California Energy Commission

STAFF REPORT

Revised Transportation Energy Demand Forecast, 2018-2030

California Energy Commission

Edmund G. Brown Jr., Governor

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PREFACE

Every two years, the Warren-Alquist State Energy Resources Conservation and Development Act requires the California Energy Commission to prepare an integrated energy policy report that contains "an overview of major energy trends and issues facing the state" (California Public Resources Code, Section 25302 of SB1389). Section 25302 further requires that "the analyses supporting this integrated energy policy report shall explicitly address interfuel and intermarket effects to provide a more informed evaluation of potential tradeoffs when developing energy policy across different markets and systems." The *Revised Transportation Energy Demand Forecast, 2018-2030* complies with these provisions and generates forecasts of transportation energy demand that inform the broader California energy demand forecast through 2030.

ABSTRACT

This report, prepared by California Energy Commission staff to support the *2017 Integrated Energy Policy Report*, provides long-term projections and forecasts of California's transportation energy demand. Toward this goal, the report lays out models and methods for forecasting the growth and changes in energy demand across multiple transportation sectors. The general methodology of the forecast is to examine existing conditions and projected market and technology trends and account for changes among different fuel types and technologies to forecast future vehicle stock and fuel consumption.

The report identifies key inputs and assumptions used in the model, including base year inputs and projected inputs. Among these inputs, the forecast relies on three – low, mid, and high – common economic and demographic growth cases that are shared with other, non-transportation sectors from the broader California energy demand forecast. Projections for vehicle attributes also influence consumers' future purchase decisions, which subsequently affect their fuel consumption.

Results from the forecasting models indicate a general trend toward alternative fuels and vehicle electrification, particularly among light-duty vehicles. Electricity demand rises in response. Conventional fuels and vehicles, such as gasoline and diesel, retain the dominant share of vehicle stock and fuel use throughout the forecast period. However, the forecasted demand for gasoline declines throughout the forecast period in each of the three forecast cases.

Keywords: California, energy, demand, forecast, transportation, fuel, gasoline, diesel, jet, electricity, natural gas, hydrogen, ethanol, E85, prices, light-duty, medium-duty, heavy-duty, vehicles, high-speed rail, renewable, zero-emission, plug-in electric, ZEV, consumer preference, surveys, behavioral models, travel

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EXECUTIVE SUMMARY

The *Revised Transportation Energy Demand Forecast, 2018-2030* is part of the broader California energy demand forecast, conducted every two years as part of the *Integrated Energy Policy Report* process. Historically, the transportation energy demand forecast has allowed the state to plan for the supplies of electricity, gasoline, diesel, natural gas, and other transportation fuels that are needed to meet the statewide demand for travel. The forecast also provides an opportunity to evaluate the state's trajectory toward its clean energy goals, including reducing greenhouse gas and other harmful air pollutant emissions. This is especially important since the transportation sector is the source of about 39 percent of the state's greenhouse gas emissions, 80 percent of nitrogen oxide emissions, and 90 percent of diesel particulate matter emissions.

Overview

The California Energy Commission uses a series of models to generate the transportation energy demand forecast. These models are designed to capture the characteristics of each major source of transportation energy demand and vehicle purchase and travel choices throughout California.

Inputs into the models fall largely into two categories: base year inputs and projected inputs. *Base year inputs* represent current conditions, such as the amount of fuel consumed in the transportation sector or the number and composition of vehicles on the road. *Projected inputs* include variables such as fuel price, economic and demographic growth, and vehicle attributes. These projections typically include a low, mid, and high range to account for the inherent uncertainty of making forecasts. Certain projected inputs, such as economic and demographic growth as well as fuel prices, are shared with the broader California energy demand forecast.

Regulatory and Policy Framework

Regulation and government policy play a significant role in determining the demand for alternative vehicles and the overall demand for transportation fuel. As a result, the *Revised Transportation Energy Demand Forecast, 2018-2030* incorporates most existing regulations and policies that directly affect the vehicle purchase and travel behavior. These regulations and policies include California's Zero-Emission Vehicle program, federal fuel economy standards for light-duty and medium- and heavy-duty vehicles, and the federal tax credit and state rebate for plug-in electric vehicles, to name a few.

Key Input Findings

The following are the key forecast inputs from the *Revised Transportation Energy Demand Forecast, 2018-2030*.

Survey Shows Battery-Electric Vehicles Continue to Gain in Popularity in California

The 2017 California Vehicle Survey shows increasing preferences for battery-electric vehicles. As a result, the forecast projects battery-electric vehicle (BEV) stock surpassing plug-in hybrid vehicle (PHEVs) stock by 2030 in different California regions. The survey also shows that current plug-in electric vehicle (PEV) owners have higher preferences for zero-emission vehicles (ZEVs) and PHEVs, care more about range, and will be repeat buyers of ZEVs.

The Cost of Driving Zero-Emission Vehicles Will Continue to Decline

The National Renewable Energy Laboratory projects hydrogen fuel prices to decline between 2017 and 2030, due to economies of scale resulting from the projected growth in fuel-cell electric vehicle (FCEV) population and hydrogen fuel consumption. Declining hydrogen prices combined with increasing fuel economy of FCEVs results in a decline in FCEV fuel cost per mile.

While the gasoline price forecast shows a broader range between the high and the low price cases, the range of the electricity price cases is small. These fuel price trends are reflected in the fuel-cost-per-mile projections and are depicted in Table ES-1.

Table ES-1: Average Fuel Cost (Cents) per Mile for Light-Duty Vehicles

Fuel Type	2017	2030
BEV	6.9	6 – 8
Gasoline	11.4	9 – 18
FCEV	23	15 - 18

Source: California Energy Commission, Demand Analysis Office.

The table shows that, through the entire forecast period, BEVs continue to remain competitive with gasoline vehicles in terms of fuel cost per mile, and the fuel cost per mile for FCEVs could become competitive with gasoline vehicles by the end of the forecast period in 2030.

Battery Electric Vehicle Prices Will Continue to Decrease

Over the forecast period, the rapidly declining price of lithium-ion batteries will change the characteristics of BEVs offered to consumers. For example, the average price of a small (compact, midsize, and subcompact) BEV car is projected to decline from roughly $35,000 in 2017 to $27,000–$28,000 in 2030. This price decline is due to a decrease in battery and power train costs for BEVs. In fact, lithium-ion battery pack costs are projected to decline from an estimated $225-$250 per kilowatt-hour (kWh) in 2017 to $90-$120 per kWh in 2030. The 2017 prices are already substantially below the $1,000 per kWh price in 2010. Because of declining prices, vehicles with significantly longer range (200 miles or more) and faster charging times are expected to be offered over the coming years. Overall, automakers are expected to offer more than 125 battery-electric and plug-in hybrid models in 2030, a fivefold increase from 2015.

Accounting for Uncertainties in PEV Adoption

Because of the many uncertainties in projecting PEV stock growth, energy commission staff devised five PEV-specific scenarios for consideration (low, mid, high, aggressive, and bookend), where each scenario represented a specific set of conditions in terms of favorability to PEV adoption. The "aggressive" and "bookend" scenarios were included to account for uncertainties regarding the potential for disruptive market penetration.

Forecasts for PEV stock in 2030 ranged from about 2.6 million in the low PEV scenario to 3.9 million in the high PEV scenario. In contrast, the highly favorable conditions used for the "aggressive" and "bookend" scenarios resulted in a dramatically higher rate of PEV growth, with PEVs reaching 5.3 million and 5.9 million, respectively, by 2030.

After careful consideration, staff developed the revised transportation electricity demand forecasts based on the low, mid, and high PEV scenarios. Staff considered these three scenarios to represent the more likely outcomes, given available information (the forecast was completed in October 2017). Still, the aggressive and bookend scenarios for PEV adoption can serve as benchmarks for what might be possible under more disruptive circumstances, including a continuation of generous incentives combined with greater than anticipated advancements and cost reductions in battery technology.

Forecast Results

The key results of the transportation demand forecast fall primarily into two categories: a vehicle stock forecast and a fuel demand forecast. Both forecasts serve key functions in ensuring California's clean energy future.

- **Vehicle Stock Forecast**

  Economic and demographic projections are mainly responsible for the growth in vehicle population and total fuel consumption. The number of light-duty vehicles is forecasted to increase from 27.8 million in 2015 to between 35.5 million and 37.7 million by 2030. In the medium- and heavy-duty sectors, the vehicle population is forecast to increase to between 1.24 million and 1.34 million by 2030, from about 1.03 million in 2015. Alternative fuel vehicles in the medium- and heavy-duty sectors are forecast to increase from 18,500 in 2015 to between 49,000 and 135,000 in 2030.

- **ZEV Forecast in Line with California Goals and Regulations**

  The number of light-duty battery-electric, plug-in hybrid electric, and fuel cell electric vehicles is expected to increase from 350,000 in 2017 to 2.8 million in the low demand case, and 4.1 million in the high demand case, by 2030. Of this 2030 total, 200,000 to 350,000 are expected to be FCEVs. Moreover, all the cases in the transportation demand forecast comply with California's Zero-Emission Vehicle Program and achieve the Governor's goal of 1.5 million ZEVs and PHEVs on California roads by 2025. The forecast also projects increasing transportation electrification in medium- and heavy-duty trucks, passenger rail, and transit buses.

Fuel Demand Forecast

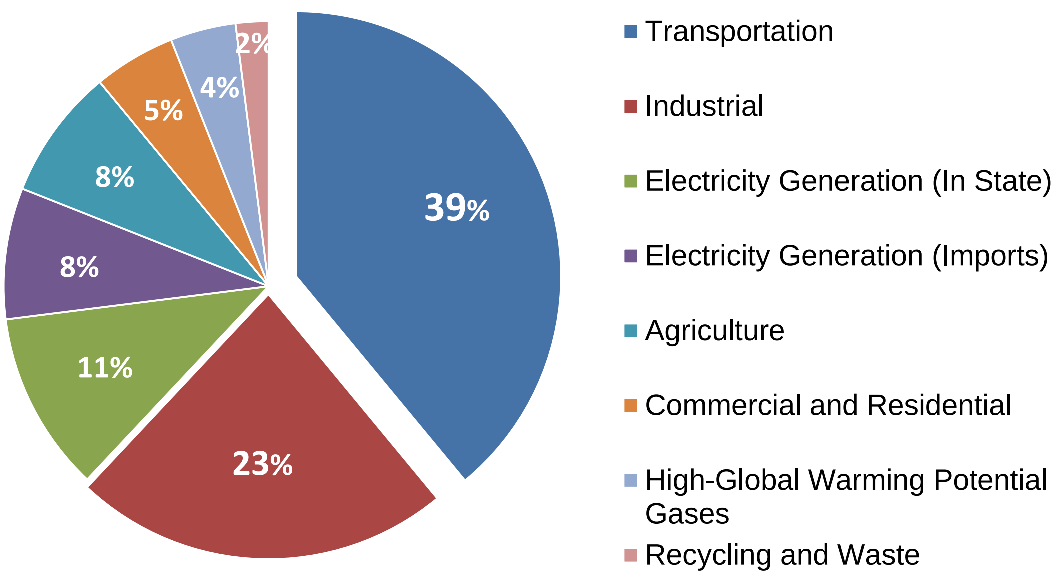
The fuel demand forecast is the primary component of the *Revised Transportation Energy Demand Forecast, 2018-2030*. In the 2017 forecast, substantial changes to fuel consumption over the forecast period are apparent:

- Though California's population and economy are expected to grow, gasoline demand is projected to decline from roughly 15.6 billion gallons in 2017 to between 12.1 billion and 12.6 billion gallons in 2030, a 19 percent to 22 percent reduction. This decline comes in response to both increasing vehicle electrification and higher fuel economy for new gasoline vehicles.
- Diesel demand continues to rise modestly, increasing from around 3.8 billion diesel gallons in 2017 to between 3.8 billion and 4.0 billion in 2030, or between 1 and 5 percent. Increasing fuel efficiency and an increasing number of alternative fuel trucks and buses entering the market offset significant growth in the demand for goods movement and services.
- Electricity consumption in the transportation sector is projected to increase to between about 12,000 and 18,000 gigawatt-hours (GWh) by 2030 , a six-fold to nine-fold increase from 2017. The growth of light-duty plug-in electric vehicles are mostly responsible for the change in electricity demand, but increasing electrification in other transportation sectors also contributes to the projected increase in electricity consumption.
- The demand for hydrogen fuel is expected to increase to at least 45 million gasoline gallons equivalent by 2030, from less than 1 million gasoline gallons equivalent in 2015.

CHAPTER 1: Introduction

California is an innovative energy policy pioneer with a long history of enacting forward-thinking legislation designed to reduce economy-wide energy consumption, greenhouse gas (GHG) emissions, and air pollution. Clean transportation policies are particularly critical to meeting these objectives, given that transportation is the source of 39 percent of GHG emissions,[1] 80 percent of nitrogen oxide emissions, and 90 percent of diesel particulate matter emissions.[2] The state's GHG emissions by sector are depicted in **Figure 1-1**.

Figure 1-1: California GHG Emissions by Sector, 2015



Source: California Air Resources Board.

Several clean transportation policies are already in place driving the market to provide more zero- and near-zero-emission options. Implementing, evaluating, and refining these policies require detailed data collection and analysis to forecast future energy demand. The California Energy Commission generates an *Integrated Energy Policy Report (IEPR)* every two years, designed to study recent energy trends, consider the effects of current energy policies, and produce a long-term forecast of future energy

1 California Air Resources Board. *California Greenhouse Gas Emission Inventory*. June 6, 2017. Available at https://www.arb.ca.gov/cc/inventory/data/data.htm.

2 California Air Resources Board. *Mobile Source Strategy*. May 2016. Available at https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf.

usage. While the *IEPR* as a whole examines energy consumed across all sectors, this staff report focuses on transportation sector energy demand trends for personal and commercial purposes.

Legislative Authority for Forecasting and Staff Report Objectives

The Energy Commission's mandate to generate these forecasts originated with the Warren-Alquist Act of 1974 (Public Resources Code Section 25000 et seq.), which created the Energy Commission and included the first reference to the Energy Commission's forecasting responsibilities. In section 25216 (b) of the act, the Commission is tasked with producing "forecasts of future supplies and consumption of all forms of energy, including electricity, and of future energy or fuel production and transporting facilities to be constructed."[3] These forecasts were meant to be analyzed with respect to demographic and economic scenarios. In 2002, Senate Bill 1389 (Bowen, Chapter 568, Statutes of 2002) expanded these duties to explicitly include assessments of transportation energy.[4]

In addition to tasking the Energy Commission with assessment of trends in transportation fuels and technologies (including alternative energy), Section 25304 (b) of the bill mandates "forecasts of statewide and regional transportation energy demand, both annual and seasonal, and the factors leading to projected demand growth including, but not limited to, projected population growth, urban development, vehicle miles traveled, the type, class, and efficiency of personal vehicles and commercial fleets, and shifts in transportation modes."[5] This report is designed to fulfill that requirement through:

- Incorporating consumer behavior pertaining to vehicle choice and use.
- Generating a long-term forecast of vehicle population and transportation energy demand in California.
- Evaluating shifts in the transportation sector from petroleum-based to alternative fuels.

Development of the 2017 Forecast

At the beginning of 2017, the Energy Commission held a pair of IEPR Commissioner workshops pertaining to multiple sectors of the broader California Energy Demand Forecast (CED), including one workshop on economic and demographic outlook (for all

3 Assembly Bill 1575 (Warren-Alquist Act), 1974. http://www.energy.ca.gov/reports/Warren-Alquist_Act/history/1974-05-16_AB_575_enrolled_bill.pdf.

4 Chaptered as Cal. Admin Code, Public Resources, Division 15 § 25301-25304.

5 Senate Bill 1389 (Bowen, Chapter 568, Statutes of 2002) http://www.energy.ca.gov/energypolicy/documents/sb_1389_bill_20020915_chaptered.pdf.

sectors) and another workshop on data inputs and assumptions. In June 2017, the Energy Commission held an IEPR Lead Commissioner workshop on the preliminary transportation energy demand forecast. After the latter workshop, staff revised the forecast based on more recently identified data and the stakeholder feedback.

In response to stakeholder interest from these initial IEPR workshops, staff convened a subgroup to the Demand Analysis Working Group (DAWG),[6] which focused specifically on transportation. The first subgroup meeting was held on August 23, 2017, in which staff outlined a series of potential scenarios (as described in Chapter 4) for inputs pertaining to plug-in electric vehicles (PEVs). Comments from this subgroup meeting resulted in the development of five scenarios for PEVs, each with a unique forecast. A follow-up webinar was held October 9, 2017, in which staff presented revised vehicle forecast numbers.

On December 4, 2017, staff held a second Lead Commissioner workshop on the revised transportation energy demand forecast. Comments and questions from stakeholders involved requests for more information on the methodology of the forecast, which is described in this report.

This staff report, *Revised Transportation Energy Demand Forecast, 2018-2030,* presents the revised demand forecast. The document reflects the revised transportation energy demand forecast workshop comments. The transportation energy demand forecasts will inform the broader CED presented for adoption as part of the larger *2017 IEPR.*

Staff Report Chapter Summary

The *Revised Transportation Energy Demand Forecast, 2018-2030* discusses transportation related trends and policies to date, the models employed to create the forecast, key model inputs, the results of the Commission's revised transportation energy demand forecast, and a qualitative analysis of policy influence and effectiveness informed by the numerical outputs.

Chapter 2

First, the context of the *Revised Transportation Energy Demand Forecast, 2018-2030* is outlined. This includes a review of historical fuel and transportation trends within California and key state policies developed in response to these trends. Finally, other current market factors are identified.

Chapter 3

Next, the forecasting models and methods of the report, along with an overview of the Energy Commission's California Vehicle Survey and the results of the latest survey, are

6 The Demand Analysis Working Group (DAWG) is a stakeholder forum for technical discussion and consensus-building on inputs and results for the electricity and natural gas demand forecasts adopted by the California Energy Commission. The Energy Commission's Energy Assessments Division sponsors and manages the DAWG (www.dawg.info).

introduced to explain the analytical foundation of the forecast. This chapter, along with details in Appendix B, outlines how forecasts of vehicle population and fuel consumption are generated.

Chapter 4

This chapter discusses various inputs and assumptions used to generate the 2017 forecast. The chapter begins with a discussion of all forecasting scenarios and demand forecast cases. The chapter also explains the process by which the scenarios were developed. The chapter then details the specific inputs to the models and the sources of input data. Both base year data and projected inputs to forecast demand in future years are obtained from public agencies, university research, and private firms. Key inputs used by the forecast include:

- Projected demographic and economic changes.
- Initial vehicle populations.
- Existing energy policies.
- Projected transportation energy prices.
- Projected offerings of alternative fuel and vehicle technologies.
- Projected vehicle fuel economy for conventional and alternative fuel vehicles.
- Projected vehicle prices.

Chapter 5

Finally, the statewide transportation demand forecast is presented. This forecast includes the growth in vehicle population and changes in vehicle, as well as the resulting demand for different transportation fuels.

CHAPTER 2: 2017 Transportation Energy Demand Forecast Context

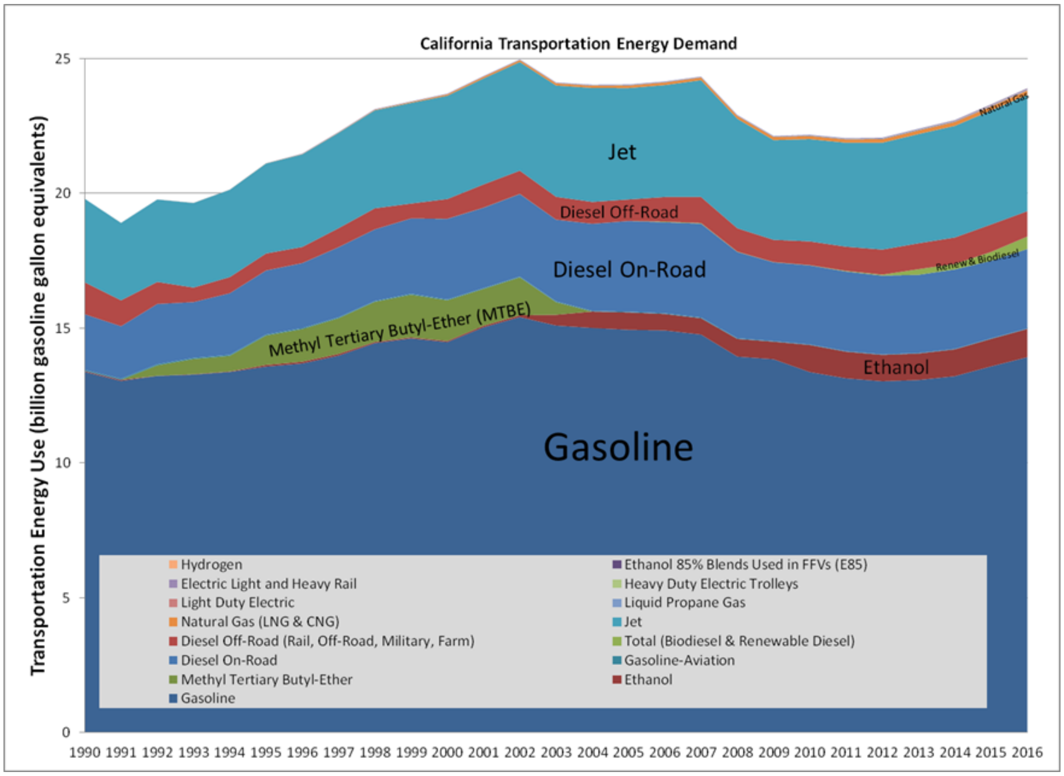
To appreciate the results of the *Revised Transportation Energy Demand Forecast, 2018-2030*, it is important to understand the historical context of California's transportation energy consumption. This chapter looks at California's historical fuel consumption, one dominated by gasoline, diesel, and jet fuels. Next, the chapter discusses gasoline prices, light-duty vehicle trends, and the growing demand for electricity in transportation. Finally, this chapter reviews policy developments in California and the United States, as well as the announcements by major nations and automakers toward decreasing the prevalence of combustion engines within their vehicle fleets.

Historical Trends and Background

California's historical demand for transportation fuels reflects a significant dependence on gasoline, diesel, and jet fuel, as shown in **Figure 2-1**. The transportation sector in California consumed more than 23.2 billion gasoline gallon equivalents (GGEs) of energy in 2015, of which 21.8 billion (or 94 percent) were fossil fuels.[7] At its peak in 2005, California consumed roughly 23.5 billion GGE of fossil fuels. Since then, a notable decline in energy consumption occurred from 2007 to 2010, reflecting the effect of the 2008 financial crisis. However, since 2012 economic growth and declining crude oil prices have led to an increase in gasoline consumption.

7 *Gasoline gallon equivalent*, or *GGE*, is a unit of measurement for energy equal to the amount of energy in one gallon of gasoline. It can be applied to multiple fuels, including diesel, natural gas, hydrogen, or electricity. Units of GGE do not, however, reflect the efficiencies of the vehicles in which they are used. For example, an electric vehicle using 1 GGE of electricity can typically travel at least three times farther than a conventional vehicle using 1 gallon of gasoline.

Figure 2-1: California Total Transportation Energy Consumption, 1990-2016

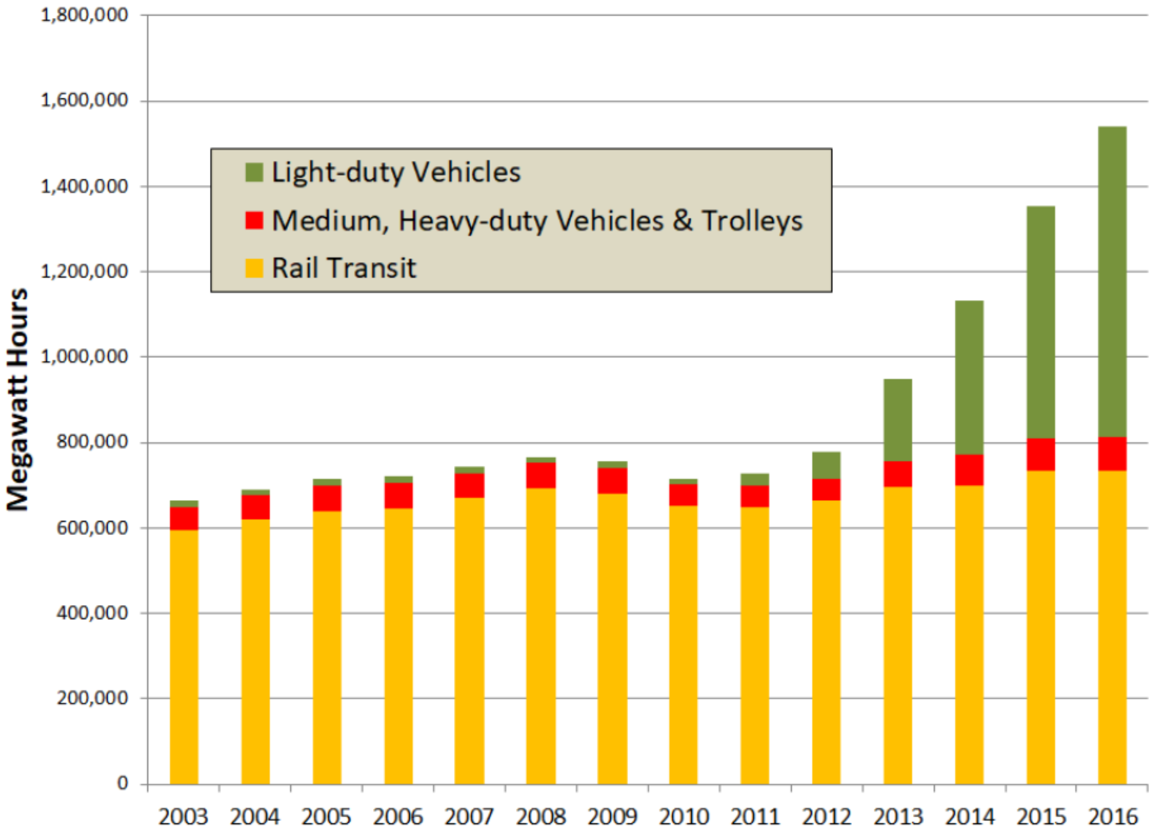


Source: California Energy Commission analysis of data from the Petroleum Industry Information Reporting Act, industry sales reports and the California Department of Tax and Fee Administration (http://www.cdtfa.ca.gov/taxes-and-fees/spftrpts.htm), adjusted to better estimate total fuel consumption rather than taxable use of fuels. "MTBE" is methyl tertiary butyl ether, an additive that was banned by the California Legislature in 2003. "Ethanol" includes ethanol used as an octane booster to gasoline as well as E85. "Other Fuels" includes aviation gasoline, biodiesel, electricity, hydrogen, natural gas, and propane.

The Energy Commission's *Transportation Fuel Supply Outlook, 2017* provides a more detailed overview of the historical fuel consumption trends in the transportation sector.[8] **Figure 2-2** provides a magnified look at the amount of electricity consumed in California's transportation sector. Through 2011, the vast majority of electricity had been used for rail transit and trolley buses. However, since 2011, increasing sales of light-duty PEVs have led to a rapid growth in the amount of electricity used in the transportation sector.

8 Schremp, Gordon, and Ryan Eggers. 2017. *Transportation Fuel Outlook, 2017.* California Energy Commission. Publication Number: CEC-200-2017-008-SF. Available at http://docketpublic.energy.ca.gov/PublicDocuments/17-IEPR-05/TN221377_20171004T145544_FINAL_STAFF_REPORT_Transportation_Fuel_Supply_Outlook_2017.pdf.

Figure 2-2: California Transportation Electricity Consumption (2003-2016)



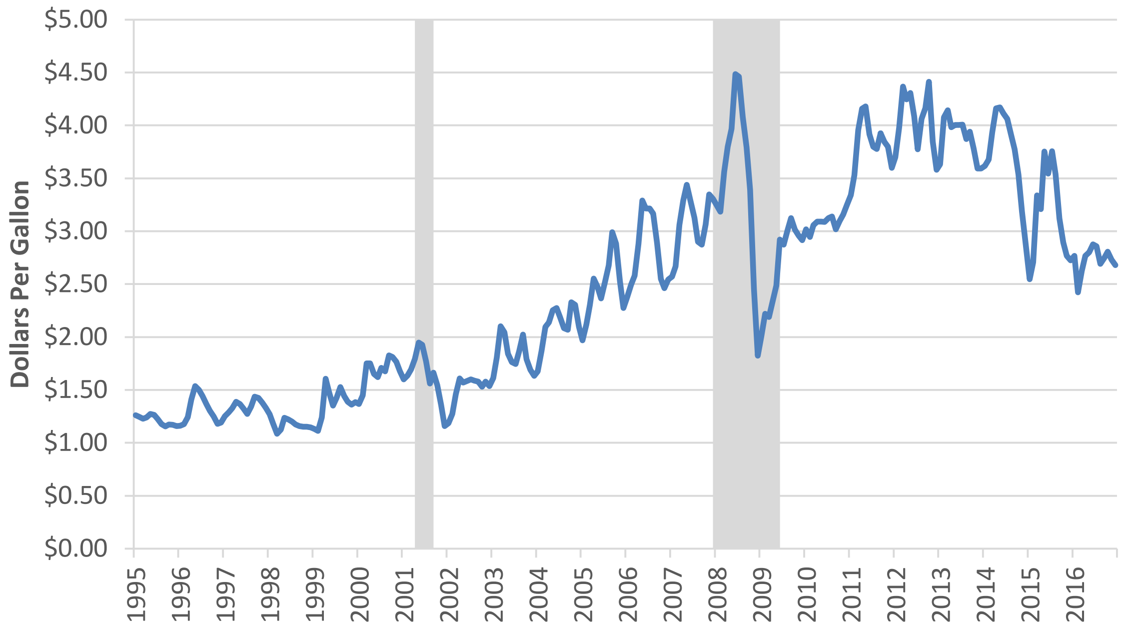
Source: California Energy Commission

Historical Gasoline Prices

Gasoline is the primary transportation fuel consumed in California. Movements in gasoline prices, therefore, have a large impact on the transportation sector. **Figure 2.3** shows the historical retail price of gasoline in California since 1995.[9] The figure shows a significant increase in the price of gasoline up until July 2008, followed by a decline in prices due to the 2008 financial crisis. By 2011, gasoline prices rebounded to the pre-crisis high. Starting in late 2014, due to a glut in supply, crude oil prices declined again.

9 U.S. Energy Information Administration *Weekly Retail Gasoline and Diesel Prices.* http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_sca_m.htm.

Figure 2-3: Retail Gasoline Prices in California (1995-2016)



Source: U.S. Energy Information Administration; Federal Reserve Bank of St. Louis. Note: Gray bars indicate economic recessions.

Vehicle Fuel Technologies

For much of the twentieth century, nearly all land-based motor vehicles used one of two fuels: gasoline and diesel. However, the end of the millennium saw technical improvements leading to the introduction of alternative forms of fueling vehicles. This report uses the following definitions:

- **Internal Combustion Engine (ICE):** ICE vehicles primarily combust fossil fuels for motive power. This includes gasoline, diesel, flex-fuel, hybrid, plug-in hybrid, natural gas, and propane vehicles.
- **Flex-Fuel Vehicles (FFV):** FFVs contain an ICE than can be powered by gasoline or E85 (gasoline blended with as much as eighty-five percent ethanol). Note that these vehicles are not compelled to use E85; drivers of FFVs may still opt to fuel these vehicles with gasoline.
- **Hybrid vehicles:** Hybrid vehicles use more than one type of energy. Typically a hybrid vehicle contains an ICE, an electric motor, and a battery that is charged by recovering energy from braking. The battery cannot directly be charged from an electrical outlet. Typically the ICE is a gasoline engine, but vehicles powered by other fuels may incorporate hybrid technology as well. In this document, "hybrid vehicle" refers to gasoline-hybrid vehicles. Examples of hybrid vehicles are the Toyota Prius and the Toyota Camry Hybrid.

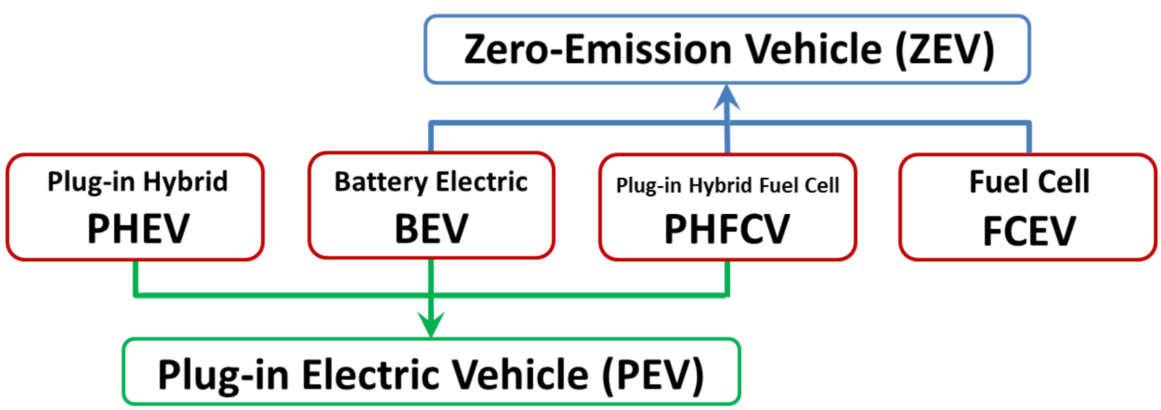
- **Plug-In Hybrid Electric Vehicles (PHEV):** PHEVs are hybrid vehicles, where the battery can be charged directly from an electrical outlet or charger. Examples include the Chevrolet Volt, Toyota Prius Prime, and Ford Fusion Energi.
- **Battery-Electric Vehicles (BEV):** BEVs contain an electric motor and are powered solely by batteries that are charged at home or at a charging station. Examples of BEVs include the Tesla Model S, Chevrolet Bolt, and Nissan Leaf.
- **Fuel Cell Electric Vehicles (FCEV):** FCEVs contain a fuel cell, electric motor, and an internal battery that cannot be charged from an electrical outlet. FCEVs are powered using hydrogen fuel. Examples include the Honda Clarity FCEV and Toyota Mirai.
- **Plug-In Hybrid Fuel Cell Vehicles (PHFCV):** PHFCVs contain a fuel cell, electric motor, and internal battery that can be charged from an electrical outlet. These vehicles are powered by hydrogen fuel and electricity deliverd from a charger**.** No vehicle currently on the market employs this technology.

