496,600	$1,734,263,980	$1,925,826,320	$1,855,501,620
MDVs	$9,081,468	$618,111,250	$1,548,776,840	$2,410,198,540	$3,625,802,880	$3,757,327,840
Buses	$70,577,232	$835,703,040	$1,331,544,760	$1,397,888,140	$1,438,073,340	$1,415,487,050
Total	$11,601,896,580	$15,089,582,710	$37,731,853,200	$51,817,098,660	$64,583,834,540	$63,746,033,510

Table X. New vehicle purchase expenditures for fuel cell electric vehicles in California in 2020 US dollars over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$86,682,000	$826,640,000	$2,962,575,000	$5,308,650,000	$6,890,707,000	$7,719,145,000
HDVs	$0	$104,490,140	$590,464,160	$1,173,740,400	$1,952,610,600	$2,142,633,120
MDVs	$0	$0	$748,440,700	$1,156,300,400	$1,696,974,500	$1,794,322,470
Buses	$0	$166,430,680	$357,080,360	$373,119,760	$376,016,460	$391,355,260
Total	$86,682,000	$1,097,560,820	$4,658,560,220	$8,011,810,560	$10,916,308,560	$12,047,455,850

Appendix F. Fuel Prices

Fuel prices are given in 2020$ per gasoline gallon equivalent (GGE) in Table Y. Price forecasts from 2020-2030 are from CEC's mid-demand forecasts. To estimate fuel costs for gasoline, diesel, and electricity through 2045, we used linear best fit calculations based on forecasted trends while removing certain outlier years. To estimate fuel costs for hydrogen, we used a flattening exponential curve.

Table Y. Forecasted fuel prices for gasoline, diesel, electricity, and hydrogen in California in 2020 US $/GGE over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
CaRFG (reformulated gasoline)	$3.27	$3.32	$3.36	$3.43	$3.50	$3.55
ULSD	$3.50	$3.50	$3.56	$3.64	$3.69	$3.74
Electricity (Commercial Rate)	$5.59	$6.17	$6.67	$7.19	$7.68	$8.18
Electricity (Residential Rate)	$6.74	$7.17	$7.67	$8.12	$8.61	$9.10
Hydrogen	$14.87	$11.73	$10.92	$9.19	$7.99	$6.94

Appendix G. Vehicle Miles Traveled

Vehicle miles traveled (VMT) is the total annual miles of vehicle travel. Tables Z-AB illustrate the average vehicle miles traveled per vehicle for each vehicle type in California. We assumed a ten-year lifetime for each vehicle. The following figures are the average of ten-year VMT estimates (for vehicles age 0 to age 9) from the CNS LC1 scenario.

Table Z. VMT for fossil fuel vehicles in California over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	14,459	14,480	14,501	14,533	14,564	14,617
HDVs	50,271	49,749	50,271	51,314	52,357	54,065
MDVs	14,723	14,739	14,739	14,657	14,719	14,703
Buses	22,037	22,016	21,967	21,942	21,904	21,881

Table AA. VMT for battery electric vehicles in California over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	14,261	14,395	14,416	14,427	14,438	14,438
HDVs	16,315	30,160	30,257	28,319	28,369	27,725
MDVs	15,048	15,681	15,946	15,946	15,702	15,540
Buses	22,336	22,268	22,241	22,215	22,178	22,157

Table AB. VMT for fuel cell electric vehicles in California over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	13,983	14,374	14,533	14,596	14,607	14,628
HDVs	N/A*	68,463	66,102	65,630	65,345	64,016
MDVs	N/A*	N/A*	15,134	15,129	14,885	14,723
Buses	N/A*	22,341	22,236	22,210	22,178	22,168

**For these values, a weighted average using percentages of the on-road fleet was not used due to lack of vehicles on the road.*

Appendix H. Fuel Efficiency

Fuel efficiency is a measure of how far a vehicle can travel per unit of fuel. Tables AC-AE illustrate the average fuel efficiency in miles per gasoline gallon equivalent (GGE) for each vehicle type from 2020-2045. These estimates come from the CNS LC1 scenario.