This report groups the various electric vehicles (BEV, FCEV, PHEV and PHFCV) in the following ways:

- **Zero-Emission Vehicle (ZEV):** Any vehicle that produces zero tailpipe emissions during operation is defined as a ZEV. BEVs, FCEVs, and PHFCV are classified as ZEVs. These vehicles lack an internal combustion engine entirely. PHEVs, which include an ICE to extend their ranges, are not considered ZEVs for purposes of this report; however, some sources, such as the Governor's Office, group PHEVs with ZEVs when describing policy goals.
- **Plug-In Electric Vehicle (PEV):** Includes PHEVs, BEVs and PHFCVs, all of which may be charged at a home electrical outlet or at an electric charging station. FCEVs, which are fueled exclusively via hydrogen, are not considered PEVs.

Figure 2-4 provides an illustration of these two categories.

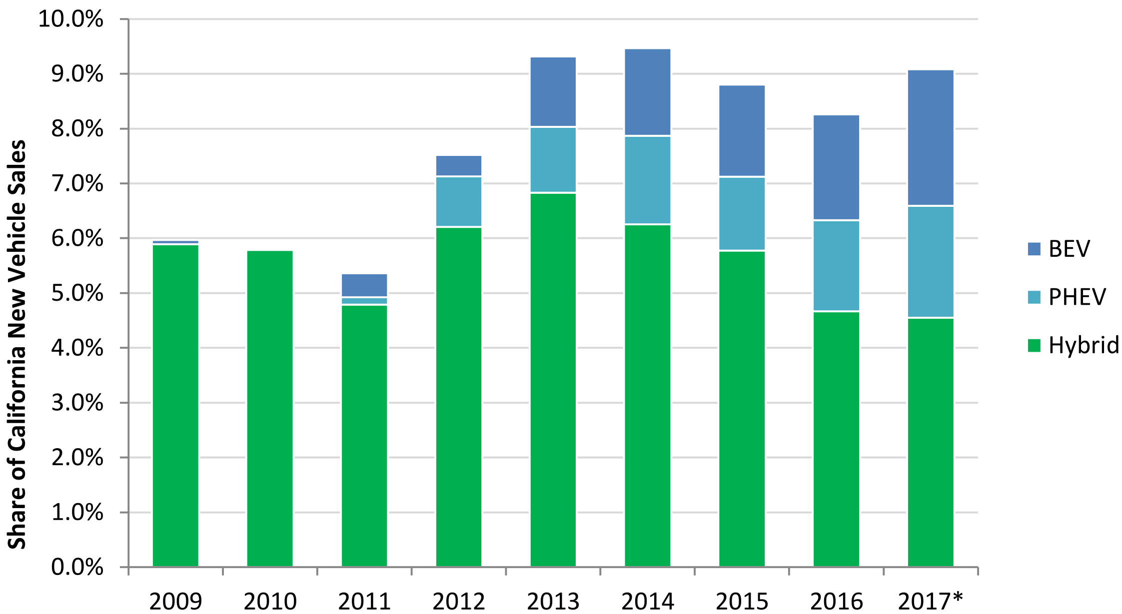
Figure 2-4: Types of Electric Vehicle Technologies



Trends in Vehicle Sales

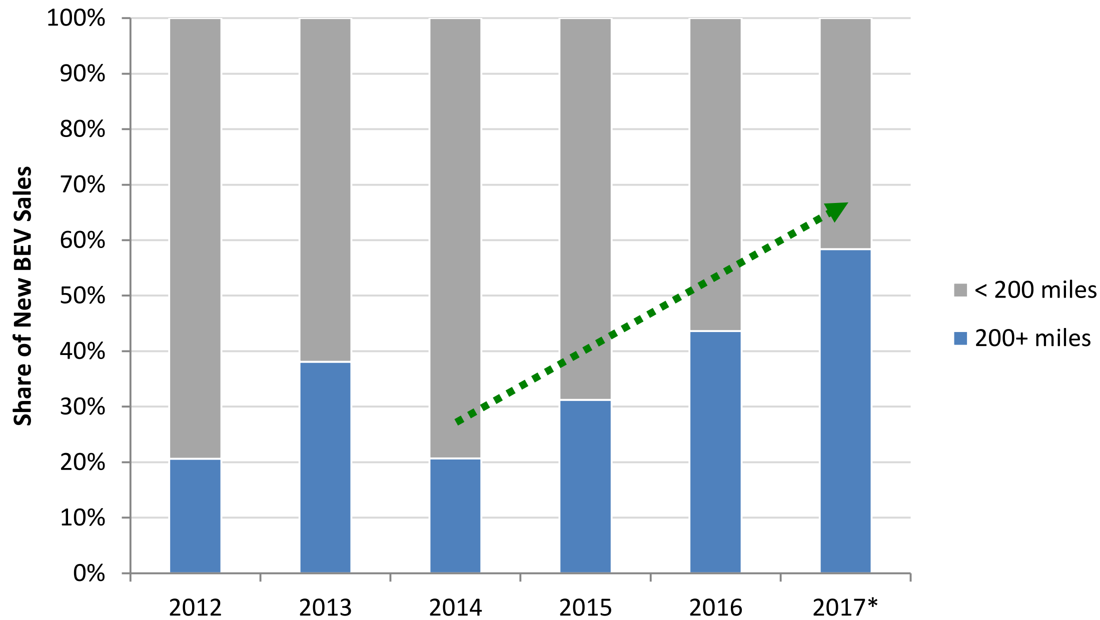
Historical sales also show that, since 2013, there has been a shift in the type of light-duty vehicles (LDVs) that have been purchased. This shift is driven largely by two factors: lower gasoline prices and increasing preferences for BEVs and PHEVs. **Figure 2-5** shows the interplay of both of these trends. The figure shows a decline in the share of hybrid vehicles sold since 2013 (likely a result of lower gasoline prices) offset by the growth in BEV and PHEV sales. **Figure 2-6** shows that the nature of the BEVs sold has also been changing, with consumers increasingly buying BEVs with range greater than 200 miles. Finally, as lower gasoline prices have persisted, **Figure 2-7** shows the shift among California consumers to purchasing larger vehicles, as light trucks now make up half of all new LDV sales.

Figure 2-5: California Hybrid, Plug-In Hybrid Electric, and Battery Electric Vehicle Sales Share



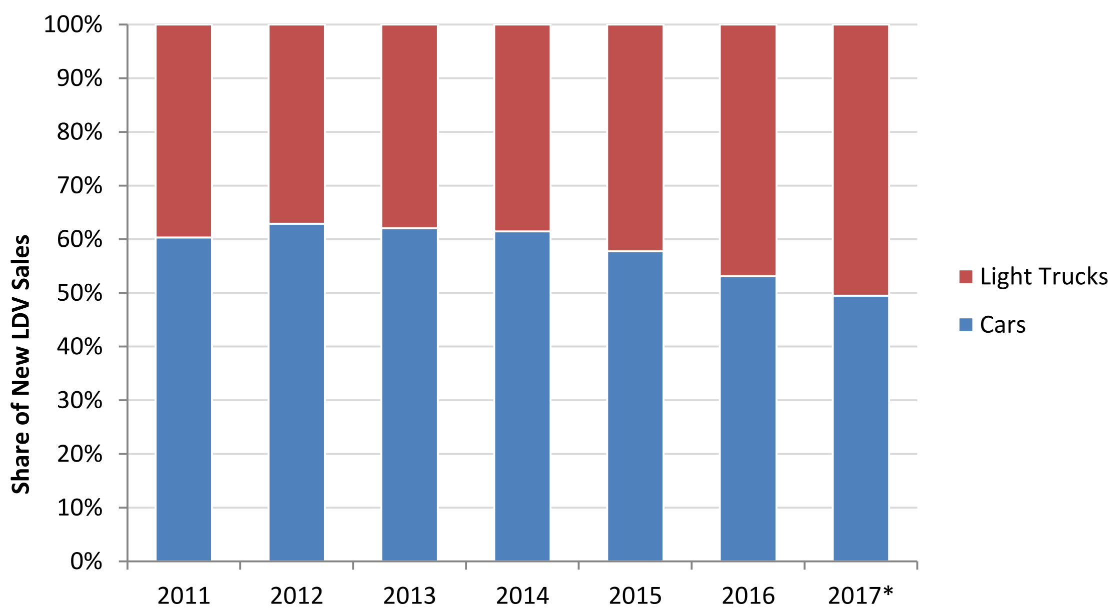
Source: California Auto Outlook by Auto Outlook, IHS Markit. *Sales data through September 2017.

Figure 2-6: Share of BEV Sales in California and Range



Source: California Energy Commission analysis of California Auto Outlook by Auto Outlook, IHS Markit. *Sales data through September 2017.

Figure 2-7: Light-Duty Car and Truck Share of New Vehicle Sales in California



Source: California Auto Outlook by Auto Outlook, IHS Markit. *Sales data through September 2017.

Policy Developments

To meet California's aggressive climate change goals and to protect public health and the environment, the state will need to reduce GHG emissions dramatically in the coming years. Numerous policy drivers and programs are in place that, if successful, will help achieve these goals. **Table 2.1** summarizes some of these policies, regulations, and programs

Table 2-1: Key Transportation Policies, Regulations, and Programs

Policy Origin	Objectives	Goals and Milestones
Assembly Bill 32 (2006); Senate Bill 32 (2016)	GHG reduction	Reduce statewide GHG emissions to 1990 levels by 2020, and 40 percent below 1990 levels by 2030
Low Carbon Fuel Standard	GHG reduction	Reduce carbon intensity of transportation fuels in California by 10 percent by 2020
Low Carbon Transportation Investments	GHG reduction Air quality	Reduce GHG emissions in the transportation sector using funding from cap-and-trade allowances
Assembly Bill 8 (2013)	GHG reduction Air quality Alternative fuel use	Transform the state's fuel and vehicle types to attain state climate change goals and improve air quality
Advanced Clean Cars Regulation (Zero Emission Vehicle Program)	Air quality GHG reduction Increase ZEVs	Require automakers to produce increasing numbers of Zero emission vehicles (ZEVs) through Model Year 2025
Executive Order B-16-12; Senate Bill 1275 (2014)	Increase ZEVs	1 million zero-emission vehicles by 2023 and 1.5 million zero-emission vehicles by 2025, including required infrastructure
Senate Bill 350 (2015)	Increase ZEVs	Require utilities to plan for and/or invest in electric vehicle charging
Executive Order B-32-15; Sustainable Freight Action Plan	Air quality GHG reduction Increase ZEVs	Improve freight efficiency and transition freight movement to zero-emission technologies
Senate Bill 1383 (2016)	GHG reduction Alternative fuel use	Adopt policies and incentives to increase the production and use of renewable gas
Federal Clean Air Act of 1970; State Implementation Plan; Mobile Source Strategy	Air quality	80 percent reduction in NO_X by 2031 Attain 12 micrograms per cubic meter standard for PM2.5 by 2025 (or earlier by district Attain 80 parts per billion standard for ozone by 2023, and 75 parts per billion standard for ozone by 2031
Corporate Average Fuel Economy (Federal Standards), 2017-2025	Reduce fuel consumption, GHG	Require automakers to offer light-duty vehicles with increasing fuel economy
U.S. EPA/NHSTA Phase 2 standards	Reduce fuel consumption, GHG	Requires fuel economy improvements in medium- and heavy-duty vehicles

Source: California Energy Commission

The policies, regulations and programs in **Table 2.1** interact with the transportation energy demand forecast in multiple ways. The forecast can be used to evaluate the state's trajectory toward ZEV goals. And, although the forecast does not look at GHG emission reductions, the resulting fuel and vehicle forecasts can be used to review potential scenarios for compliance with the Low Carbon Fuel Standard or the broader *2017 Climate Change Scoping Plan* update.[10]

The forecast incorporates funding incentive programs for alternative fuel vehicles, such as the Low Carbon Transportation Investments and Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007). For instance, state rebates for ZEVs are relevant to LDV choice when consumers and fleet owners will choose to invest in alternative fuel vehicles. Public investments into alternative fueling infrastructure (such as charging stations or hydrogen refueling stations) from AB 118 (under the Alternative and Renewable Fuel and Vehicle Technology Program) are similarly considered when assessing consumers' refueling expectations for their new vehicles.

Model inputs also incorporate the effects of these policies, regulations, and programs. The price projections for gasoline and diesel, for instance, include the estimated costs of compliance with the Low Carbon Fuel Standard, as well as conventional fuels that fall "under the cap" of the Cap-and-Trade Program under Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006).

Recent Announcements

Following the Paris Agreement to reduce GHG emissions, several nations have announced plans to transition their automotive fleets away from gasoline and diesel combustion engines. China, the most populous nation in the world, has proposed to end the sale of gasoline and diesel vehicles, with a date to be determined. Leaders in India, the second most populous nation, have proposed 2030 as the year in which all new cars should be electric. Norway has set a goal of eliminating gasoline and diesel car sales by 2025, and a similar plan is under consideration in the Netherlands. The Bundesrat in Germany passed a resolution (not legally binding) to ban combustion engines in that country by 2030. Leaders in France and the United Kingdom have also announced plans to end the sale of gasoline and diesel vehicles by 2040.

In response to government policy, many automakers have also announced their own shift in strategy. **Table 2.2** summarizes some of the key announcements made by original equipment manufacturers (OEMs) over the last year.

10 California Air Resources Board. January 20, 2017. Revised November, 2017. Adopted December, 2017. *2017 Climate Change Scoping Plan Update.* https://www.arb.ca.gov/cc/scopingplan/2030sp_pp_final.pdf.

Table 2-2: Major Announcements by Automakers on Vehicle Electrification in 2017

Company	Target Year	Announcement
BMW	2025	will offer 25 electrified vehicles – 12 will be fully-electric
Mercedes Benz	2022	10 plug-in electric vehicles, rest will have hybrid option
Fiat Chrysler	2022	More than half of Maserati models will use some form of electric powertrain
Ford	2022	13 new electric (and plug-in hybrid) models
Volvo	2019	every ***new*** model will be electric, plug-in hybrid, or hybrid
GM	2023	20 new fully electric models
Hyundai Kia	NA	electric cars at the center of future product stategy
Jaguar Land Rover	2020	every ***new*** model will be electric, plug-in hybrid, or hybrid
Renault - Nissan	2022	12 pure electric models to be launched
Volkswagen Group	2030	will electrify (electric, plug-in hybrid, and hybrid)entire model portfolio by 2030

Source: OEM Announcements. Note: These announcements refer to OEMs global strategy. Not all models will be available in the United States. Current as of October 1, 2017

These announcements help shape expectations for vehicle electrification[11] within the transportation energy demand forecast. In particular, the rapid growth in electric vehicles in markets outside California has the potential to dramatically improve the economies of scale associated with electric vehicles. This creates opportunities to reduce the price of the vehicle, or improve the perceived value or both. While these announcements are not directly used as objective inputs into the model (with the exception of automakers' announcements regarding number of models), they provide subjective support for the notion that California's own vehicle fleet can similarly transition away from combustion engines.

11 The term *electrification* or *electrified* has been used by automakers to refer to hybrid (including mild hybrid), plug-in hybrid, battery-electric, and fuel cell vehicles.

CHAPTER 3: Analytical Foundation: Forecasting Models and California Vehicle Survey

This chapter briefly describes two key foundational elements in developing the forecast: models used by the Energy Commission to generate the forecasts in the *Revised Transportation Energy Demand Forecast, 2018-2030* and the California Vehicle Survey (CVS), the results of which are used to develop the light-duty vehicle choice models.

The Energy Commission uses a combination of models to ultimately generate the transportation energy demand forecast. Two of the key models, the Personal Vehicle Choice model and the Commercial Vehicle Choice model, are choice-based models that are derived from the results of the CVS, which is designed to understand consumers' and businesses' current and potential vehicle preferences. Since consumer perspectives change with new market offerings, the CVS is periodically conducted every to capture evolving consumer preferences. The latest CVS was conducted between 2015 and 2017 and is the basis for the light-duty vehicle choice models used in the 2017 transportation forecast.

Transportation Energy Forecasting Models

Forecasting transportation energy demand is complex. Demand comes from a variety of sources, each with different fuel consumption characteristics. To maintain a satisfactory forecasting capability and a framework that allows for meaningful policy analysis, the Energy Commission uses a host of models that capture the characteristics of each major source of transportation energy demand. The various models characterize vehicle purchase and travel choices and the movement of people, goods, and services throughout California.

Overview of Models

For its analysis, Energy Commission staff relies primarily on a mix of six vehicle demand models and five travel demand models. The vehicle demand models include:

- Personal Vehicle Choice.
- Commercial Vehicle Choice.
- Government.
- Rental.
- Neighborhood Electric Vehicles (NEV).
- Argonne National Laboratory's TRUCK 5.1 Market Penetration Model (Truck Model).

The travel demand models are:

- Urban Travel.
- Intercity Travel.
- Freight Energy Demand.
- Air Travel.
- Other Bus Travel.

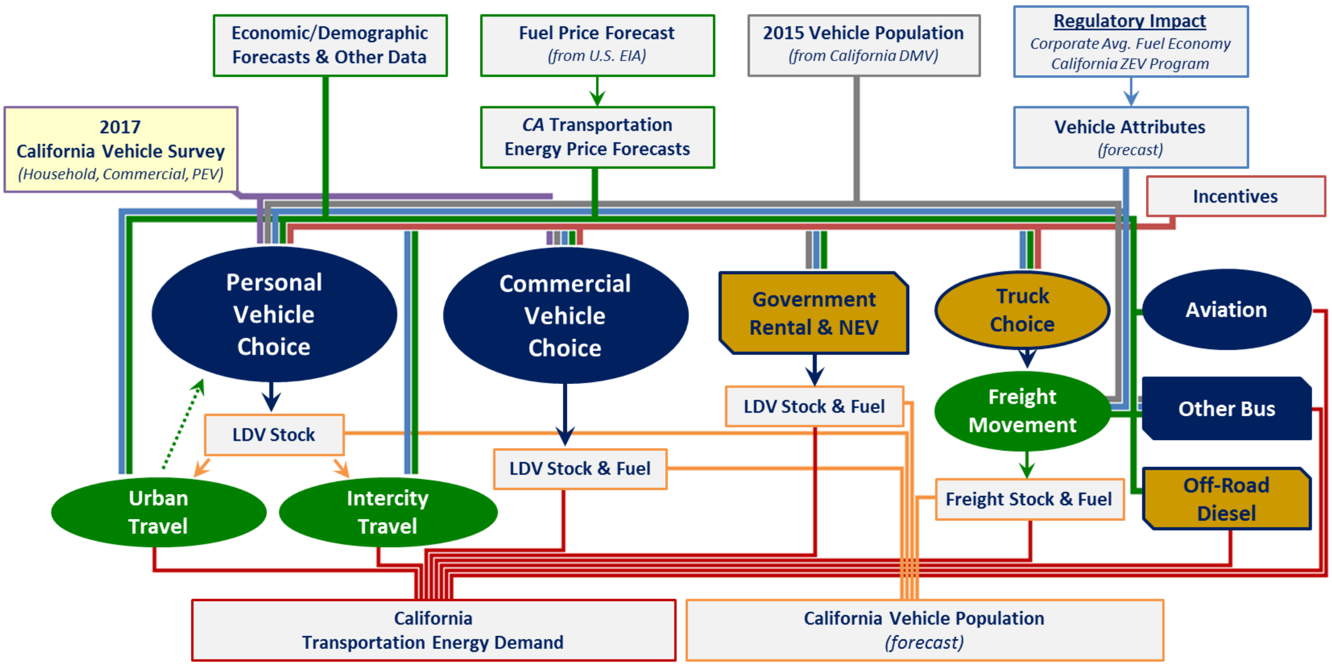
Table 3-1 and **Figure 3-1** showshe transportation models used in generating the forecast and the relationships among the models, and the model inputs and outputs; a more detailed model explanation is found in Appendix B.

Table 3-1: Energy Commission Transportation Forecasting Models

Model Category	Model	Description	Key Inputs
Vehicle Demand Models	Personal Vehicle Choice (LDV)*	Generates forecast of household demand for light-duty vehicles by 15 size class and 10 fuel types, in 3 market segments, based on consumer preferences and behavior.	-Fuel cost -Vehicle attributes and incentives -Household population and income
	Commercial Vehicle Choice (LDV)	Generates forecast of commercial demand for light-duty vehicles by 15 size class and 10 fuel types, based on consumer preferences and behavior.	-Fuel cost -Vehicle Attributes and incentives -Gross State Product
	Government (LDV)	Uses rules to grow government LDVs by fuel/technology types, from their base year stock	-Gross State Product - Fuel economy
	Rental (LDV)	Uses rules to grow rental vehicles from their base year stock	-Gross State Product -Fuel economy
	Neighborhood Electric Vehicles	Grows vehicles from their base year stock	-Gross State Product
	Truck Choice model (Medium/Heavy Duty)	Uses TRUCK 5.1 model to project different truck fuel type and technology market penetration.	-Fuel cost -Fuel economy -Vehicle prices and incentives
Travel Demand Models	Urban Travel	Predicts choices between travel modes (including auto, bus, rail, and others) and forecasts short distance personal travel and fuel demand for all travel modes	-Fuel cost -Travel cost -In-and-out of vehicle travel time -Population -Personal income
	Intercity Travel	Composed of two models, one predicts volume of travel and the other predicts choice between long distance travel modes (auto, rail, airplane)	-Fuel cost -Travel cost -Departure frequency -Personal income
	Air Travel	Composed of two models, one predicts passenger aviation and another predicts freight aviation	-Travel cost -Personal income -Population
	Freight Energy Demand (Freight Movement)	Composed of two models; one forecasts vehicle movement and fuel demand for goods movement and modal choice for truck vs. rail; the other forecasts local and regional movement and fuel demand for medium- and heavy-duty delivery, services, recreation and other economic activities	-Fuel cost -Shipment size -Travel time -Gross State Product
	Other Bus Travel	Model predicts growth of school buses, demand response (paratransit), and shuttle buses	-Population -Income -Gross State Product

Source: California Energy Commission.

Figure 3-1: Transportation Forecasting Models



Source: California Energy Commission

Most of the transportation energy models are housed within a software framework known as the Dynamic Simulation, or DynaSim for short. After all the models have been run, outputs such as vehicle stock, vehicle miles traveled (VMT), and fuel consumption are summed across all the models to arrive at aggregate, or combined, values. The Truck Choice, Government, Rental, and NEV models are run outside DynaSim. Forecasting energy demand for the off-road sector (including sea ports, airports,[12] construction, agricultural equipment, and other vehicles/equipment) and high-speed rail is also performed outside DynaSim. The forecasting results for all these sectors are integrated into the total vehicle stock and transportation energy demand forecasts.

California Vehicle Survey

The California Energy Commission periodically conducts the California Vehicle Survey, which is designed to understand consumers' and businesses' current vehicle holdings and potential vehicle choices. Through detailed questions about respondents' vehicle ownership and preferences for different fuel and vehicle technologies, the survey greatly expands staff's understanding of consumer behavior and the shifts in consumer preferences.

The data obtained from the survey inform the Personal and Commercial Vehicle Choice models discussed in Appendix B. Therefore, the survey is designed around these two models and contains questions that relate to the inputs into these models. The survey is

12 *Off-road airport equipment* refers to ground transportation not modeled by the Aviation model.

not an opinion survey; rather the preferences are captured through choices that respondents make in various situations.

The following categories of questions appeared in the most recent (2015-17) version of the survey:

Model-Based Questions

- Economic and demographic information
- Number and type of vehicles currently owned ("revealed preferences")
- Vehicle replacement and addition plans
- Price and characteristics of the next vehicle planned for purchase
- A set of eight vehicle choice exercises, as seen in Figure 3-3 ("stated preferences")

Other Questions

- Current and past vehicle purchases, characteristics, and financing
- Dwelling and parking information
- Opinions on automated vehicles
- Vehicle attributes of most significance to the respondent
- Current solar energy status and plans
- Respondent's expectations of future gasoline prices

PEV Owner Questions

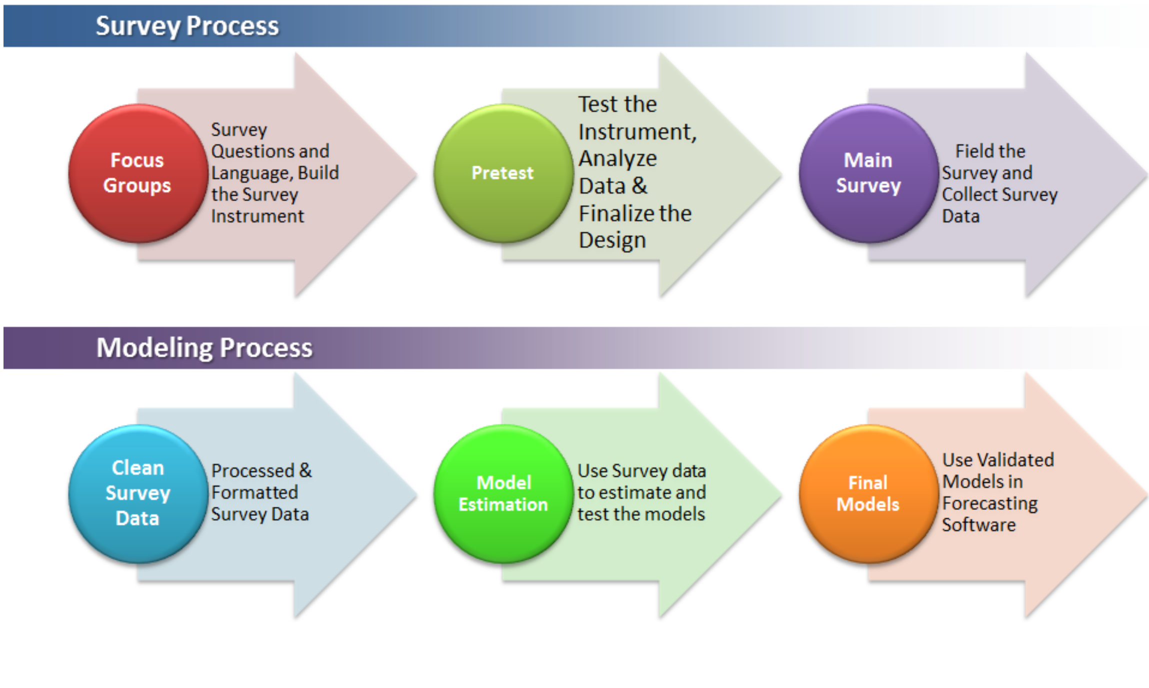
- Charging behavior
- Prices paid for electricity
- Motivations to purchase PEVs and intentions for the next vehicle purchase

Survey Structure

Resources Systems Group conducted the 2015-17 vehicle survey in three stages, as depicted in the top half of **Figure 3-2**. The process began with focus group sessions designed to solicit important variables that could influence respondents' vehicle choices, as well as determine respondent-friendly language and formatting. There were nine focus group sessions, including one in Spanish and one composed of commercial and residential PEV owners. These sessions were held in March 2016 in four cities: San Francisco, Los Angeles, Fresno, and Sacramento, each representing different California regions. Based on this feedback, the questionnaire was revised and used in the pretest survey, carried out in July 2016. Pretest survey results, including the survey length, were then analyzed to revise and finalize the questions and the questionnaire as necessary. The main survey was carried out between November 2016 to February 2017, using the finalized survey questionnaire and format.

Since commercial fleet owners and households have different behavior, separate surveys were conducted for each market segment.

Figure 3-2: California Vehicle Survey Project Design



Source: California Energy Commission

Figure 3-3 shows an example of the choice exercises that were used to solicit consumer preferences for different vehicles. The choices seen by each respondent were uniquely designed for that respondent, based on the answers they provided in the earlier section of the survey on the fuel type, class, and price of the vehicle they planned to purchase next. Respondents identified their choice after reviewing the attributes of each hypothetical vehicle, having the option to hover their cursor over each attribute for a definition, if needed. The survey, conducted online, used an algorithm that generated these hypothetical vehicles in real time to enable the respondent to complete the seamless survey in one Web session.

The choices presented to respondents were not limited to vehicle models that exist in the market. Stated preferences surveys allow for the solicitation of preferences for vehicle attribute combinations that do not exist in the market at the time of survey.

Figure 3-3: Sample of Stated Preferences Survey Instrument

CALIFORNIA
VEHICLE SURVEY

Please carefully review each vehicle and all its features below. Assuming these are the only vehicles available to you to purchase, **please select the ONE vehicle you would most likely purchase.**

Vehicle Choice 3	Vehicle A	Vehicle B	Vehicle C	Vehicle D
Vehicle Type	Midsize car	Cross over, midsize	Midsize car	SUV full-size/large
Fuel Type	Hybrid (Gasoline)	Gasoline-ethanol Flex Fuel vehicle (E85 FFV)	Hybrid (Gasoline)	Plug-in Hybrid Electric vehicle (PHEV)
Vehicle Models Available	27	4	27	2
Model Year	Used (2014)	Used (2011)	Used (2014)	Used (2013)
Vehicle Price	$10,700	$11,100	$10,700	$20,800
Purchase Incentive	None	None	None	None
MPG / Fuel Economy	34.2	17.3	34.2	29.2
Fuel Cost per 100 miles	$17.02	$24.62	$17.02	$27.26
Refueling Station (Time is takes to get to this type of station)	Refuel at station (10 min)	Refuel at station (5 min)	Refuel at station (3 min)	Plug-in at a charging station (10 min)
Refueling Time	10 min	5 min	8 min	8 hours charging time (5 min to refuel with gas)
Vehicle Range	487 miles	381 miles	564 miles	767 miles
Trunk/Cargo Space	12 cubic feet (3 suitcases)	28 cubic feet (7 suitcases)	12 cubic feet (3 suitcases)	16 cubic feet (4 suitcases)
Annual Maintenance Cost	$506	$360	$304	$534
Acceleration Rate (0-60 mph)	6.3 secs	5.8 secs	6.3 secs	8.9 secs
Select One:	○	○	○	○

Source: Resources Systems Group

Each respondent had to complete eight choice exercises and answer all questions to qualify for survey incentives. Incentives were set at $10 per household and $20 per commercial fleet owner. The same amount was offered to PEV owners in both market segments.

Survey Participants

In total, there were 5,526 completed surveys: 3,614 household surveys (including 315 PEV owner surveys) and 1,712 commercial fleet owner surveys (including 284 commercial PEV owners). Targeted sampling of PEV owners was necessary to reach the goal of 500 surveys, since without it the residential and commercial sampling frames generated only 100 PEV owner surveys. PEV owners who participated in the survey were asked the same questions that other participants responded to, as well as additional questions related to charging behavior, electricity rates, and other PEV-related subjects.

Tables 3-2 to **Table 3-6** summarize the residential survey respondents by region, household vehicle count, household income, household size, and respondent age, alongside comparisons to the California population from the American Community Survey (ACS).[13]

Table 3-2: Completed Surveys by Segment and Region

Region	Residential	Commercial	Total
San Francisco	854	415	1,269
Los Angeles	1,513	748	2,261
San Diego	342	175	517
Sacramento	275	82	357
Central Valley	314	128	442
Rest of State	316	164	480
Total	**3,614**	**1,712**	**5,526**
PEV Owners Included	**315**	**284**	**599**

Source: 2017 California Vehicle Survey

Of the 3,614 households who completed the survey, 14 did not own any vehicle at the time of survey completion. **Table 3-3** shows distribution of households by household vehicle count. Compared with the 2015 ACS distribution, the survey slightly underrepresents the two vehicle households and over represents the three vehicle households.

13 The American Community Survey is an annual survey developed by the Census Bureau designed to capture nationwide economic and demographic data through sampling. More information is available at https://www.census.gov/programs-surveys/acs/.

Table 3-3: Household Vehicle Count: Survey vs. ACS Estimates

Household Vehicles	Count	Percent	ACS Percent
1 Vehicle	1,244	35%	35%
2 Vehicles	1,636	45%	41%
3 or more Vehicles	720	20%	25%
Total	**3,600**	**100%**	**100%**

Source: 2017 California Vehicle Survey & 2015 American Community Survey

Table 3-4: Household Distribution by Income Category: Survey vs. ACS Estimates

Annual Household Income	Count	Percent	ACS Percent
Less than $9,999	56	2%	6%
$10,000 to $24,999	178	5%	14%
$25,000 to $34,999	247	7%	9%
$35,000 to $49,999	383	11%	12%
$50,000 to $74,999	667	18%	17%
$75,000 to $99,999	632	17%	12%
$100,000 to $149,999	794	22%	15%
$150,000 to $199,999	307	8%	7%
$200,000 or more	350	10%	8%
Total	**3,614**	**100%**	**100%**

Source: 2017 California Vehicle Survey & 2015 American Community Survey

Table 3-5: Residential Respondent Household Size vs. ACS Estimates

Household Size	Count	Percent	ACS Percent
1 person (I live alone)	771	21%	24%
2 people	1,513	42%	30%
3 people	593	16%	17%
4 or more people	737	20%	29%
Total	**3,614**	**100%**	**100%**

Source: 2017 California Vehicle Survey & 2015 American Community Survey

Table 3-6: Residential Respondent Age vs. ACS Estimates

Age Category	Count	Percent	ACS Percent
18 to 34	923	25%	33%
35 to 64	1,839	51%	51%
65 or older	852	24%	16%
Total	**3,614**	**100%**	**100%**

Source: 2017 California Vehicle Survey & 2015 American Community Survey.

While the regional distribution of household respondents aligns well with sampling targets, the household survey overrepresented households in the $75,000-$150,000 income range, two-person households, and older respondents, while underrepresenting households with income less than $25,000, households with four or more people, and younger respondents.

Table 3-7 summarizes the commercial survey completion by commercial fleet size. While the regional distribution of commercial fleet aligns well with sampling targets, the fleet size distribution underrepresents one-vehicle fleets and overrepresents two to five vehicle fleets compared to overall statewide data. However, among the California Secretary of State, InfoGroup, IHS Automotive, and Department of Motor Vehicles (DMV) data, there are varying accounts of the number of commercial entities and the commercial fleet sizes.

Table 3-7: Commercial Respondent Fleet Size

Fleet Size	Total
1 Vehicle	43%
2 Vehicles	25%
3–5 Vehicles	22%
6–9 Vehicles	5%
10+ Vehicles	5%
Total	**100%**

Source: 2017 California Vehicle Survey

Compared to the 2013 survey, the 2017 survey results showed a change in consumer preferences in favor of BEVs and increased preferences for vehicle range, in both the commercial and residential market segments. The PEV owner surveys showed that current PEV owners are repeat buyers of PEVs and overall are more likely to buy ZEV vehicles.

CHAPTER 4: Demand Cases, Inputs, and Assumptions

The transportation energy demand forecast is based on a wide variety of inputs and assumptions. As with any forecast, there is a large amount of uncertainty as to the conditions that will exist in the future. In particular, forecasts are sensitive to projections of population and income growth, vehicle characteristics, and energy prices. Different demand cases partially capture these uncertainties.

This chapter will first describe different transportation demand cases in the *Revised Transportation Energy Demand Forecast, 2018-2030*, and then details the inputs and assumptions used in generating the forecast.

Demand Cases

For the transportation energy demand forecast, Energy Commission staff groups important forecast inputs and assumptions into three demand cases. These three cases are called the high electricity demand case, mid electricity demand case, and low electricity demand case. Together, these cases represent a range of economic, demographic, and fuel price conditions used in forecasting transportation energy demand. These cases are also consistent with other energy demand forecasts made by the Energy Commission, in that they use the same population, income, and fuel price projections as inputs, hence referred to as "common" demand cases **(Table 4.1**). This allows for comparison and integration with demand forecasts in other sectors. Apart from the common inputs, transportation specific inputs such as vehicle attributes are selected.

High Electricity Demand Case

The high demand case is designed to represent a set of economic, demographic, fuel price, vehicle attribute, and incentive conditions that would result in a high level of demand for transportation electricity. In this scenario, high projections of population and income growth, as well as low electricity and natural gas prices, are assumed to exist simultaneously.

Mid Electricity Demand Case

The mid demand case represents a set of economic, demographic, and fuel price conditions that would result in a moderate amount of transportation electricity demand. Projections of population and income growth, as well as fuel prices that fall between the available high and low projections are typically used.

Low Electricity Demand Case

The low demand case assumes a set of economic, demographic, fuel price, vehicle attribute, and incentive conditions that result in a low level of transportation electricity demand. In this scenario, low estimates of population and income growth, as well as high electricity and natural gas price projections are input in the transportation demand models.

Table 4-1 defines the inputs of these common demand cases.

Table 4-1: Common Electricity Demand Cases Inputs

Demand Case	Population	Income	Fuel Prices	
			Petroleum Fuels	Electricity / Natural Gas / Hydrogen
High Demand	High	High	High	Low
Mid Demand	Mid	Mid	Mid	Mid
Low Demand	Low	Low	Low	High

Source: California Energy Commission

The differences in the assumptions inherent in each case allow the Energy Commission to consider the potential range of future transportation energy demand that may be observed in California.

PEV-Specific Input Scenarios

The growth in future transportation electricity consumption is expected to come primarily from light-duty PEVs. Because of the uncertainties in projecting PEV characteristics over the forecast period, the Energy Commission sought additional feedback from stakeholders in the transportation electricity sector. As a part of this effort, the Energy Commission convened the first DAWG transportation subgroup, composed of state agencies, utilities, and OEMs.

For the DAWG transportation subgroup meeting, Energy Commission staff generated a set of eight potential PEV scenarios. Each scenario used one of the three sets of common electricity demand cases shown in **Table 4-1**. The more aggressive scenarios, for instance, used the “high demand” inputs for transportation energy price and economic and demographic growth. Additional inputs and assumptions specific to PEVs were also proposed for each scenario, including variations in battery price, incentive availability, and recharging convenience. Based on stakeholder feedback in the meeting, as well as docketed items after the meeting, staff narrowed the scenarios for consideration to five (low, mid, high, aggressive, and bookend), which are defined in **Table 4-2**. Note that these meetings concerned PEVs only, and not FCEVs. Therefore the table compares only PEV forecast results.

Table 4-2: Inputs Selected for PEV Scenarios

	PEV SCENARIOS				
INPUTS	**Low**	**Mid**	**High**	**Aggressive**	**Bookend**
PREFERENCES					
Consumers' PEV Preference	Constant at 2017 level	Increase with PEV Market Growth	Increase with PEV Market Growth	Increase with PEV Market Growth	Increase with PEV Market Growth
INCENTIVES					
Federal Tax Credit	Eliminated after 2019	Decreasing starting in	Decreasing starting in	Constant Through 2030	Constant Through 2030
State Rebate	To 2020	To 2025	To 2025	To 2030	To 2030
HOV Lane Access	To 2021	To 2025	To 2025	To 2025 for PHEV / 2030 for EV	To 2025 for PHEV / 2030 for EV
ATTRIBUTES					
Availability of PEVs (in 2030)	PEV models available in **11** of 15 CEC LDV classes	PEV models available in **11** of 15 CEC LDV classes	PEV models available in **11** of 15 CEC LDV classes	PEV models available in **13** of 15 CEC LDV classes	PEV models available in all CEC LDV classes
Vehicle / Battery Price (by 2030)	PEV prices based on battery price declining to **~ $120/kWh**	PEV prices based on battery price declining to **~ $100/kWh**	PEV prices based on battery price declining to **~ $89/kWh**	PEV prices based on battery price declining to **~ $73/kWh**	PEV prices reach parity with gasoline vehicles
Avg. Range (2030)	~ 230 miles	~ 230 miles	~ 270 miles	~ 270 miles	~ 270 miles
Refuel Time (2030)	15 - 21 min	15 - 21 min	10 - 16 min	10 - 16 min	Same as Gasoline
Time to Station (2030)	7 - 8 min	Same as gasoline	Same as gasoline	Same as gasoline	Same as gasoline by 2025
FORECAST RESULT					
PEV STOCK in 2030	**2.6 mil**	**3.3 mil**	**3.9 mil**	**5.3 mil**	**5.9 mil**

Source: California Energy Commission

Low, Mid, and High PEV Scenarios

Each scenario represents a specific set of conditions in terms of favorability to PEV adoption. The low PEV scenario represented what staff considered a conservative application of PEV preferences and incentives, and conservative estimates of PEV characteristics (such as price, range, model availability, and charging time) and infrastructure. The mid PEV scenario represented estimates that staff considered moderate but also more likely to occur. The high scenario represented estimates that required a higher level of technological advancement coupled with stronger battery price declines, making PEVs price competitive with gasoline vehicles in many vehicle classes.

Aggressive and Bookend PEV Scenarios

The "aggressive" and "bookend" scenarios were included to account for more uncertainties regarding the potential for disruptive market penetration. The aggressive scenario was based on the high scenario but assumed more make and model availability in more vehicle classes, even lower battery costs than in the high case, extended availability of existing federal tax credits (without being phased out for manufacturers as is stipulated), and state rebates until 2030. The bookend scenario represented the best possible conditions for PEV growth, assuming the same incentives as in the aggressive scenario but where PEV characteristics (such as vehicle price, charging time, and model availability) were on par with gasoline vehicles by 2030 in all light-duty vehicle classes.

After the PEV scenarios were constructed, staff ran the light-duty vehicle demand models to generate a forecast of PEV stock for each scenario. As shown in **Table 4-2**, forecasts for PEV stock ranged from about 2.6 million in the low PEV scenario to 3.9 million in the high PEV scenario. In contrast, the highly favorable conditions used for the “aggressive” and “bookend” scenarios resulted in a dramatically higher rate of PEV growth, with PEVs reaching 5.3 million and 5.9 million, respectively, by 2030.

While acknowledging that the “aggressive” and “bookend” scenarios captured more of the uncertainties regarding potential technological disruption that may occur, staff developed the final transportation electricity demand forecasts based on the low, mid, and high PEV scenarios. Staff considered these three scenarios to represent the more likely outcomes, given available information. The three recommended scenarios were also generally more consistent with other state agencies’ projected pathways for PEV growth. Still, the “aggressive” and “bookend” scenarios for PEV deployment can serve as benchmarks for what might be possible under more disruptive circumstances, including a continuation of generous incentives combined with greater than anticipated advancements and cost reductions in battery technology.

Inputs and Assumptions

The inputs used in the transportation models can be divided into two categories: “base year inputs” and “projected inputs.” The influence of the inputs discussed in this chapter can be seen throughout the forecast results, which will be discussed in Chapter 7. The demand forecast is anchored by base year input data, while projected inputs contribute to changes over time. These inputs are the main drivers of the forecast.

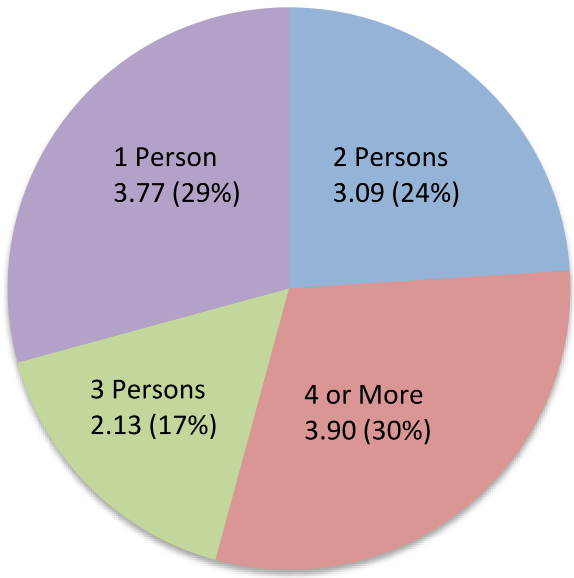
Base Year Inputs

Base year inputs encompass all 2015 data that are presently known or estimated, while projected inputs refer to the data that are predicted throughout the forecast period (through 2030). Base year (2015 for this forecast) inputs are used as a common starting point for all demand cases and in automated and manual calibration of the forecasting models. This section describes base year inputs for the *Revised Transportation Energy Demand Forecast, 2018-2030*, while the subsequent section describes projected inputs and PEV-specific scenarios.

Economic and Demographic Data

Energy Commission staff used the 2015 American Community Survey for the total number of households in the state, as well as the distribution of these households by size, income category, and number of vehicles. Population and income are necessary inputs because vehicle stock data are heavily influenced by changes in population and income. In the light-duty vehicle forecasting models, about 97 percent of the growth (or decrease) in vehicle stock results from changes in population and income, indicating the utmost importance of these variables. The household size distribution, which is necessary to provide base year population data, is displayed in **Figure 4-1**, showing almost 4 million households with four or more members.

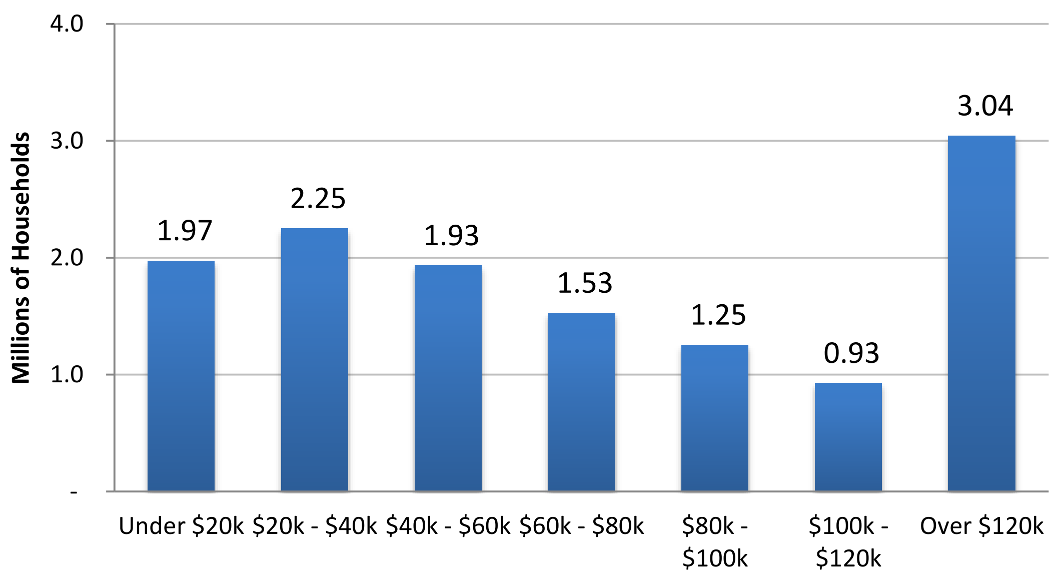
Figure 4-1: California Household Distribution by Size, 2015 (in Millions of Households)



Source: California Energy Commission Analysis of the 2015 American Community Survey. http://www.census.gov/programs-surveys/acs/data.html.

Figure 4-2 shows household distribution by income category. In 2015, of 12.9 million California households, more than 6 million earned less than $60,000 a year, and more than 3 million earned more than $120,000 a year.

Figure 4-2: California Household Distribution by Annual Income, 2015 (in Millions of Households)



Source: California Energy Commission Analysis of the 2015 American Community Survey.

Vehicle Stock

Vehicle stock refers to all on-road vehicles registered in California. The data are obtained from the California DMV and processed to obtain vehicle counts by class, fuel type, and location. Furthermore, staff uses an algorithm to classify each vehicle by ownership type to populate the Personal Vehicle Choice, Commercial Vehicle Choice, Government, and Rental models with stock from each sector. The California Air Resources Board's (CARB) Emission Factors model (EMFAC2014)[14] is used to obtain vehicle counts for specific bus and certain medium- and heavy-duty (MD-HD) truck classes. DMV data are used to identify MD-HD vehicles by region, truck type, and fuel type. **Table 4-3** displays vehicle stock by ownership and fuel type. While the LDV fleet is 90 percent gasoline vehicles, the freight stock is 65 percent diesel trucks.

Table 4-3: On-Road Registered California Vehicle Stock by Sector, 2015

Fuel Type	Light-Duty				Medium- and Heavy-Duty		Grand Total
	Commercial	Personal	Rental	Government	Truck and Motorhome	Other Buses (School, Shuttle,	
Diesel	404,808	150,245	1,504	5,545	685,041	10,460	**1,257,603**
Diesel-Electric Hybrid					401		**401**
Direct Electric							**0**
Electric	7,438	77,866	511	1,272	952	154	**88,193**
E85/Gasoline	280,633	1,140,411	82,115	51,254			**1,554,413**
Gasoline	2,759,199	22,331,585	323,039	140,485	273,442	27,150	**25,854,900**
Gasoline-Electric Hybrid	135,987	738,035	4,637	12,247		3	**890,909**
Hydrogen Fuel Cell	73	106		18			**197**
Natural Gas	8,445	15,956	21	3,222	8,436	5,137	**41,217**
Plug-In Hybrid	4,472	79,344	107	494			**84,417**
Propane					1,122	4,634	**5,756**
Total	**3,601,055**	**24,533,548**	**411,934**	**214,537**	**969,394**	**47,538**	**29,778,006**

Source: California Energy Commission Analysis of DMV data

14 California Air Resources Board. *EMFAC2014 Web Database*. https://www.arb.ca.gov/emfac/2014/.

Finally, the 2015 National Transit Database[15] (NTD) is used to obtain vehicle counts by transit mode and fuel type for transit vehicles. **Table 4-4** displays transit vehicle stock by transit mode and fuel type.

Table 4-4 Transit Vehicle Stock, 2015

Transit Vehicles	Natural Gas	Diesel	Battery Electric	Direct Electric	Gas	Hybrid Diesel	Hybrid Gas	Fuel Cell	LPG	NA	Total Fleet
Bus	*7,406*	*3,949*	*40*	*274*	*2,158*	*298*	*198*	*18*	*266*	*7*	*14,614*
Rail		*117*		*1,421*						*446*	*1,984*
Heavy Rail Passenger Car				*773*							*773*
Light Rail Vehicle		*12*		*644*							*656*
Commuter Rail Locomotive		*97*									*97*
Commuter Rail Passenger Coach		*8*								*446*	*454*
Automated Guideway Vehicle				*4*							*4*
Cable Car				*47*							*47*
Ferryboat		*18*									*18*
Street Car				*64*							*16*
Total Transit Vehicles	*7,406*	*4,084*	*40*	*1,806*	*2,158*	*298*	*198*	*18*	*266*	*453*	*16,679*

Source: California Energy Commission Analysis of National Transit Database

Fuel Consumption

In 2015, the total amount of energy consumed by the transportation sector in California was equal to 23.2 billion gallons of gasoline,, including 15.5 billion gallons of finished gasoline and 3.7 billion gallons of diesel. The 2015 fuel consumption data are obtained from the state's Board of Equalization. Because fuel is taxed in California, the Board of Equalization collects data on all petroleum fuels sold in the state, which Energy Commission staff can analyze to determine reliable estimates of fuel consumption.

Vehicle Miles Traveled

The Energy Commission's Supply Analysis Office has developed a method to estimate total VMT in the base year of the forecast, by fuel type, as described in Appendix B. The transportation forecast then uses a calibration process to align VMT for 2015 to the estimate.

The process starts when LDV trip links are distributed to Urban Travel and Intercity Travel model inputs based on the ratio of short-distance and long-distance trips and trip lengths collected from Caltrans' California Statewide Travel Demand Model (CSTDM).[16] Resulting light-duty VMT are summed across the Energy Commission models and subtracted from the Supply Analysis Office estimate for light-duty VMT. The difference is used as a target to adjust the Urban Travel model VMT.

15 Federal Transit Administration. *The National Transit Database*. August 17, 2017. https://www.transit.dot.gov/ntd.

16 California Department of Transportation. *California Statewide Travel Demand Model*. 2012. http://www.dot.ca.gov/hq/tpp/offices/omsp/statewide_modeling/cstdm.html.

In the current forecast, the difference between bottom-up model totals and statewide estimated VMT for medium- and heavy-duty vehicle VMT was small, so no calibration was required. Miles-per-vehicle data for service trucks, motor coaches, school buses, shuttle buses, transit demand response, motor homes, and refuse trucks are drawn from CARB's EMFAC2014 data. Urban Transit vehicle VMT are drawn from the Federal Highway Administration's National Transit Database. Freight truck VMT is a bottom-up calculation from freight cargo volume, truck payload, and the fraction of movement when trucks are empty.

Passenger Miles

Passenger miles traveled is an important measure of overall travel and serves as an input to the Urban and Intercity Travel Demand models. Base-year passenger miles are calculated from vehicle miles traveled and passenger miles per vehicle, the latter of which is drawn from CSTDM. The share of travel among different transportation modes or modal share is calculated as a proportion of passenger miles for each travel mode. In 2015, passengers traveled more urban miles than intercity miles[17] in all modes except for air travel.

Freight Ton-Miles

Freight ton-mile data are obtained from the Federal Highway Administration's Freight Analysis Framework (FAF) 4.4,[18] which collects and categorizes data on freight movement from the Census Bureau's Commodity Flow Survey and other sources. Tons shipped and ton-miles of movement by commodity are necessary to the Freight Energy Demand model because the bulk density of different commodities have unique payload volume, meaning that the number of trucks to move a given volume varies by commodity. FAF data are organized by mode, commodity, and origin and destination, which allows for a better accounting of interstate and intrastate freight movement.

Aviation Data

The Federal Bureau of Transportation Statistics publishes a wealth of data pertaining to the passenger and freight aviation industries in the United States, including airplane capacity, load factor (that is, the percentage of seats filled per flight), and flight segment lengths. The Bureau also makes available a restricted dataset consisting of a 10 percent sample of all flight itineraries originating, terminating, or passing through the United States, from which can be inferred ticket prices and historical passenger miles.[19] Finally,

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17 *Urban travel* is defined by the Energy Commission as trips under 50 miles. *Intercity travel* is defined as trips of more than 50 miles.

18 Oak Ridge National Laboratory. *Freight Analysis Framework Version 4*. July 13, 2017. http://faf.ornl.gov/fafweb/.

19 Bureau of Transportation Statistics. *Airline Origin and Destination Survey (DB1B)*. https://www.transtats.bts.gov/Tables.asp?DB_ID=125&DB_Name=Airline%20Origin%20and%20Destination%20Survey%20%28DB1B%29&DB_Short_Name=Origin%20and%20Destination%20Survey.

a report from the International Air Transport Association provides the relationship between ticket prices and air travel demand.[20]

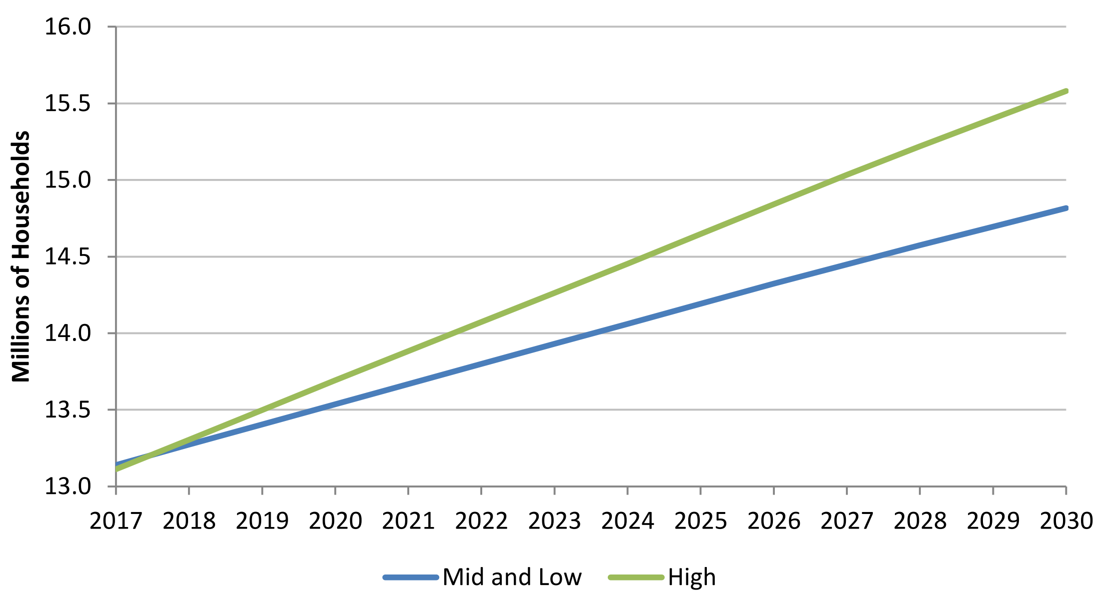
Projected Inputs

Projected inputs incorporate expected changes in variables such as fuel prices, income, population, and so forth. The values of these variables are determined outside the model by staff as well as various forecasting agencies and sources. The uncertainty in projected inputs is the rationale for having different demand cases (high, medium, and low).

Economic and Demographic Forecasts

Energy Commission staff used population projections consistent with the common energy demand cases as input for the Personal Vehicle Choice model. In the revised forecast, staff used one population forecast from California Department of Finance and two projections for household population: a projection for the high case and a projection for both mid and low cases. The household projections are presented in **Figure 4-3.**

Figure 4-3: Projected California Household Population

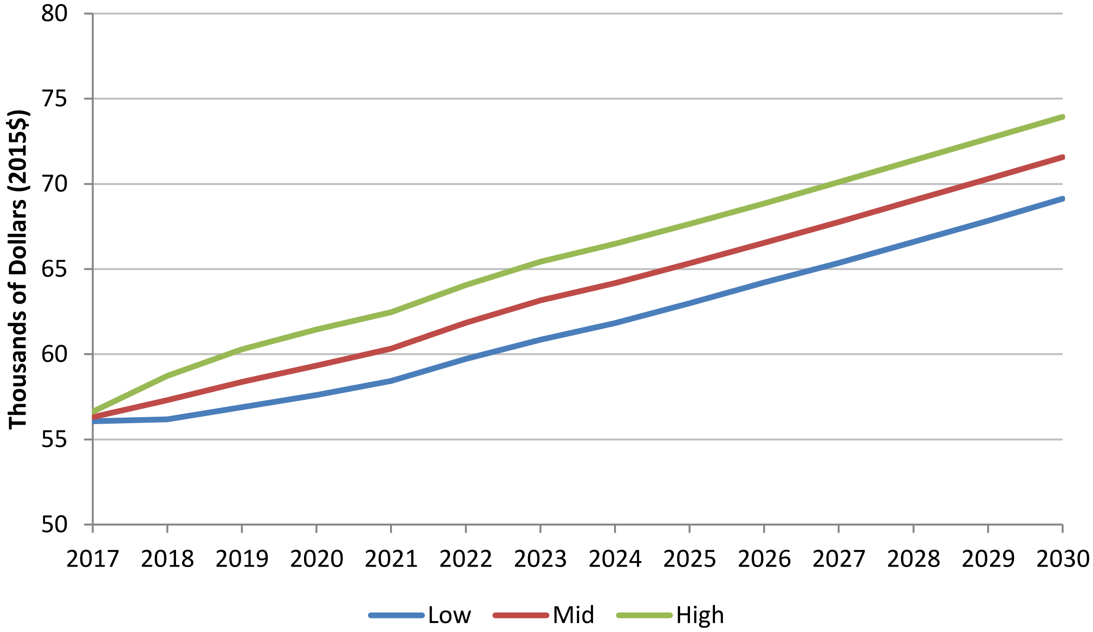


Sources: California Energy Commission and California Department of Finance

In addition to population and households, three projections for both per capita income and gross state product are used in the forecast, as shown in **Figures 4-4** and **Figure 4-5.**

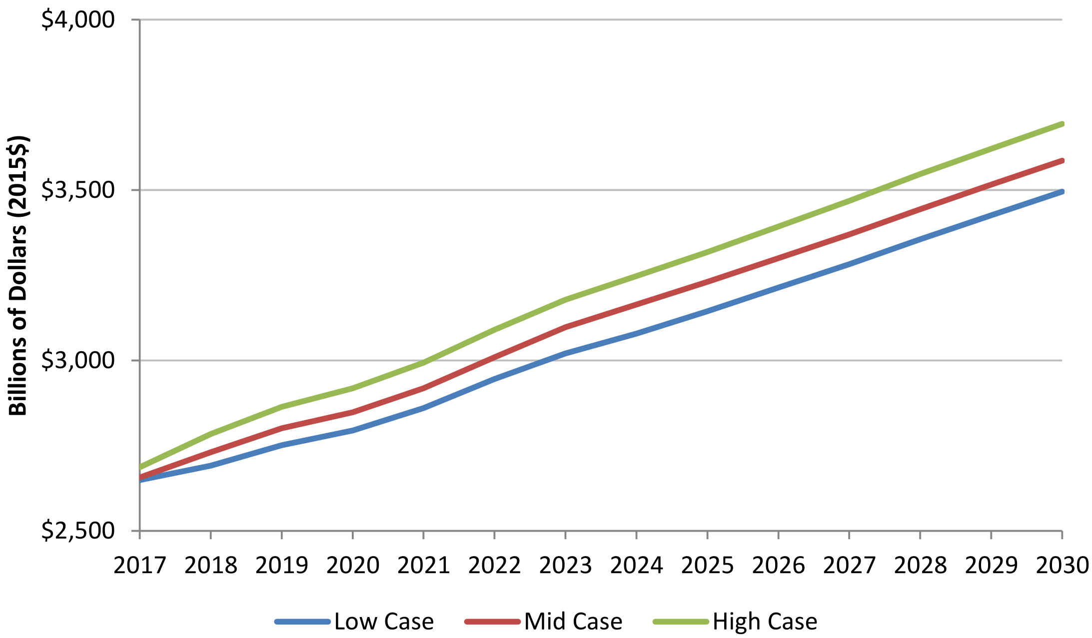
20 International Air Transport Association, *Air Travel Demand: IATA Economics Briefing No. 9*, April 2008. http://www.iata.org/publications/economic-briefings/air_travel_demand.pdf.

Figure 4-4: California Per Capita Personal Income Forecast



Source: Moody's Analytics.

Figure 4-5: California Gross State Product Forecast



Sources: Moody's Analytics

Light-Duty Vehicle Attributes

Vehicle attributes refer to characteristics such as vehicle price, fuel economy, range, performance, cargo capacity, and refueling time. These attributes affect the choices of vehicles that are purchased in the marketplace and, in turn, influence the vehicle class and fuel type composition of the forecast statewide fleet. Moreover, projections of fuel economy directly influence the Energy Commission's forecast of fuel consumption.

Attributes affect the decisions made by consumers and businesses about the types of new vehicles that are purchased. Under an agreement with the Energy Commission, the National Renewable Energy Laboratory (NREL) developed projections for many of these attributes for various fuels and vehicle technologies in the light-duty sector. The collaborative process incorporated an iterative cycle of review and feedback with Energy Commission staff. For BEVs and PHEVs, some attributes such as vehicle price and range were generated by Energy Commission staff based on research.

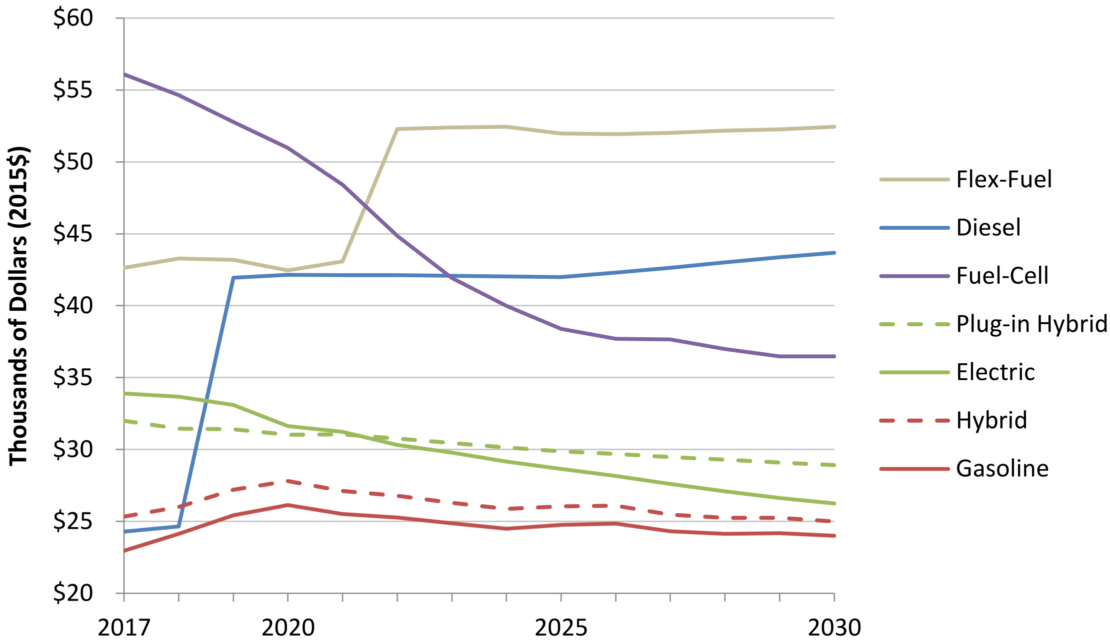
Vehicle Price

The Energy Commission's California Vehicle Survey, as well as market data and other surveys and studies, shows that vehicle prices tend to be an important factor in vehicle purchase decisions. In this section, vehicle price forecasts for combinations of fuel types and vehicle classes are described.

Estimates of vehicle prices over time were initially generated by NREL. However, on the occasions where there was a mismatch between the prices generated by NREL and the price observed by Energy Commission staff for the base year, staff calibrated NREL's price projections to match staff-observed values. For some classes of hybrid vehicles, staff generated hybrid vehicle prices based on NREL gasoline vehicle prices and estimates of additional hybrid component costs bases on International Council on Clean Transportation (ICCT) estimates.[21] **Figure 4-6** shows the final retail price projections for compact passenger cars (as an example) for all fuels and technologies covered by the transportation energy demand forecast.

21 German, John. 2015. *Hybrid Vehicles Technology Development and Cost Reduction.* http://www.theicct.org/sites/default/files/publications/ICCT_TechBriefNo1_Hybrids_July2015.pdf.

Figure 4-6: New Vehicle Price Projections for Compact Cars by Fuel Type, Mid Case



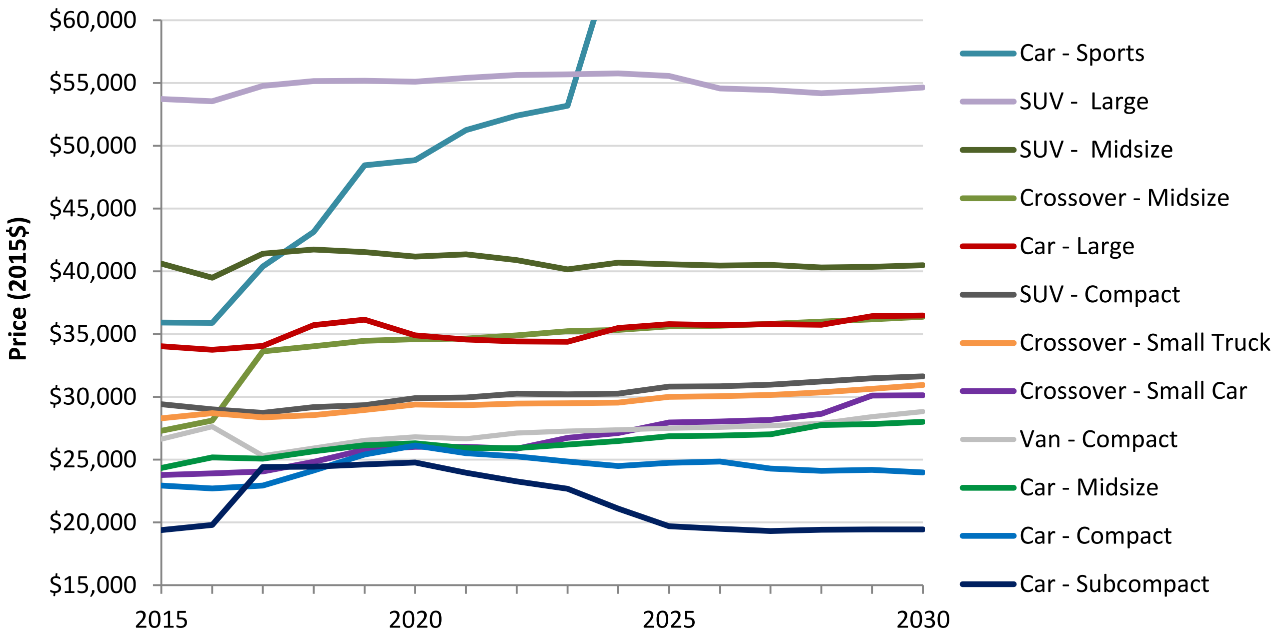
Source: California Energy Commission and National Renewable Energy Laboratory (NREL).

Several trends in vehicle prices are evident:

- Gasoline vehicle prices generally show a slight increase for most vehicle classes. This increase is due to the costs of improving fuel economy and engine performance.
- Hybrid and PHEV prices tend to move in the same direction as gasoline vehicle prices, but the cost premium over gasoline vehicles declines over time as the costs of battery and hybrid components decrease.
- BEV prices are projected to increase in the short run in response to larger battery size (and driving range) but then decline significantly over time as lithium-ion battery pack prices decline. (Battery prices are discussed further in Appendix C). The cost per mile of range for BEVs declines steeply over the forecast period. Battery capacity and price (and the subsequent impact on BEV prices and range) were two of the vehicle attributes to be differentiated by case and scenario, as explained in the “PEV Scenarios” section of this chapter. In the high case, BEV prices are estimated to be at or below parity with gasoline vehicles in many vehicle classes.
- FCEV prices are forecast to decline significantly over time due to improving manufacturing scale.
- In response to more stringent air quality standards and shifting federal and state policies, many diesel and flex-fuel models are expected to be pulled from the market by automakers over time. The remaining models tend to be models with higher performance and prices; this leads to an increase in forecast vehicle prices for these fuel types.