Table AC. Fuel efficiency for fossil fuel vehicles in California in mi/GGE over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	34	35.5	37.1	38.2	39.5	40.6
HDVs	5.3	6.4	6.8	7.2	7.6	8
MDVs	15	18.9	19.1	19.9	21	21.9
Buses	5.6	6.7	7.2	7.7	8.2	8.6

Table AD. Fuel efficiency for battery electric vehicles in California in mi/GGE over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	126.3	128.4	131.9	132.4	132.8	133.7
HDVs	12.9	15.7	16.2	17	17.7	18.3
MDVs	57.9	60.3	66.8	69.4	73.7	78
Buses	13.5	17	18.2	19.3	20.7	21.9

Table AE. Fuel efficiency for fuel cell electric vehicles in California in mi/GGE over 5-year increments, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	67.6	63.6	62.3	61.8	62.5	63
HDVs	N/A*	8.8	9.9	10.4	10.8	11.3
MDVs	N/A*	N/A*	41.3	43.5	46.2	48.8
Buses	N/A*	10.8	12.6	13.4	14.3	14.9

**For these values, a weighted average using percentages of the on-road fleet was not used due to lack of vehicles on the road.*

Appendix I. Annual Fuel Cost Per Vehicle

The annual fuel cost per vehicle is the estimated cost of fueling a vehicle over the course of a year, depending on vehicle miles traveled (VMT) and a price per gasoline gallon equivalent

(GGE) of fuel. Tables AF-AH estimate annual fuel cost per vehicle from 2020-2045 using the VMT estimates from Appendix G and the fuel efficiency estimates provided in Appendix H.

Annual fuel cost per vehicle is calculated by multiplying fuel price (Appendix F) by annual vehicle miles traveled (Appendix G), then dividing by fuel efficiency (Appendix H). Annual fuel cost per vehicle = (fuel price x annual VMT)/fuel efficiency

Table AF. Annual fuel cost per fossil fuel vehicle in California over 5-year increments in 2020 US dollars, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$1,391	$1,354	$1,313	$1,305	$1,290	$1,278
HDVs	$33,198	$27,206	$26,318	$25,942	$25,421	$25,275
MDVs	$3,435	$2,729	$2,747	$2,681	$2,586	$2,511
Buses	$13,773	$11,501	$10,861	$10,373	$9,857	$9,516

Table AG. Annual fuel cost per battery electric vehicle in California over 5-year increments in 2020 US dollars, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$761	$804	$838	$885	$936	$983
HDVs	$7,070	$11,853	$12,458	$11,977	$12,309	$12,393
MDVs	$1,453	$1,605	$1,592	$1,652	$1,636	$1,630
Buses	$9,249	$8,082	$8,151	$8,276	$8,228	$8,276

Table AH. Annual fuel cost per fuel cell electric vehicle in California over 5-year increments in 2020 US dollars, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$3,076	$2,651	$2,547	$2,171	$1,867	$1,611
HDVs	N/A*	$91,258	$72,913	$57,994	$48,343	$39,316
MDVs	N/A*	N/A*	$4,002	$3,196	$2,574	$2,094
Buses	N/A*	$24,265	$19,271	$15,232	$12,392	$10,325

**For these values, a weighted average using percentages of the on-road fleet was not used due to lack of vehicles on the road.*

Appendix J. Fuel Expenditure Calculations

We obtained our fuel expenditure estimates by multiplying the on-road fleet (Appendix B) by average annual fuel cost per vehicle (Appendix I). Tables AI-AK provide detailed figures for fuel expenditures.