Price forecasts are also prepared for different classes of vehicles, as shown for gasoline-powered vehicles in in **Figure 4-7**.

Figure 4-7: New Vehicle Price Projections of Gasoline Vehicles by Class, Mid Case

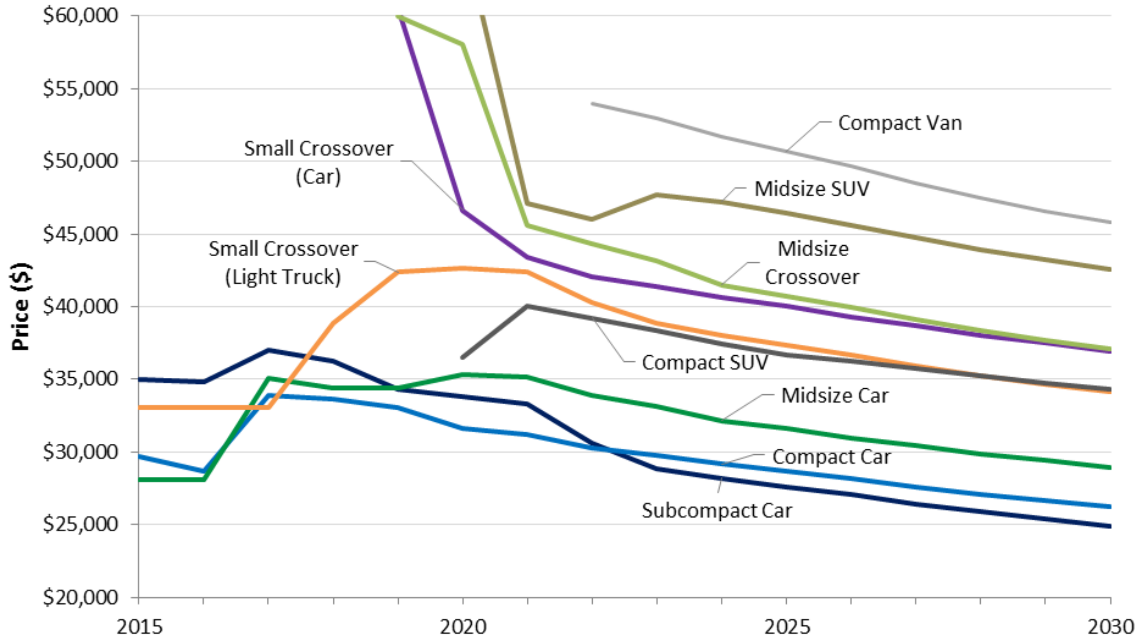


Source: California Energy Commission and NREL

In contrast to the smooth trends of gasoline-powered vehicles shown in **Figure 4-7**, **Figure 4-8** shows that the retail price forecast for BEVs is notably "bumpier" in the early years. This reflects the effect of having a few new models introduced with drastically different characteristics. Specifically, the rise in average prices between 2015 and 2020 is directly related to the release of BEVs with a longer driving range. (See **Figure 4-9** in the "Battery Electric Vehicle Range" subsection.) Beyond 2020, the vehicle price forecast anticipates that consumers will demand (and automakers will supply) vehicles with lower upfront costs, in exchange for more modest increases in driving range.

Energy Commission staff developed BEV prices based on a methodology that incorporated estimates of battery pack prices through 2030. This methodology was supported by a literature review and publicly available market forecasts made by private organizations and government agencies. For a further explanation of the sources considered, please see Appendix C, "Battery Pack and Plug-In Electric Vehicle Prices."

Figure 4-8: Projected Average BEV Price by LDV Class



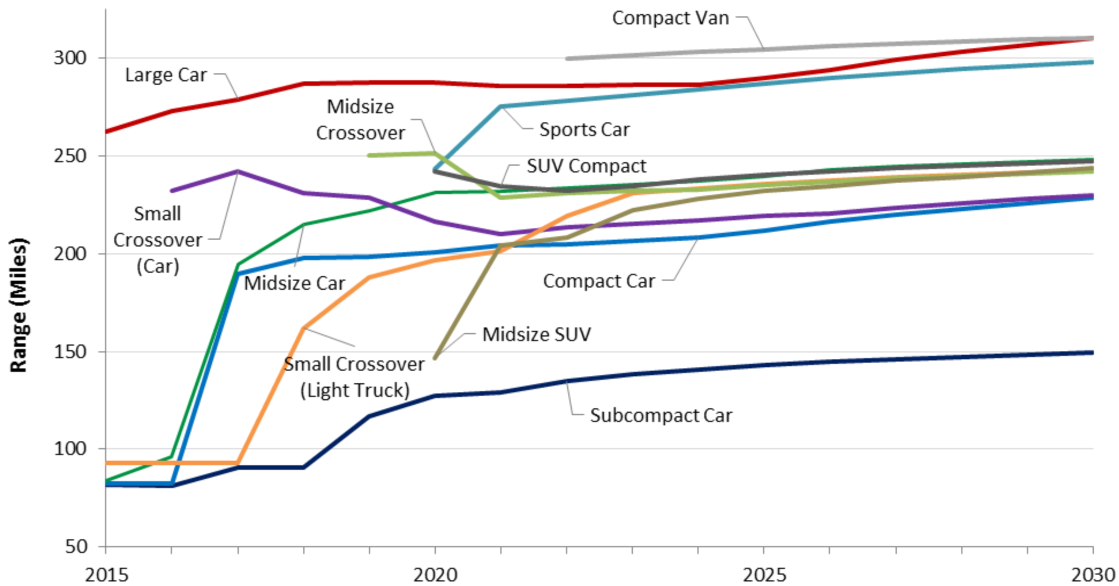
Source: Energy Commission. Note: Projected "Large Car" and "Sports Car" prices, which are dominated by luxury vehicles, are above the displayed price axis for the forecasted period.

Battery-Electric Vehicle Range

One key attribute for potential BEV buyers is driving range. In 2015, range for non-luxury BEVs was limited to 100 miles or less. However, beginning in Model Year 2017, several automakers announced plans for non-luxury BEVs with increased driving range. For the forecast period, average BEV range is expected to increase significantly by 2020, after which the range is anticipated to increase at a more moderate rate.

Figure 4-9 depicts the projected average driving range of light-duty BEVs in the mid demand case. These projections, generated by Energy Commission staff, are based on recent industry announcements, as well as assumptions about long-term manufacturer strategy in response to regulations, projected battery costs, and other market factors.

Figure 4-9: Projected Average BEV Range by LDV Class, Mid-Case

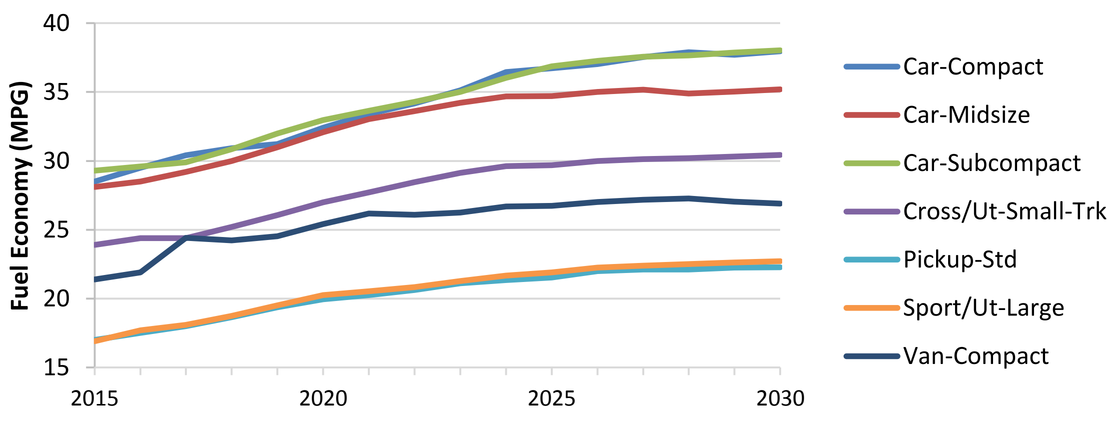


Source: California Energy Commission.

Fuel Economy

The average fuel economy of new LDVs is forecast to rise through 2025 as automakers respond to more stringent Corporate Average Fuel Economy (CAFE) standards. The increase in overall fuel economy is primarily a result of improvements in the fuel economy of gasoline vehicles, as well as increased hybridization and electrification of the statewide vehicle fleet. **Figure 4-10** focuses specifically on the average expected fuel economy for new gasoline LDVs in California.

Figure 4-10: Average LDV Fuel Economy in Gasoline Vehicles by Class



Source: California Energy Commission and NREL.

NREL provided projections of average fuel economy by fuel type and vehicle class. In some instances, Energy Commission staff adjusted NREL's fuel economy projections when 2017 model year values did not match staff observed values.[22] Other than for BEVs, a common set of fuel economy inputs was used in all demand cases.[23] Improvements in fuel economy generally met CAFE requirements. However, given recent developments, such as OEMs requesting the federal government to loosen CAFE standards and the potential willingness of the federal government to consider this request, staff decided that fuel economy improvements beyond the federal requirements would be unlikely.

Even though the fuel economy inputs are the same for all cases except BEV, the forecast projects differences in the final average fuel economy among the high, mid, and low cases. These differences are due to differing projections in the composition of new vehicle sales (in terms of both fuel type and class type) in each case. Thus, for example, due to higher BEV and PHEV sales, the high case would have a higher overall fuel economy than the mid and low cases.

Vehicle Technology Introduction

Energy Commission vehicle choice models include more detailed LDV classes than most models. As such, the forecast is more sensitive to the class in which a specific technology is introduced. **Table 4-5** shows the combination of vehicle classes and fuel types that are anticipated to be offered by manufacturers over the forecast period as well as the introduction years. The cells in green indicate NREL and the Energy Commission's prediction of the technology introduction year. Red indicates the year in which new models in a particular vehicle class were eliminated from the LDV market. The Energy Commission's LDV classes are described in more detail in **Table A-1** in Appendix A.

While gasoline vehicles dominate the vehicle market today, the number of available ZEV models has grown over time. With frequent announcements of new electrified vehicles, and shifts in automakers' strategic plans, the forecast projects a continued increase in BEV, PHEV, and FCEV offerings over the forecast period. **Figure 4-11** depicts the number of ZEV models that are anticipated to be offered over the coming years. In the mid case, the projected number of available models of these vehicles grows from fewer than 23 in 2015 to more than 200 in 2030.

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22 Staff compared NREL's projections of fuel economy in 2017 with actual 2017 fuel economy values from the EPA. In a few instances, NRELs projections were different from these observed values. In those instances, staff adjusted the NREL projected values to match observed fuel economy values from the EPA.

23 Staff generated two sets of fuel economy input scenarios for BEVs to reflect the uncertainty of the technology.

Table 4-5: Technology Introduction Table

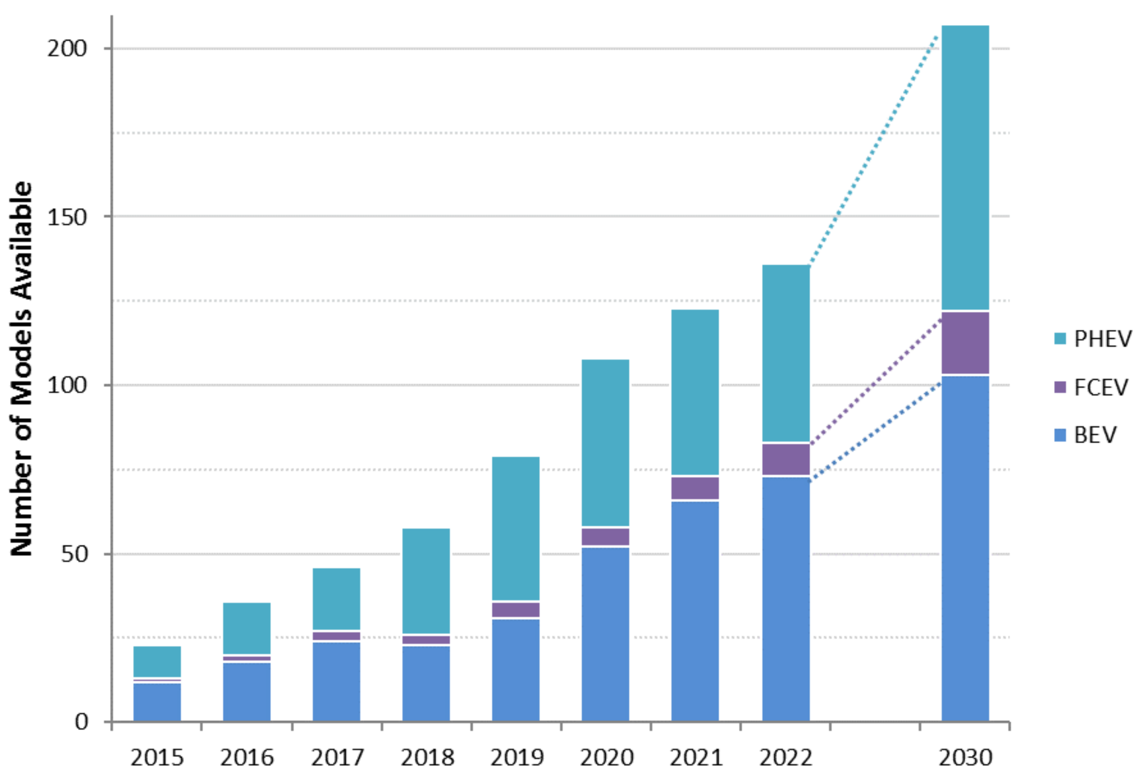
	Class	Gasoline	Hybrid	PHEV	BEV	FCEV	Diesel	FFV	PHFCV
1	Car - Subcompact						2017		
2	Car - Compact								
3	Car - Midsize					2017			
4	Car - Large						2017		
5	Car - Sport		2017		2020		2015	2015	
6	Crossover - Small Car			2018	2016				
7	Crossover - Small Truck						2015		
8	Crossover - Midsize			2016	2019	2027	2016		2019
9	Sports Utility - Compact			2019	2020	2020	2017		
10	Sports Utility - Midsize			2016	2019	2023			
11A	Sports Utility - Large		2019						
12	Van - Compact		2019	2017	2022				
13A	Van - Large			2020					
14	Pickup - Compact		2020	2019		2023	2016		
15A	Pickup - Standard		2017						

Exists 2015 - 2030	
Introduced	YEAR
Eliminated	YEAR
Never Introduced	
Introduced in High / Mid	YEAR

Source: California Energy Commission, NREL fueleconomy.gov

Makes and Models

Figure 4-11: Projected Number of Light-Duty ZEV Models, Mid Case



Source: California Energy Commission and NREL

Refueling Convenience and Duration

Each station is assumed to have the same service area and radius for each fuel type. For example, gasoline stations are calculated to have a service area of 17.5 square miles apiece, which works out to a radius of 2.4 miles. The travel time to a gasoline station from the edge of the related service area is assumed to be 5.0 minutes. Therefore, the rate of travel is 2.1 minutes per mile. This rate of travel is assumed the same for all other types of stations. The time to fueling station for other fuels is estimated as the product of the service radius and the assumed rate of travel.

Two scenarios were developed for the total number of future EV charging stations: one for the low case and another for the mid and high cases. The low case assumes that growth in the number of charging stations depends largely on state funding. The total number of nonresidential stations grows at an annual average of 2.9 percent and then declines to 2.6 percent growth, resulting in a five-minute travel time in 2050. The mid and high cases assume a more aggressive 7 percent growth rate every year until 2030, which achieves a five-minute travel time equivalent to gasoline by 2030. (Differences among scenarios for PEVs were discussed in the "PEV-Specific Scenarios" subsection.)

Hydrogen fuel cell vehicles and refueling stations are concentrated in what are considered three clusters for the forecast: Los Angeles, Orange, and Santa Clara Counties. The size and number of clusters are both estimated to grow to estimate changes in the time to refueling stations throughout the state. The estimate assumes that the goals of the 2016 AB 8 report will be achieved, including the operation of 90 stations statewide by 2022 and smaller numbers leading up to that in 2018-2021.[24] The number of new stations then increases gradually to 80 per year in 2026 and remains constant thereafter.

Today, the time to charge a BEV up to 80 percent charge is about 30 to 60 minutes, depending on the battery capacity. As battery capacity and vehicle range increase, the forecast assumes that refueling time will increase slightly in the short run. Starting in 2020, the forecast assumes (based on OEM plans) BEVs that support faster charging (150 kW and eventually 350 kW charging) will be released, dramatically decreasing charging times.

Clean Vehicle Incentives

Incentive programs are designed to encourage the widespread penetration of alternative fuel vehicles and affect vehicle choice either by decreasing price or increasing the utility of the vehicle. Current incentives reflected in the light-duty vehicle choice models are state rebates, federal tax credits, and high-occupancy vehicle (HOV) lane access. Below are the specific assumptions about these incentives in different PEV scenarios

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24 Baronas, Jean, Gerhard Achtelik, et al. 2017. *Joint Agency Staff Report on Assembly Bill 8: 2016 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California.* California Energy Commission. Publication Number: CEC-600-2017-002.

- The Clean Vehicle Rebate Program is a statewide program that offers $2,500 rebates to purchasers of BEVs, $1,500 rebates to purchasers of PHEVs, and $5,000 rebates to purchasers of FCEVs. In the mid and high scenarios, this incentive was discontinued after the end of the ZEV mandate in 2025, while in the low scenario, it ended in 2019.
- The federal tax credit offers a tax deduction of up to $7,500, depending on the vehicle purchased. Since the amount of tax credit for PHEVs depends on battery size, staff generated an average tax credit and adjusted that value based on staff's assessment of when the credits begin to expire for some OEMs. Different values were used for each scenario, but in the low scenario, the tax credit expires in 2019.
- HOV lane access allows alternative fuel vehicles to be driven in the carpool lane. Staff assumed that the incentive will discontinue after 2021 in the low case, and after 2025 in the mid and high case.

Accounting for Future Changes in Consumer Preferences

Chapter 3 described the role the California Vehicle Survey plays in identifying consumers' relative preferences for various vehicle attributes. This includes identifying consumers' general views on advanced vehicle technologies, such as PEVs or FCEVs. However, the survey can capture consumers' preferences only at a given moment in time; it cannot provide a trajectory for future vehicle technology preferences.

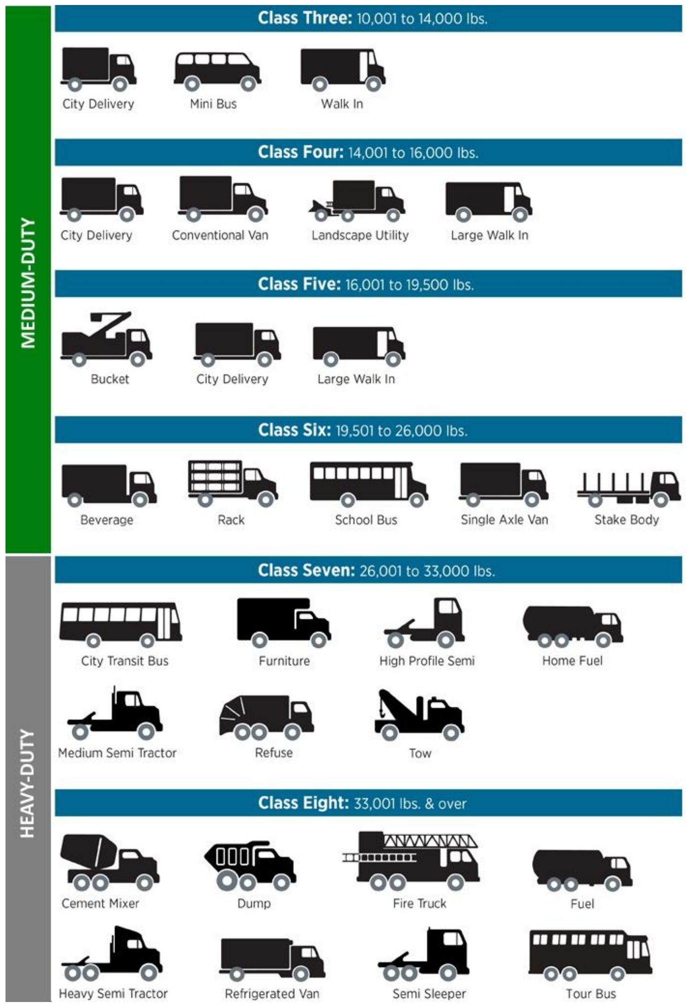
The continuous growth of PEVs in the California market supports the assumption of increasing preferences for these vehicles, whether due to OEM and utility advertising, word of mouth, or increasing education and awareness or all of these factors. While there is general agreement that consumer preferences for PEVs will increase over time, there is greater uncertainty regarding the amount of increase.

The Energy Commission's 2017 California Vehicle Survey confirmed that most of the consumers who own a PEV have higher preferences for ZEVs, and they are more likely to buy another ZEV when in the market for a new car. Staff used this finding to increase the fuel type preferences for PEVs in each forecast year by the share of PEVs in previous year's stock, in a two-step forecasting process, in all but the "low" PEV scenario. (See **Table 4-2** in the "PEV Scenarios" subsection.)

Medium- and Heavy-Duty Trucks

The Energy Commission classifies medium- and heavy-duty vehicles in several truck classes based on gross vehicle weight rating (GVWR) and vocation. The exact description of the Energy Commission's truck classes can be found in Appendix A (**Table A-2**). **Figure 4-12** summarizes the vehicle classes (3 to 8) by weight (but ignores vocation) and identifies each class as either medium- or heavy-duty.

Figure 4-12: Medium- and Heavy-Duty Vehicle Classes by GVWR



Source: Alternative Fuels Data Center, www.afdc.energy.gov/data/10381. Modified by California Energy Commission

Medium- and Heavy-Duty Vehicle Technology Introductions

The introduction of new or replacement vehicles in the Freight Energy Demand Model is influenced by historical truck retirement rates and economic growth factors. In regions where certain fleets are retired by regulatory requirement to achieve air quality improvements, such as the South Coast Air Quality Management District, Energy Commission staff also imposes a forced retirement and replacement to approximate the effect of these agencies' fleet rules.

Table 4-6 shows an assessment of fuels and vehicle technologies expected to be commercially available in each class of medium- and heavy-duty vehicles, by staff and H-D Systems, the Energy Commission's medium- and heavy-duty vehicle attribute consultant. As new or replacement vehicles enter the market, Energy Commission staff relies on the Argonne Truck 5.1 Model[25] (Truck Model) to identify the market shares of various fuel technologies. The Truck Model incorporates the Energy Commission's fuel price forecasts, as well as fuel economy and vehicle price forecasts generated by H-D Systems.

Table 4-6: Medium- and Heavy-Duty Vehicle Technology Introduction

Truck or Bus Class	Vehicle Type	Gasoline	Gasoline Electric Hybrid	Diesel	Diesel Electric Hybrid	Diesel Hydraulic Hybrid	Battery Electric Vehicles	Direct Electric Vehicles	Fuel Cell Vehicles	E85 (ethos engine)	Compressed Natural Gas (inc. Cummins Westport)	Liquefied Natural gas (LNG)	Propane
GVWR 3	GVWR 3		2020										
GVWR 4 to 6	GVWR 4 and 5		2020										
	GVWR 6												
GVWR 7 & 8	GVWR 7 & 8 Single Unit												
GVWR 8	Tractor-trailer (in-state day cab)							2019	2019				
GVWR 8	Refuse and Recycling												
GVWR 8	Tractor-trailer (interstate sleeper)												
Motorhomes	GVWR 3												
	GVWR 4 to 6												
Bus	Urban Transit								2021				
	MotorCoach												
	School Bus												
	Shuttle Bus												

Exists 2017 - 2030	
Introduced	YEAR
Never Introduced	

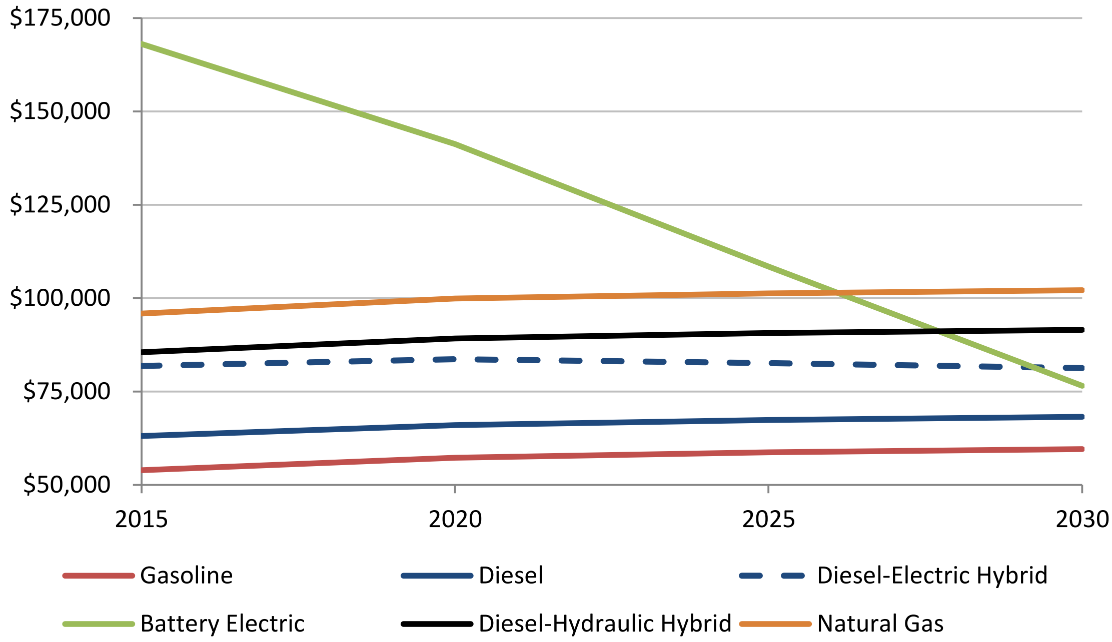
Source: California Energy Commission, H-D Systems. Many technologies marked as existing in 2015 are available only at low-volume production.

Vehicle Price Projections by Fuel Type and Technology

The upfront cost of the new vehicle is critical in predicting the market share of different fuel type alternatives. In the projections developed by H-D Systems, price trends for truck technologies are expected to remain relatively stable, with some notable exceptions. As an example, **Figure 4-13** highlights an expected rapid decline in price for battery-electric class 6 trucks. Similar reductions were visible for battery electric trucks in weight classes 3-5 as well (not pictured).

25 Argonne National Laboratory. *Truck Heavy Vehicle Market Penetration Model.* https://www.anl.gov/energy-systems/project/truck-heavy-vehicle-market-penetration-model.

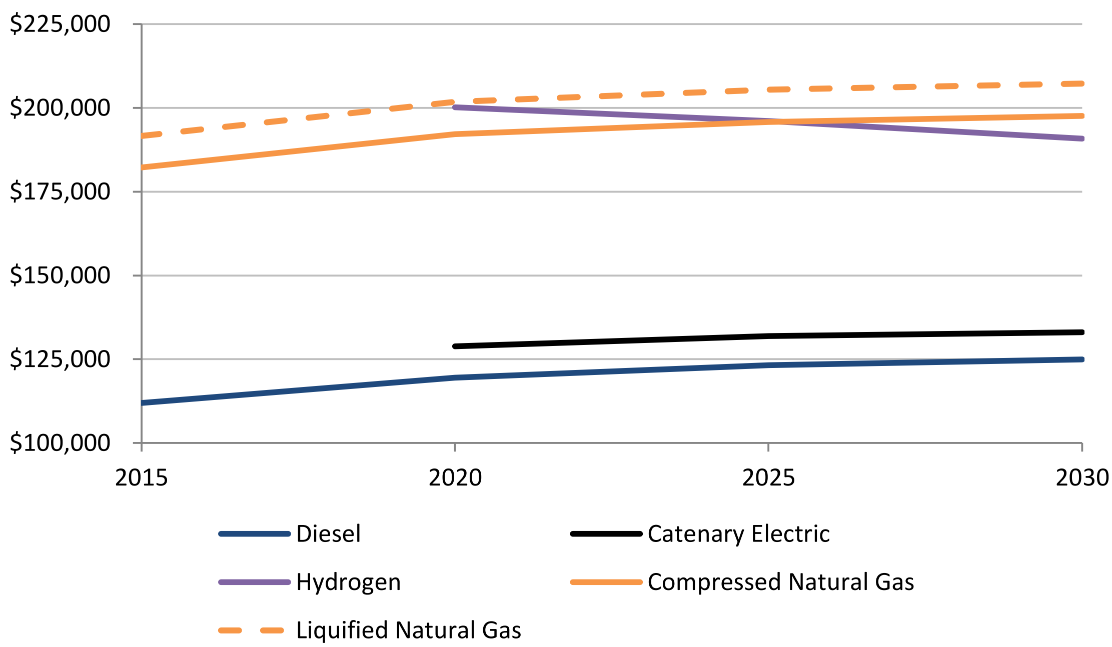
Figure 4-13: Class 6 Truck Price Projections



Source: California Energy Commission

In the heavier classes, diminishing prices for hydrogen fuel cell trucks were also apparent after the anticipated commercial introduction, as shown for Class 8 in-state tractor-trailers in **Figure 4-14.** Once they reach high-volume production, catenary electric trucks are also price-competitive in this class.

Figure 4-14: Class 8 (In-State Tractor-Trailer) Truck Price Projections



Source: California Energy Commission

Selection of Fuel and Technology Types for Truck Model

Staff identified multiple fuel and technology types for trucks for potential consideration in the Truck Model, including diesel, gasoline, compressed natural gas (CNG), liquefied natural gas (LNG), diesel-electric hybrid, gasoline-electric hybrid, diesel-hydraulic hybrid, dedicated ethanol (E85 Ethos), battery-electric, catenary-electric, and hydrogen fuel cell. However, for each truck class, the Truck Model is limited to a baseline technology and three alternatives. For this reason, a series of preliminary runs of the Truck Model were used to select fuels and technologies that projected the greatest market share (and remove fuels that did not).

No subsidy or voucher was applied in the low demand case. For the mid and high demand cases, the voucher amount is set at levels granted to date for ZEV, hybrid, and low NOx engines and was subtracted from the purchase price.

Key inputs and assumptions used by staff in selecting the fuels and technologies for each truck class under the Truck Model are noted here:

- Fuel price, vehicle price, and fuel efficiency are the main drivers in the Argonne Truck Model. Therefore, variations in these factors are responsible for creating the range of market share results for different fuel types and technologies.
- The duty life of new trucks varies by class and application type. This can be as low as 5 to 7 years for interstate long-haul tractor-trailers moving 80,000 to 200,000 miles a year or 20 years or longer for service vehicles trucks that transport a technician with tools or equipment a few times a day between service calls within a town.
- For all classes, staff explicitly included fuel and truck type combinations that have applied for incentives under CARB's Heavy-Duty Hybrid and Zero-Emission Truck and Bus Incentive Project.
- Gasoline-electric hybrid trucks were included in Truck Model runs for classes 3-6, while diesel-electric hybrid vehicles were included in remaining classes except motorhomes and tractor-trailers.
- For classes 3-6, staff divided each class into two subgroups based on the distance of typical trips. This differentiation allowed staff to consider more carefully battery-electric trucks based on the anticipated driving range. The battery electric and electric hybrid fuel types were applied where trips are typically less than 100 miles in urban driving conditions. Where trips average more than 100 miles (or are considered "varied), natural gas, propane, and E85 trucks were included instead. As a result, hybrid and battery electric trucks may be underrepresented among the "varied" duty-cycle trucks, while gaseous and E85 trucks may be underrepresented among the shorter duty-cycle trucks. However, when combined relative to the base year values, these differences are small and should even out.
- For classes 3-5, the dedicated E85 "Ethos" engine developed by Cummins was included.

- For class 8 tractor-trailers, catenary-electric and hydrogen fuel cell options were included in preliminary runs of the Truck Model. The catenary-electric truck proved sufficiently competitive to be included in final runs applied to the subset of class 8 port drayage trucks. The incremental price of catenary-electric trucks was low enough that staff entered them in the Truck Model with no subsidy or voucher.

Aviation Projections

The Energy Information Administration (EIA) publishes projections regarding aircraft characteristics as part of its *Annual Energy Outlook,*[26] such as fuel efficiency, aircraft capacity and ticket prices. The Aviation model was developed to incorporate these projections after adapting them for the California market, where appropriate. The Aviation model also incorporates the fuel price and economic and demographic projections used across the other transportation models.

Transportation Fuel Prices and Fuel Cost per Mile

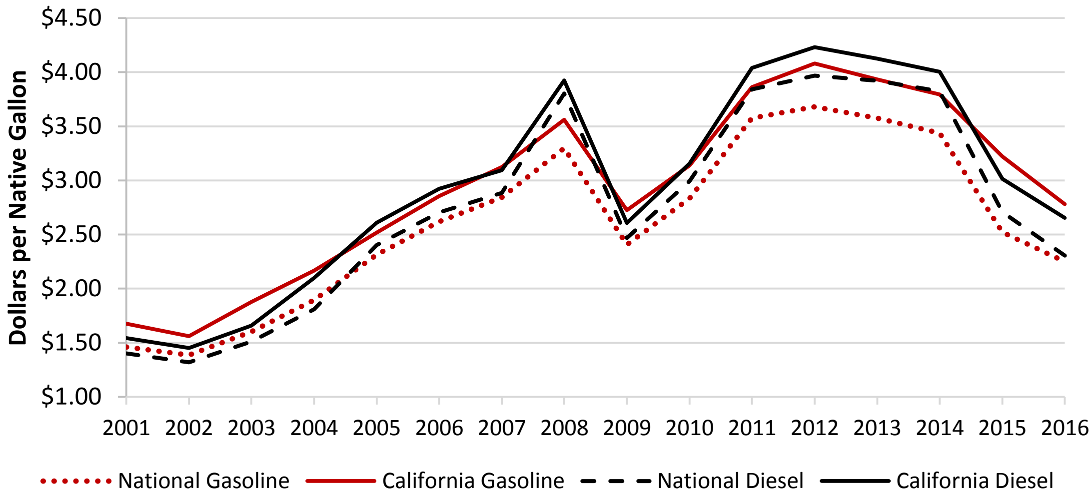
Within the forecast, fuel prices affect both the type of vehicles purchased and the aggregate number of miles traveled per year. Specifically, higher prices for a particular fuel makes a consumer less likely to buy a vehicle that uses it, less likely to use it in a vehicle that can utilize multiple fuels, less likely to use that vehicle for travel, and more likely to buy a vehicle with greater fuel economy. All transportation fuel price forecasts are developed by the Energy Commission staff (with the exception of hydrogen prices).

Gasoline, Diesel, and E85 Price Projections

California fuel price scenarios for gasoline and diesel begin with the EIA's nationwide forecasts of gasoline and diesel prices in its 2017 *Annual Energy Outlook*. To transform EIA's national transportation fuel price cases into California transportation fuel price scenarios, Energy Commission staff considered the historical relationship between annual U.S. retail prices and California retail prices. Due to state taxes and regulations, California fuel prices are typically higher than those in the rest of the United States. These historical comparisons are shown in **Figure 4-15**.

26 Energy Information Administration. January 5, 2017. *Annual Energy Outlook*. https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf.

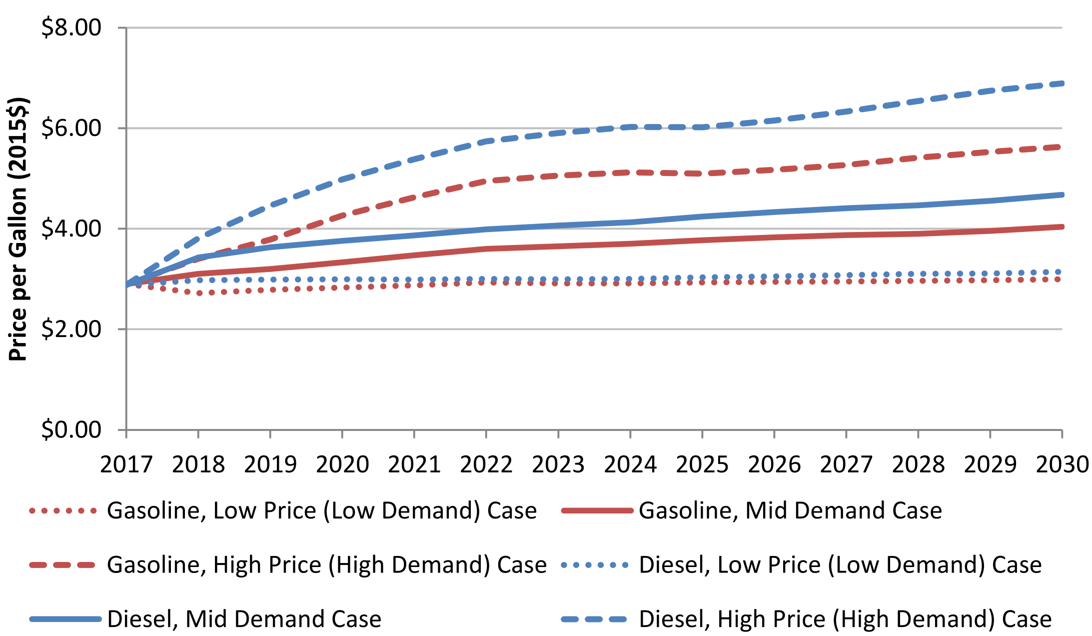
Figure 4-15: Comparison of Historical California and National Gasoline and Diesel Prices



Source: U.S. EIA

In addition to historical relationships, the gasoline and diesel price forecasts incorporated changes in state and federal taxes and three carbon price forecasts. The resulting price scenarios for the low, mid, and high demand forecasts are shown in **Figure 4-16.**

Figure 4-16: Projected California Gasoline and Diesel Prices (Statewide Average)

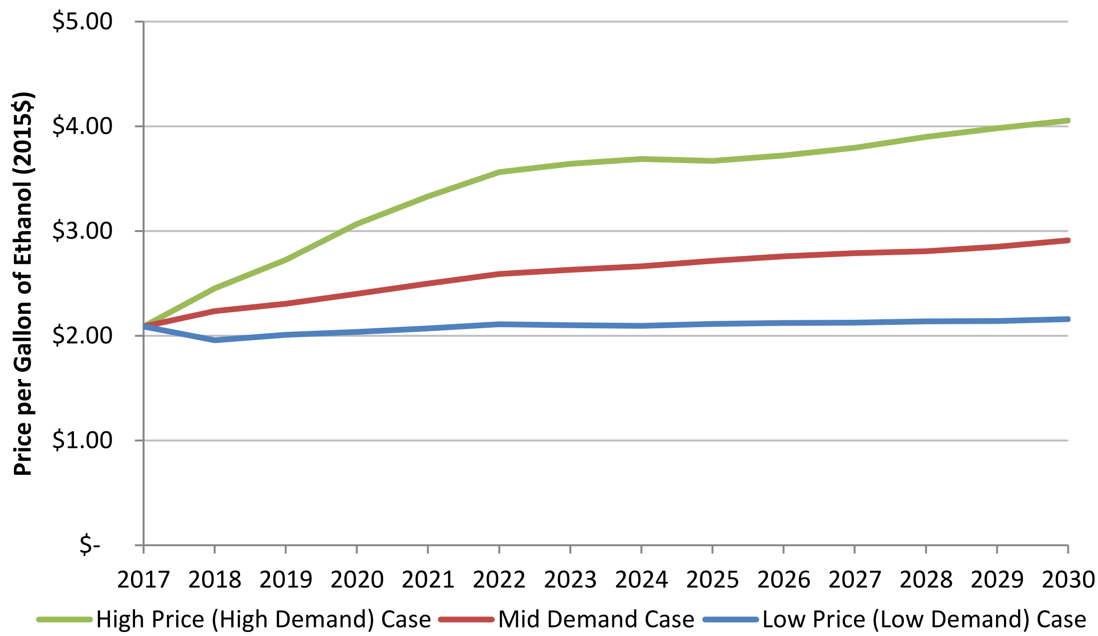


Source: California Energy Commission

Projected E85 prices were derived from projections of gasoline prices. This reflects the fact that one gallon of E85 is the energy equivalent of roughly 0.72 gallons of gasoline and the assumption that E85 will be priced at 72 percent of the price of gasoline. **Figure**

4-17 shows E85 prices continuing to increase over the entire forecast period in each case, reflecting changes in the price of gasoline.

Figure 4-17: Projected E85 Prices



Source: California Energy Commission. Note: one gallon of E85 is the energy equivalent of roughly 0.72 gallons of gasoline.

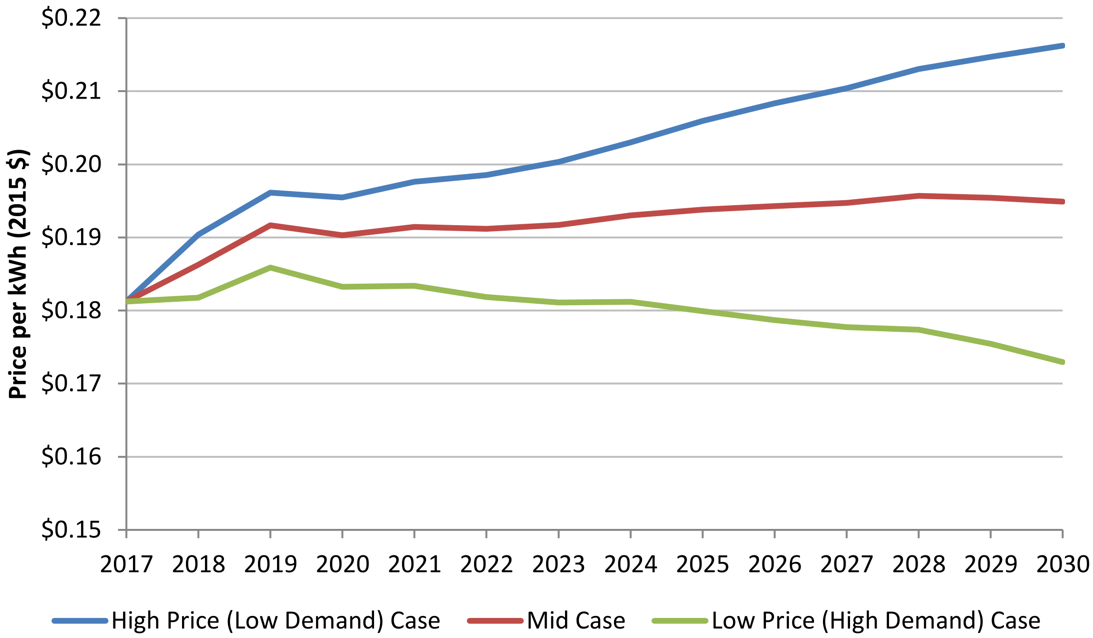
Electricity, Natural Gas, and Hydrogen Price Projections

As stated in **Table 4-1**, the demand cases used alternative fuel price scenarios that matched the design of each demand case. This means for electricity, natural gas, and hydrogen, the "low price scenario" is used in the high demand case, and the "high price scenario" is used in the low demand case.

Electricity Prices

Projected electricity prices for transportation use a statewide residential rate for light-duty vehicles and a statewide industrial rate for transit electricity. These are based on factors discussed in the broader California energy demand forecast. The projected rates assumed no changes in charging behavior, the future design of special tariffs for electric vehicle customers, or time-of-use rates.

Figure 4-18: Projected Electricity Prices for Light-Duty Transportation



Source: California Energy Commission.

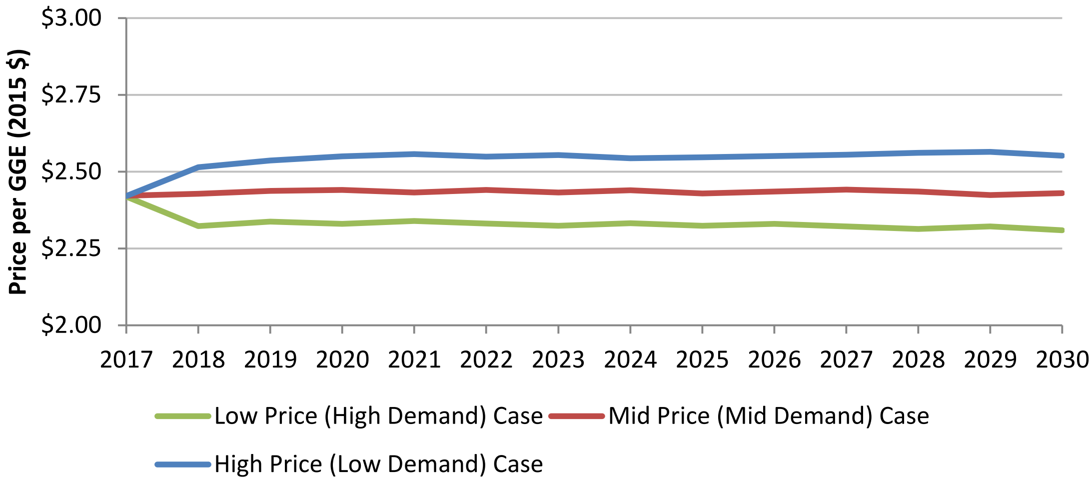
In **Figure 4-18** electricity prices decline in the low price scenario but increase in both the mid and high price cases.

Natural Gas Prices

Energy Commission staff generates an end-user price forecast, using the North American Natural Gas (NAMGAS) Model, for residential, commercial, and industrial users. Details about the model and these price forecasts can be found in the *2017 Draft Natural Gas Market Trends and Outlook*.[27] Since there is no natural gas forecast specifically for transportation end users, a nationwide forecast of transportation natural gas from EIA was used to determine how the price for transportation users varies with the prices for residential, commercial, and industrial users. Transportation end users pay a substantial premium to the price paid by other end users. EIA forecasts this premium to decline over time, which results in prices remaining essentially flat after 2018 for transportation end users throughout the United States and California, as seen in **Figure 4-19**.

27 Brathwaite, Leon D, Jason Orta, Peter Puglia, Anthony Dixon, and Robert Gulliksen. 2017. *2017 Natural Gas Market Trends and Outlook*. California Energy Commission. Publication Number: CEC-200-2017-009-SD.

Figure 4-19: Projected Compressed Natural Gas Prices for Transportation



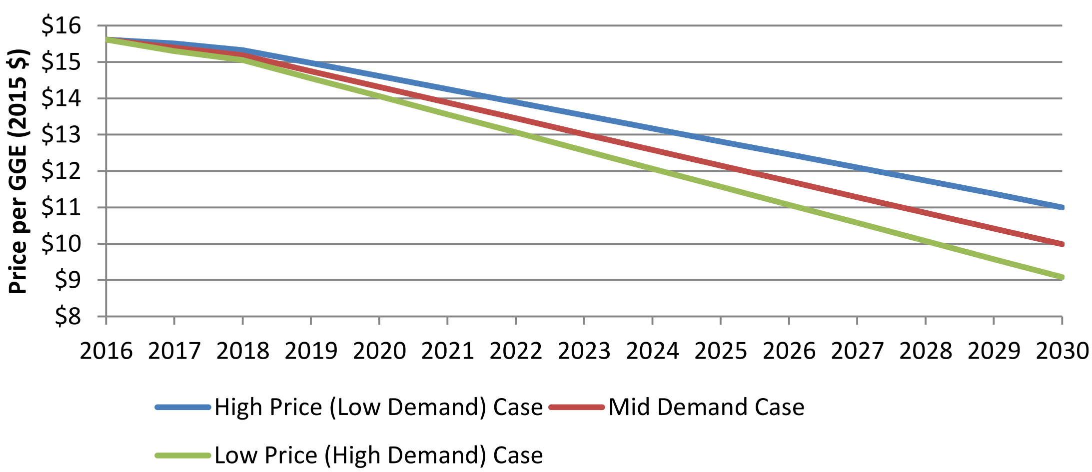
Source: California Energy Commission and Energy Information Administration.

Hydrogen Prices

Hydrogen prices are consistent with projections developed by NREL as part of the 2017 version of an annual hydrogen station assessment by the Energy Commission and CARB. This price incorporates the end-user prices for natural gas and electricity developed for the *2017 IEPR*, plus estimates of other supply costs and margins generated by NREL. The price also incorporates the state requirement that hydrogen produced meet a 33 percent renewable content requirement, which is assumed to add 50 cents per kilogram.

Figure 4-20 shows the price scenarios for hydrogen dispensed as a transportation fuel at public refueling stations. The price, though listed in GGE, is almost identical to the price in kilograms: 1 GGE is equivalent to 1.019 kilograms of hydrogen. Most fuel cell electric vehicles are offered for lease by automakers with limited complementary hydrogen refueling for a fixed number of years.

Figure 4-20: Projected Hydrogen Prices for Transportation

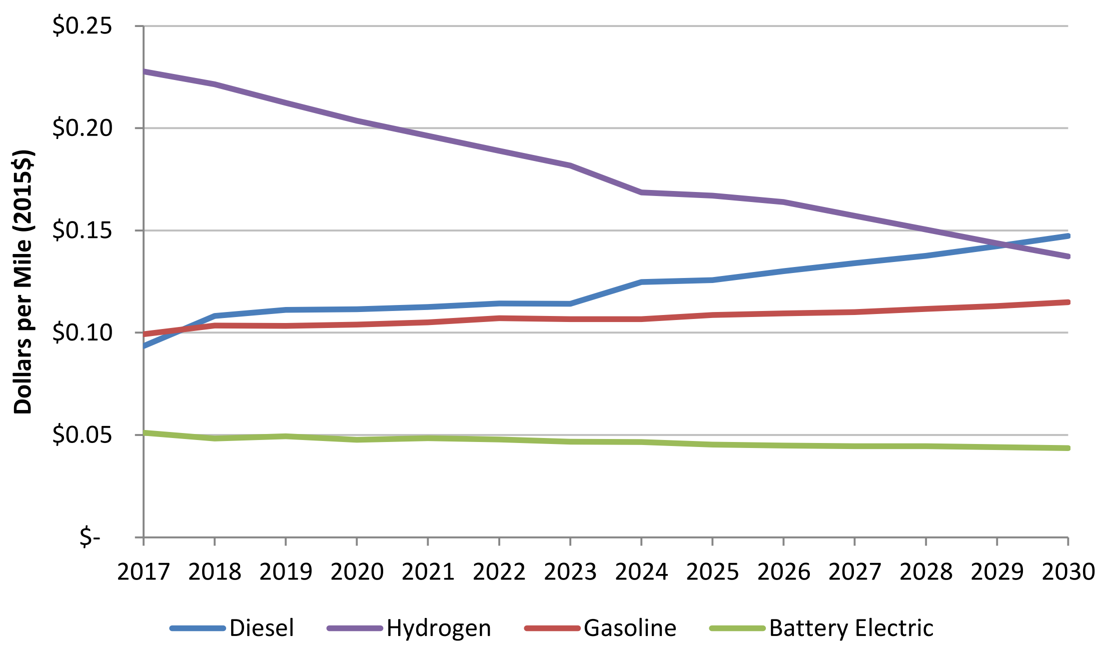


Source: California Energy Commission and National Renewable Energy Lab (NREL).

Overall On-Road Fuel Cost Per Mile

While the costs for each fuel type can be compared directly using generic energy units such as GGE, the light-duty vehicle demand models do not directly use fuel prices in this way. Instead, the models compute fuel cost per mile using projections of energy prices forecasts and fuel economy. As an example of the comparative costs, **Figure 4-21** depicts the fuel cost per mile by different fuel and vehicle technologies for midsize cars. Through the forecast period, the cost per mile for BEVs is lower than all other technologies in the compact class and remains consistent at just under $0.05 per mile. Despite an increase in gasoline prices, the fuel cost of $0.11 per mile for midsize gasoline cars is forecast to remain roughly constant, due to projected increase in fuel economy.

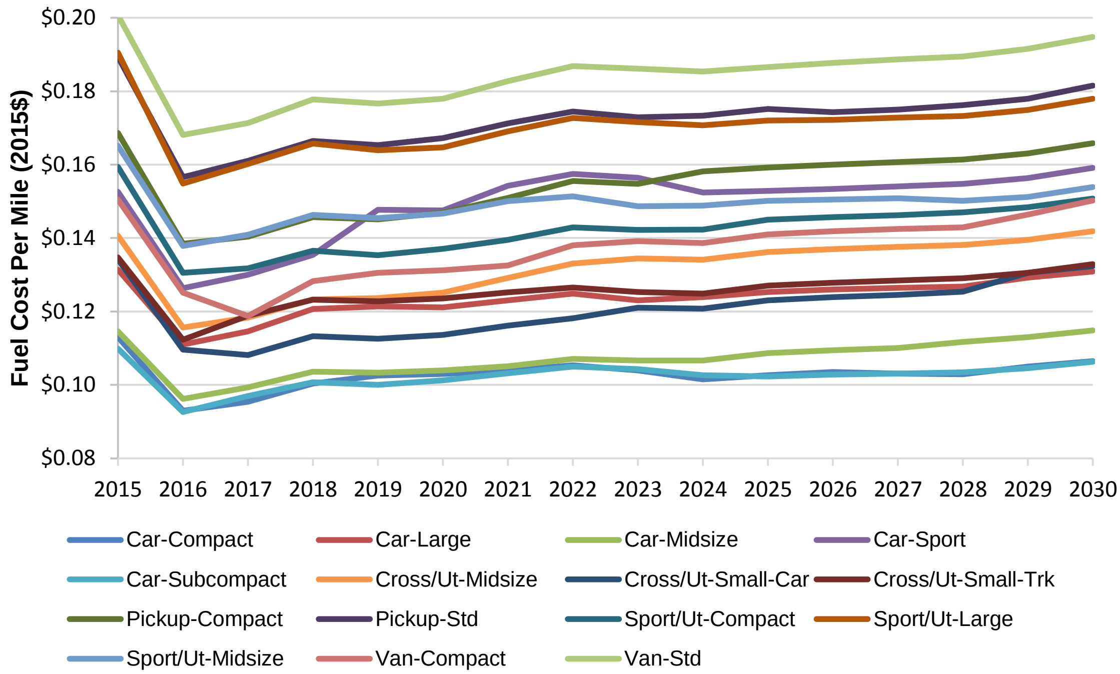
Figure 4-21: Fuel Cost per Mile for Midsize Cars, Mid Demand Case



Source: California Energy Commission.

The cost per mile across multiple gasoline vehicle classes, as shown in **Figure 4-22**, shows the interplay of increasing fuel economy and gasoline prices. After the initial price drop in 2016, the impact of increasing gasoline prices in subsequent years is tempered by a simultaneous increase in gasoline vehicle fuel economy across all classes.

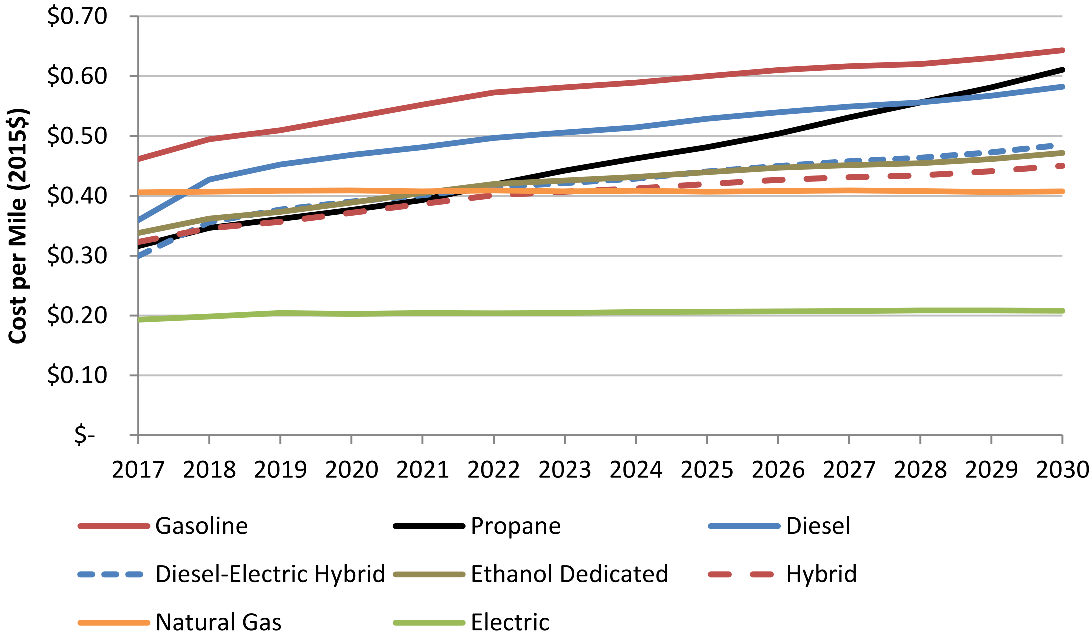
Figure 4-22: Fuel Cost per Mile of Gasoline Vehicles by Class, Mid Case



Source: California Energy Commission.

The Truck Model also considers the cost per mile for all commercially available fuel types in medium- and heavy-duty trucks. **Figure 4-23** shows the cost per mile for the fuel types available for medium-duty classes 4 to 6, which exhibits the most commercially available technologies and contains a large truck population. **Figure 4-23** shows that, in this class, electric vehicles have the lowest cost per mile, which helps offset the higher incremental price for the truck. Gasoline trucks have the highest cost per mile, followed by diesel.

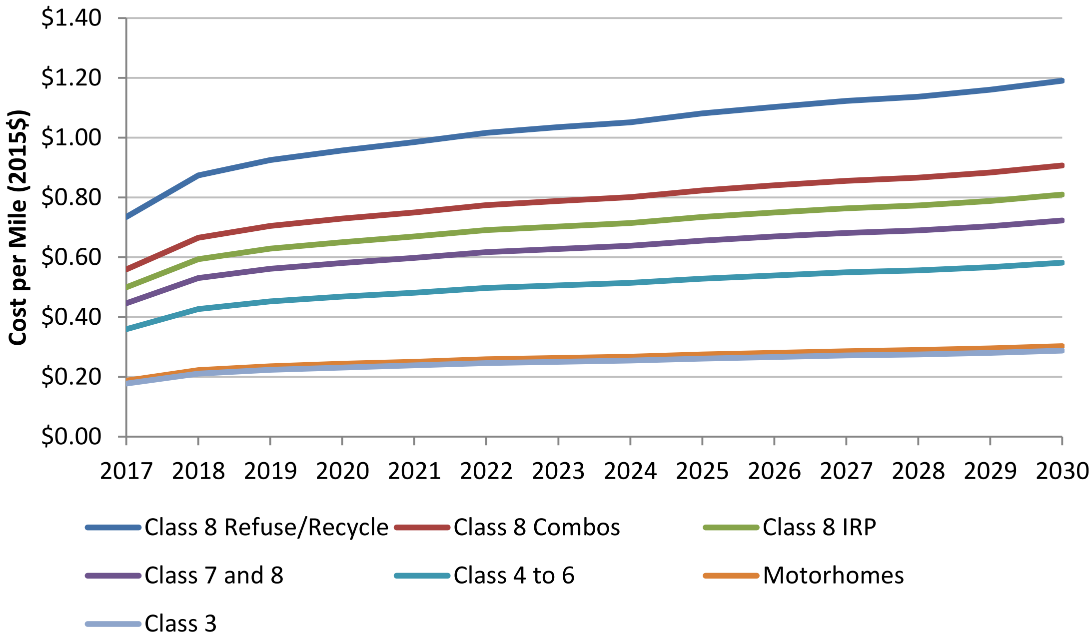
Figure 4-23: Fuel Cost per Mile for Classes 4 to 6 Trucks, Mid Case



Source: California Energy Commission.

The cost per mile for diesel-fueled trucks of several classes is shown in **Figure 4-24**. The trend lines indicate that the cost per mile generally follows the weight of trucks. The heavier the vehicle class, the more it typically costs per mile due to lower fuel economy. The fuel economy can also vary by truck application or duty cycle. Refuse and recycling trucks, for example, have the most stops and starts and, therefore, have the lowest fuel efficiency and highest cost per mile.

Figure 4-24: Fuel Cost per Mile of Diesel Trucks by Class, Mid Case



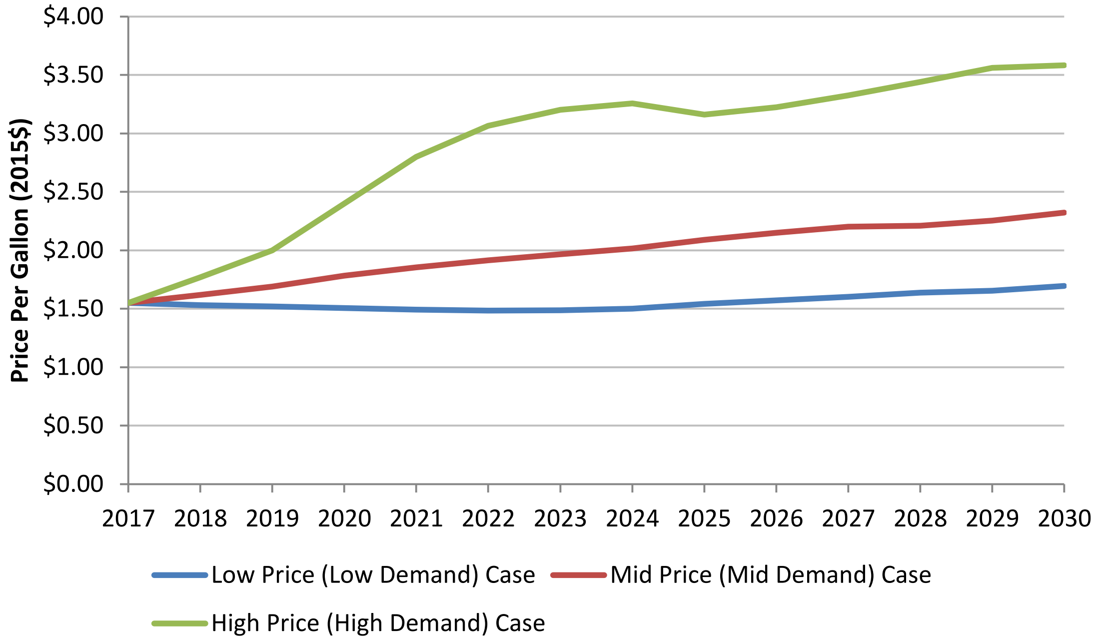
Source: California Energy Commission.

Jet Fuel Prices

Historically, California jet fuel prices are almost identical to U.S. jet fuel prices. Consequently, the EIA price forecast scenarios were used as the California projected price scenarios shown in **Figure 4-25.** The exception is for 2017, when the three projected prices were replaced by a combination of historical prices and a price estimate from the *EIA Short-Term Energy Outlook.*[28]

28 Energy Information Administration. *Short-Term Energy Outlook.* https://www.eia.gov/outlooks/steo/.

Figure 4-25: Projected Jet Fuel Prices



Source: California Energy Commission and Energy Information Administration (EIA)

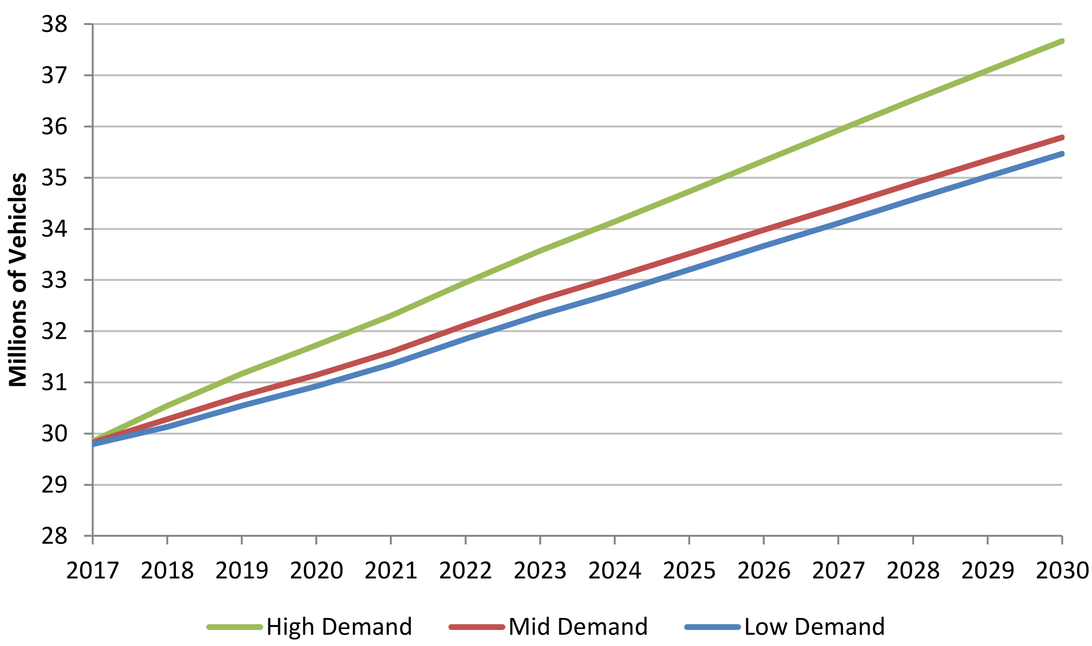
CHAPTER 5:
Transportation Energy Demand Forecast

To generate a forecast of fuel consumption, the transportation models generate a forecast of light-duty vehicle stock by class and fuel type, as well as the market share of new trucks by fuel type in different classes of medium- and heavy-duty vehicles. The following sections will first discuss the vehicle demand forecast before moving on to the discussion of the fuel demand forecast.

Light-Duty Vehicle Stock Forecast

In the vehicle demand models, population and household income are the primary drivers of the size of California's light-duty fleet. Therefore, in the vehicle stock forecast, the light-duty fleet size grows the most in the case where population and household income growth are highest. The light-duty fleet, which consisted of almost 30 million vehicles in 2015, is projected to rise to about 35.5 million in 2030 in the low demand case and 37.7 million vehicles in 2030 in the high demand case. The total forecast of light-duty vehicle stock is shown in **Figure 5-1**.

Figure 5-1: Light Duty Vehicle Stock Forecast



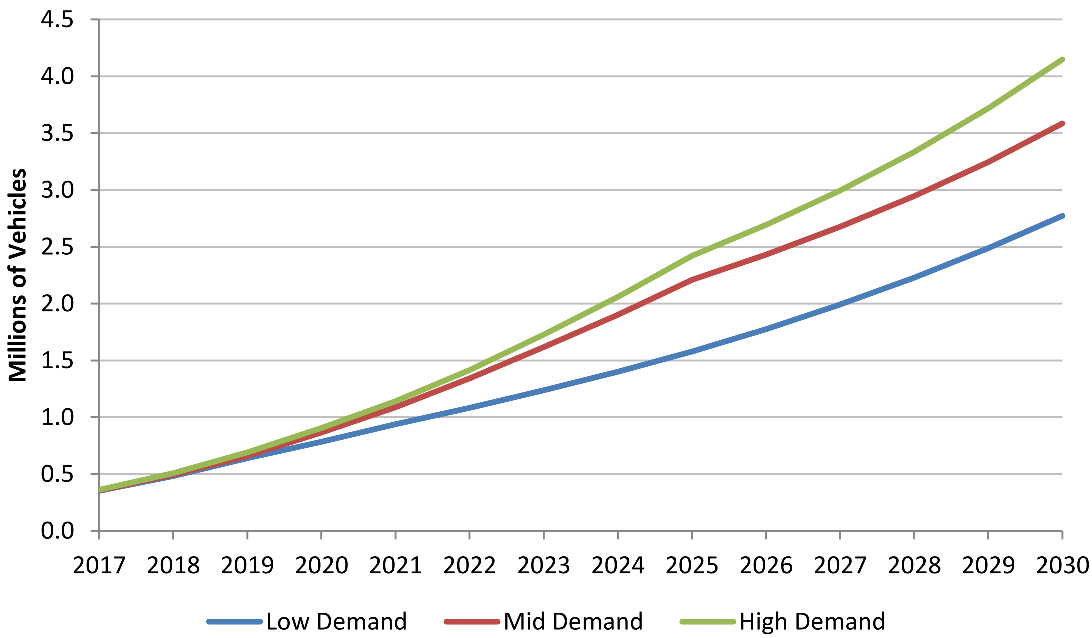
Source: California Energy Commission

Zero-Emission Vehicle Stock Forecast

California benefits from a suite of policies and goals intended to improve air quality, reduce greenhouse gases, and reduce petroleum dependence. The electrification of light-duty vehicles, whether via BEVs, PHEVs, or FCEVs, will play a critical role in achieving all these objectives. For this reason, during development of the *Revised Transportation Energy Demand Forecast, 2018-2030*, staff devoted extra time and attention to this subject. This includes convening a new subsection of the DAWG, focused on the growth and characteristics of PEVs.