Fuel expenditures = on road fleet x annual fuel cost per vehicle

Table AI. Fuel expenditures for fossil fuel vehicles in California over 5-year increments in 2020 US dollars, 2020-2045

	2020	2025	2030	2035	2040	2045
LDVs	$40,895,223,219	$39,398,685,025	$33,823,992,906	$26,607,450,107	$18,181,586,987	$10,912,310,549
HDVs	$10,092,140,377	$8,706,075,000	$7,869,185,771	$6,122,330,356	$3,991,050,107	$2,198,958,713
MDVs	$4,661,792,567	$3,602,866,667	$3,390,000,867	$2,831,113,713	$1,900,958,850	$1,039,522,241
Buses	$716,202,500	$540,542,090	$412,735,522	$300,804,873	$177,422,400	$76,648,889
Total	$56,365,358,663	$52,248,168,782	$45,495,915,065	$35,861,699,048	$24,251,018,344	$14,227,440,391

Table AJ. Fuel expenditures for battery electric vehicles in California over 5-year increments in 2020 US dollars, 2020-2045

	2020	2025	2030	2035	2040	2045
LDVs	$266,363,413	$808,655,942	$2,586,130,942	$6,157,308,483	$11,334,970,472	$16,490,539,340
HDVs	$162,606	$50,516,156	$261,610,987	$634,795,372	$1,095,524,231	$1,462,364,973
MDVs	$450,374	$41,717,181	$199,026,609	$517,089,260	$989,929,075	$1,483,034,000
Buses	$9,304,251	$56,573,819	$171,170,158	$306,210,179	$427,874,690	$521,387,597
Total	$276,280,644	$957,463,097	$3,217,938,696	$7,615,403,294	$13,848,298,467	$19,957,325,910

Table AK. Fuel expenditures for fuel cell electric vehicles in California over 5-year increments in 2020 US dollars, 2020-2045

	2020	2025	2030	2035	2040	2045
LDVs	$21,530,924	$185,573,764	$827,891,124	$1,857,952,709	$2,952,294,389	$3,727,172,606
HDVs	$0	$91,258,067	$729,125,091	$1,913,808,663	$3,577,396,731	$4,796,554,591
MDVs	$0	$0	$120,045,966	$319,621,862	$535,447,602	$678,392,395
Buses	$0	$24,264,808	$96,356,000	$121,856,657	$161,092,927	$154,878,443
Total	$21,530,924	$301,096,640	$1,773,418,181	$4,213,239,892	$7,226,231,650	$9,356,998,035

Appendix K. Maintenance Cost per Mile

Maintenance costs per mile include default maintenance (scheduled) and repair (unscheduled) costs.

We rely on estimates for LDVs from "Update on Electric Vehicle Costs in the United States through 2030" published by ICCT[27], which provides maintenance cost per mile estimates for cars, crossovers, and SUVs. Since our LDV vehicle categories are strictly cars and light-duty trucks, we adapted the ICCT estimates to fit our categories. For cars, we use the halfway figure between cars and crossovers from ICCT. For light-duty trucks, we use the SUV figure from ICCT. This applies to both fossil fuel LDVs and electric LDVs.

Estimates for HDVs, MDVs, and buses are provided primarily by "Comparison of Medium- and Heavy-Duty Technologies in California" published by ICF.[28] For fossil fuel medium-duty trucks and buses, we assumed that maintenance costs for gasoline trucks and buses would be ⅓ less than their diesel counterparts. Maintenance costs per mile for all other medium- and heavy-duty fossil fuel and battery electric trucks and buses were adopted from ICF.

For fuel cell electric vehicles, we use maintenance cost per mile figures for LDVs and MDVs provided by the CNS LC1 scenario. For fuel cell electric HDVs, we rely on ICF. For fuel cell electric buses, we use the value given for "articulated bus", whereas for fossil fuel and battery electric buses, we use the values given for "school bus."