Based on the inputs and scenarios described in Chapter 6, the forecast stock of ZEVs (used here to include BEVs, PHEVs, FCEVs, and plug-in hybrid FCEVs) is expected to rise from slightly more than 350,000 in 2017 into the multimillions by the end of the forecasted period (2030). **Figure 5-2** presents the forecasted ZEV and PHEV stock for the three main demand cases. As shown, forecasts for ZEV stock range from about 2.8 million in the low case to 4.1 million in the high case.

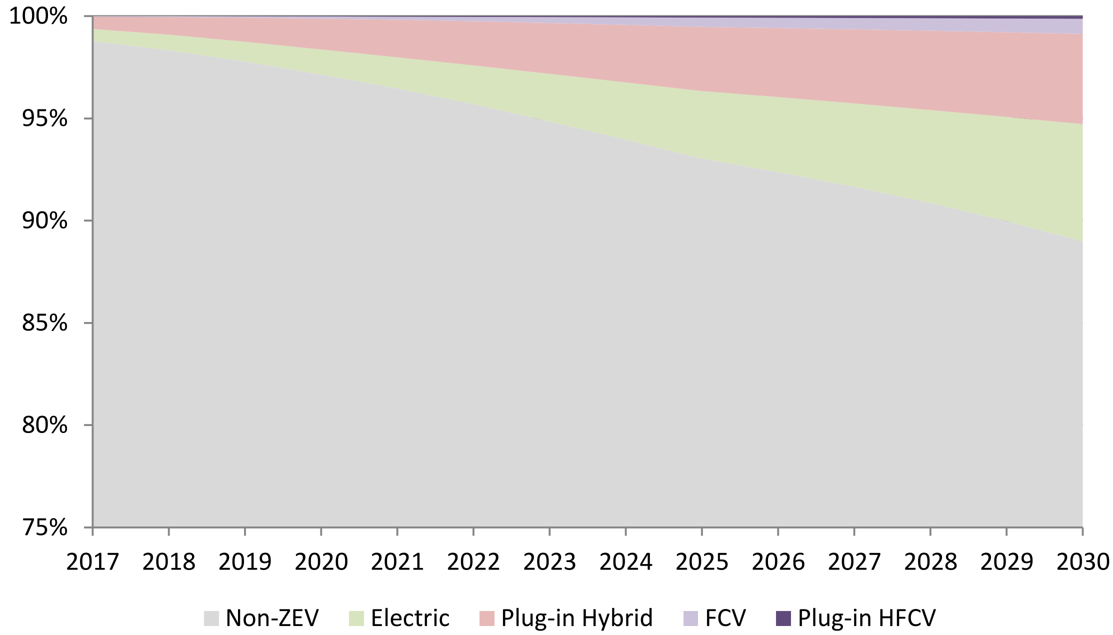
Figure 5-2: ZEV and PHEV Stock Forecast



Source: California Energy Commission

The forecast of ZEV stock share (including PHEVs) compared to the share of non-ZEVs (including gasoline, gasoline-hybrid, diesel, flex-fuel, and natural gas vehicles) is shown in **Figure 5-3** for the high case.

Figure 5-3: ZEV and PHEV Share of Light-Duty Vehicle Stock (High Demand Case)



Source: California Energy Commission

The forecast of PEV stock provides a key basis for determining the amount of electricity that utilities will need to provide, fulfilling a historical objective of the larger California electricity demand forecast. Results from the PEV forecast, when combined with FCEV forecast, can also serve as a useful check on the progress and trajectory toward the state's goals for emissions reductions in the transportation sector.

Comparison to ZEV Policies and Goals

The ZEV regulation under the CARB Advanced Clean Cars (ACC) program requires automakers to generate or procure a certain number of credits each year based on total vehicle sales in that year. Each ZEV, depending on its attributes, such as fuel type and zero emission driving range, generates a distinct number of credits.

In 2012, the initial statement of reasons for the 2012 ACC rulemaking anticipated that the established system of credit requirements would likely result in roughly 1.4 million ZEVs by 2025.[29] However, as California's mix of new ZEVs began to favor more BEVs over PHEVs, BEVs with longer driving range, and PHEVs with longer electric range, the number of vehicles needed to achieve the same number of credits dropped. The "banking" of credits generated early in the life of the regulation also reduced the number of new ZEV credits needed later.

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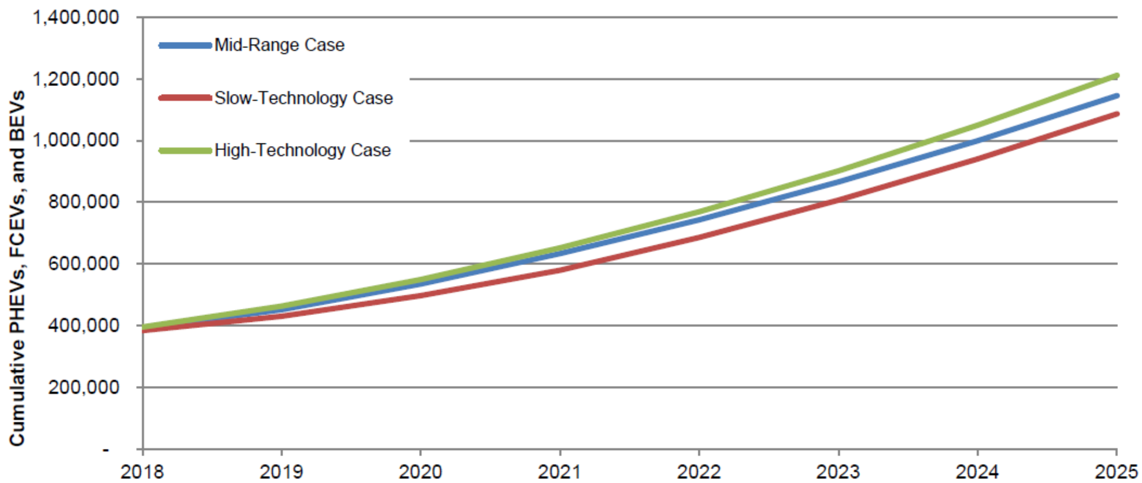
29 CARB. January 18, 2017. *California's Advanced Clean Cars Midterm Review, Appendix A: Analysis of Zero Emission Vehicle Regulation Compliance Scenarios*, https://www.arb.ca.gov/msprog/acc/mtr/appendix_a.pdf.

In 2015, CARB staff reviewed progress under the ZEV regulation as part of the ACC Midterm Review.[30] In its analysis, CARB staff differentiated between slow, mid-range, and high ZEV technology advancement cases to come up with a range of expectations for the cumulative number of ZEVs needed to meet regulatory requirements. Through model year 2025, CARB staff estimates that between about 1.1 million and 1.2 million ZEVs will effectively be required to meet the current ZEV regulation, depending on the level of technology advancement, as shown in **Figure 5-4**.

Figure 5-4: CARB Estimate of Cumulative ZEVs and PHEVs to Meet ZEV Regulation (2015)



Source: CARB, "California's Advanced Clean Cars Midterm Review (Appendix A)"

In addition to regulatory requirements for ZEV credits, California also has goals for actual ZEV deployment. In 2012, Executive Order B-16-12 set a goal of achieving 1.5 million ZEVs by 2025. Senate Bill 1275 (2014) subsequently codified an interim goal of 1 million ZEVs by 2023. Unlike ZEV credits, both of these goals are based on the number of ZEVs on California roadways.

In the low demand case, Energy Commission staff anticipates a stock of around 1.6 million ZEVs and PHEVs by 2025. This result suggests that, even under less favorable conditions, California could meet the *ZEV Action Plan* goal of 1.5 million ZEVs (and PHEVs) by 2025.[31]

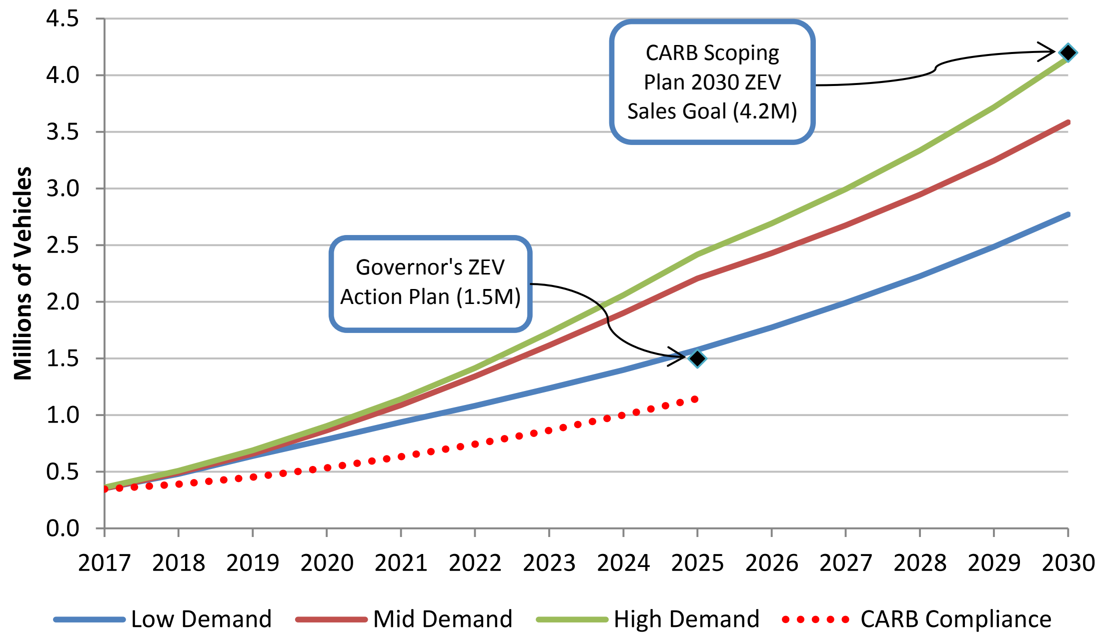
Looking further to 2030, forecasts of ZEV stock can be compared to proposed pathways for light-duty ZEVs set under CARB's 2017 update to the AB 32 Scoping Plan. Within the *2017 Climate Change Scoping Plan Update*, the proposed pathway incorporates reference assumptions under the Cleaner Technology and Fuels Scenario of the Mobile

30 Ibid.

31 Governor's Office of Planning and Research. February 2013. *ZEV Action Plan* http://opr.ca.gov/docs/Governor%27s_Office_ZEV_Action_Plan_(02-13).pdf

Source Strategy.[32] This includes the need to transform California's on-road passenger fleet toward a goal of 4.2 million ZEVs and PHEVs by 2030.[33] This 4.2 million target is shown in **Figure 5-5**, in comparison to Energy Commission's ZEV forecast in the three demand cases.

Figure 5-5: On-Road Zero-Emission Vehicle and PHEV Stock Forecast



Source: California Energy Commission

As shown, the goal of 4.2 million ZEVs and PHEVs by 2030 as specified under CARB's *2017 Climate Change Scoping Plan Update* is nearly reached in the high demand forecast (4.14 million ZEV stock). However, the Energy Commission's forecast of ZEV stock includes a greater number of pure ZEVs (BEV and FCEV) than the *Scoping Plan* and, in theory, can achieve higher GHG reduction goals than targeted in the *Scoping Plan.* Further differentiation about the types of ZEVs (for example, BEV versus PHEV) needed to meet these goals will also be necessary.

Comparison to FCEV Automaker Survey

The ZEV stock forecast for FCEVs and plug-in hybrid FCEVs (PHFCVs) can be compared to the automaker surveys of anticipated FCEV deployment conducted by CARB.[34] As shown in **Figure 5-6**, both the automaker survey and the Energy Commission's forecast

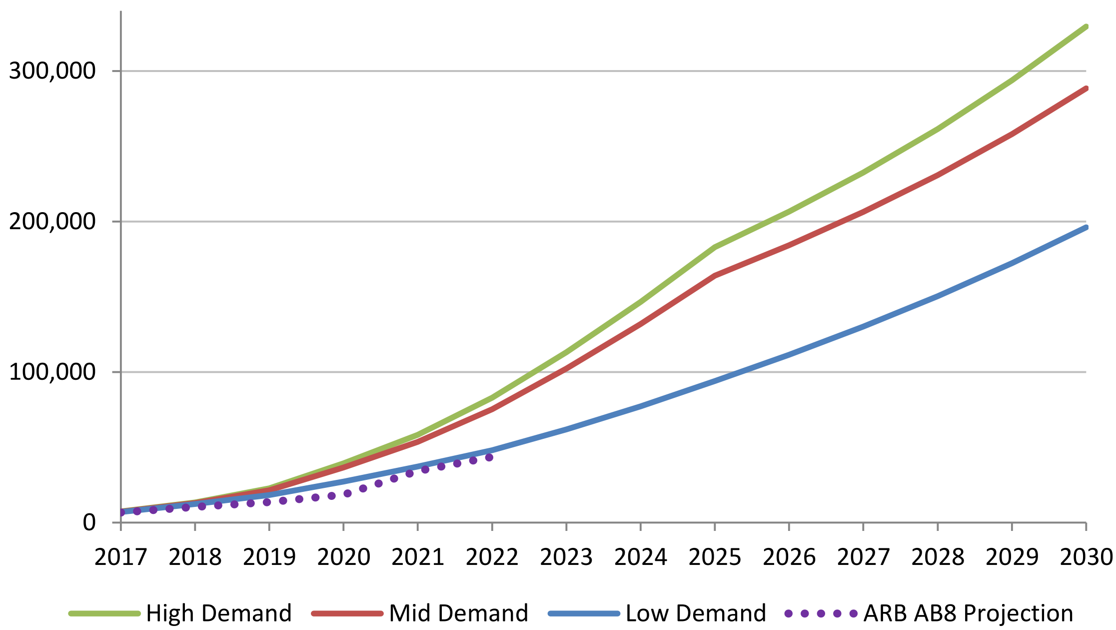
32 California Air Resources Board. January 20, 2017. Revised November, 2017. Adopted December, 2017. *2017 Climate Change Scoping Plan Update.* https://www.arb.ca.gov/cc/scopingplan/2030sp_pp_final.pdf.

33 California Air Resources Board. May 2016. *Mobile Source Strategy.* https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf.

34 California Air Resources Board. June 2016. *2016 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*, https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2016.pdf.

anticipate rapid growth in the number of light-duty vehicles utilizing hydrogen as refueling stations are successfully deployed. While the automaker survey considers only FCEV projections, the Energy Commission forecast shows the sum of FCEVs and PHFCVs.

Figure 5-6: FCEV and Plug-In Hybrid FCEV Forecast Stock and CARB Automaker Survey Projections



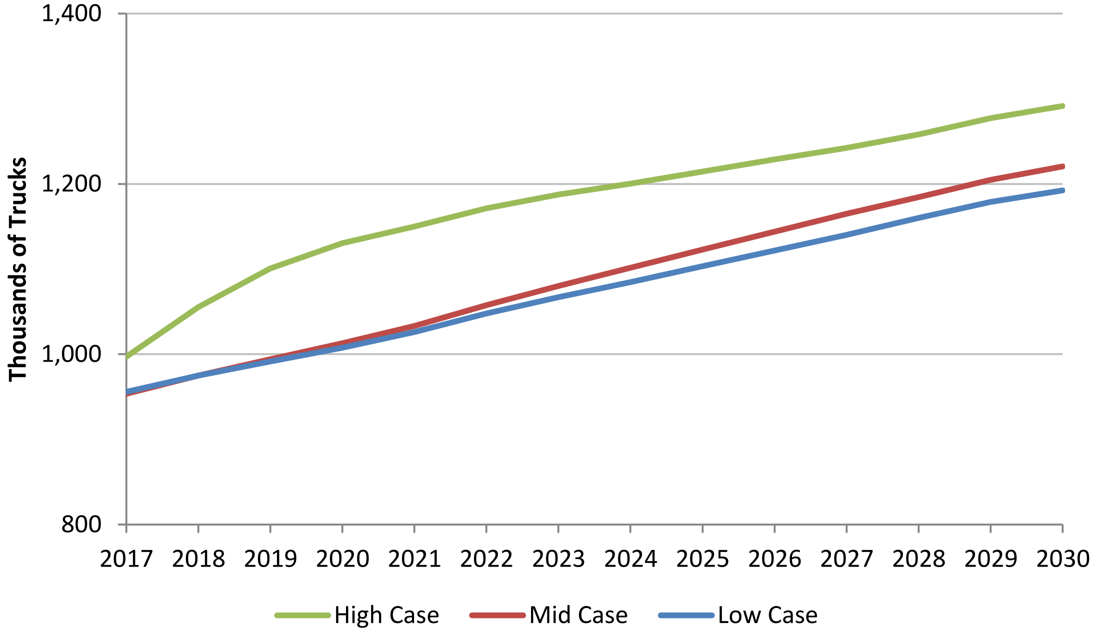
Source: California Energy Commission, CARB

Medium- and Heavy-Duty Vehicle Stock Forecast

The forecast growth in the number of medium- and heavy-duty trucks in California is determined chiefly by economic growth. As these projections rise, so too does the forecasted number of trucks needed to serve and support economic activity. **Figure 5-7** presents the total truck stock forecast through 2030 for each demand case. Not all trucks are alike. Before considering the variety of fuel and technology types, trucks can be disaggregated, or broken down, by weight class and application.

The ownership cycle of new trucks can be as low as 5 to 7 years for long-haul tractor-trailers moving 80,000 to 200,000 miles a year or 20 years or longer for service vehicles trucks that move a technician a few times a day between service calls within a town. For this reason, a high market share for an alternative fuel may result in only gradual growth in the truck stock for that fuel type as fleets turn over.

Figure 5-7: Medium- and Heavy-Duty Truck Stock Forecast by Case



Source: California Energy Commission

Growth in Alternative Fuel Truck Stock

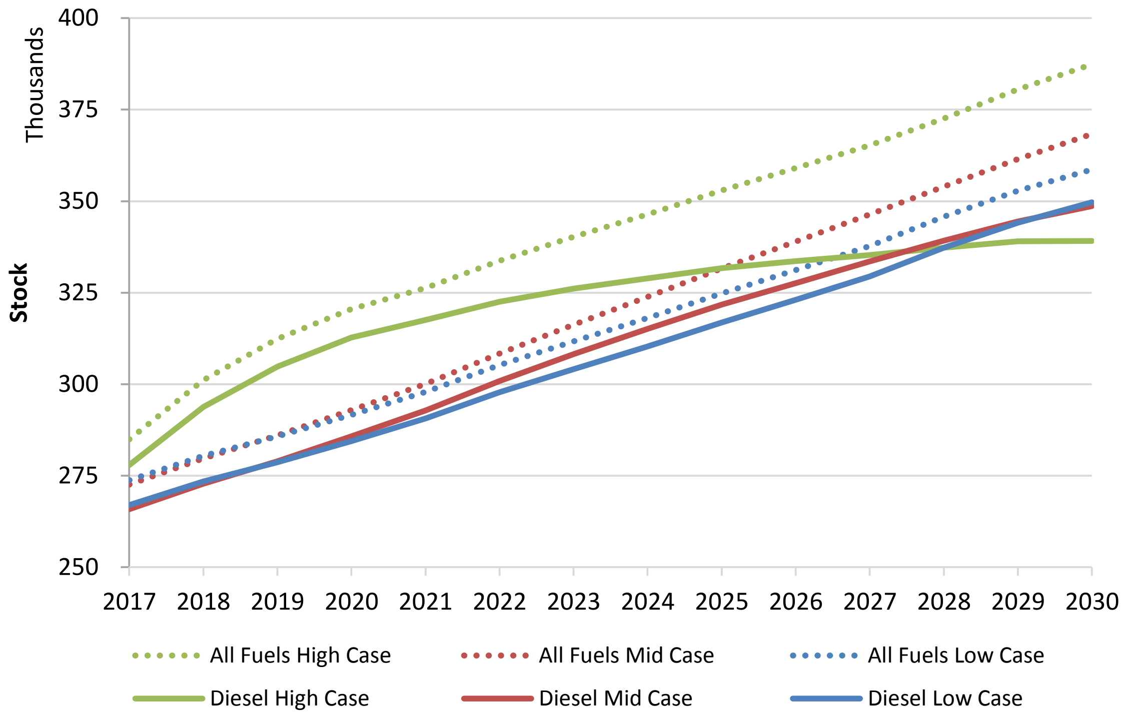
While demographic and economic trends determine the number and class of new trucks in each forecast year, staff uses the Truck Model to produce a forecast of market share for new trucks by fuel and technology type. As a result, trends in alternative fuel vehicle demand can also be viewed over time. For a definition of the truck classes discussed here, refer to **Figure 4-12**.

Heavy-Duty Trucks

As one example, **Figures 5-8** and **Figure 5-9** show the forecasts for diesel and non-diesel trucks (respectively) among two important truck classes: class 8 in-state tractor-trailers and classes 7 and 8 single-unit trucks.[35] Combined, these classes of heavy-duty trucks accounted for about 51 percent of the diesel fuel consumed within the medium- and heavy-duty truck sectors. **Figure 5-8** also includes the total of trucks across all fuel types. Total truck counts reflect economic growth, while individual technologies reflect economic growth and fuel type technology choices based on vehicle price and operating cost per mile.

35 For class 8 in-state trailers, the fuel types considered by staff using the Argonne Truck 5.1 model included diesel, catenary-electricity (limited to the port drayage share), and natural gas. The fuel types considered for classes 7 and 8 single-unit trucks included diesel, diesel-electric hybrid, gasoline, natural gas, and propane. Propane is not shown due to near-zero stock throughout the forecast period.

Figure 5-8: Heavy-Duty Truck Stock – Diesel and All Fuels (Mid and High Case)



Source: California Energy Commission. Does not include GVWR 8 refuse and recycling trucks

Classes 7 and 8 In-state Trucks

For class 8 in-state tractor-trailers and classes 7 and 8 straight trucks,[36] natural gas is the dominant alternative fuel, growing to over 37,500 trucks by 2030 in the high case, and 15,900 trucks in the mid case. Diesel-electric hybrid trucks in the class 7 and 8 straight truck class reach significant numbers only in the high case, due to rather high incremental up-front cost and modest efficiency improvement. The market penetration of catenary electric for the port drayage trucks exceeds 50 percent by 2030 in both the mid and high cases. Since the stock of port trucks is a small fraction of the total for this class, stock growth is modest at about 1,200 in the mid case and over 1,400 in the high case. The fuel price advantage of diesel in the low case sustains the historic dominance of these technologies. Refuse and recycling trucks are projected by fuel type in their current proportions, but are not forecast using the Truck Model since their unique access to renewable natural gas rather than cost drives purchases of these trucks.

Classes 4 to 6 Medium-Duty Trucks

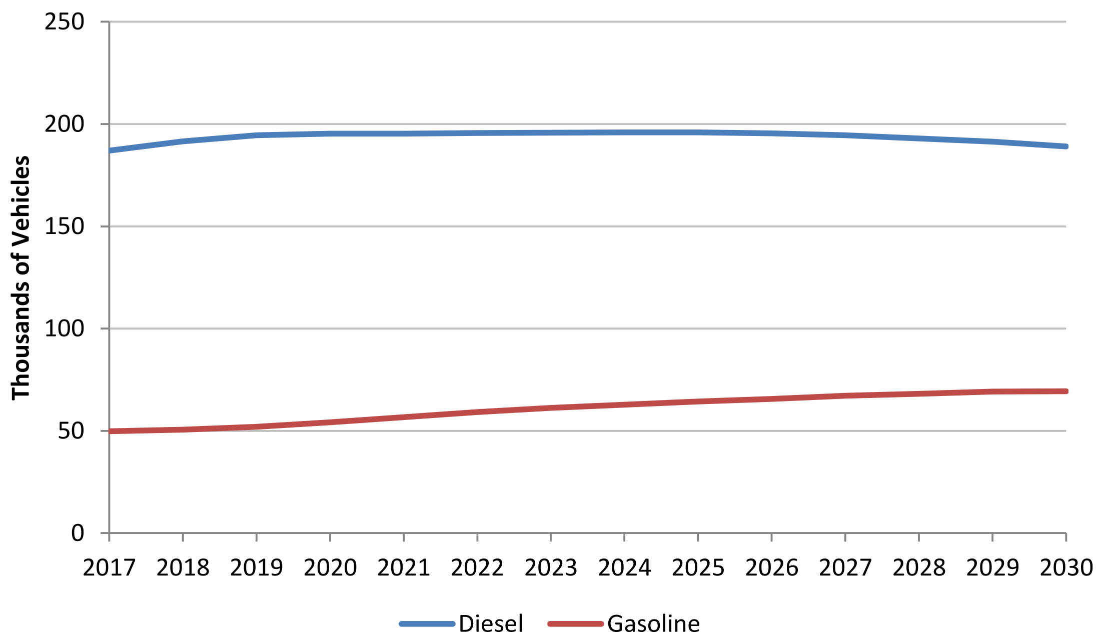
Looking at another example, classes 4 to 6 medium-duty trucks provide a variety of services, including last-mile delivery of parcels and other goods, on-site location for onboard equipment such as utility or bucket trucks, emergency vehicles, and more.

36 A "straight truck" is so defined in contrast to an articulated truck like a tractor-trailer. Most trucks are straight trucks.

These classes of trucks and step vans have been the object of considerable effort to develop alternative fuels; as a result, there are more fuel options from which to choose.

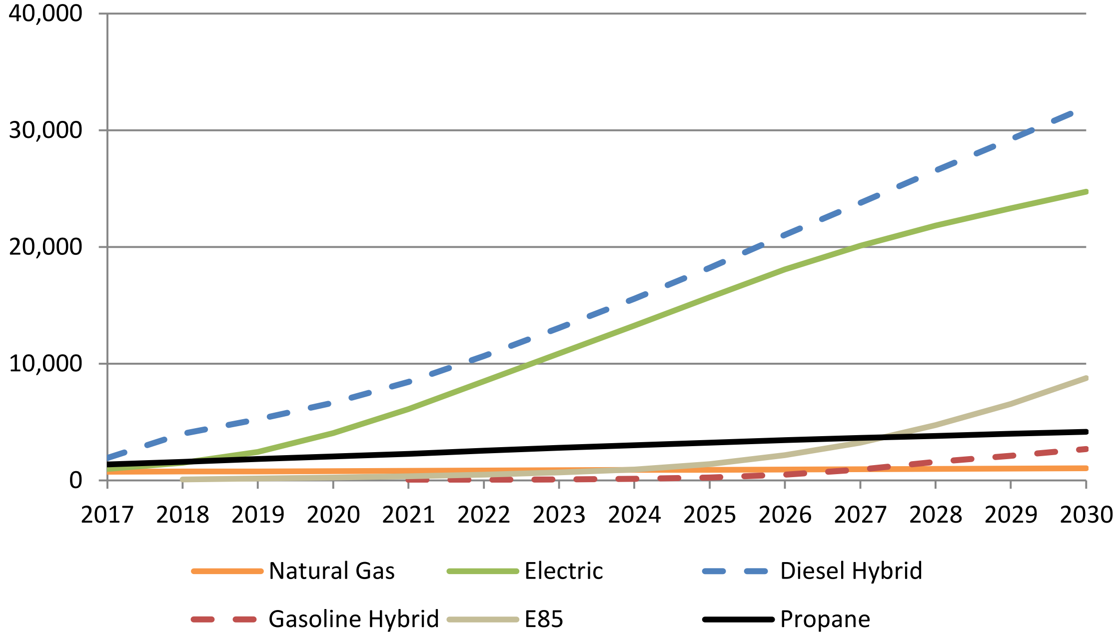
Figure 5-9 shows the forecasted diesel and gasoline trucks in this class under the mid case, reflecting a small increase in the share of gasoline trucks over time. **Figure 5-10** shows the corresponding forecast for alternative fuel trucks. Natural gas is most successful for class 6 trucks that have some trips greater than 100 miles. Battery-electric trucks and diesel-electric hybrids grow through the forecast period, since the associated high-efficiency and voucher incentives are able to overcome the higher vehicle price. The dedicated E85 truck with Cummins Ethos engine and the gasoline-electric hybrid also show significant growth. Propane trucks hold a constant share relative to gasoline, which is reasonable given that propane is an aftermarket conversion of a gasoline engine.

Figure 5-9: Conventional Classes 4 to 6 Truck Stock Forecast, Mid Case



Source: California Energy Commission

Figure 5-10: Alternative Fuel Classes 4 to 6 Truck Stock Forecast, Mid Case



Source: California Energy Commission

Overview of Total Truck Stock

The total number of trucks by alternative fuel and technology type can also be aggregated across all weight classes. **Table 5-1** on the following page presents the total number of trucks for each fuel and technology type for 2017, as well as the low, mid, and high case forecasts for 2030.

Table 5-1: Truck Stock Forecast by Fuel Type and Case

Case	Fuel Type	2017	2020	2025	2030
High case	Diesel	748,041	852,973	886,491	887,741
	Diesel-Electric Hybrid	2,802	10,449	21,169	41,715
	Electric	1,166	6,690	19,851	42,580
	Ethanol		756	2,639	16,085
	Gasoline	233,183	243,272	245,682	231,347
	Gasoline Hybrid		112	694	5,045
	Natural Gas	9,939	13,164	33,307	61,117
	Propane	1,996	3,156	4,785	5,829
Mid case	Diesel	710,322	757,938	827,310	866,487
	Diesel-Electric Hybrid	1,919	6,665	18,244	32,233
	Electric	1,020	4,207	16,562	29,722
	Ethanol		441	2,707	16,582
	Gasoline	229,129	229,248	235,893	237,505
	Gasoline Hybrid		54	597	3,826
	Natural Gas	9,642	11,919	17,938	29,653
	Propane	1,626	2,349	3,616	4,622
Low case	Diesel	712,314	754,492	823,344	877,244
	Diesel-Electric Hybrid	1,999	6,490	16,707	29,683
	Electric	830	819	1,099	5,085
	Ethanol		323	1,775	10,459
	Gasoline	229,485	231,473	241,053	242,483
	Gasoline Hybrid		99	679	4,429
	Natural Gas	9,658	11,562	15,090	18,664
	Propane	1,672	2,451	3,460	4,174

Source: California Energy Commission analysis

Key Takeaways from the Medium- and Heavy-Duty Vehicle Forecast

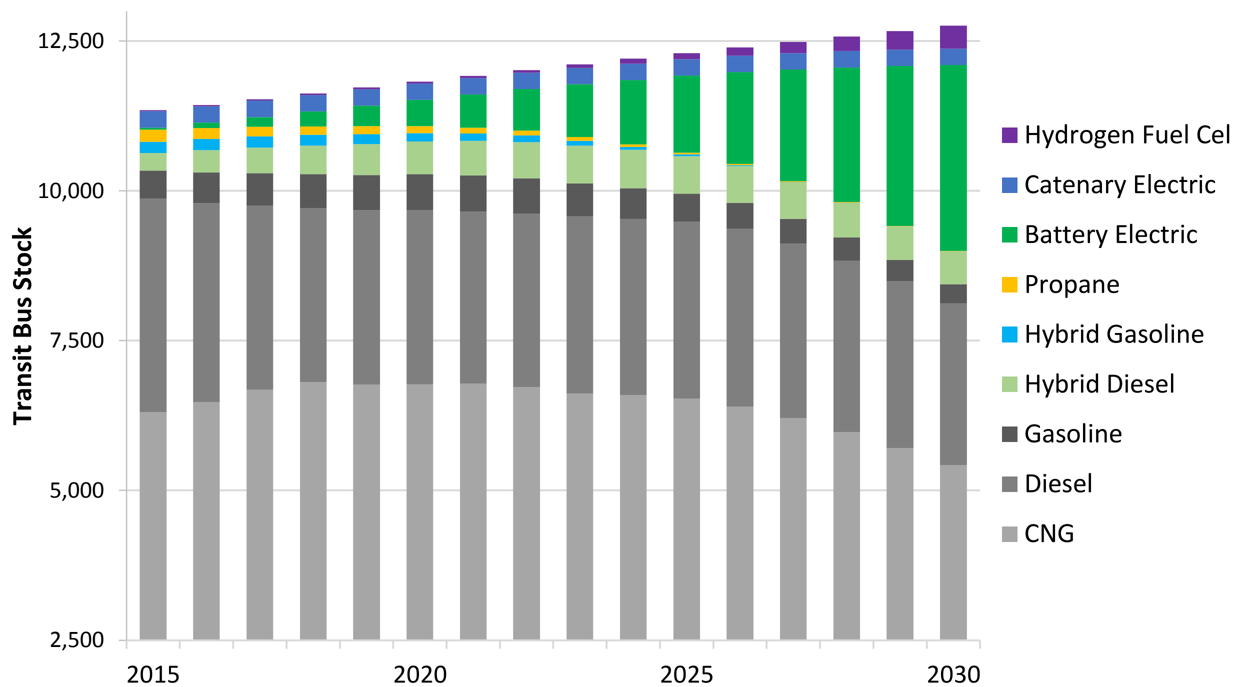
- Total new truck sales are determined by the rates of truck retirement and truck stock growth (which is determined by economic growth).
- The market growth of alternative fuel trucks is significant, and the rate at which alternative fuels appear in the vehicle stock is governed by the fuel type percentage of new trucks from the Truck Model, in addition the level of new truck sales.
- Overall, gasoline and diesel trucks continue to dominate truck stock, even as the share of alternative fuels increases. Vehicle prices of gasoline trucks for classes 3 to 6 are the lowest of any fuel type, while diesel is the lowest for classes 7 and 8. Vehicle price is a key driver in the Truck Model. The gradual turnover of fleets means that many newer trucks on the road today will still be on the road in 2030.
- Natural gas trucks emerge in the heavy-duty classes, where the high mileage, low fuel price, and voucher incentive is able to overcome the high initial vehicle cost.

- Battery-electric trucks show meaningful growth through the forecast period in the high and mid cases, as decreasing battery prices, sustained voucher incentives, and the moderate price of electricity can overcome the high (if decreasing) cost of the new vehicles.

Transit Bus Stock Forecast

The forecast of transit bus population is depicted as **Figure 5-11**. The overall stock of transit buses is grown at the rate of gross state product, and bus retirement occurs gradually between the 12th and 18th year, which is supported by an analysis of NTD data.

Figure 5-11: Forecast of Transit Bus Population by Fuel Type



Source: California Energy Commission, National Transit Database. Note: Forecast of active fleet vehicles only

The fuel type of new transit bus purchases is determined largely by policy goals. Specifically, it is based on California's goal for more zero-emission urban transit buses as stated in CARB's Advanced Clean Transit initiative[37] and public announcements made by transit agencies around the state as of April 2017. The forecast also assumes that current federal grants for transit funding, which cover 80 percent of the capital cost of a vehicle, remain in place. At this level of funding, battery electric buses become more competitive with conventional fuel types. Because of these reasons, the transportation

37 California Air Resources Board. 2015. *Advanced Clean Transit.* https://www.arb.ca.gov/msprog/bus/workshoppresentation.pdf.

forecast shows the share of battery electric buses growing significantly over the forecast period.

Fuel Demand Forecasts

The transportation fuel demand forecast covers all the fuel types discussed in this report: gasoline, diesel, E85, natural gas, electricity, jet fuel, and hydrogen. As expected, greater numbers of ZEVs and increasing fuel economy of light-duty gasoline vehicles result in lower gasoline demand. Unless otherwise specified, all fuel demand forecasts in this section include light-duty personal, commercial, government, and rental vehicles, as well as medium- and heavy-duty trucks and buses.

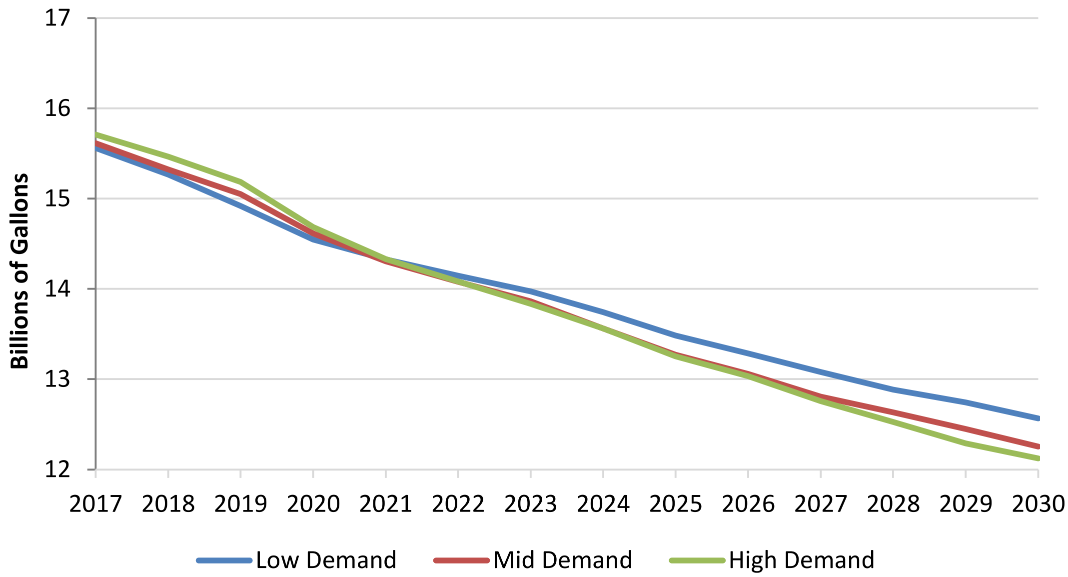
In the revised IEPR forecast and report staff replaced an existing fuel consumption calculation with one that is post-processed using the HD Systems' fuel economy forecast directly. Truck stock was unaffected, since the Truck Model had initially used the HD Systems' fuel economy forecast.

Gasoline

The gasoline demand forecast ranges from 12.1 billion to 12.6 billion gallons in 2030, depending on the case. Most of this gasoline demand in California is generated by light-duty vehicles. While the models grow the number of light-duty vehicles with population and income over the forecast horizon, total gasoline demand shows a continuous decline in all three demand cases, as shown in **Figure 5-12**. The declining trend in gasoline consumption is primarily due to increasing fuel economy (stemming from federal CAFE regulations) and gasoline displacement from the increasing market penetration of ZEVs.

The Energy Commission's vehicle choice models account for substitution among different fuels and technologies. Therefore, the growth in ZEVs (due to growing differences between gasoline and electricity prices and driving costs) comes at the expense of new gasoline vehicle purchases and gasoline consumption.

Figure 5-12: On-Road Gasoline Demand Forecast



Source: California Energy Commission

In general, improvements in fuel economy keep gasoline demand declining in all cases. However, the larger volume of light-duty gasoline vehicle stock in the high case overcomes the effect of higher gasoline prices and keeps gasoline demand higher in the high electricity demand case than the low demand case. But as the substitution effects of higher ZEV stock become more dominant and gasoline prices continue to rise, gasoline demand in the high demand case falls below the low demand case after 2021.

Diesel

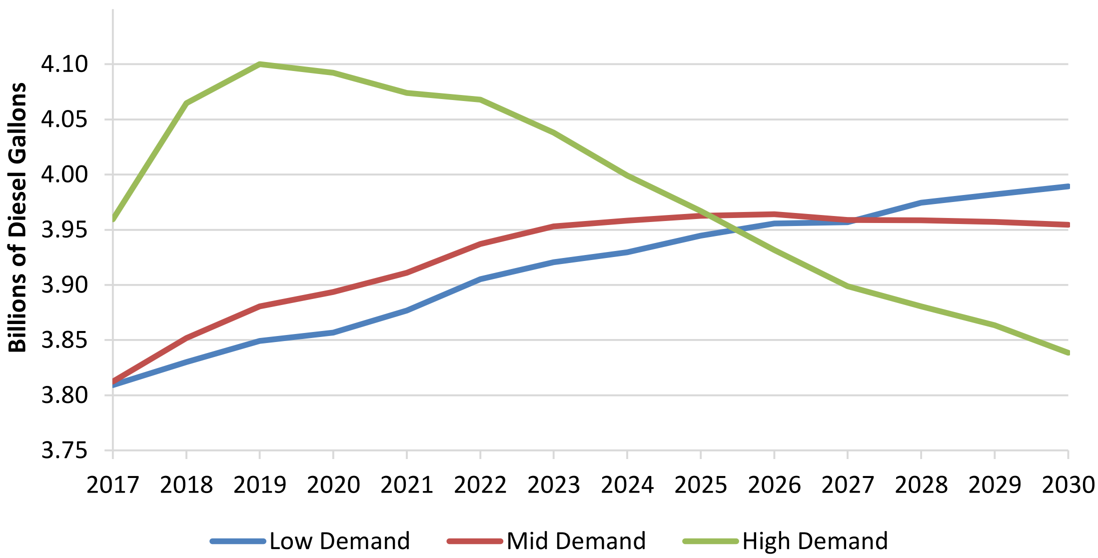
Figure 5-13 shows total diesel demand for on-road vehicles, including rail. Forecast diesel demand in 2017 is between 3.81 and 3.96 billion gallons, tracking the growth of California's goods movement and services for the three cases. Diesel demand tracks closely in the low and mid demand cases, but rises in the high case through 2019 in response to a more favorable commercial economic growth forecast. Starting in 2021, the proposed U.S. EPA/NHSTA Phase 2 *Greenhouse Gas and Fuel Efficiency Standard for Medium- and Heavy-Duty Engines and Vehicles* are assumed to go into effect, as planned.[38]

A dramatic decline in high case diesel consumption is evident in **Figure 5-13.** Market penetration of alternative fuel trucks, most prominently natural gas trucks, displaces diesel trucks the most in the high case and the least in the low case (refer to Table 5-1 on page 73). Economic growth in the high demand case causes introduction of new trucks. In the high case new trucks early in the forecast are replaced with more efficient

38 Environmental Protection Agency, National Highway Traffic Safety Administration. October 25, 2016. *Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2.* https://www.gpo.gov/fdsys/pkg/FR-2016-10-25/pdf/2016-21203.pdf.

Phase 2 trucks later in the forecast, in greater numbers than for the other cases. Combined, the high case higher economic growth, new trucks, and further replacement with newer trucks produce the dramatic reduction of diesel consumption. By 2026, diesel trucks consume less fuel in the high case than in other cases.

Figure 5-13: On-Road Diesel Demand Forecast



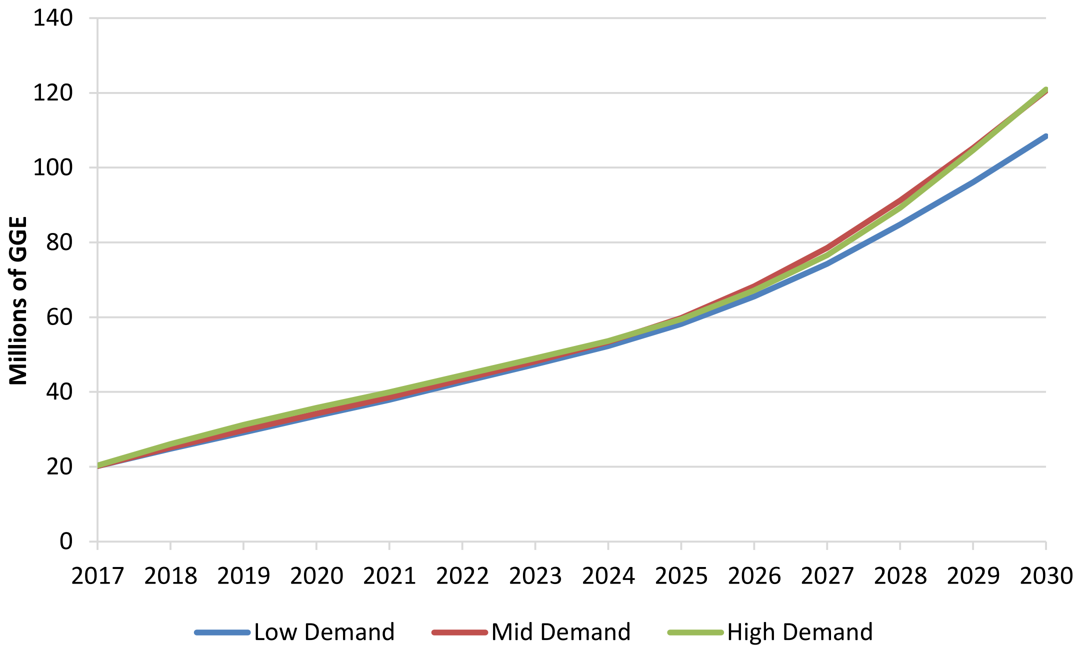
Source: California Energy Commission

E85

E85-capable vehicle stock is dominated by flex-fuel vehicles (FFVs), which can use either gasoline or E85. The forecasting models do not include a fuel choice model for dual-fuel vehicles, so the fuel demand attributed to FFVs is allocated between gasoline and E85 in a post-processing calculation. Studies show that FFV owners fuel their vehicles mostly with gasoline, filling up with E85 less than 5 percent of the time in 2015, which equals approximately 13 gallons per FFV.

The forecast also includes increasing market penetration of dedicated E85 trucks in the medium-duty fleet, starting in 2021. **Figure 5-14** shows the Energy Commission staff forecast of demand for E85, which ranges from 108 million to 121 million GGE by 2030. The dedicated E85 Cummins Ethos engine in medium-duty fleets contributes to this growth in later years.

Figure 5-14: California E85 Demand Forecast



Source: California Energy Commission

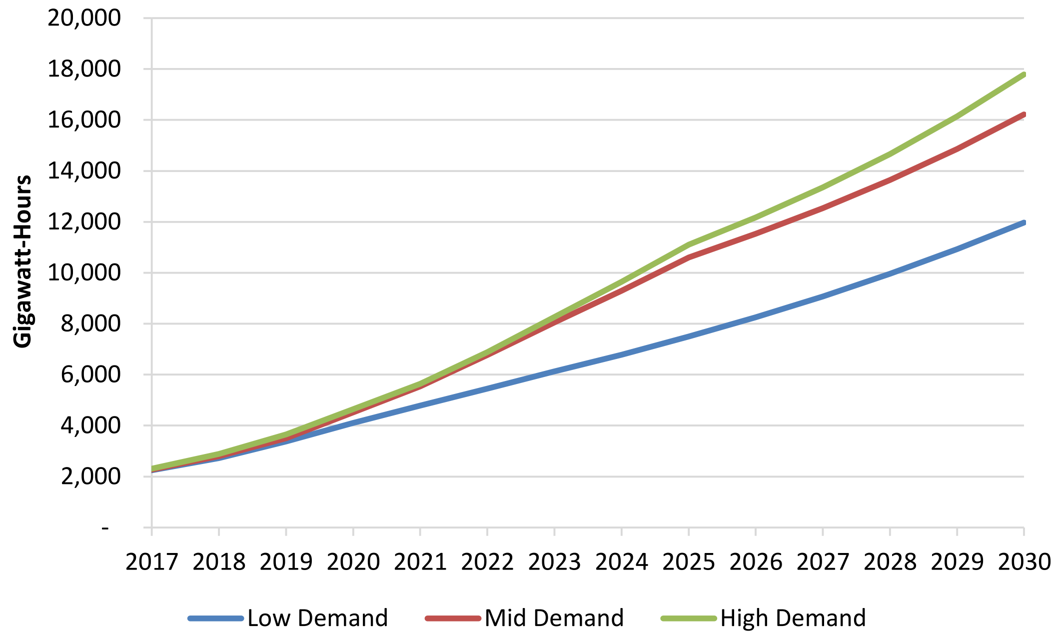
Electricity

Electricity is used in multiple transportation modes, including light-duty vehicles, catenary-electric transit buses,[39] and light and heavy rail. It is forecast to emerge in battery-electric medium-duty trucks, battery-electric buses, catenary-electric port drayage trucks, and high-speed rail. **Figure 5-15** aggregates the statewide electricity demand for these various vehicle types and transportation modes.

The transportation electricity demand in 2030 is forecast to be approximately 12,000 gigawatt-hours in the low case, 16,000 gigawatt-hours in the mid case and 18,000 gigawatt-hours in the high case. The wider gap between the low and mid cases illustrates less favorable conditions for light-duty PEV adoption and heavy-duty vehicle electrification. The 2025 change in the growth rate of electricity demand in the mid and high cases stems from the discontinuation of state rebates for light-duty PEVs. Medium- and heavy-duty battery trucks and buses and catenary-electric trucks also emerge in the mid and high cases, but since there are roughly 20 light-duty vehicles for each medium- and heavy-duty vehicle, the contribution of medium and heavy duty to electricity use is relatively small.

39 *Catenary electric buses* are also known as trolleybuses and are operated by San Francisco MUNI.

Figure 5-15: Transportation Electricity Demand Forecast



Source: California Energy Commission.

Because the High-Speed Rail (HSR) forecast was generated independently by the California High-Speed Rail Authority, **Figure 5-15** excludes electricity demand for HSR.

High-Speed Rail Electricity Demand Forecast

California's HSR is scheduled to begin operation with 100 percent renewable electricity in 2025, which drives the increase in transportation electricity demand in the final years of the forecast period. Rollout of HSR is being done incrementally, with an initial operating section slated to run 300 miles from San Jose to the Bakersfield area in 2025, followed by the completion of Phase One with extensions to San Francisco and Los Angeles/Anaheim in 2029. The forecast includes all of Phase One of the HSR network, shown in blue in **Figure 5-16**, as it is projected to be in operation by the conclusion of the forecast.

The HSR energy consumption forecast, presented in **Figure 5-17**, was provided by the California High-Speed Rail Authority and was developed in support of the authority's *Connecting California 2016 Business Plan.*[40]

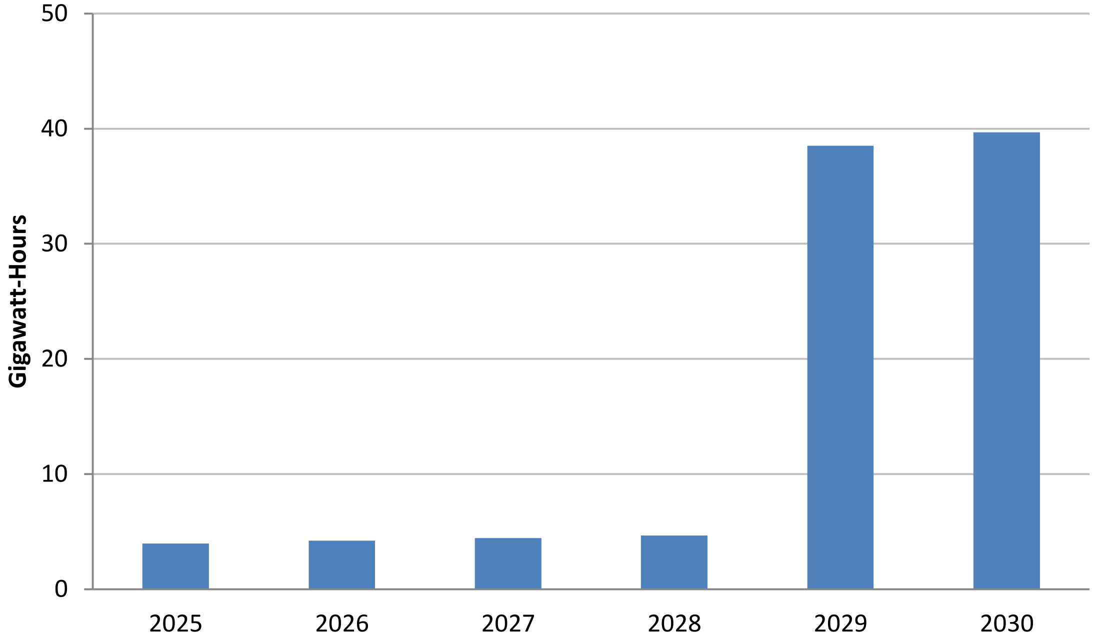
40 California High Speed Rail Authority, *2016 Business Plan.* http://www.hsr.ca.gov/docs/about/business_plans/2016_BusinessPlan.pdf.

Figure 5-16: Planned High-Speed Rail Construction

Source: California High-Speed Rail Authority.

The HSR forecast should be considered an “add-on” to the mid electricity demand case because the economic and demographic assumptions used by the California High-Speed Rail Authority most closely align with those used in that case.

Figure 5-17: High-Speed Rail Electricity Demand Forecast



Source: California High-Speed Rail Authority, *"Connecting and Transforming California 2016 Business Plan.*

Transportation Natural Gas

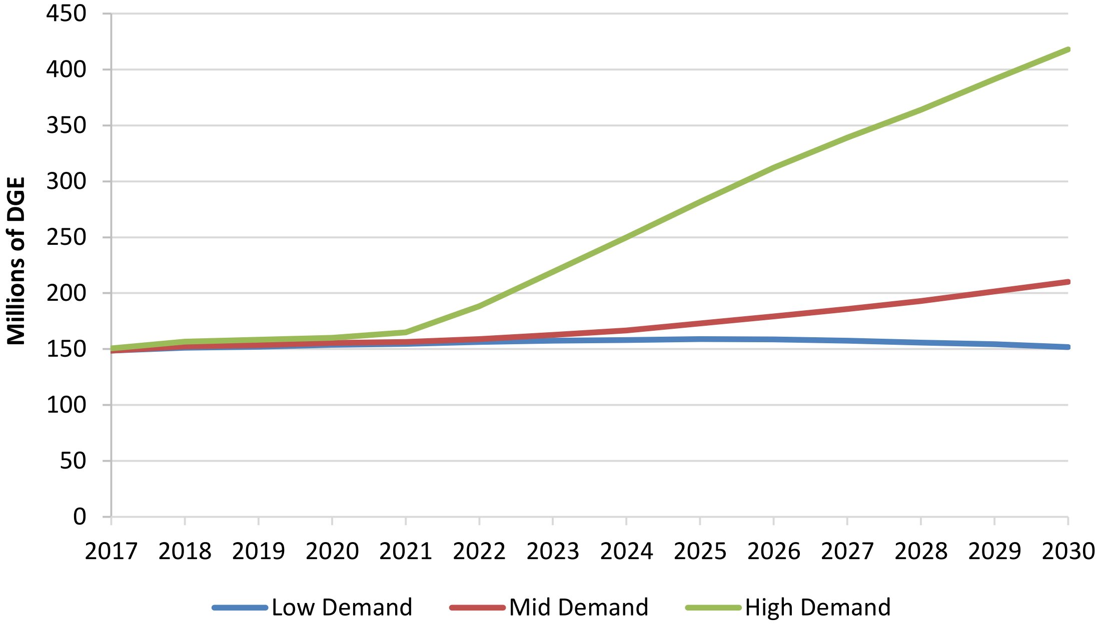
Natural gas competes primarily with diesel in the medium- and heavy-duty vehicle sectors, especially for fleets where an alternative fuel vehicle is required by regulation. Most of the future growth of natural gas is expected to remain in the heavy-duty truck segment, where alternative fuel truck rules, cheaper per-mile costs, voucher incentives, and higher annual mileage lead to a faster payoff on natural gas engines. While there are a limited number of light-duty natural gas vehicles in operation, the only model available on the U.S. market was discontinued in 2015, and the existing natural gas stock makes up a very small percentage of the LDV fleet. The transportation natural gas demand forecast is shown in **Figure 5-18.**

In the low case, there is no assumption of voucher incentives for heavy-duty trucks, and electric buses replace natural gas buses in urban transit. These two factors lead to a decline in natural gas demand in the low case.

For instance, LA Metro, the largest transit agency, has pledged a 100 percent ZEV bus fleet by 2030. Even if some newly purchased natural gas buses remain, sustaining the current majority of natural gas transit buses is unlikely.

The penetration of natural gas trucks depends on the CARB voucher incentive funds applied to low-NOx engines, so the low demand case, which assumes no CARB voucher funds, shows little or no growth in this fuel. In the high demand case, CARB vouchers and the combination of high diesel price and low natural gas price create a competitive niche for natural gas trucks. The steep rise in natural gas demand in the high demand case for 2022 stems from the introduction of low-NOx engines in the heaviest trucks.

Figure 5-18: Transportation Natural Gas Demand Forecast

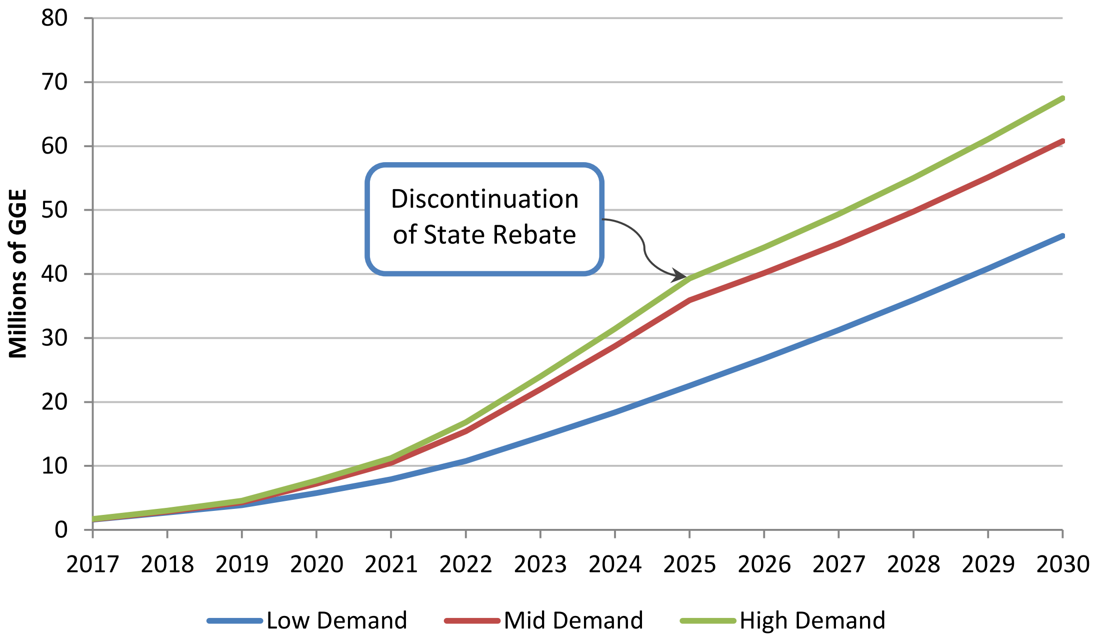


Source: California Energy Commission

Transportation Hydrogen

Hydrogen demand exceeds 45 million GGE by 2030 in the low case and reaches nearly 70 million GGE in the high case. The hydrogen demand shows a continuous increase over the forecast period, due to the predicted increase in light-duty FCEVs, and is displayed in **Figure 5-19**. The change in the growth rate of hydrogen demand follows the pattern in FCEV demand and is because of the discontinuation of the state rebate for ZEVs, including FCEVs.

Figure 5-19: Transportation Hydrogen Demand Forecast



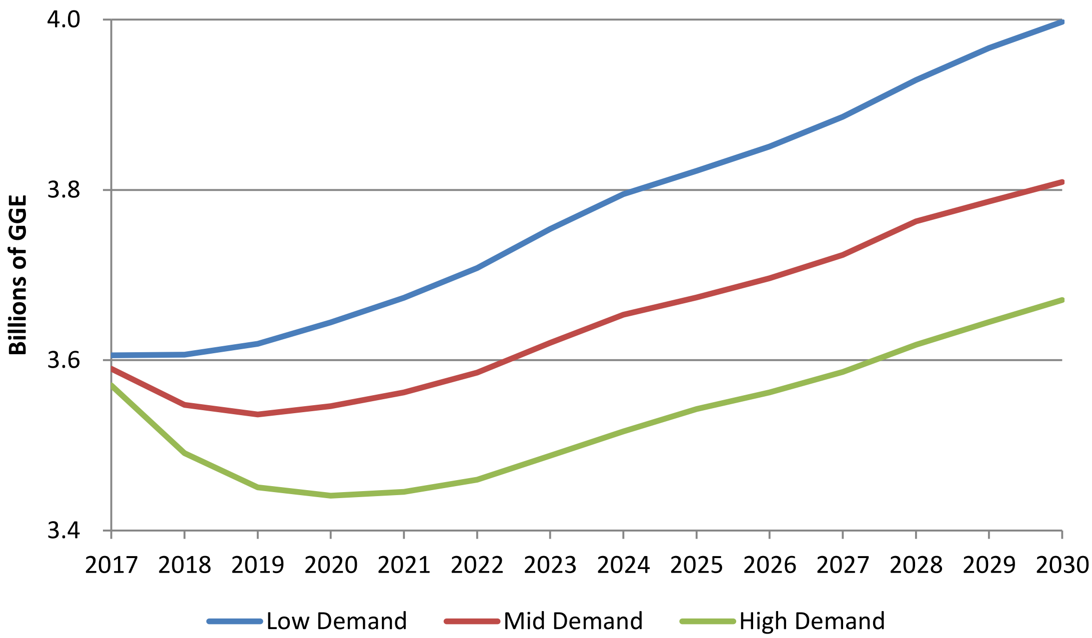
Source: California Energy Commission

Jet Fuel Demand Forecast

Energy Commission analysis shows the demand for passenger and freight aviation, excluding military, in California will be driven by changes in fuel price and economic growth, as well as the cost of air travel to domestic and foreign destinations originating from California airports.

Jet fuel demand for California, shown in Figure 5-20, is forecast to be between 3.8 billion and 4.1 billion GGE by 2030.

Figure 5-20: Commercial Jet Fuel Demand Forecast



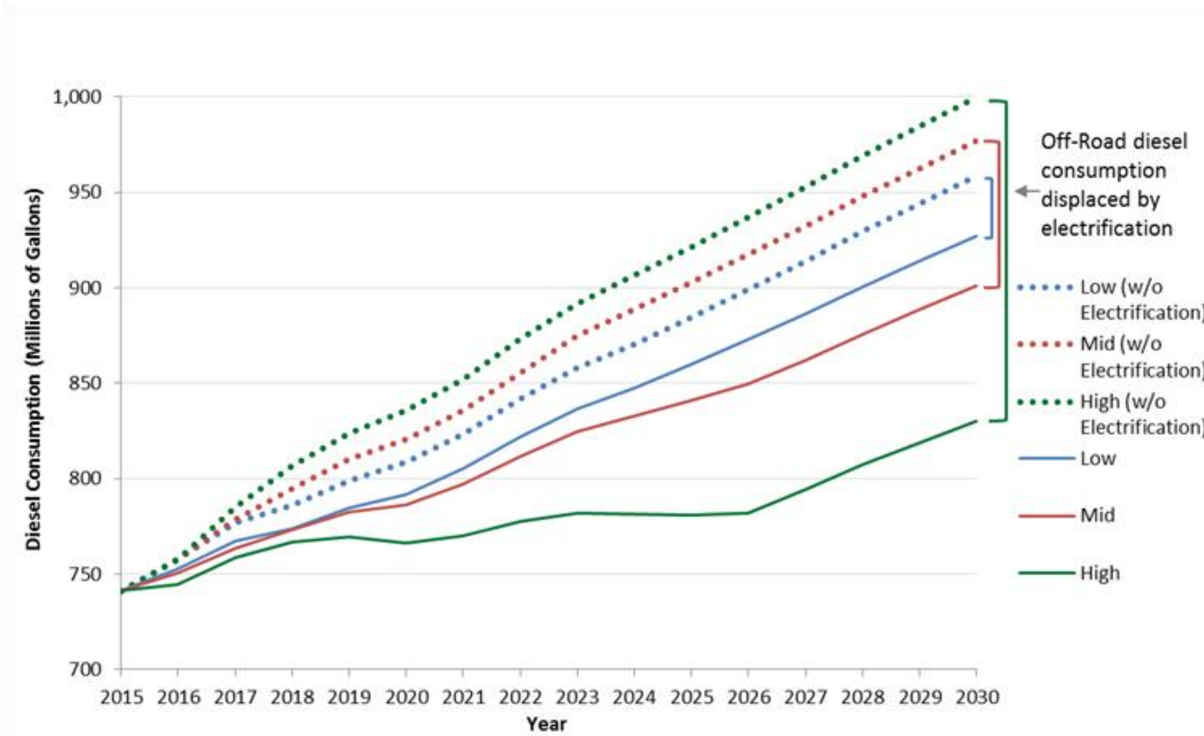
Source: California Energy Commission

The relatively rapid rise in the price of jet fuel (see **Figure 4-25**, page 63) leads to a short-term "dip" in air travel demand in the high case, and a smaller dip in the mid case. In the longer term this upward trend in jet fuel prices tapers off, allowing upward demand pressure from economic and demographic factors to outweigh fuel efficiency gains, resulting in an increase in jet fuel demand.

Off-Road Diesel Demand Forecast

In addition to on-road transportation, diesel is used in a variety of off-road applications in multiple economic sectors, including commercial, industrial, mining, sea port, and airport and other equipment and vehicles. Staff first generates a forecast of diesel demand for these off-road applications and then modifies the forecast for the growing electrified portion of these vehicles and equipment. This forecast is depicted in **Figure 5-21**.

Figure 5-21: Off-Road Diesel Demand, Adjusted for Off-Road Transportation Electrification Demand



Source: California Energy Commission.

CHAPTER 6: Summary and Conclusion

The *Revised Transportation Energy Demand Forecast, 2018-2030* allows the State of California to plan for the supplies of electricity, gasoline, diesel, natural gas, and other transportation fuels needed to meet statewide demand for travel. The forecast also provides a tool to evaluate the state's progress towards its clean energy goals.

The *Revised Transportation Energy Demand Forecast, 2018-2030* also represents an important update from previous forecasts. The forecast incorporates the results of the Energy Commission's 2016-17 California Vehicle Survey that makes assessment of consumer preferences for light-duty vehicles. The Energy Commission also expanded efforts to seek stakeholder feedback on light-duty plug-in electric vehicles. Third, the forecast incorporates major updates to the vehicle attributes provided by NREL and HD Systems, as well as the research conducted by Commission staff. Finally, refinements were made to the models, methods, and assumptions to improve the reliability of the forecast.

As a result, the 2017 forecast projects a major increase in the demand for cleaner transportation fuels like electricity and hydrogen and a decrease in the demand for gasoline. Specifically, the forecast projects that:

- The demand for gasoline will decline to 12.1 billion gallons in the high case and 12.6 billion gallons in the low case by 2030 from roughly 15.6 billion gallons in 2017, or a reduction of more than 19 percent.
- Diesel demand rises modestly from 3.8 billion gallons in 2017 to between 3.8 billion in the high demand case and almost 4.0 billion gallons in the low case by 2030, or an increase between 1 and 5 percent.
- Electricity demand in the transportation sector increases, even in the low case, to 12,000 GWh by 2030, a six fold increase from 2015, and to 18,000 GWh by 2030 in the high case, a nine fold increase from 2015.
- Hydrogen fuel demand increases to over 60 million GGE by 2030 in the mid case, from less than 1 million GGE in 2015.
- Overall, the decline in gasoline demand primarily results from the projected improvement in fuel economy of all gasoline vehicles, as well as the growing consumer purchases of BEVs, PHEVs, and FCEVs.
- Total light-duty ZEV and PHEV stock is forecasted to increase from 350,000 in 2017 to 2.8 million in the low demand case and 4.14 million in the high demand case, by 2030. The forecasts projects full compliance with the state's ZEV regulation.

- Alternative fuel truck stock also increases significantly in the medium- and heavy-duty sectors, but the forecast growth is not fast enough to offset significant commercial economic growth.

A major theme seen throughout this forecast period is the continuation of the current statewide shift toward transportation electrification. The California Vehicle Survey reveals greater preferences for PEVs, including an increasing preference by households and businesses for BEVs over gasoline vehicles. Research conducted by Energy Commission staff and third parties show that the choices consumers have will continue to expand over the forecast period, as automakers bring significantly more BEV, PHEV, and FCEV models to the market. These vehicles are expected to have more favorable characteristics such as longer range and lower prices, due in part to California's ZEV Program and the decreasing cost of lithium-ion battery packs.

The forecast projects similar innovation in the freight and transit sectors, as the cost-competitiveness of alternative fuel vehicles increases over the forecast period. For example, the forecast reveals that battery-electric trucks are projected to grow in market share for medium-duty trucks, and that a competitive potential exists to develop catenary-electric port trucks in the heavy-duty sector. Increased electrification is also forecast for transit buses – because of state policies and increased cost–competitiveness which drives commitments by transit agencies – and rail, where Caltrain[41] and California High-Speed Rail are known next steps.

This narrative of increasing electrification across broad parts of the transportation sector drives the growing demand for transportation electricity and hydrogen in this forecast. It also leads to the forecast of decreasing gasoline demand through 2030.

Finally, while ZEV regulation and incentives have been, and continue to be, important in increasing transportation electrification, any disruption of these policies could impede progress toward the state's clean transportation goals. For example, in the mid and high electricity demand cases of the transportation forecast, the rate of PEV growth noticeably slows after 2025 because of the potential expiration of California PEV rebates. This outcome shows the important role that policies and regulations continue to play in the deployment of clean transportation options and the need for their continuation to meet long-term air pollution and greenhouse emission goals. Given a stable policy and regulatory environment, the forecast projects that California is making progress toward its clean energy goals.