Table AL. Maintenance costs per mile for fossil fuel vehicles in California over 5-year increments in 2020 US dollars/mile, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$0.077	$0.078	$0.078	$0.079	$0.080	$0.082
HDVs	$0.190	$0.190	$0.190	$0.190	$0.190	$0.190
MDVs	$0.240	$0.247	$0.248	$0.250	$0.252	$0.253
Buses	$0.769	$0.799	$0.847	$0.878	$0.896	$0.940

Table AM. Maintenance costs per mile for battery electric vehicles in California over 5-year increments in 2020 US dollars/mile, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$0.031	$0.032	$0.033	$0.033	$0.033	$0.033
HDVs	$0.170	$0.130	$0.130	$0.140	$0.140	$0.150
MDVs	$0.200	$0.190	$0.190	$0.190	$0.190	$0.200
Buses	$0.660	$0.690	$0.700	$0.710	$0.730	$0.740

Table AN. Maintenance costs per mile for fuel cell electric vehicles in California over 5-year increments in 2020 US dollars/mile, 2020-2045.

	2020	2025	2030	2035	2040	2045
LDVs	$0.473	$0.324	$0.264	$0.239	$0.235	$0.227
HDVs	N/A*	$0.170	$0.170	$0.170	$0.170	$0.170
MDVs	N/A*	N/A*	$0.177	$0.179	$0.179	$0.180

[27] Lutsey, Nic, and Michael Nicholas. 2019.
[28] ICF International. 2019.

Buses	N/A*	$1.180	$1.074	$1.048	$1.016	$1.005

**For these values, a weighted average using percentages of the on-road fleet was not used due to lack of vehicles on the road.*

Appendix L. Maintenance Cost Calculations

We calculated maintenance cost estimates by multiplying vehicle miles traveled (Appendix G), maintenance cost per mile (Appendix K), and on-road fleet vehicle totals (see Appendix B).

Maintenance cost = VMT x maintenance cost per mile x on-road fleet vehicle totals

Table AO. Maintenance expenditures for fossil fuel vehicles in California over 5-year increments in 2020 US dollars, 2020-2045

	2020	2025	2030	2035	2040	2045
LDVs	$32,741,190,944	$32,859,927,360	$29,130,913,890	$23,409,901,730	$16,415,375,680	$10,233,595,572
HDVs	$2,903,652,960	$3,024,739,200	$2,855,895,510	$2,300,919,760	$1,561,809,310	$893,694,450
MDVs	$4,794,986,640	$4,805,503,560	$4,510,605,648	$3,869,448,000	$2,726,253,180	$1,540,021,626
Buses	$881,215,556	$826,766,848	$707,029,862	$558,687,204	$353,267,712	$165,676,368
Total	$41,321,046,100	$41,516,936,968	$37,204,444,910	$30,138,956,694	$16,415,375,680	$10,233,595,572

Table AP. Maintenance expenditures for battery electric vehicles in California over 5-year increments in 2020 US dollars, 2020-2045

	2020	2025	2030	2035	2040	2045
LDVs	$154,731,850	$463,403,840	$1,467,620,880	$3,313,117,269	$5,769,381,486	$7,995,374,574
HDVs	$63,792	$16,710,450	$82,601,610	$210,126,980	$353,477,740	$490,732,500
MDVs	$932,976	$77,464,140	$378,717,500	$948,308,620	$1,804,944,900	$2,828,280,000
Buses	$14,830,211	$107,554,440	$326,942,700	$583,588,050	$841,876,880	$1,032,959,340
Total	$170,558,828	$665,132,870	$2,255,882,690	$5,055,140,919	$8,769,681,006	$12,347,346,414

Table AQ. Maintenance expenditures for fuel cell electric vehicles in California over 5-year increments in 2020 US dollars, 2020-2045

	2020	2025	2030	2035	2040	2045
LDVs	$154,731,850	$463,403,840	$1,467,620,880	$3,313,117,269	$5,769,381,486	$7,995,374,574
HDVs	$63,792	$16,710,450	$82,601,610	$210,126,980	$353,477,740	$490,732,500
MDVs	$932,976	$77,464,140	$378,717,500	$948,308,620	$1,804,944,900	$2,828,280,000
Buses	$14,830,211	$107,554,440	$326,942,700	$583,588,050	$841,876,880	$1,032,959,340
Total	$170,558,828	$665,132,870	$2,255,882,690	$5,055,140,919	$8,769,681,006	$12,347,346,414

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