41 See http://www.caltrain.com/ .

Acronyms and Abbreviations

2017 IEPR	*2017 Integrated Energy Policy Report*
AB 8 Report	*Joint Agency Staff Report on Assembly Bill 8: Assessment of Time and Cost Needed to Attain 100 Hydrogen Fueling Stations in California*
ACS	American Community Survey
AEO	Annual Energy Outlook
AFV	Alternative fuel vehicle
BEV	Battery-electric vehicle
BOE	California State Board of Equalization
BTS	Bureau of Transportation Services
CAFE	Corporate Average Fuel Economy
Caltrans	California Department of Transportation
CARB	California Air Resources Board
Energy Commission	California Energy Commission
CNG	Compressed natural gas
CO_2	Carbon dioxide
CVC	Commercial Vehicle Choice model
CVRP	Clean Vehicle Rebate Program
DAWG	Demand Analysis Working Groups
DMV	California Department of Motor Vehicles
E85	A blend of 15 percent gasoline and 85 percent ethanol used to fuel both dedicated ethanol powered vehicles and flex-fuel vehicles
EIA	U.S. Energy Information Administration
EMFAC	Emissions factor model
EV	Electric vehicle (same as BEV)
FAA	Federal Aviation Administration
FCEV	Fuel cell electric vehicle

FFV	Flexible fuel vehicle
GGE	Gasoline gallon equivalent
GHG	Greenhouse gas
GVWR	Gross vehicle weight rating
GWh	Gigawatt hours
HOV	High-occupancy vehicle
HSR	High-speed rail
IEPR	*Integrated Energy Policy Report*
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IRP	International Registration Program
LCFS	Low Carbon Fuel Standard
lb	Pound
LDV	Light-duty vehicle
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas (typically propane)
MPG	Miles per gallon
MTBE	Methyl tertiary butyl-ether
NAICS	North American Industry Classification System
NAMGAS	North American Natural Gas
NEV	Neighborhood electric vehicle
NHTSA	National Highway Traffic Safety Administration
NOx	Nitrogen oxides
NREL	National Renewable Energy Laboratory
NTD	National Transit Database
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
PHFCV	Plug-in hybrid fuel cell vehicle
OEM	Original equipment manufacturer

RSG	Resource Systems Group, Inc.
TCU	Transportation, communications, and utilities
Truck Model	Argonne National Laboratory 5.1 TRUCK Model
U.S. EPA	United States Environmental Protection Agency
VMT	Vehicle miles traveled
ZEV	Zero-emission vehicle

APPENDIX A:
Definition of Vehicle Classes

Table A-1: Light-Duty Vehicle Classes

Car Classes			
	Class	**Interior Volume Definition**	**Examples**
1	Subcompact (1 - 6000 lbs)	Less than 89 cubic feet	Nissan Versa, Mitsubishi i-Miev
2	Compact (1 - 6000 lbs)	89 to 95 cubic feet	Honda Civic, Ford Focus, Chevy Volt
3	Midsize (1 – 6000 lbs)	96 to 105 cubic feet	Honda Accord, Toyota Camry, Nissan Leaf, Toyota Prius, Ford Fusion
4	Large (1 – 6000 lbs)	Over 105 cubic feet	Tesla Model S, Porsche Panamera S E-Hybrid
5	Sport (1 – 6000 lbs)	Two-door, high-performance subcompact (Weight/HP ratio less than 18)	Ford Mustang, Chevrolet Camaro
6	Cross Utility – Small* (1 – 6000 lbs)	Small wagons (passenger volume less than 95 cubic feet); with flexible seating (fold down rear seat to provide flat floor to front seat)	Chrysler PT Cruiser, Toyota Matrix
Light Truck Classes			
	Class	**Interior Volume Definition**	**Examples**
7	Cross Utility – Small* (1 – 6000 lbs)	Unibody SUV less than 140 cubic feet	Toyota RAV4, Honda CRV, Ford Escape
8	Cross Utility – Midsize (1 – 6000 lbs)	Unibody SUV over 140 cubic feet	Toyota Highlander, Honda Pilot, Lexus RX300
9	Sport Utility – Compact (1 – 6000 lbs)	Body on frame SUV less than 140 cubic feet	Nissan XTerra, Hyundai Tucson
10	Sport Utility – Midsize (1 – 6000 lbs)	Body on frame SUV 140 to 180 cubic feet	Acura MDX
11A	Sports Utility – Large (6,001 – 8,500 lbs)	Body on frame SUV over 180 cubic feet	Chevrolet Tahoe, Ford Expedition
11B	Sports Utility – Heavy (8,501 – 10,000 lbs)	Body on frame SUV over 180 cubic feet & 8501 – 10000 GVW	Chevrolet R2500 Suburban, Ford Excursion

12	Van Compact (1 – 6000 lbs)	Less than 180 cubic feet	Chrysler Pacifica
13A	Van – Large (6,001 – 8,500 lbs)	Over 180 cubic feet	Ford Econoline
13B	Van – Heavy (8,501 – 10,000 lbs)	Over 180 cubic feet & 8,501 to 10,000 GVW	Chevrolet Express Van G30
14	Pickup – Compact (1 – 6000 lbs)	Inertia weight (IWT) less than 4,250 lbs (2WD); IWT = curb weight + 300 lbs (rounded to nearest 250 lbs)	Chevrolet S10, Ford Ranger, Nissan Frontier
15A	Pickup – Standard (6,001 – 8,500 lbs)	Inertia weight over 4250 lbs (2WD)	Ford F150, GMC Sierra, Toyota Tundra
15B	Pickup – Heavy (8,501 – 10,000 lbs)	Inertia weight over 4250 lbs (2WD) & 8,501 – 10,000 lbs	Ford F350
16	Neighborhood Electric Car (1 – 6000 lbs)	Small Car with top speed of 25 MPH (per NHTSA Definition 49 CFR Part 571)	Ford Think, Club Car, Dynasty, Global Electric

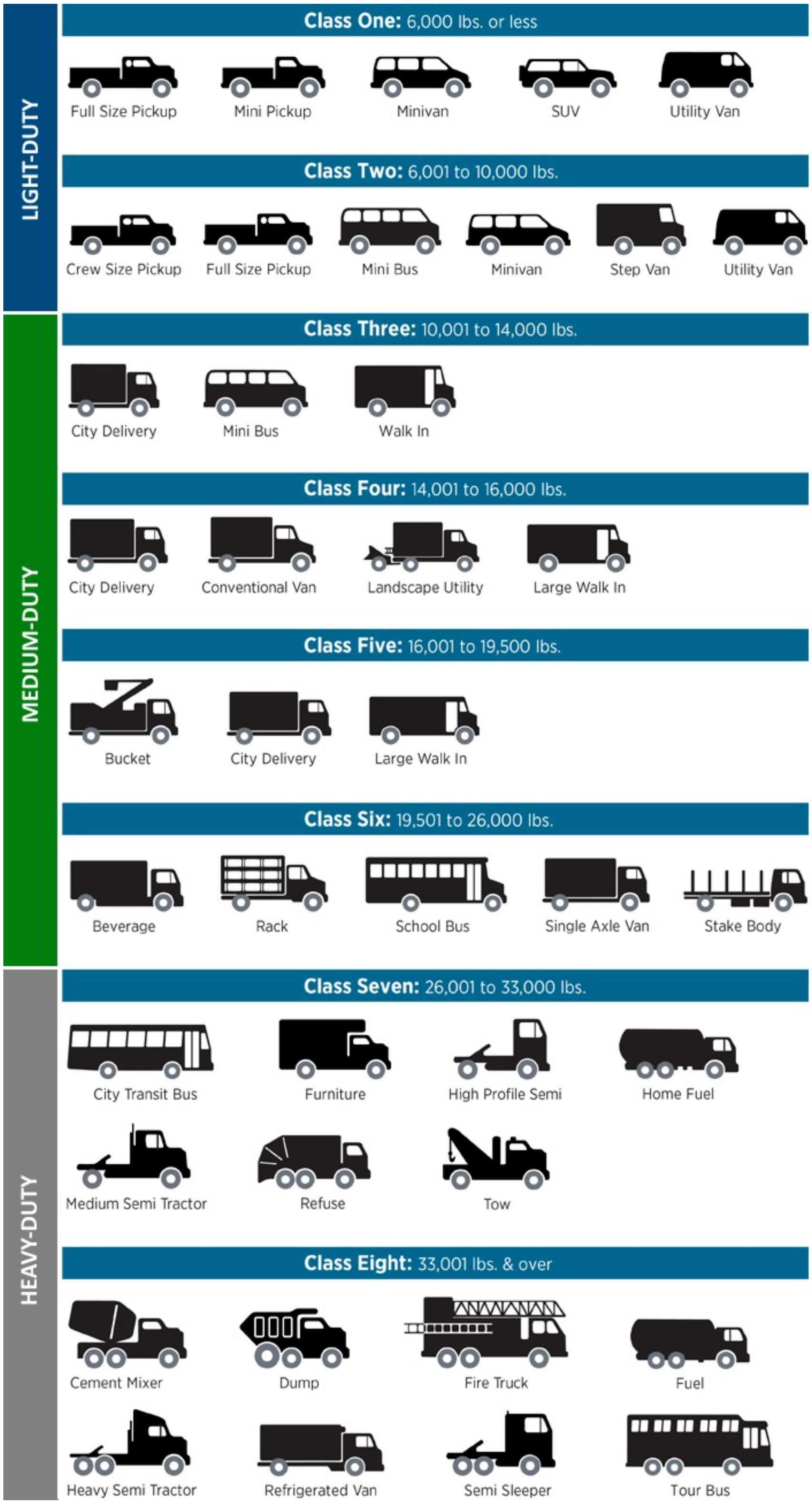
Source: California Energy Commission

Table A-2: Medium- and Heavy-Duty Vehicle Classes

Rating		Weight	Duty	Examples
GVWR 3		10,001 - 14,000	Medium	Pickups and Vans with 4 to 6 wheels
GVWR 4 to 6	GVWR 4	14,001 - 16,000	Medium	Delivery box trucks, step-vans (includes "last-mile"), tow trucks, etc.
	GVMR 5	16,001 - 19,500	Medium	
	GVWR 6	19,501 - 26,000	Medium	
GVWR 7 & 8	GVWR 7	26,001 - 33,000	Heavy	All single unit (straight) trucks: delivery, beverage, vocational etc
	GVWR 8 Single Unit	33,001 and more	Heavy	
GVWR 8	Combination	33,001 and more	Heavy	Tractor-trailer combinations (articulated) used within CA. Typically day cabs. Includes port drayage.
GVWR 8	Garbage	33,001 and more	Heavy	Refuse and recycling pickup and refuse transfer
GVWR 8	International Registration Program	33,001 and more	Heavy	Tractor-trailer combinations (articulated), operating in CA and other states. Typically sleeper cabs.
GVWR 3 to 8	Motorhomes	-	Medium/Heavy	Powered recreational vehicles with sleeping quarters, all weight classes

Source: California Energy Commission

Figure A-1: Vehicle Classes for Light-, Medium-, and Heavy-Duty Trucks



Source: Alternative Fuels Data Center, www.afdc.energy.gov/data/10381. Modified by California Energy Commission.

APPENDIX B: Description of Models

There are six vehicle demand models and five travel demand models used to forecast the transportation energy demand, as described below. Other off-road transportation energy demand forecasts are generated separately.

Vehicle Demand Models

Energy Commission uses several models to forecast vehicle demand and market penetration of different fuel types and vehicle technologies. These include several light-duty vehicle demand models, and well as a truck choice model. These vehicle demand models are used in generating the generating transportation energy demand forecast by fuel type. The light-duty vehicle choice models account for substitution among different classes of vehicles and among different fuel and technology types to generate a forecast of fleet size and composition of light-duty vehicles.

Personal Vehicle Choice

The Personal Vehicle Choice model forecasts the stock and composition of household light-duty vehicles (LDV) used for personal travel in California. The model forecasts the size and composition of household vehicle fleets by integrating the number of vehicles households own, vehicle replacement and addition, the choice of new or used vehicles, and the choice of vehicle class and fuel type.

The Energy Commission collects base year information such as the mix of available vehicles by class and age; demographic and economic information on households; and the percentage of households with zero, one, two, and three or more vehicles. The model then separates this base year data across 362 household types and simulates personal vehicle ownership decisions for each household type.[42]

Households' vehicle choices are based on the relative household preferences for future vehicles. These preferences are estimated based on primary data obtained from the California Vehicle Survey (discussed in Chapter 4), which was most recently conducted for the California Energy Commission by Resources Systems Group in March 2017.

The forecast of vehicle stock and composition are used as inputs for the Urban and Intercity Travel Models.

Commercial Vehicle Choice

The Commercial Vehicle Choice model forecasts the stock and composition of light-duty vehicles used for commercial or business purposes in California.

42 *Household types* are the classifications of households by the number of individuals in the household, the number of workers in the household, and the household's income level. This information is typically collected by the American Community Survey conducted by the U.S. Census Bureau.

The model forecasts the future mix of commercial vehicles using information about the current composition of vehicles, firms' vehicle purchase preferences (which are also obtained by the California Vehicle Survey), and economic data from sectors that use commercial vehicles. The Commercial Vehicle Choice model starts with base year vehicle distributions for an economic sector and increases the total number of vehicles based on the projected increase in economic activity of the sector. The model also incorporates estimates of projected vehicle demand and vehicle retirements. A firm's likelihood for purchasing different types of vehicles is determined by fuel and other operating costs, and several other attributes.

Once vehicle stock and composition have been forecast, the model also generates VMT forecasts based on staff-generated assumptions of VMT per vehicle, as well as a VMT decay rate. Finally, the model uses fuel economy by fuel type to forecast fuel consumption.

Government Vehicles

The forecast of government vehicles and fuel demand is based on a spreadsheet model that accounts for state and local government light-duty vehicles, and grows vehicle stock as a function of economic growth. Vehicles are retired at a designated age and replaced with new vehicles. The composition of the new vehicles purchased for replacement or addition follows guidelines established by current requirements for California state government's vehicle fleet.

Rental Vehicles

The rental vehicle model is a spreadsheet model that accounts for light-duty vehicles in rental business. Compared to light-duty vehicles in other models, these vehicles have a higher VMT and are replaced early in the associated life span. The fleet size grows with the economy, and fleet composition generally follows the actual fleet composition in the base year. The VMT per vehicle is estimated based on actual data in 2017 and is held constant over the forecast horizon.

Neighborhood Electric Vehicles

The Neighborhood Electric Vehicles model is a simple spreadsheet model. The fleet size grows with the economy, and the VMT per vehicle and the fuel economy are held constant over the forecast horizon.

Truck Choice Model

Energy Commission staff uses Argonne National Laboratory's TRUCK 5.1 model (Truck Model) to generate a forecast of market penetration rates by fuel types in different truck classes. The Truck Model uses truck prices, fuel prices, maintenance cost, subsidy for alternative fuel trucks, and fuel economy forecasts as inputs to calculate the market shares for fuel types within each truck class. Truck price and fuel economy forecasts are generated by HD Systems, as discussed in Chapter 6.

The Truck Model is limited to comparison of a base fuel (gasoline in classes 3 to 6) and three alternative fuels (one of which is diesel in these classes). For this reason, with urban and varied driving conditions combined for classes 3 to 6, nominal hybrid market share under the varied conditions, and gaseous and E85 share under urban conditions may be underestimated. However, the total penetration of alternative fuels with respect to the base fuel will be accurate when the two driving conditions are combined.

Travel Demand Models

Much of California's transportation energy use is associated with travel in automobiles. However, public transit has an important role in California's household transportation, and good movement is responsible for a significant share of transportation energy use in California. Therefore, different models are necessary to properly capture the characteristics of different travel modes in different sectors. Output variables of the travel demand models are mostly based on (1) the base year values of those variables, (2) the base year values of explanatory variables, and (3) the forecasted values of the explanatory variables.

Urban Travel

A significant portion of California's transportation energy use is associated with short-distance trips of 50 miles or less. These trips typically involve routine household activities such as commuting to work and school, shopping, and traveling to nearby leisure activities. The Urban Travel model is used to calculate fuel consumption for these types of household trips.

The Urban Travel model is used to forecast transportation energy demand for short-distance trips by considering different travel modes such as a personal vehicle, carpooling, or local transit options. Each mode of personal travel accounts for a fraction or share of all trips, determined from personal utility based on the travel cost and time. This "mode share" of trips is multiplied by typical trip length and average vehicle occupancy for each mode to calculate VMT by mode. Fuel consumption for transit modes is generated by using the VMT, vehicle population, and fuel economy associated with each transit mode and fuel type. Once the personal automobile VMT is distributed to different fuel types fuel consumption is calculated using VMT, vehicle population, and fuel economy associated with each fuel type under the aforementioned Personal Vehicle Choice model.

Intercity Travel

The Intercity Travel demand model develops forecasts of fuel consumption for long-distance household trips greater than 50 miles. Long-distance personal trips can be taken by a choice of transportation modes, such as personal vehicles, intercity rail, motor coach, or regional airline service. Personal preference for each travel mode is determined from the utility of trips based on the trip cost, travel time, and frequency of service. Growth in all intercity travel is represented by the growth in personal income, generating a forecast of intercity trips. VMT is calculated from the forecast of personal trips, average vehicle occupancy, and a typical trip length for each travel mode. Fuel consumption is then calculated from VMT using the fuel economy associated with the mode and fuel type, including the vehicle classes and fuel types forecast by the Personal Vehicle Choice model.

Freight Energy Model

The Freight Energy Demand model forecasts vehicle population, miles of travel, and fuel use using economic projections, a modal choice function, after the truck fuel type shares projected in the Truck Model. Growth in demand for freight transportation is separated into commodity flows and service industries.

For commodity flows forecast in the Federal Highway Administration's Freight Analysis Framework, the choice between tractor-trailer combinations and freight rail modes is implemented using a modal choice function that evaluates shipment cost, travel time, travel cost, and the size of shipments. Truck payloads are drawn from the Vehicle Inventory and Use Survey, last conducted by the U.S. Census in 2002.[43] Rail payloads and allocation of freight to rail car types are drawn from the U. S. Surface Transportation Board Rail Waybill data. Commodity flow is allocated to truck and rail and then interpreted as vehicle miles of travel using the payloads.

For services and local deliveries, the projection from base year truck miles is directly related to the growth in 14 industry NAICS sectors published by Moody's Analytics. Base year service industry vehicle miles and the allocation of truck types to service industry sectors are drawn from the Vehicle Inventory and Use Survey.

The projections of truck and rail miles and truck fuel type shares from the Truck Choice model are used to forecast rail and truck fuel consumption.

Air Travel

The Air Travel model forecasts jet fuel consumption for intrastate, interstate, and international air travel for passenger and cargo traffic. The model consists of two components, one for commercial passenger air travel and the other for air freight and is run for sets of origin-destination pairs. The commercial aviation model is capable of generating air travel demand for personal, commercial, domestic, and international purposes given the availability of appropriate input data.

Passenger air travel is computed using base year passenger miles, where changes in passenger income and travel cost are used to forecast change from base year passenger miles by aircraft class. The model then forecasts fuel consumption, using fuel economy by aircraft class. Forecasted air freight demand is also determined from a baseline

43 United States Census Bureau. *2002 Vehicle Inventory and Use Survey.* https://www.census.gov/svsd/www/vius/products.html.

forecast that is adjusted according to forecasted changes in fuel price. Jet fuel consumption is then derived using projected increases in fuel economy.

Other Bus Travel

The Other Bus model accounts for travel demand and fuel consumption of all other vehicles that are not accounted for in other models. These vehicles include demand response transit vehicles, school bus, shuttle bus and others that do not exist in other models. The model grows vehicles by income and uses VMT and vehicle-specific fuel economies to arrive at fuel consumption.

Other Models and Methods

Staff uses other models and methods to forecast inputs or generate data for use by others or both. This includes the new model used in forecasting petroleum-based prices, developed load shapes for PEVs, and an improved method to estimate the base year VMT.

Petroleum Fuel Price Model

For 2017, staff changed the methodology used to forecast the petroleum-based fuel prices. For this forecast, staff used the relationship between nominal California and U.S. retail gasoline prices to forecast California retail gasoline prices, while separating the effect of LCFS on California prices. Staff then used the EIA's forecast of gasoline prices published in the *Annual Energy Outlook* to generate a forecast of California gasoline prices. While there are price fluctuations specific to California, due to maintenance and outages for different reasons, these fluctuations are typically short-term and unpredictable and, therefore, excluded from the annual price forecast.

Since the *2017 Annual Energy Outlook* is comparable to the 2016 AEO with updated inputs, the three 2017 forecast prices are removed and replaced with the single 2017 price from the *Short-Term Energy Outlook*, which includes all available historical prices for 2017. Prices in subsequent years show the same change as they did in the original AEO forecast. The resulting scenarios are smoothed in 2017, 2018, and 2019, as necessary. The objective is to remove abrupt price changes resulting from the combination of historical, *Short-Term Energy Outlook*, and *Annual Energy Outlook* prices.

Historical tax rates are included in historical retail prices, so only changes from past tax rates need to be added to forecast years. The carbon price forecast and the numerous changes in the state excise tax are added to the forecast prices, with an assumption of 100 percent pass through of any tax changes. Finally, the nominal price is calibrated to the base year values and then converted to real prices.

PEV Load Shape

While the electricity demand has always included the impact of PEVs on annual electricity demand, in 2017 the electricity demand forecast will also incorporate the impact of PEVs on the load shape. Energy Commission staff, under a contract with Lawrence Berkeley National Laboratory, generated a forecast of PEV electricity consumption alongside the results of Caltrans California Household Travel Survey using the Lawrence Berkeley National Laboratory's V2GSim model.[44] The model does not differentiate between residential and commercial use and does not respond to electricity prices. Therefore, to generate responses to time of use, it was run for different scenarios with difference aggregate response rate to time of use electricity price.

Base Year VMT Method

Because it is not feasible to record VMT for every vehicle, the Energy Commission's Supply Analysis Office has developed a method to estimate VMT for any given year, by fuel type. Observed fuel sales (F) of any fuel type (*f*) in any given year (y) are set equal to the estimated level of fuel use in that year. The latter is a product of vehicle population (VP) and annual miles travelled per vehicle (mileage accrual rate, or MAR), by vehicle class and age in year y', divided by an estimate of fuel economy (MPG) by class and vintage in the most recent available year. This equation solves for a calibrating factor (∝) that ensures the equality of the two sides of the equation given fuel type and year. The product of this calibrating factor and MAR is our estimate of statewide on-road VMT for light-duty vehicles and medium- and heavy-duty vehicles.

$$F_y^f = \sum_{c=1}^{Class} \sum_{g=1}^{Age} VP_{cgy}^f . \frac{MAR_{cgy'}^f . \propto_y^f}{MPG_{cg}^f}$$

$$VMT_{cgy}^{f*} = MAR_{cgy'}^f . \propto_y^f$$

Y = year

f = fuel type: gasoline, diesel, hybrid, FFVs, PHEVs, CNG, propane, fuel cell and electric

F_y^f = fuel use by fuel type f (from Board of Equalization) in year y

VP_{cgy}^f = vehicle population of class c and age g of any fuel type f. There are 15 classes for LDVs and 6 classes for heavy duty vehicles, for 32 model years or age. Age is the calendar year minus the model year (from DMV)

44 Lawrence Berkeley National Laboratory, *V2G-SIM*. http://v2gsim.lbl.gov/.

$MAR^{f}_{cgy'}$ = the mileage accrual rate – an estimate of annual miles travelled per vehicle by class, age, and fuel type *f*, for year y' which could be equal or different than y (from Bureau of Automotive Repair Smog Check Data).

$\propto^{f}_{y}$ = a calibrating factor that makes the two sides of the equation equal for any fuel type *f* and any year *y*.

MPG^{f}_{cg} = fuel economy of vehicle class c and age *g* for any vehicle of fuel type *f* (EPA combined cycle – on road adjusted).

VMT^{f*}_{cgy} = estimated VMT for fuel type *f* in year y classified by vehicle class and age.

APPENDIX C:
Battery Pack and Plug-In Electric Vehicle Prices

Battery Pack Prices

For the *2017 IEPR*, Energy Commission staff developed projections of vehicle prices for battery electric and plug-in hybrid vehicles for use as input in the Energy Commission's transportation demand models. To generate these price estimates, staff conducted a thorough literature review and researched the market forecasts made by automakers, private organizations, and government agencies to develop a method that incorporated estimates of battery pack prices through 2030. **Table D-1** presents the results of staff research on battery pack cost projections.

The estimates of battery pack costs were then used to generate three projections of battery pack costs. The low electricity demand case used projections based on published manufacturer estimates. The high electricity demand case used projections aligned with one of the more aggressive estimates. The low, mid, and high case battery pack projections are shown in
Figure D-1.

Plug-In Electric Vehicle Prices per Mile of Driving Range

Staff projects average BEV prices to increase through 2020, then declining at a fast pace afterward. The price increase is a result of significant improvements in electric vehicle range over time and not due to an increase in BEV component prices. Analysis by the International Energy Agency shows that average BEV prices have been rising since 2012 primarily because of increasing range in vehicles.[45] To understand the relative cost of high range BEVs a new metric must be used that considers the improvement in range. "Sales Price per Mile of Range" is one metric that has been developed to show that BEV prices have continued to decline once range is considered. Figure D-2 provides the Energy Commission staff's estimate of sales price per mile of BEV range which show the decline in BEV prices when range is held constant.

45 International Energy Agency. 2017. *Energy Snapshot*, https://www.iea.org/newsroom/energysnapshots/average-ev-price-and-range.html.

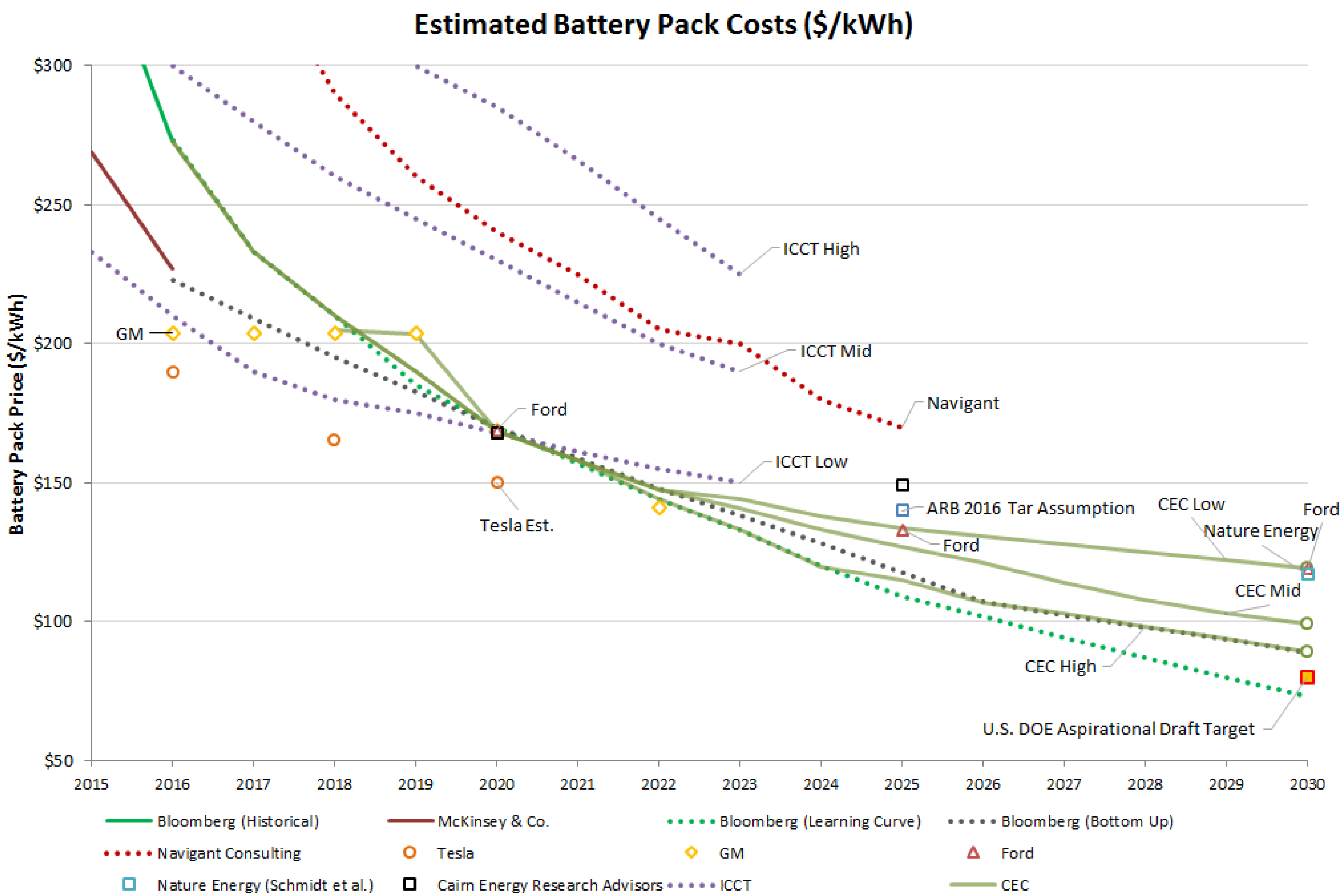
Table C-1: External Estimates of Battery Pack Costs

External estimates of Battery Costs

Battery Pack Costs ($/kwh)	Time of Estimate	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Bloomberg	Historical	$1,000	$800	$642	$599	$540	$350	$273														
McKinsey & Co.	Historical						$269	$227														
Bloomberg (Learning Curve Est.)	2017							$273									$109					$73
Bloomberg (Bottom Up Cost Model)	2017							$223		$195		$170		$148		$128		$107		$98		$89
Navigant Consulting	2017							$360	$340	$280-$300	$255-$275	$230-$255	$215-$240	$195-$225	$180-$215	$170-$205	$155-$190					
Nature Energy (Schmidt et al.)	2017																					$117
UBS (for Tesla)	2017									$165												
ARB 2016 TAR Assumption	2017																$140					
U.S. DOE Aspirational Draft Target	2017																					$80
Ford	2016											$169					$133					$119
Panasonic	2016									$190-$222												
Tesla	2016							$190				$150										
Cairn Energy Research Advisors	2016											$168					$149					
International Council on Clearn Transportation (ICCT)	2016						$233-$415	$210-$390	$190-$355	$180-$325	$175-$300	$168-$285	$161-$266	$155-$245	$150-$225							
General Motors	2015							$204	$204	$204	$204	$169		$141								

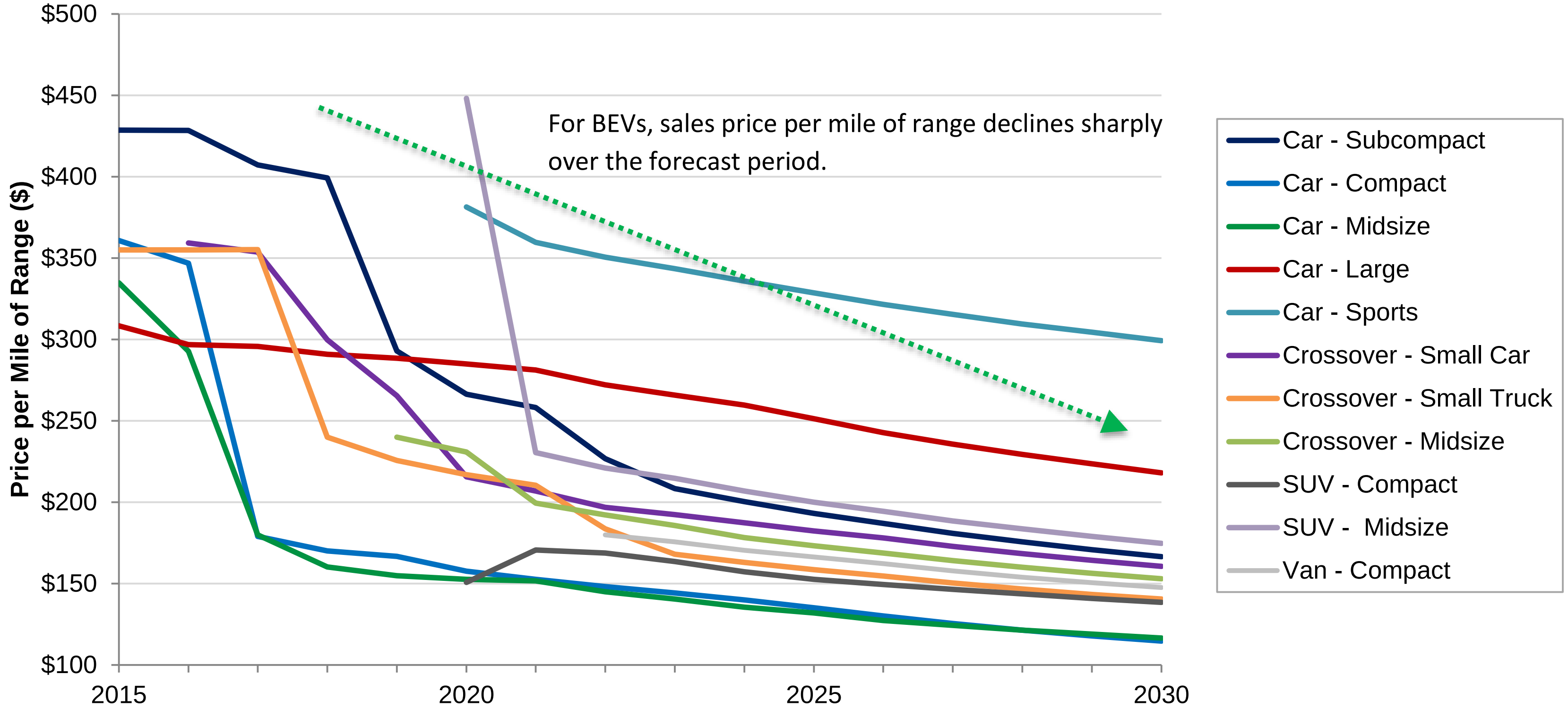
Sources: BNEF, McKinsey & Co., Navigant Consulting, UBS Research, ICCT, General Motors, Ford, Tesla, California Air Resources Board, Nature Energy. Note: Estimates by Ford and General Motors were made for battery cell costs, which are a subcomponent of battery packs. A literature review found that cell costs typically consist of 70-73 percent of battery pack costs, and this value was used to convert battery cell costs to battery pack costs.

Figure C-1: Comparison of Battery Pack Cost Trends



Source: California Energy Commission analysis.

Figure C-2: BEV Sales Price per Mile of Range by Vehicle Class, Mid Case



Source: California Energy Commission analysis.